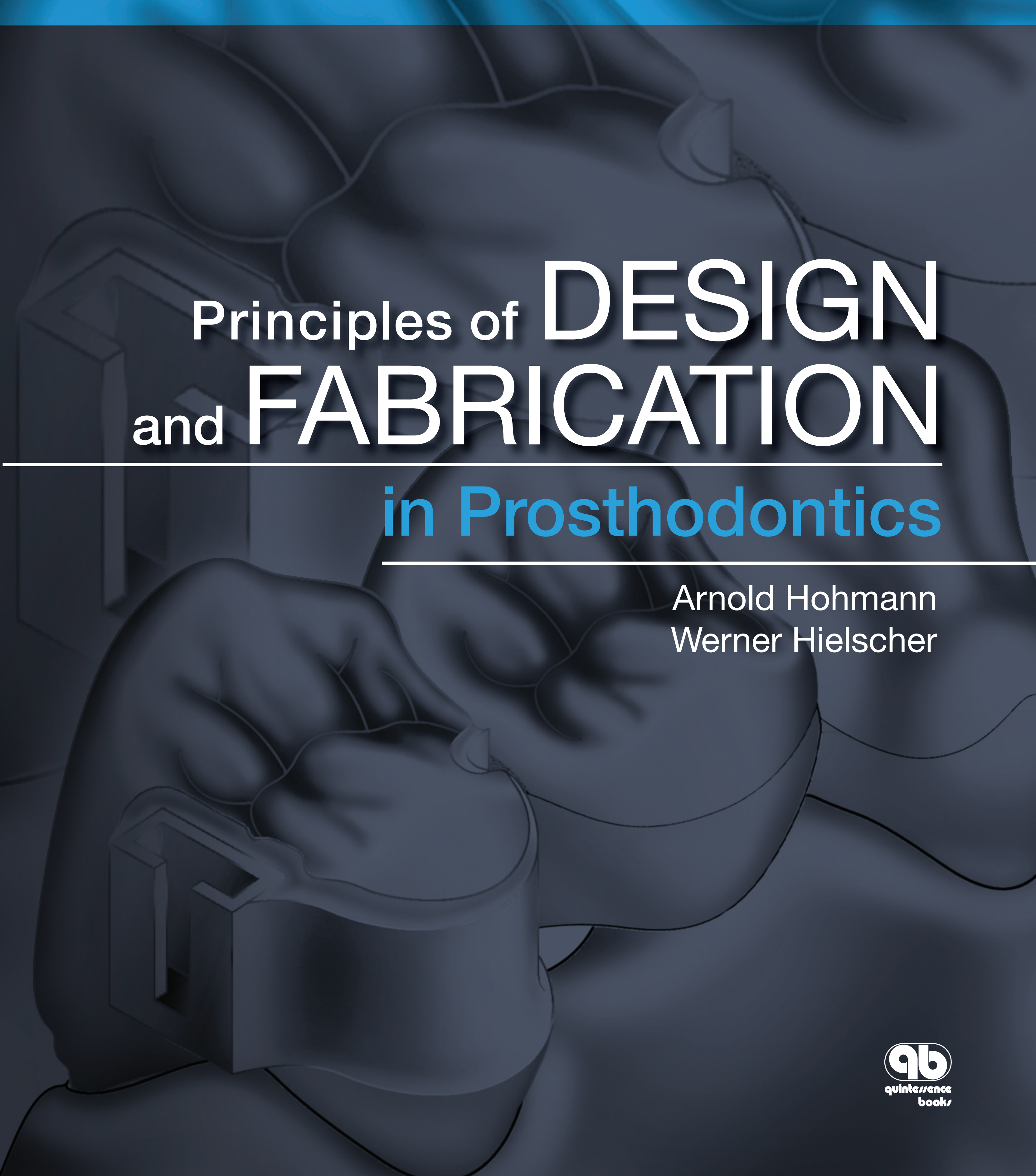

Principles of DESIGN and FABRICATION in Prosthodontics

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Contents

Introduction

This textbook is designed for the specialized teaching of advanced dental students and technicians. It is written and illustrated by people who have a passion for their craft and take joy in passing on their knowledge. The text describes the philosophy behind prosthodontic design and systematically details all of the working steps in designing and fabricating restorations and dentures. Unlike other prosthodontic texts, this one is written from a design perspective first and foremost, explaining the rationale behind the most minute of design considerations, such as different extension arms in removable partial denture clasps. Because prosthodontists must possess the skills required to physically fabricate restorations, the book includes comprehensive instructions on fabrication, clearly delineating the clinical work from the laboratory work. It also presents each technique as an illustrated algorithm with detailed legends; these algorithms provide a quick orientation and visual aid for the reader. Multiple working methods for complete denture fabrication are presented, and the final chapter describes how to incorporate sound prosthodontic design into implant therapy. Armed with this book, the dental student will be well prepared to create esthetic, stable, and durable restorations.

1

Preprosthetics

Functional Disorders After Tooth Loss

The masticatory system is a unit made up of functionally oriented tissue parts, and it only functions properly if all parts of the system are present and working smoothly. If normal functioning of the masticatory system no longer exists—whether because of loss or because disease has changed one part of the system—this is referred to as a *functional disorder*, *malfunction*, or *dysfunction*. In relation to the position and size of an edentulous space between teeth or a shortened dental arch, changes in facial expression and articulation may be observed as well as effects on masticatory function, the muscles of mastication, and the temporomandibular joints (TMJs). Above all, however, there is an adverse effect on the remaining dentition.

If there is an edentulous space, the supporting function of the closed dental arch afforded by the approximal contact points is lost and the teeth migrate into the space (Fig 1-1). Under the pressure of tooth migration, the bony alveolar wall opposing the edentulous space is broken down. At the same time, the alveolar bone beneath the space is resorbed. The consequence is the formation of a periodontal pocket in the area bordering the edentulous space. In addition, the approximal contacts with adjacent teeth become loose. As a result, the interdental areas open up and are no longer protected against food particles, which can become trapped there. This is followed by the formation of approximal caries and inflammation, which will damage the marginal periodontium.

As a result of the tipping of teeth, the normal occlusal contacts with the opposing teeth are lost. The occlusal surface inclines toward the normal occlusal level, so that some occlusal points migrate beyond the normal level and others fall below what is normal. The antagonists then overerupt until they regain occlusal contact, giving rise to severe malocclusions.

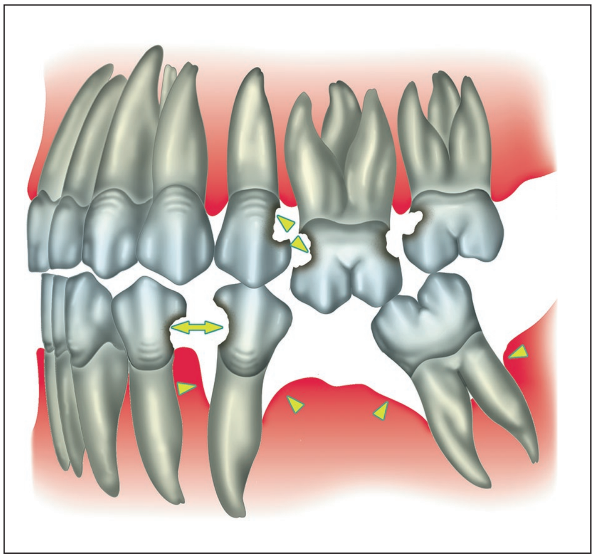


Fig 1-1 If a tooth is missing within an arch, the remaining teeth migrate into the edentulous space. As a result, the supporting function is lost, the interdental papillae are no longer protected, and caries develops in the approximal areas. In areas bordering the space, pocketing occurs at the marginal periodontium. In addition, the opposing tooth overerupts into the space, potentially causing tooth mobility, loss of support, and approximal caries in that arch as well.

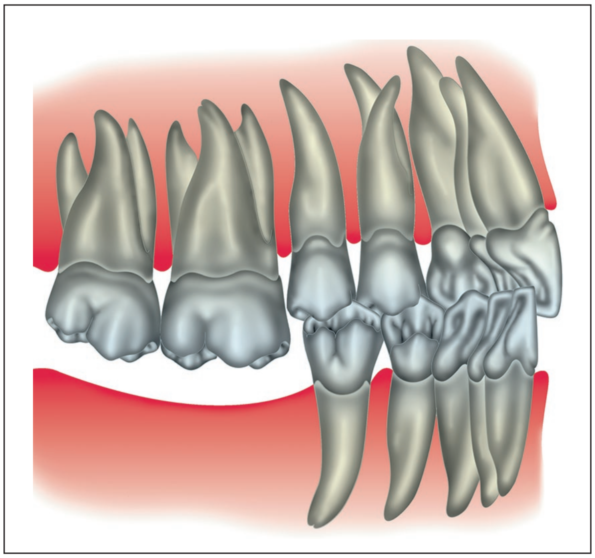


Fig 1-2 If the antagonists are missing, the teeth overerupt until they are stopped by the opposing jaw. This overeruption looks like lengthening of the tooth and is referred to as *elongation*. This exposes the cervical areas of the teeth so that cervical caries may develop. Prosthetic restoration becomes difficult under these conditions.

The elongation (lengthening) of teeth may be due to the reactive behavior of the periodontal tissues (Fig 1-2): If the tooth is not pressed into the socket by masticatory force, the pressure in the blood vessels lifts the tooth out of the socket. The gentle but continuous pull on the ligamentous apparatus acts as a stimulus on the alveolar bone, which grows in the direction of the pull until the tooth is held by antagonist contact or the opposing jaw.

The overeruption of an antagonist has two repercussions. First, in the dental arch from which the tooth is overerupting, all of the teeth become more mobile, bringing consequences such as loss of sagittal support, opening of the interdental spaces, approximal caries, and damage to the marginal periodontium. Second, the elongation gives rise to an occlusal disorder as the overerupting tooth interferes with gliding movements (Fig 1-3). Smooth occlusal gliding out of centric occlusion is no longer possible.

Enlargement of edentulous spaces means that the stresses on the residual teeth become greater and the periodontal damage more pronounced. Deterioration of the dentition progresses rapidly (Fig 1-4).

Malocclusions in a partially edentulous dentition arise because the continuous masticatory field is interrupted and sagittal or occlusal support contacts are lost. As a result, centric stops no longer meet simultaneously in their contact areas: some have premature contact and others no contact at all. This brings about uneven distribution of forces in the masticatory field: some teeth are overloaded and others underloaded. Because the sagittal support is missing, tipping and migration of teeth will occur whereby the tipped and migrated teeth are loaded eccentrically and hence nonphysiologically.

In all lateral or protrusive movements, all the mandibular teeth glide downward and forward on the posterior sloping surfaces of their maxil-

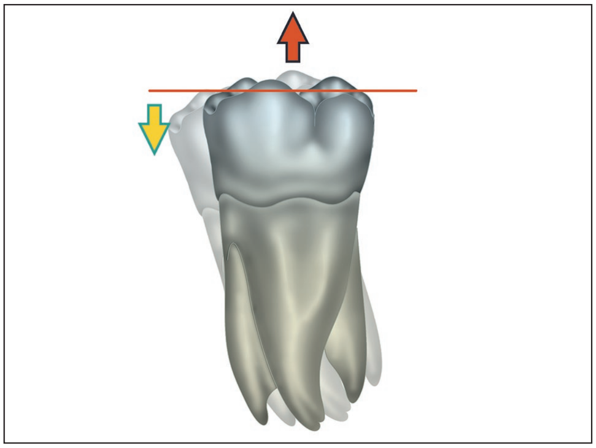


Fig 1-3 As a result of tipping, the distal occlusal points migrate beyond the occlusal line and the mesial points migrate below it. Consequently, the stress relationships for the affected teeth are also altered. Interference with gliding movements within the dental arch occurs during mandibular movements.

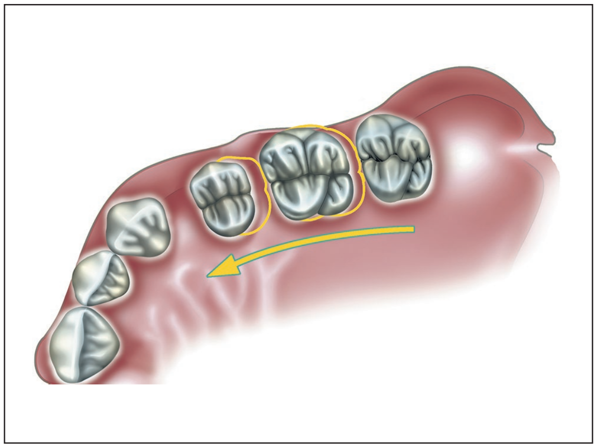


Fig 1-4 Early signs of destruction of a partially edentulous dentition can be seen from the migration of posterior teeth, which results in loss of interdental support. Tipping of teeth and hence a change in occlusal relationships are always associated with tooth migration.

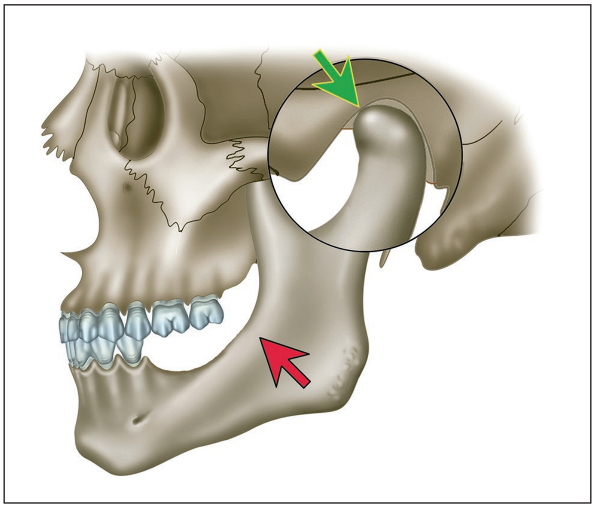


Fig 1-5 In the fully dentate dentition, the condyle is in a neutral position in the fossa when in centric occlusion. If the supporting function of the teeth is lost because of shortening of the dental arch, there is inevitably abnormal loading of the TMJs. The condyle is pressed into the mandibular fossa by the activity of the masticatory muscles. This leads to traumatic changes to the TMJs.

lary antagonists because of condylar, neuromuscular, and tooth guidance. If the cuspal paths are no longer arranged in the right spatial inclination because of tipping of teeth, the centric stops lose their antagonist contact.

Condylar and neuromuscular guidance are therefore abnormally stressed, which may result in TMJ and muscle diseases (Fig 1-5). Joint damage is often evident as disc dislocation with acute joint clicking when the disc pops out of its normal position beyond the edge of the mandibular fossa. This will result in pain of varying severity on loading.

Myopathies are diseases of the neuromuscular system that are evident initially as muscle tension and induration and later as disorders of metabolic breakdown and associated muscle pains.

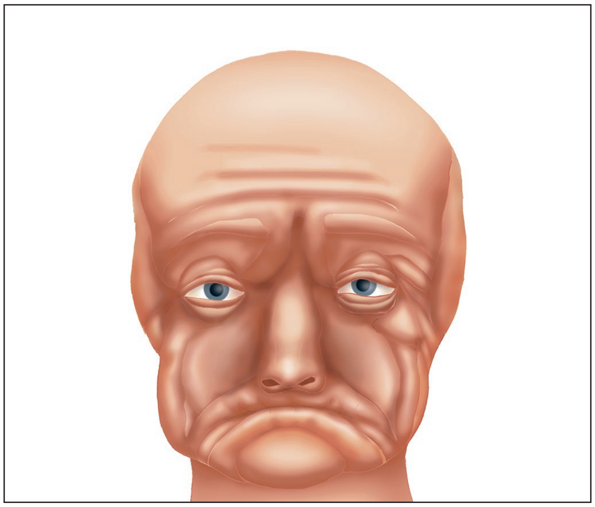


Fig 1-6 In the face of an aged edentulous patient, the extreme wrinkling around the sunken mouth becomes pronounced, the nose appears to lengthen, the cranial fossae at the sides are also sunken, and the slack buccal muscles cause the cheeks to sag. The facial proportions are therefore shifted.

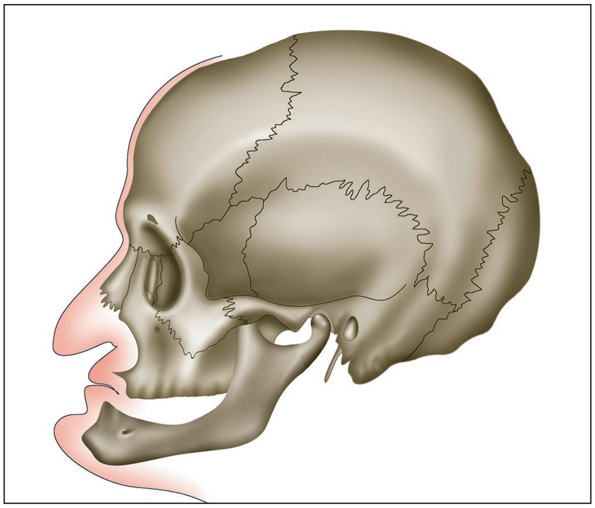


Fig 1-7 Changes to the masticatory system and face are most striking in complete edentulism: The alveolar ridges and bony tissue for the muscle attachments are resorbed, the mandible moves closer to the maxilla, lip support is lost, the vermilion of the lips disappears, and the face looks more aged.

Functional Disorders and Loading of Residual Dentition

Abnormal loading of the TMJs and the masticatory muscles appears when the supporting function of the posterior teeth is lost and the muscles of mastication press the condyle into the mandibular fossa. The abnormal loading of the masticatory muscles leads to displacement of the bite position; the mandible is shifted forward, which accelerates deleterious changes in the TMJ.

Displacement of the bite position influences the residual dentition. Either the remaining anterior teeth are moved labially by occlusal pressure, or an edge-to-edge bite arises with severe abrasion of the incisal edges. This results in severe mobility of teeth and even complete deterioration of the dentition.

The progressive destruction of a partially edentulous dentition may be delayed over prolonged periods. For instance, given normal loading and a resistant periodontium, a dentition may even make up for the loss of several molars itself. In most cases, however, the described symptoms occur within a few years and quickly lead to loss of all the teeth if the deterioration is not halted by prosthetic treatment.

The changes are most striking in complete edentulism. As a result of complete tooth loss, the mandible or maxilla collapses, lip support is lost, and the vertical dimension of occlusion is reduced, which inevitably pushes the mandible forward. All of these changes cause the lips to cave in; in addition, the vermilion of the lips disappears, the mouth becomes thin, and the lower part of the face is shortened. This results in an aged facial appearance with pronounced wrinkles around the mouth area caused by general slackness of the muscles of mastication and the perioral musculature, because normal masticatory function no longer places any load on these tissue parts (Figs 1-6 and 1-7). The bony areas to which the masticatory muscles attach are also resorbed.

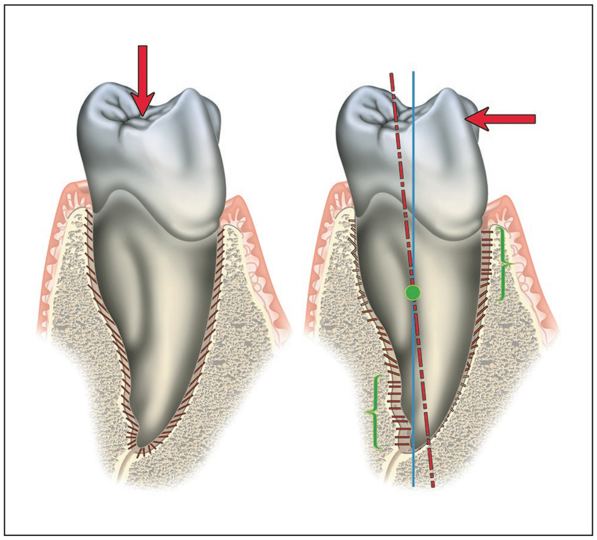


Fig 1-8 If a force hits the tooth centrally, the whole periodontium is physiologically under tension. On transverse loading and tooth tipping, only a third of the periodontal fibrous surface is physiologically under tensile stress *(green bracket)*, a third remains neutral and unloaded, and a third is nonphysiologically compressed.

Impaired masticatory function affects the entire digestive process. The inability to crush food properly, together with insufficient insalivation and predigestion, will initially lengthen the time food stays in the stomach; the stomach muscles slacken, and diseases of the intestinal tract develop because of the abnormal decay and fermentation processes.

The consequences of tooth loss that impairs function suggest that prosthetic replacement of missing teeth is indispensable. The prosthetic replacement has to be anchored to the residual teeth that are still present or supported on the mucosa, which is unsuitable for absorbing masticatory forces.

Periodontal tissues are far better suited to absorbing masticatory forces than the mucosal and bony foundation for a denture base (Fig 1-8). The cells of the periodontal tissue have differentiated to absorb forces: Sharpey fibers convert pressure into tension, stabilizing the alveolar cortical bone, which can dissipate force effectively. Bone is known to grow in the direction of pull and is broken down under pressure—a functional relationship that is exploited to achieve orthodontic tooth movements.

The mucosal and bony base can absorb moderate masticatory force because of shifts of fluid in the soft tissue. The mucosa transfers masticatory force to the bone, for which a moderate masticatory force is favorable because the periosteum here is stimulated by fibrous anchorage of the attached mucosa. The bone will atrophy if there is complete inactivity. However, even at masticatory forces that are normal for the periodontium, the bone is subject to compressive loading to such an extent that it is resorbed; this has to be corrected by constant rebasing.

If the loading of the residual dentition is greater than normal because of the prosthetic replacement, there is a pronounced increase in the Sharpey fiber bundles, and hence periodontal loading capacity is higher. It is important that the higher load contacts the periodontium centrally and does not tip the tooth, causing nonphysiologic loading of the fibrous tissue.

In a fully dentate dentition, tipping of the teeth is compensated for by the sagittal support from approximal contacts, tissue interlinking, double interlocking with antagonists, and the neuromuscular reflex arc. In a partially edentulous dentition, sagittal support, tissue interlinking, and antagonist contacts are largely lost; only the reflex arc remains. However, the arc only works when there is overloading and not with below-threshold continuous loads. This can give rise to and explain specific denture requirements.

Function of Dental Prostheses

The term *prostheses* refers to all mechanical devices that serve as a functional or cosmetic replacement for lost anatomical tissue. Hence every tooth replacement—whether a crown or a partial denture—is a prosthesis. The term *partial prosthesis* is actually a tautology because any prosthesis is essentially a partial replacement. The following grouping of teeth replacements is useful in distinguishing the different types of prostheses, and their names emphasize the design features of the specific replacements (Fig 1-9):

- A *crown* replaces hard dental tissue in a wide variety of fixed designs; in the broadest sense, this also includes restorative treatment.
- A *fixed partial denture* replaces teeth, dental hard substance, and alveolar bone; this fixed prosthetic replacement is firmly spanned between abutments, which is why they are also called *bridges*.
- A *removable partial denture* is a removable tooth replacement that replaces single teeth and alveolar bone in a partially edentulous dentition.
- A *complete denture* is a removable full denture that replaces all the teeth and missing alveolar bone.

Depending on the amount of time a prosthesis is used, a distinction is made between interim/provisional or immediate prostheses and definitive prostheses. The terms *immediate prosthesis* and *interim prosthesis* denote the instant prostheses used for a specific indication.

An immediate prosthesis is fabricated according to a model prepared before extraction of the teeth that are going to be replaced. The teeth are ground on the model and replaced by a prosthesis construction. An immediate denture is inserted directly after extraction of the teeth.

An interim prosthesis is a provisional removable tooth replacement that is fabricated and inserted immediately after tooth extraction as a form of wound closure and is used until the definitive replacement is inserted. After tooth extraction, an impression is taken, models are made, and the prosthesis is fabricated with the same design features and functions as an immediate prosthesis.

Interim prostheses offer good wound closure and better adaptation of the alveolar ridge tissue to loading. Researchers have observed that patients who are fitted with interim prostheses experience less shrinkage of the alveolar ridge than those who are not. Interim prostheses offer an esthetic replacement until the definitive restoration is inserted; they maintain the vertical dimension of occlusion, allow natural chewing movements, and as spacers prevent any displacement of teeth bordering edentulous spaces. Another advantage of these interim prostheses lies in the recording of the maxillomandibular relationship for the definitive prosthesis, especially in the case of complete dentures. Furthermore, speech function is preserved for the patient. Definitive prostheses are the form of tooth replacement that is intended to be in place in the long term.

The aim of prosthetic treatment is to replace lost tissue and avoid, or at least reduce, all the functional disorders that occur because of tooth loss. The specific functions of a tooth replacement can thus be identified as follows (Fig 1-10):

- *Biomechanical function* involves restoring the closed dental arch by replacing the missing tissue parts. The aim is to secure the supporting function within the dental arch, create a normal occlusal situation, and enable physiologic loading of the available tissue.
- *Therapeutic function* involves halting any deterioration of the dentition that has already started. This also relates to delaying or preventing changes to other tissue parts of the masticatory system by means of correct prosthetic design.
- *Prophylactic function* means stopping secondary damage resulting from the prosthetic replacement and preventing future pathologic changes.
- *Regulating function* concerns prosthetic measures intended to improve or establish the functioning of a masticatory system. This includes esthetic aspects and unimpaired phonetics.

Design principles and the criteria of functional testing can be deduced from this general description of functions. Descriptions of specific prostheses in the following sections not only explain the constructional measures but also cover the functional references of the tooth replacement. Possible errors that may result are examined in detail.

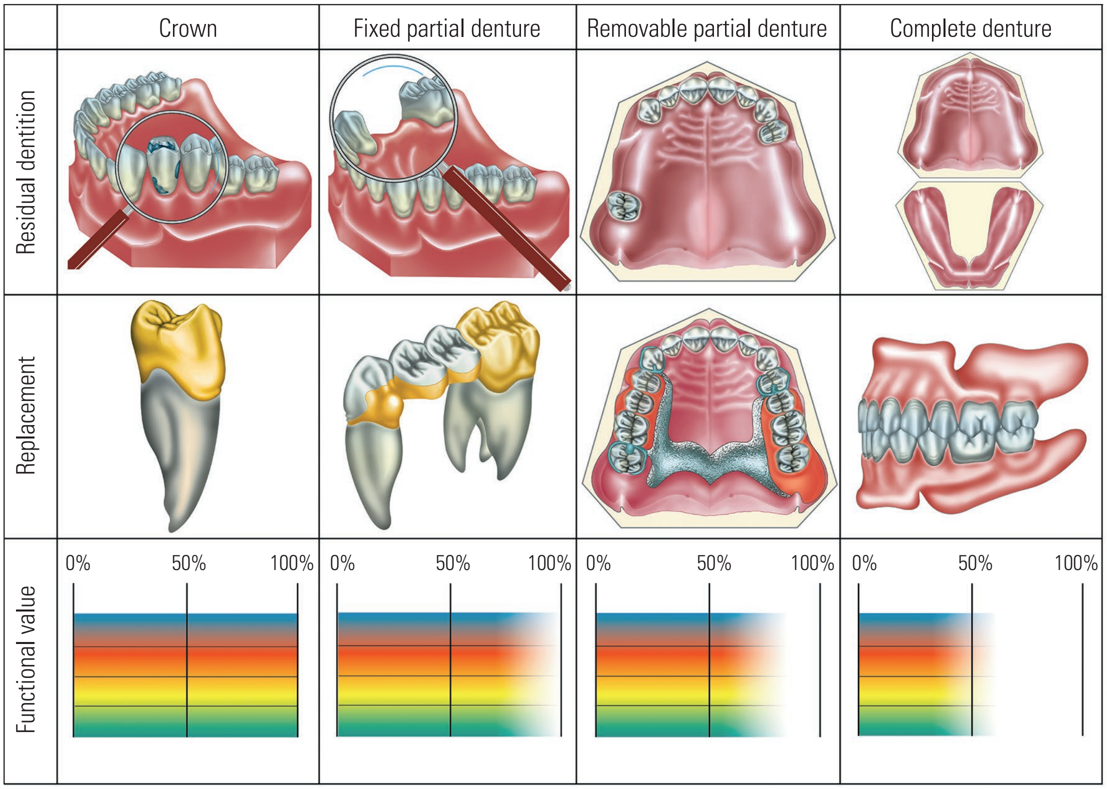


Fig 1-9 The possible functional value that can be achieved by a dental replacement in the ideal situation can be correlated with the different prosthesis and tooth replacement groups. A functional value of 100% in single-tooth rehabilitation can be achieved by dentistry and dental technology methods, whereas severe loss of masticatory function can be expected in the case of complete prostheses.

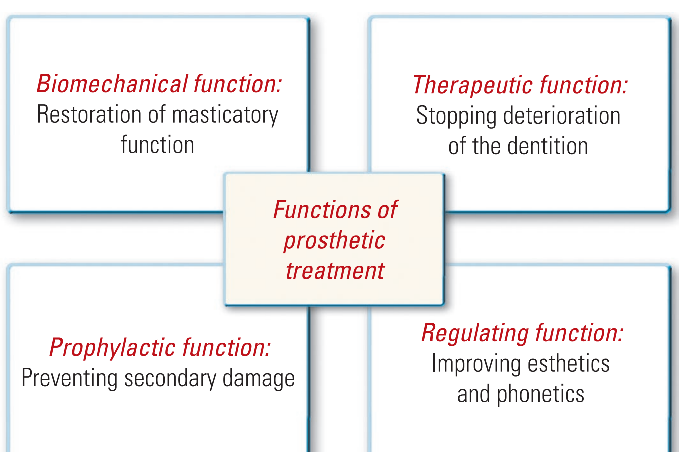


Fig 1-10 The functions of prosthetic treatment can be broken down into four functional areas for teaching purposes. No area has particular priority, and all functions need to be accomplished equally.

Restorative Treatment

Restorative treatment refers to a single-tooth restoration in which the diseased dental hard substance is replaced by tissue-compatible material. Restorative treatment becomes necessary for dental defects resulting from chipping of the teeth during trauma, caries lesions, or abrasive wear.

Restorations are intended to restore the original morphology of the tooth and to be resistant to conditions in the oral cavity, dimensionally stable, and tissue compatible. Their color should not differ from that of the natural tooth, and restorations should be cost-effective to produce. The margins of the restoration are placed in areas that are accessible to mechanical oral hygiene measures or subject to self-cleaning. The restoration must withstand masticatory loads and must not fall out. Restorations can be classified according to the following:

- The extent of dental destruction or the dimensions of the tooth surfaces to be replaced
- The nature of the restorative material (ie, plastic or metal)
- The nature of the fabrication process (ie, direct or indirect fabrication)

Cavity or *tooth preparation* refers to preparing the tooth to receive a restoration. The process involves removing the caries or preparing the defect in the dental tissue and treating the wound in the dentin. To remove the soft carious tissue with a low-speed drill, the hard enamel layer is first removed at high speed under water cooling. Tooth preparation is intended to spare hard dental tissue, provide permanent retention for the restoration, and prevent new caries from developing. It is done with rotary instruments at low or normal speed (4,500 rpm and above) and under water cooling and is not extended to the gingival margin.

The cavity to receive a restoration has the following basic features (Fig 1-11):

- The cavity floor is the interface directed toward the pulp, which must be a minimum of 1.5 mm from the tooth surface in order to create high enough walls for the restoration.
- The cavity walls are the lateral borders to the enamel and dentin. The transitions between the floor and wall are rounded. For plastic restorative materials, the cavity walls are slightly undercut. For metal restorative materials, the floor and wall form a nearly 90-degree angle.
- The cavity margin, or the border between the cavity wall and the tooth surface, forms the subsequent restorative margin. For cast restorations and adhesive restorations made of composite, the cavity margin is beveled in the enamel.
- Extension surfaces are the cavity walls that border the vertical pulpoaxial cavity floor on the approximal surfaces.

Caries lesions are subdivided into five classes according to Black's classification (Fig 1-12):

- *Class I caries* refers to occlusal lesions in the area of the pits and fissures in molars and premolars. The term is used for fissure caries that starts in spots in the fissures and runs along the dentinoenamel junction. Any overhanging enamel areas that arise will break off under masticatory pressure.
- *Class II caries* describes approximal lesions in premolars and molars. An approximal defect in posterior teeth in a closed dental arch can only be prepared occlusally so that a multisurface cavity is formed. A box-shaped preparation with rounded transitions is required to restore an approximal caries lesion. The approximal-cervical shoulder lies perpendicular to the crown axis or slopes slightly from the outside inward.
- *Class III caries* refers to approximal cavities in anterior teeth without involvement of the incisal edge. The small, round cavity opening in the area of the anterior teeth is prepared from the lingual, and the cavity margins are extensively beveled to achieve a wide retentive surface on the dental enamel.
- *Class IV caries* relates to approximal defects in anterior teeth involving damage to the incisal edge. Loss of the incisal edge necessitates extensive beveling of the enamel (1 to 2 mm), which is mainly restored with a tooth-colored restoration retentively fixed to the dental enamel by the enamel etching technique.
- *Class V caries* denotes defects close to the gingiva on the labial and buccal tooth surfaces. Cervical cavities are surrounded by enamel on all sides.

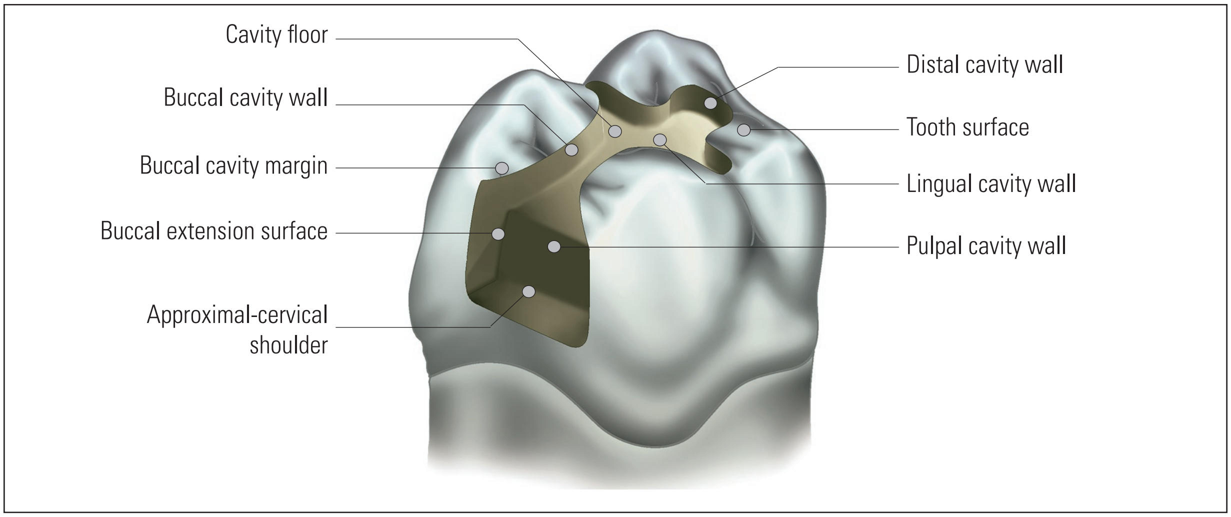


Fig 1-11 Tooth preparation removes carious dental hard substance and shapes a cavity to receive a restoration.

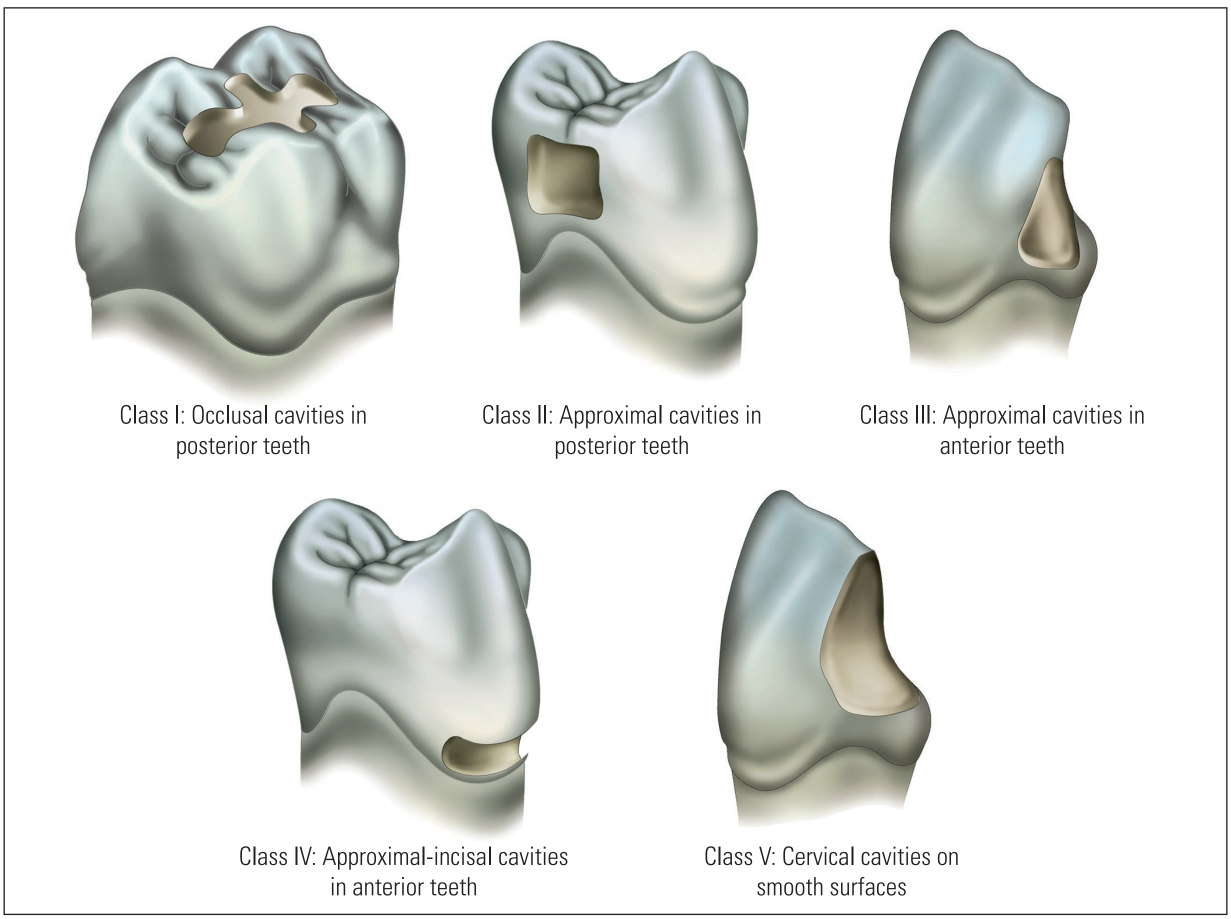


Fig 1-12 Caries classes I through V can be distinguished based on Black's systematic classification.

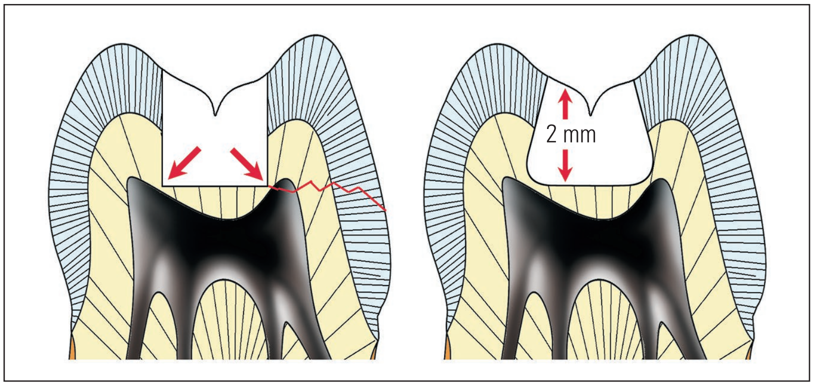


Fig 1-13 The buccal and lingual cavity walls for an amalgam restoration are prepared slightly undercut. The minimum cavity depth is 2 mm. The transitions are rounded at the cavity floor to prevent a notching effect with the dental tissue.

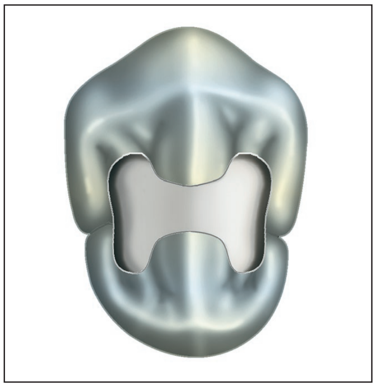


Fig 1-14 The approximal cavity walls for an amalgam restoration are prepared slightly divergent, in an occlusal direction, so that the marginal ridge areas cannot break. The buccal and lingual walls are slightly undercut to give the restoration material sufficient retention.

Restorative Materials

Restorations made from plastic restorative material are fabricated by the dentist in the patient's mouth using the direct method. A distinction is made between a provisional restoration as a temporary seal and the definitive restoration for the long-term restoration. Hardening substances in the form of ready-to-use mixtures of zinc and calcium sulfate from tubes, zinc oxide–clove oil with additives, and heat-deformable gutta-percha are used as temporary restorative materials.

Amalgam, composites, glass-ionomer cements, and gold leaf or crystalline gold (sponge gold) are used for definitive restorations. Tooth preparation is performed as described, depending on the restorative material used.

Amalgam restorations for caries treatment in conservative dentistry are made of a heterogeneous alloy of mercury with other metals. They are used in the occlusion-bearing posterior region and to build up cusps (Figs 1-13 and 1-14); amalgam restorations are not used for anterior restorations for esthetic reasons. The liquid mixture of mercury and other metals can be readily packed into the cavity before it hardens into its solid form. The ready-to-use amalgam alloy is mechanically blended from two components at a 1:1 ratio of liquid mercury and powdered amalgam particles. Correctly prepared amalgam restorations are extremely durable and leak only small amounts of mercury. However, because of this leakage, amalgams are suspected of being deleterious to health. Measurements of mercury in saliva, blood, and urine show a correlation between the concentration of inorganic mercury compounds and the number of teeth filled with amalgam. Therefore, amalgam restorations are unsuitable for children younger than 6 years, pregnant women, and patients with kidney disease. Owing to the hazard posed by mercury vapors and their chemical affinity for precious metals, amalgams are rarely used. Similarly, amalgam in direct contact with metallic crowns will release mercury because of electrogalvanic corrosion.

Composite restorations are made of tooth-colored acrylic resin reinforced with inorganic fillers. The composite is packed into the cavity in its liquid state and sets chemically or under ultraviolet light. Composite is not as mechanically durable as amalgam because it shrinks during curing and has high thermal expansion. Composites are not as suitable for posterior restorations as they are for the anterior region. They can be

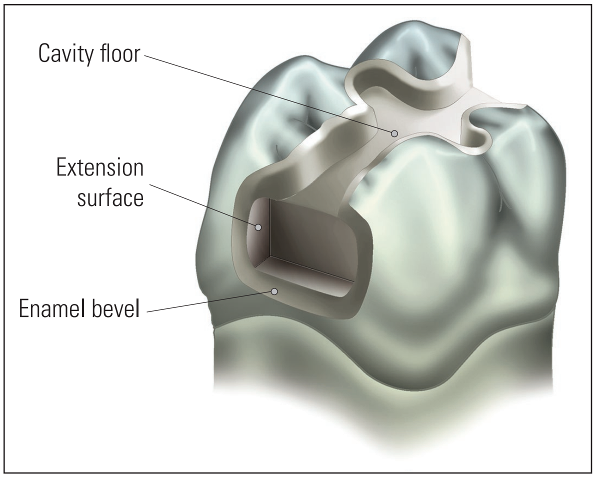


Fig 1-15 In a multisurface cavity for a composite restoration, the cavity floor is at least 2 mm deep. The approximal extension surfaces are clearly directed in a lingual and buccal direction. The cavity margin is encircled by an enamel bevel. Conditioning with an etchant gel is performed in this enamel area.

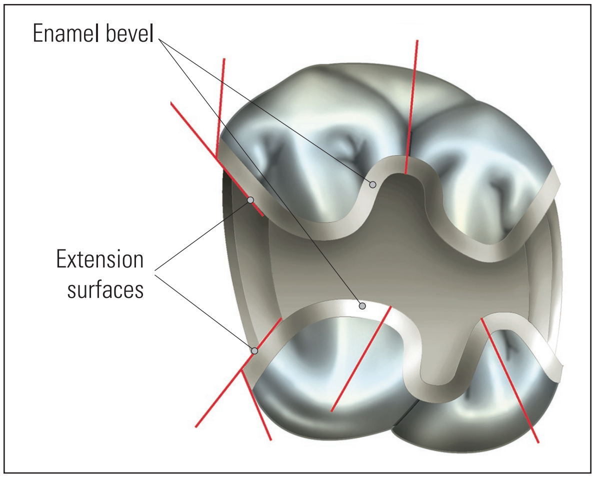


Fig 1-16 For a multisurface cavity, a gold inlay restoration is generally made; the same design is chosen as in Fig 1-15, with a depth of 2 mm, the extension surfaces, and the enamel bevel. The occlusal antagonist contacts must always lie outside the cavity margin.

used for small occlusal cavities if the antagonist contacts lie on the natural dental hard substance. Composite restorations are adhesively and retentively bonded to the dental enamel by the enamel etching technique, for which an absolutely dry cavity must be maintained (rubber dam).

The marginal integrity of composite restorations is ensured by the preparation of mechanical retentions (grooves, adhesive points) and with dentin bonding agents. In addition, a tight, acid-resistant cavity lining is placed to protect the pulp against the acrylic resin monomer or phosphoric acid (etching gel). The composite material is applied layer by layer, finished, and polished and thus provides esthetically superior restorations with a tight marginal seal (Fig 1-15).

Glass-ionomer cement restorations may be used for small caries lesions. Glass-ionomer cements bond well to dentin and enamel so that a restoration with marginal integrity is produced. Cements cannot be polished, are light impermeable, and are not abrasion resistant. Their use is confined to cervical caries lesions bordered by enamel as well as caries lesions in the cementum. Glass-ionomer cement is mainly used as a tooth preparation lining material and for buildups on crown stumps.

Gold compaction restorations are very rarely fabricated for small occlusal and approximal caries lesions. Tooth preparation must be box shaped with sharp edges. The cavity walls are parallel or undercut to provide sufficient retention (Fig 1-16). The restorative material consists of a special gold foil (gold leaf) or crystalline gold. The core of the restoration is built up with the crystalline gold, which is coated on the outside with gold leaf. The gold is packed in portions into the cavity and cold-welded with hammer blows so that it wedges into the cavity with a tight marginal seal. Fabrication is time-consuming and costly but does produce long-lasting, dimensionally stable inlay restorations that are appropriate when a patient is allergic to other restorative materials and their ingredients.

Inlay Restorations

Inlay restorations made from metal, ceramic, or composite can be used to restore occlusal, approximal, or approximal-incisal cavities caused by carious defects, fracture, or other damage after they have been prepared. Inlay restorations are only indicated for patients who have good oral hygiene, minimal susceptibility to caries, and healthy periodontal conditions. Inlay restorations can be placed over several surfaces and may be retained by shoulders and pins (Fig 1-17). They differ depending on the amount of tooth structure to be replaced (Fig 1-18). The term *inlay restorations* encompasses inlays, onlays, overlays, and onlay partial crowns.

While an inlay is fixed entirely intracoronally without covering the occlusal surface of a tooth, an onlay covers the entire occlusal surface, and an overlay encompasses the occlusion-bearing cusps and includes both approximal surfaces. There is a smooth transition from overlay to partial crown when the cervical area of the tooth and the occlusal and approximal defects need to be restored.

The design for inlay restorations is extended and demands plenty of dental hard tissue, especially if a metal and porcelain restoration covering the occlusal surface is to be placed. The cavity walls are not undercut occlusally, in contrast to the preparation for plastic restorative materials (Fig 1-19). Cavity walls close to the pulp are coated with a lining so that even undercut areas are blocked out. The cavity walls and the liner should be smoothed, and then an impression is taken. The prepared teeth are fitted with a temporary acrylic resin restoration until an inlay restoration has been made in the dental laboratory.

Inlay restorations are fabricated using dental technology measures. First an impression is taken of the cavity, and the restoration is made indirectly on a model by the following methods:

- Cast in metal using the lost wax technique
- Milled out of a ceramic block using computer numeric controlled (CNC) technology
- Compressed in ceramic by the extrusion technique
- Ceramic fired onto galvanic carrier layers
- Cured in composite using the layering technique

After fabrication, inlay restorations are inserted with cement or special bonding agents. They adhere to the cavity walls by a gripping effect and static friction.

Metal inlay restorations are made from gold alloys; other metal alloys (non–precious metal and palladium alloys) are rarely used. A working model and opposing jaw model are first fabricated from artificial stone and placed in the articulator. By the traditional method, the inlay restoration is carved in wax, sprued, invested, and cast. Metal inlay restorations can also be milled out of a full metal block using CNC technology.

Composite and ceramic inlay restorations can be fabricated by the indirect technique using an impression and plaster cast and adhesively fixed in the cavity by the acid-etching technique.

Various methods are used for fabricating ceramic inlay restorations. In the sintering method, a split model made of plaster and a duplicate model made of castable material are prepared, onto which the restoration is sintered. If the ceramic inlay restoration is made of castable ceramic (eg, glass-ceramic) or pressed ceramic, the restoration must be carved out of wax on the working model and invested. For fabrication by computer-controlled techniques, an optical impression of the prepared cavity must be made using special imaging methods. On the basis of this impression, the inlay restoration is ground out of a compact ceramic block using CNC techniques. In the copy-grinding method, a restorative block made of acrylic resin is mechanically scanned, and a ceramic duplicate is milled out of a ceramic block.

Composite inlay restorations are made of composite with a high proportion of inorganic fillers. They can be fabricated directly in the mouth or by indirect fabrication on a working model in the dental laboratory.

In the case of electroformed inlays, tooth-colored ceramic is fired onto a thin carrier layer of electroformed gold. A thin gold layer is electrogalvanically deposited on the model die in order to fire on a ceramic layer. These inlay restorations have very good accuracy of fit and are inserted using phosphate cement. A thin gold margin remains visible, which is esthetically unsightly.

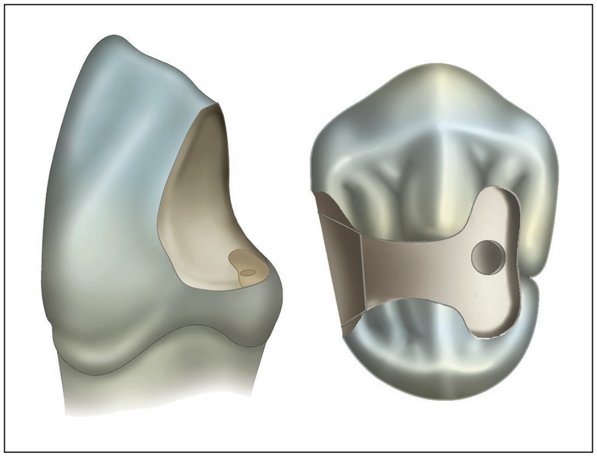


Fig 1-17 An extensive cavity restoration can be created with additional retentions in the form of pinholes. Short pins engage in these holes to secure the restoration. The term *pinlays* is used for restorations that mainly gain their retention in the dental tissue by means of pinholes or pins.

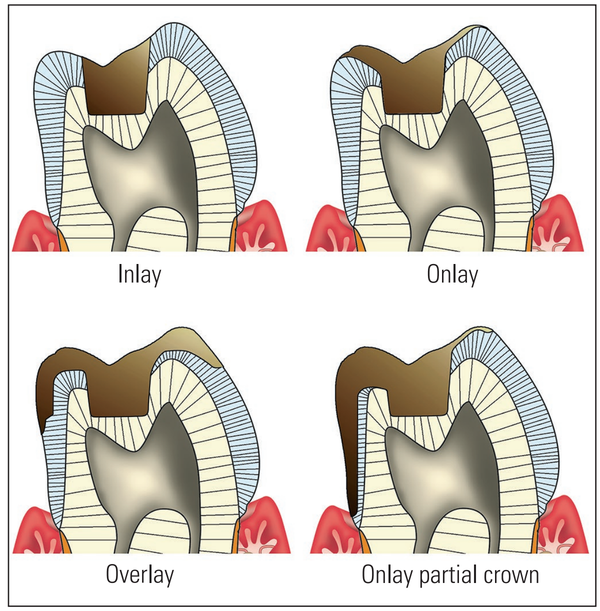


Fig 1-18 The term *inlay restoration* encompasses restorations made of metal in differing dimensions; they are classified according to the amount of dental substance to be replaced—inlays: intracoronal cavities; onlays: cavities on occlusal surfaces; overlays: cavities on occlusal surfaces and the occlusion-bearing cusps; onlay partial crowns: cavities involving the vertical smooth surfaces outside the portion visible from the vestibular view.

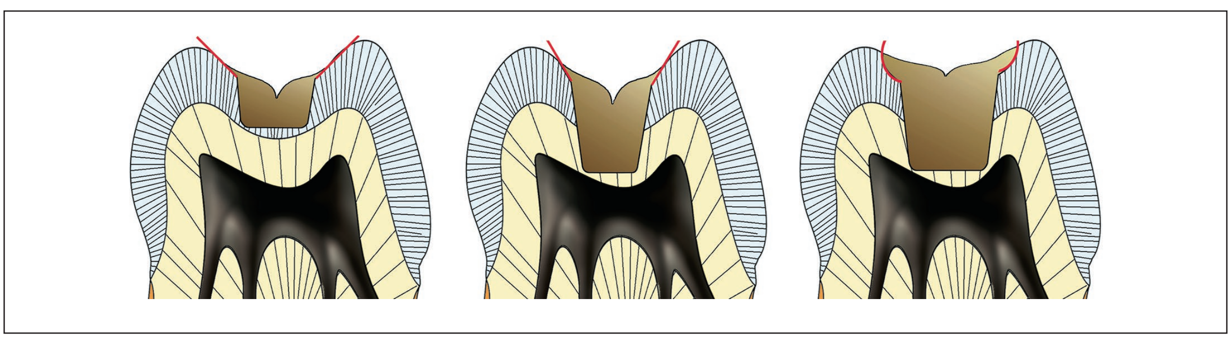


Fig 1-19 The bevel of the cavity margins for metal inlay restorations is designed differently, depending on the cavity volume: A flat cavity is given 45-degree bevels; a very deep cavity is given steeper bevels; and very deep and wide cavities are prepared with round bevels.

Occlusal inlays

For occlusal inlays, the width of the cavity is half the intercuspal distance in order to maintain the stability of the dental substance and leave the occlusal contacts on the natural dental tissue. An occlusal cavity is 1.5 mm wide and deep and includes the main fissures. The cavity walls have a common path of insertion without undercuts. The inner edges of the cavity are rounded, and

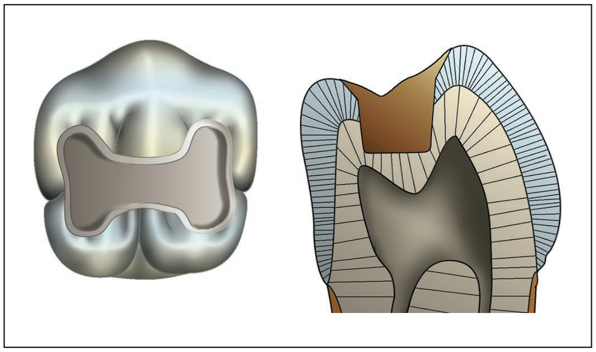


Fig 1-20 The cavity for a single-surface metal inlay has a minimum depth of 1.5 mm; preparation is slightly divergent, and there are no undercuts. The cavity margin does not lie in the area of occlusal contacts and is prepared with an enamel bevel.

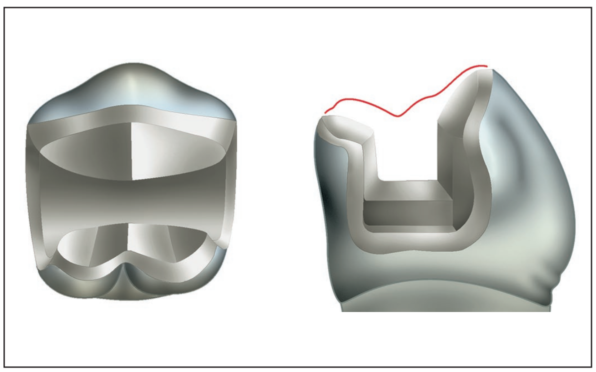


Fig 1-21 An onlay incorporates the whole occlusal surface and extends into the approximal surfaces. The approximal extensions run lingually or vestibularly; an approximal-cervical shoulder is usually prepared. An enamel bevel is prepared around the cavity margin.

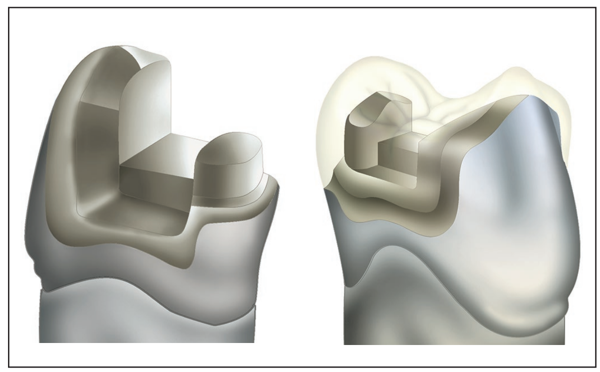


Fig 1-22 The overlay replaces the occlusal surface and fully encompasses the occlusion-bearing cusps. A shoulder is usually prepared around these cusps, while the nonsupporting cusp is surrounded by a simple enamel bevel.

the occlusal margin is beveled so that the margin of the metal restoration can be refined by reworking (Fig 1-20). Antagonist contacts lie either completely on the natural dental substance or on the surface of the restoration.

Inlay splints refer to cast restorations that are soldered together; they are used to fix mobile teeth to adjacent teeth and stabilize them. Inlays can be used to anchor partial dentures, but they offer less retention to abutment teeth than the use of crowns.

Onlays and overlays

Onlays or overlays are prepared when the dental hard tissue is weakened by large caries lesions and occlusal corrections are also necessary. For an onlay, preparation involves the occlusal surface, including the cusp tips, and usually extends into both approximal surfaces (Fig 1-21). Overlay preparation incorporates the bearing cusps and ends in a shoulder preparation with bevel. The preparation margin runs level with the height of the contour and extends into both approximal surfaces. There is a smooth crossover between overlays and partial crowns (Fig 1-22).

A core buildup made of plastic restorative materials (glass-ionomer cement or composite) becomes necessary for badly damaged teeth before the onlay or overlay preparation can be started. All restorative margins must lie within healthy dental hard substance and not in the buildup material. Such core buildups are anchored with parapulpal pins in the form of root canal screws unless a cast post and core is being fabricated.

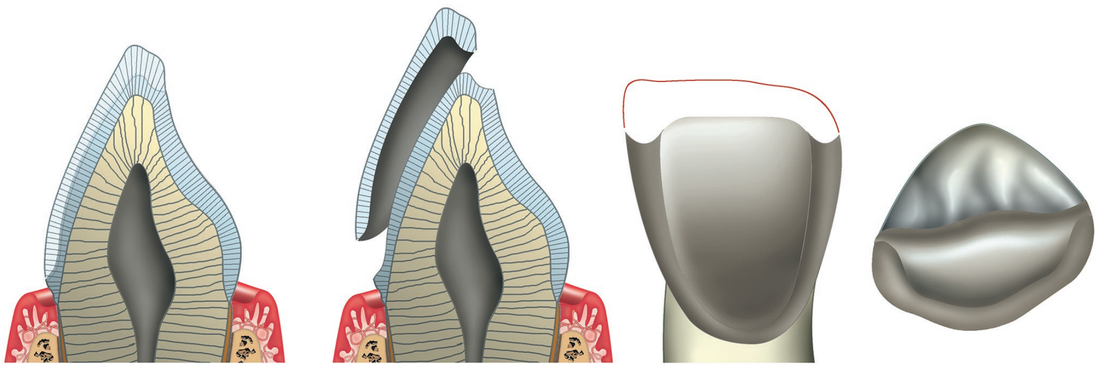


Fig 1-23 Veneers replace the labial facet of an anterior tooth. For this purpose, a consistent layer approximately 0.8 mm thick is ground out of the enamel into the approximal areas; the incisal edge is prepared into the lingual area. The approximal crown width is retained, and undercuts are avoided. The prepared surface is conditioned by acid etching to receive the ceramic veneer and therefore must lie solely within the enamel area. A composite bonding agent is used to achieve the adhesive bond.

Veneers

Veneers, also known as *laminates* or *facings*, are fabricated when circular preparation of dental crowns is to be avoided in order to preserve ample natural dental tissue as well as esthetics. Veneers can be made individually out of acrylic resin, composite, and ceramic directly in the mouth or in the dental laboratory, or they can be milled out of prefabricated ceramic blocks using CNC machining. Veneers are indicated for discolored facets or large anterior restorations, enamel cracks or chips, and morphologic or positional corrections.

To prepare a veneer stump, the labial enamel and the incisal edge into the approximal surfaces are removed to a thickness of about 0.5 mm without exposing the dentin. The preparation surface is slightly curved in the horizontal and vertical direction and should be smooth without undercuts. The approximal surfaces can be incorporated as far as halfway; if the approximal areas are intact and not discolored, the approximal contact made of natural dental tissue can remain unchanged.

The veneers are retained on the dental enamel by micromechanical adhesive means. For the purposes of micromechanical retention, the enamel is conditioned at the cavity margin using the acid-etching technique, which enlarges the surface of this enamel area and renders it wettable (Fig 1-23). The inside of the veneer is also conditioned (porcelain veneers are etched with hydrofluoric acid) and prepared with adhesive silane as a bonding agent to the composite. Adhesive cementation can be done with self-curing dual cement or light-curing composite cement.

The acid-etching technique is used to condition the surface of the enamel for adhesive cementation of ceramic or composite inlay restorations. The enamel surfaces intended for adhesive bonding are cleaned and treated with orthophosphoric acid (H_3PO_4) or phosphoric acid gel so that the apatites of the enamel prism cores partially dissolve. After 30 to 60 seconds, the etchant and dissolved enamel constituents are rinsed off. This leaves surface roughness between 5 and 8 μm deep, creating an enlarged surface with pores for micromechanical retention of the cementing acrylic resin. The roughened cavity margins and the restoration etched on the underside are silanized and cemented in place with a composite bonding agent. During acid etching and insertion with the composite bonding agent, irritation of the pulp and prolonged hypersensitivity of the restored tooth can arise if dentin areas are touched. Therefore, the cavity margins for adhesively cemented inlay restorations must lie within the area of etchable enamel.

2

Coronal Restoration

Definition and Classification

Single-tooth rehabilitation is a significant area of dental technology work. When an individual tooth is so damaged by caries, fractures, or other harmful factors that other dentistry measures are no longer able to preserve the tooth, an artificial crown may be placed on the prepared tooth like a cap. With this type of prosthetic single-tooth restoration, the masticatory function and health of the existing teeth can be maintained and restored.

An artificial dental crown must take on the functions of a natural crown and must accurately reproduce the ideal functional form of the natural tooth shape. Accurate knowledge of tooth morphology is therefore an essential requirement for dental technicians when fabricating a coronal restoration. Every tooth has specific functional shape characteristics that must be addressed by coronal restoration. Artificial crowns have many important functions, as outlined below. Figure 2-1 provides an overview of the various types of artificial crowns.

The occlusal surfaces of artificial crowns adapted to the antagonists should do the following:

- Achieve full functional contact
- Stop jaw movement
- Allow transfer of forces to the periodontium during mandibular movements with tooth contact (Fig 2-2)
- Allow interference-free gliding without overloading the periodontium

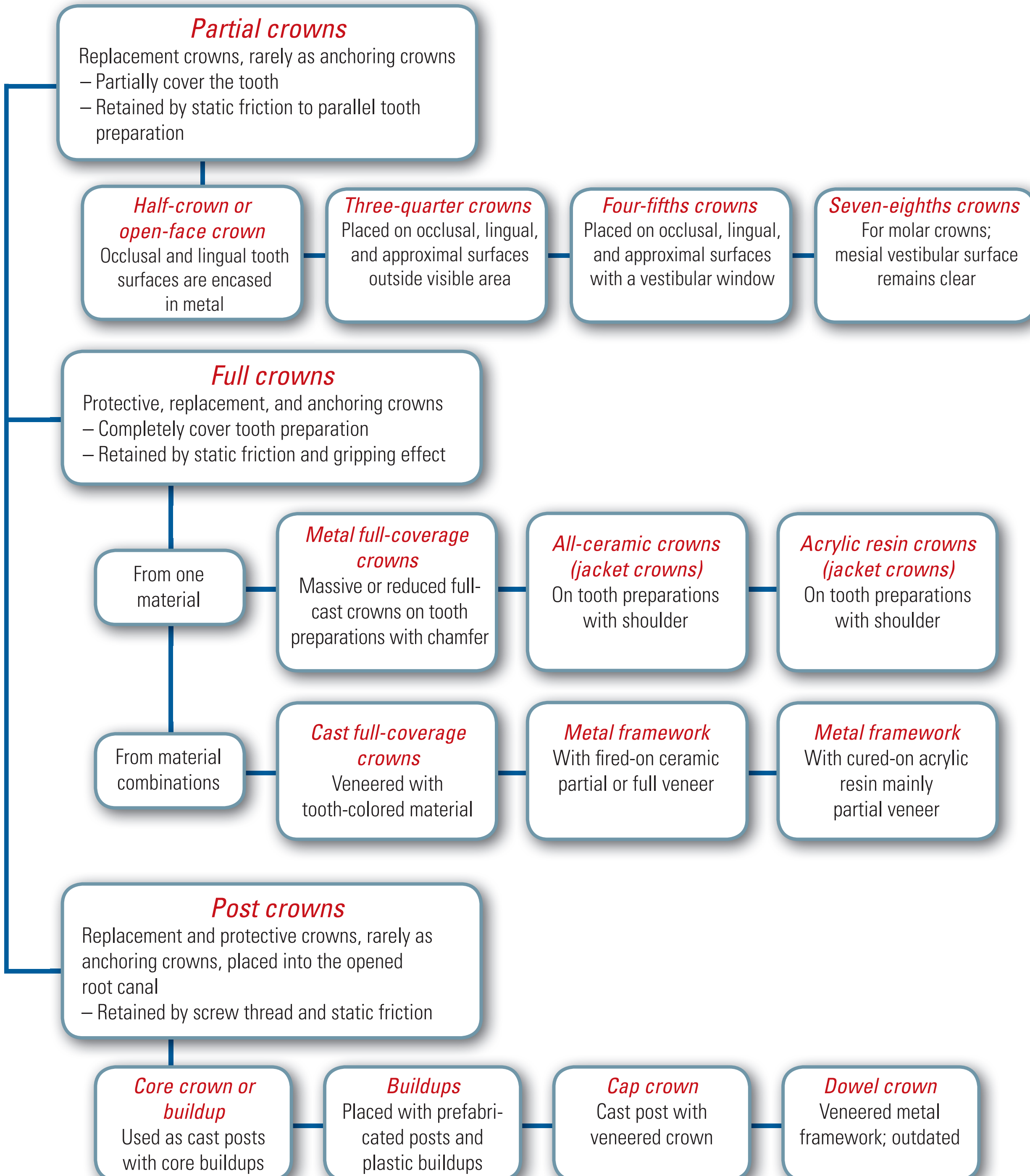
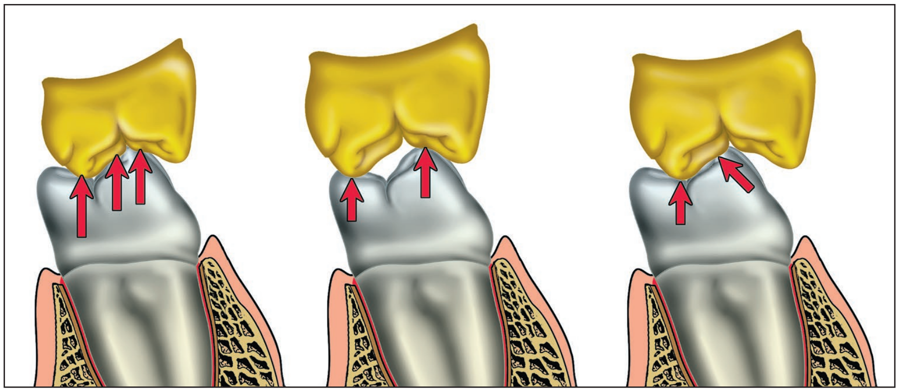


Fig 2-1 Diagram of crown types.

Fig 2-2 When fabricating an artificial occlusal relief, the functional surfaces must be adapted to the antagonists to ensure precise transfer of forces. Incorrect contouring of occlusal surfaces leads to faulty contacts and harmful transverse thrust. A lack of occlusal contacts can result in displacement of teeth.



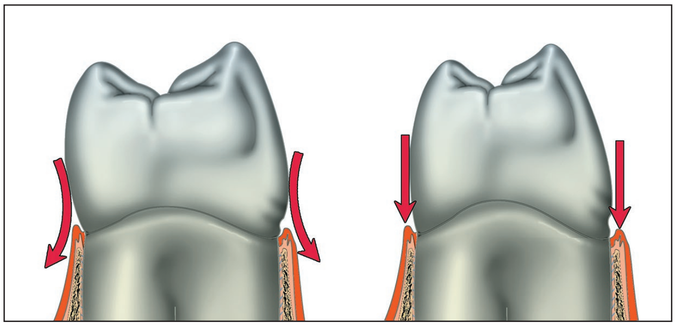


Fig 2-3 The anatomical surface bulges are functional shape characteristics that must be reproduced in artificial crowns. The so-called vertical curvature characteristics serve to protect the marginal periodontium; excessive curvatures produce undercuts that inhibit self-cleaning of the teeth. The horizontal curvatures of the vestibular surfaces also have to be reproduced to ensure that no niches are formed where contaminants may accumulate.

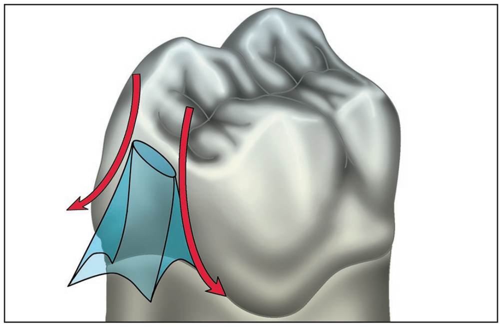


Fig 2-4 The approximal surfaces form the approximal contact point that covers and protects the interdental papilla. When this contact is reproduced in artificial crowns, space must be created for the interdental papilla.

The precise anatomical surface curvature of the artificial crown does the following:

- Protects the marginal periodontium (Fig 2-3)
- Creates approximal contacts
- Protects the interdental papilla (Figs 2-4 to 2-7)
- Guarantees support in the dental arch
- Aids self-cleaning of the masticatory system (Figs 2-8 and 2-9)
- Fulfills esthetic demands
- Supports phonetic functions

A precise and accurate fit enables the artificial crown to do the following:

- Form a unit with the prepared tooth
- Preserve the tactile sense (Fig 2-10)
- Prepare food for digestion

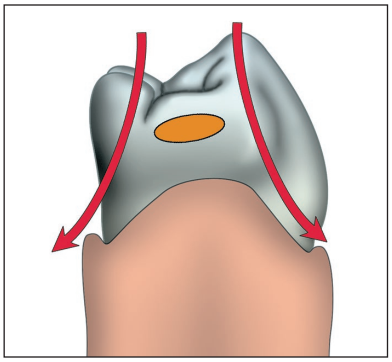


Fig 2-5 If the interdental papilla is well preserved, punctate shaping of the approximal contact is enough to maintain the protective function.

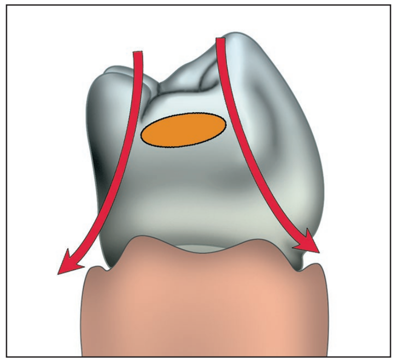


Fig 2-6 If the interdental papilla is reduced, the approximal contact must have a wider shape to secure the protective function.

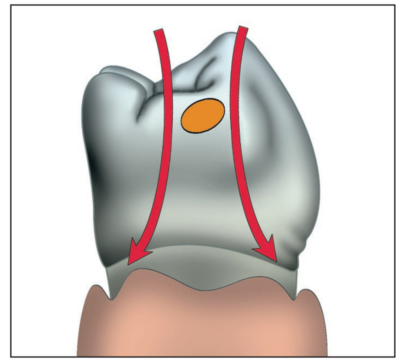


Fig 2-7 If the interdental papilla is reduced and shaping of the approximal contact is punctate, food is no longer deflected away from the interdental space.

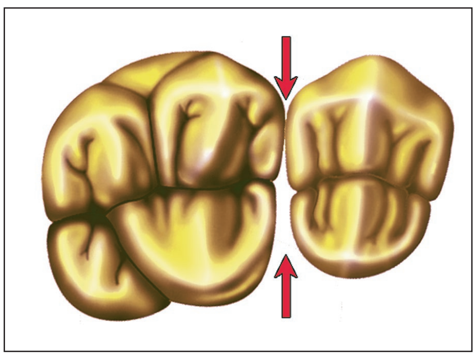


Fig 2-8 The approximal contact points viewed occlusally lie in the direction of the buccal cusps so that smaller niches are formed on the vestibular rather than the lingual side. The lingual areas of the teeth are easier to clean because of the action of the tongue.

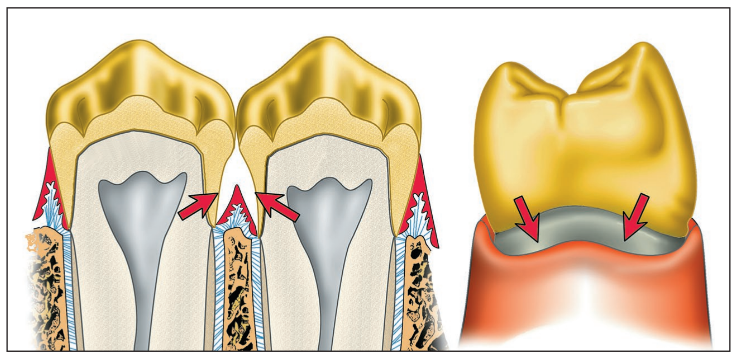


Fig 2-9 Contact points that overhang too much will create large interdental niches that are no longer filled with tissue. Deposits can accumulate because self-cleaning is prevented. This can result in chronic inflammation, and damage to the periodontal tissue cannot be ruled out.

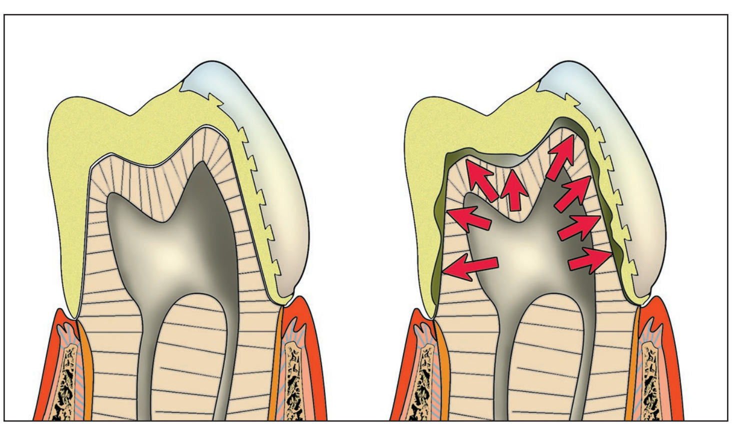


Fig 2-10 Accuracy of fit is not merely a requirement that sets the standard for technical expertise but also a functional necessity. Precise accuracy of fit allows the tooth to preserve a tactile sense and, as a mechanical unit, allows smooth transfer of forces. In the marginal area, accuracy of fit prevents damage to the marginal periodontium.

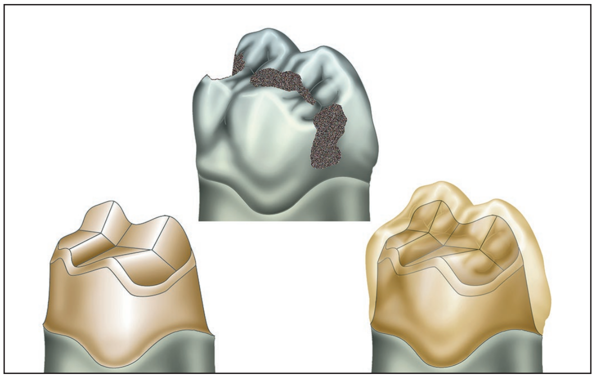


Fig 2-11 Artificial crowns replace lost hard tissue from teeth. If natural dental crowns are partly destroyed by caries and a tooth needs to be protected against further harmful influences, a protective crown should be fabricated that fully covers the natural dental crown.

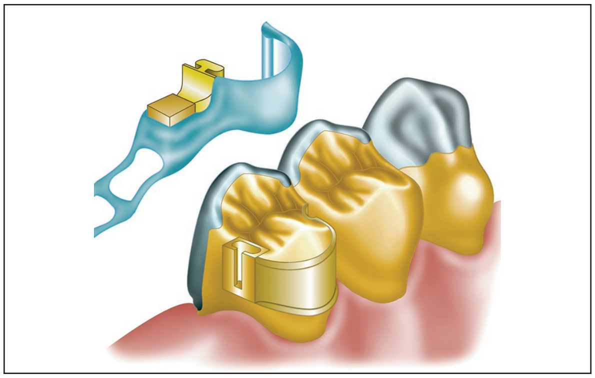


Fig 2-12 Artificial crowns can be used to bear retention parts. They are also used to protect teeth that will receive clamps. Generally speaking, anchoring crowns are associated with parallel fits, tapered designs, or prosthetic auxiliaries.

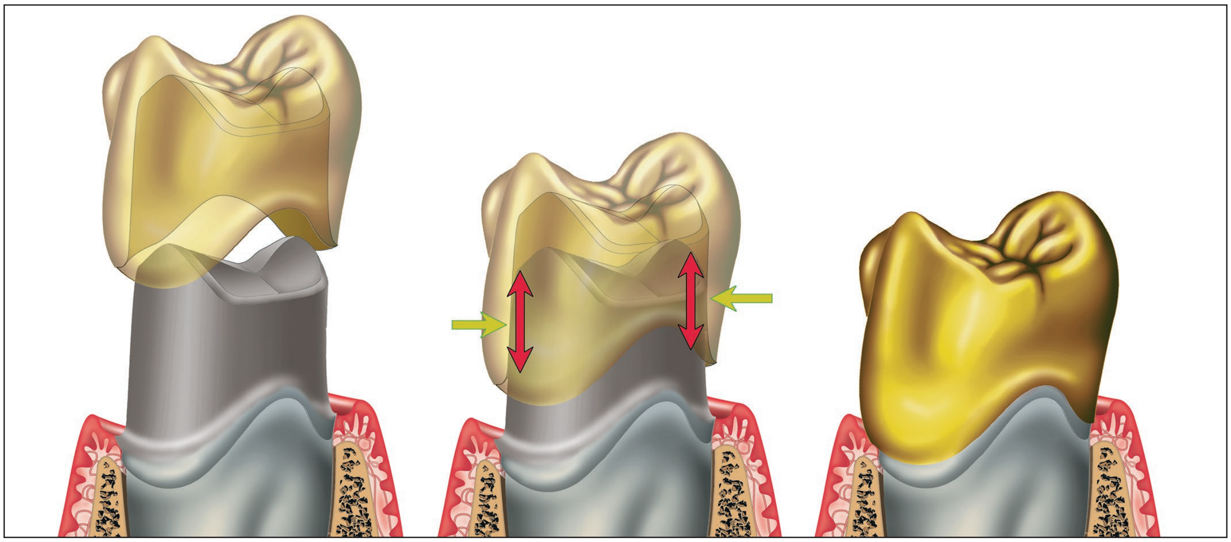


Fig 2-13 Retention of artificial crowns onto the tooth preparation can be achieved by two physical mechanisms: static friction and a gripping effect. Both are produced by the complete enclosure involved in a full crown and guarantee secure retention of the crown.

All of these functions are equally important and must be fulfilled within the broad range of applications for artificial crowns.

Classification of artificial crowns is based on their specific range of functions:

- *Replacement crowns* replace lost hard substance of the tooth, which can no longer be restored by other (conservative) dentistry measures.
- *Protective crowns* protect the tooth preparation against harmful influences (caries or defects caused by clamps) by completely covering the organic dental substance (Fig 2-11).
- *Supportive or anchoring crowns* support and anchor fixed partial dentures and partial prostheses as abutments or carriers for attachments or prosthetic auxiliaries (Fig 2-12); they are fixed to the prepared tooth.
- *Full crowns* cover the clinical tooth preparation completely, while fixation (retention) is achieved by static friction resistance and a gripping effect (Fig 2-13).

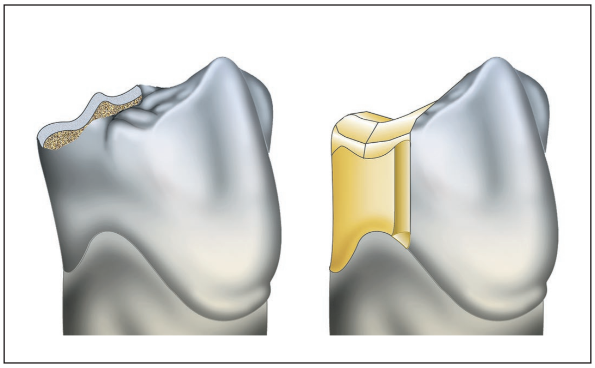


Fig 2-14 If a dental crown is destroyed by fractures only in isolated places, the missing hard substance can be replaced by a partial crown. These partial crowns do not cover the tooth completely but only individual surfaces of the dental crown.

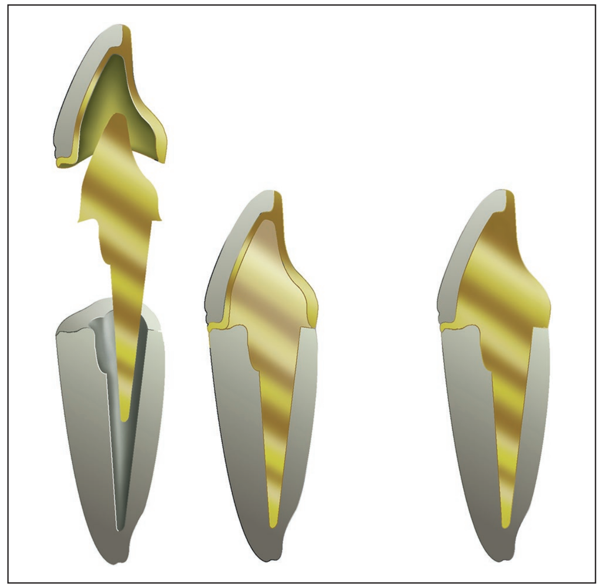


Fig 2-15 If the dental crown is completely destroyed, a post crown can be fabricated by inserting a post that will bear the replacement crown into the opened root canal. A long, accurately fitting post creates adequate static friction. The post with the core buildup and the replacement crown are fabricated separately.

- *Partial crowns* only partially cover the prepared tooth—usually lingually, occlusally, and approximally—in order to preserve the natural dental substance and color in the labial and buccal area (Fig 2-14). Retention is achieved by static friction resistance of parallel surfaces, grooves, and pins.
- *Post crowns* come in the form of dowel crowns and cast coping crowns or (root) buildups. These constructions involve inserting a post into the exposed pulp canal, which seals the root canal and bears a core buildup for the actual crown (Fig 2-15). The post is held in the root canal via a screw thread, static friction resistance, and a gripping effect.

Full and partial crowns are made from a variety of materials:

- Metal (full-coverage cast)
- Ceramic (fired, pressed, milled)
- Acrylic resin (polymerized)

Full and partial crowns (including post crowns) made from combinations of materials are veneered metal frameworks with fired-on ceramic or cured-on acrylic resin.

Indications for Coronal Restoration

Coronal restoration is indicated whenever the biomechanical and hence supportive function within the dental arch has to be secured. Similarly, coronal restoration is performed as a therapeutic function to stop any deterioration of the dentition that has already begun. A coronal restoration should also fulfill prophylactic functions, stop secondary damage, and prevent disease-related changes, thus taking on a protective function. Coronal restoration can improve or restore the function of the masticatory system and therefore has a regulating function (see Fig 1-10).

Substance loss from a tooth due to caries or fractures makes coronal restoration necessary. The remaining tooth preparation must be stable and offer adequate retention, while the periodontium must not be damaged. In this situation, the artificial crown mainly performs a protective function against advancing organic decline and replaces lost tissue. Abrasion of the incisal edges and the occlusal relief requires coronal restoration if the entire occlusal field needs to be corrected. Here the artificial crown takes on a replacement and supporting function if missing supports from centric occlusion need to be built up again.

Completing an interrupted dental arch with a fixed or removable partial replacement can be done by coronal restoration. The artificial crown may be a fixed partial denture abutment, a telescopic anchoring crown, a protective crown for clamps, or an anchoring crown for attachments. In this process, the artificial crown takes on a protective or supporting function in combination with several teeth.

Coronal restoration is also carried out when there are esthetic concerns (eg, morphologic defects, discoloration, or positional anomalies) if orthodontic measures are ruled out. In this situation, the artificial crowns take on regulating tasks because they fulfill replacement, protective, and supportive functions. Faulty tooth shapes are always associated with functional deficiencies, while discolorations may be an indication of destroyed pulp. Positional corrections help to preserve the periodontium, support the self-cleaning function, and restore the function of the closed dental arch.

A risk-benefit assessment should be undertaken for every dental procedure. If an artificial crown is being fabricated, a sufficient quantity of natural dental tissue has to be removed, which means pulp damage may have already occurred when the tooth was being prepared. Thus, coronal restoration is contraindicated, for instance, for adolescent teeth with a large pulp cavity and wide dentinal tubules as well as incomplete root growth. Coronal restoration is also contraindicated if the tooth has characteristics of disease such as pathologic apical processes, incomplete endodontic treatment, or inflammatory changes to the marginal periodontium. These problems must first be treated and cured.

Tooth mobility, gingival and bony pockets, and resorption of a socket beyond the apical third of the root are also regarded as contraindications, as is excessive loss of substance from the tooth preparation, because there is no longer sufficient mechanical retention to hold the crown in place.

For esthetic reasons, fabrication of a full-metal crown may be contraindicated in the anterior region. Certain types of crown may thus be contraindicated, although this is subject to the dentist's own judgment and is not necessarily discernible on a working model. Determining when a coronal restoration is indicated remains a matter of the dentist's expert diagnosis, but dental technicians should be aware of the general criteria for using coronal restorations.

Poor oral hygiene is always a contraindication for coronal restoration because deposits (plaque) lead to caries and periodontal disease. Before coronal restoration is considered, the patient must first be motivated to take adequate oral hygiene measures after receiving suitable dental education and instruction.

Fabrication of a crown is the result of collaborative teamwork between the dentist and the dental technician. The tooth is first prepared, and an impression is taken so that the technician can prepare a working model; adjust it in an articulator; and carve, cast, and finish the artificial crown. The dentist cements the finished crown in place on the tooth preparation.

Preparation of a Tooth

If a tooth is to be fitted with a crown, it must be prepared; that is, enough dental tissue must be removed to enable the artificial crown to be pushed over the tooth. Pushing a thin metal sleeve over an unprepared tooth would enlarge the natural tooth by the thickness of the metal plate. It would then interfere with the opposing dental arch, protrude out of the arch, and, if the sleeve could actually be pushed over the approximal contact points, cause faulty relationships. Furthermore, the sleeve would not fit closely in undercut areas. This is why a tooth needs to be prepared before receiving a crown.

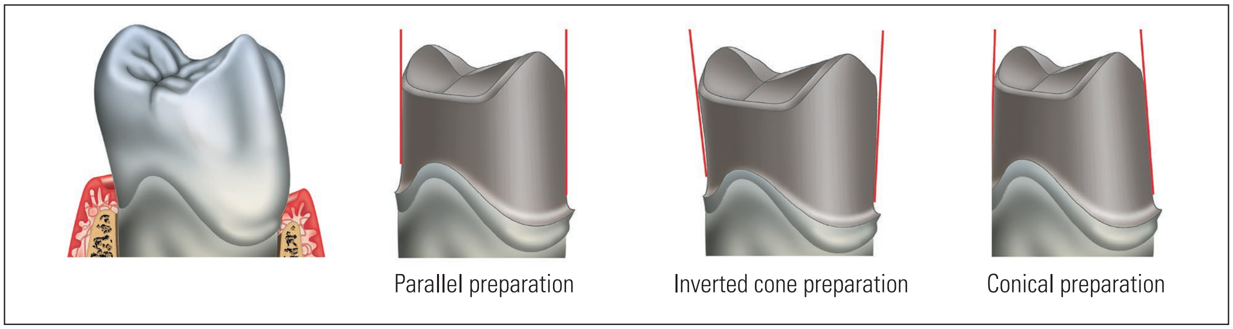


Fig 2-16 Preparation of a cylindric stump is at the limit of what is technically feasible because precise parallelism cannot be seen with the naked eye. The preparation shapes illustrated here are achieved by chance.

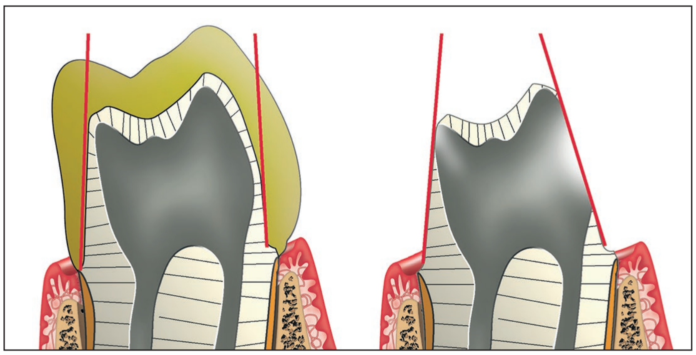


Fig 2-17 A preparation with parallel walls requires less loss of hard substance than a tapered preparation, and the risk to the pulp is also lower.

The aim of preparation is to remove the damaged dental substance and, if necessary, remove enough healthy dental tissue to ensure that the widest circumference of the tooth lies at the lowest point on the tooth preparation. An attempt is made to smooth the area around the tooth without creating any undercuts.

One approach to preparation is to create a cylindric preparation that would have almost parallel walls and would result in the least amount of hard tissue loss (Figs 2-16 and 2-17). As exact parallelism is impossible to see with the naked eye, this kind of fabrication would be at the limit of what is technically feasible. Furthermore, errors would arise when taking an impression and cementing the crown in place because of the piston effect of a parallel fit.

A better preparation design is a slightly conical (ie, tapered) preparation with a preparation angle between 3 and 8 degrees toward the occlusal surface. This design allows interference-free, accurate impression-taking and guarantees adequate retention due to static friction and a gripping effect (Figs 2-18 to 2-21). When the restoration is being cemented in place, the cement is able to flow away more easily until tactile contact of all surfaces is achieved, leaving a minimum thickness of cement equivalent to its grain size, which increases the friction and gripping resistance.

A basic tooth preparation has the following characteristics:

- At its widest circumference, it meets the preparation margin.
- There is sufficient height for mechanical retention.
- The shape is slightly conical and has an angle of 3 to 8 degrees.
- The preparation surfaces are not undercut.
- An interocclusal rest space is prepared.

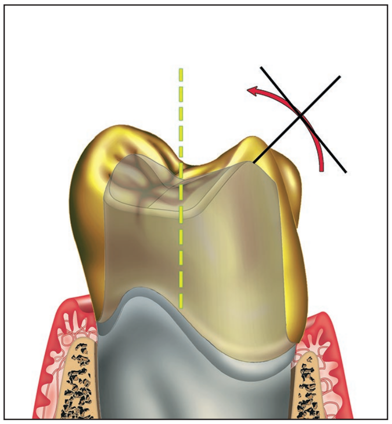


Fig 2-18 A tall tapered preparation with a preparation angle up to 6 degrees offers the best retention for a coronal restoration. The crown cannot tip off the preparation even with eccentric loading.

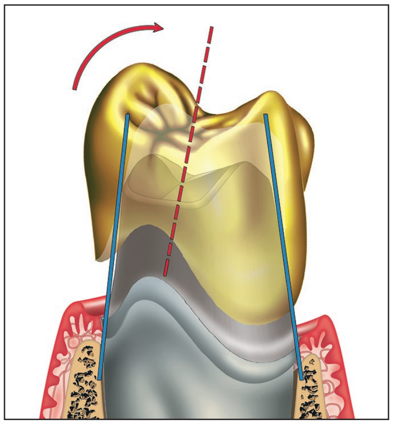


Fig 2-19 A very steeply tapered preparation with a preparation angle greater than 6 degrees offers less retention for the coronal restoration. The crown can tip off the preparation if exposed to eccentric loading.

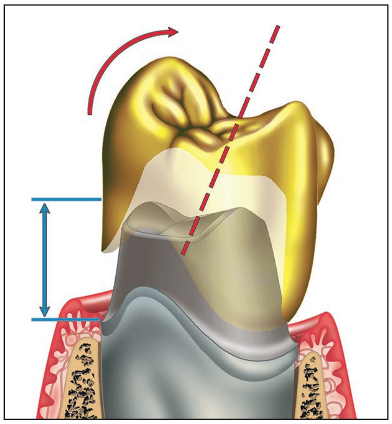


Fig 2-20 A very tapered and very short preparation offers the least retention for a coronal restoration. Even slight eccentric loading will tip the crown off the preparation.

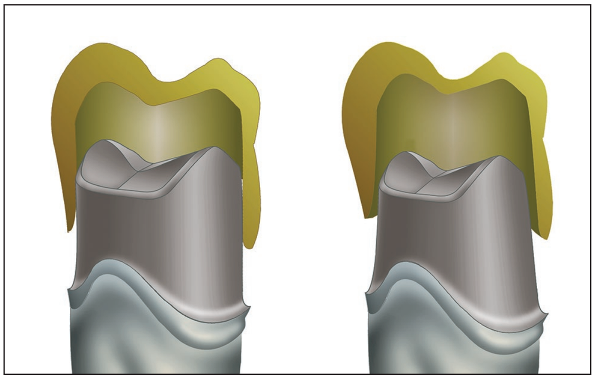


Fig 2-21 A cylindric preparation with parallel walls will result in a so-called piston effect during impression-taking and crown placement, making these processes extremely difficult if not impossible. An impression can easily be taken of a tapered preparation, and the crown can be placed and cemented in place with equal ease, without causing any buildup of cement.

Shaping the Preparation Margin

The preparation margin is the border between the prepared and unprepared tooth surface (Figs 2-22 to 2-24). It is the responsibility of the dentist to make a clear preparation margin, and it is the responsibility of the dental technician to ensure that the crown margin ends exactly at the preparation margin. Thus, the technician is less focused on how far a tooth is prepared at the neck or how deep or high the preparation margin is in relation to the marginal periodontium. However, if the crown margin lies above the preparation margin, caries will ensue. If it lies below the preparation margin (ie, in the gingiva) damage to the gingival margin will occur.

For the purposes of accurate and safe fabrication, a supragingival preparation margin is chosen, which is markedly above the gingival crevice. This means that the crown margin is kept clear of the periodontium and cannot damage the

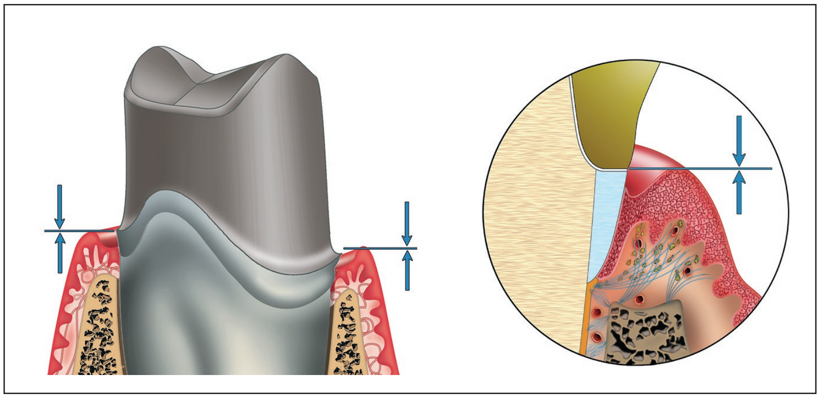


Fig 2-22 A gingival preparation margin runs level with the gingival margin but not deep in the gingival crevice. As a result, the marginal periodontium is untouched and undamaged. The eventual crown margin can be clearly seen and is usually esthetically satisfactory.

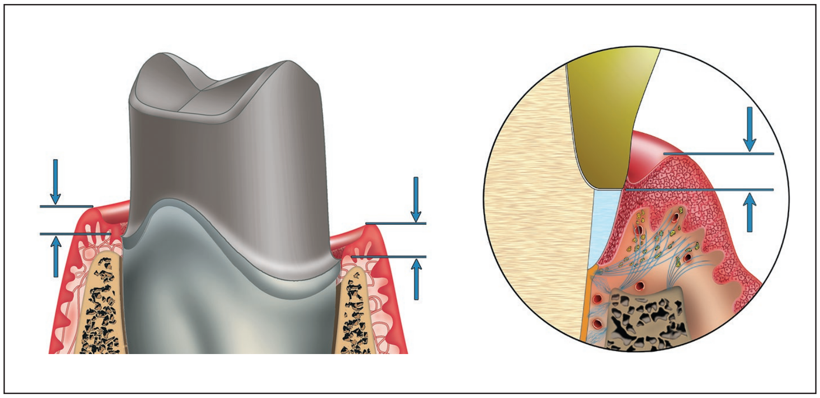


Fig 2-23 A subgingival preparation margin runs deep in the gingival crevice and affords very good caries prevention provided the position of the crown margin fits accurately. Because it is difficult to check the crown margin, however, irritation of the marginal periodontium and even gingival retraction may occur.

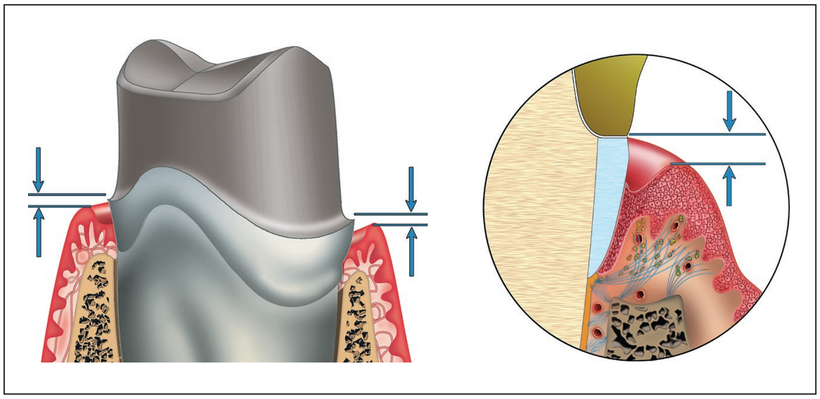


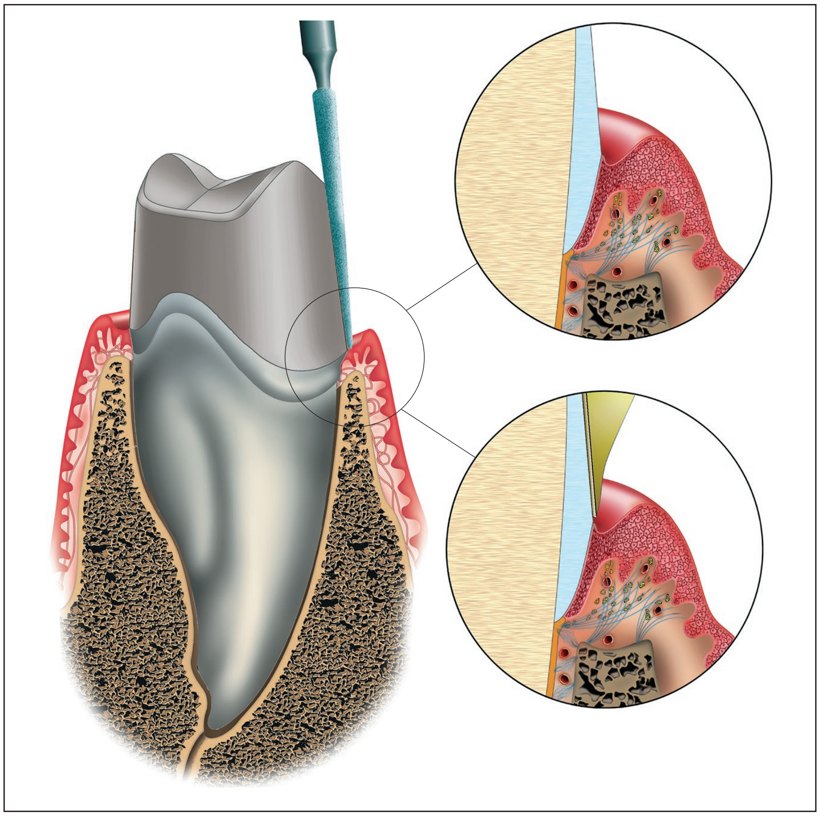
Fig 2-24 A supragingival preparation margin lies well above the gingival margin. This course is very beneficial for periodontal hygiene but unsatisfactory esthetically, and it provides no protection against caries in the presence of plaque.

periodontal tissue, the critical area can be kept clean, and it is easier to take an impression of the preparation margin.

However, supragingival preparation has serious drawbacks: If the margin is placed too high, the tooth preparation becomes too short and does not offer enough mechanical retention for the crown. If the finish line is in the visible region, the esthetics will be unsatisfactory. For cervical defects, the preparation must follow an infragingival course, just as infragingival finish lines offer better caries protection in dentitions with active caries.

During crown fabrication, special attention must always be paid to the crown margin, which is defined by the preparation margin. The quality

Fig 2-25 In tangential preparation, the widest circumference of the conical preparation and the preparation margin coincide. The coronal restorative material overlaps the tooth and can displace the marginal periodontium in some circumstances. If the crown margin is shaped like a tapered margin, it runs razor-sharp into the depth of the gingival crevice. This tapered margin is rarely stable enough not to deform when the crown is fitted.



of the transition from tooth to coronal restorative material is determined by how accurately the crown margin fits the preparation margin. The accuracy that is achievable depends on the shaping of the finish line. At the preparation margin, the crown material should not overlap the tooth preparation but should be sunk into the tooth.

Three forms of preparation margin are used: *(1)* tangential preparation, *(2)* chamfer preparation, and *(3)* shoulder preparation.

Forms of Preparation Margin

A tangential preparation is ground like a tapered margin (Fig 2-25). Tangents can be placed in a vertical direction all over the basic conical shape of the tooth preparation. Ideally, the preparation margin should describe the root cross section and the crown margin finish line. The preparation margin finish line should lie at the bottom of the gingival crevice; subgingival preparation is only done for protective crowns in dentitions with active caries.

Given this preparation finish line, the crown margin must taper off sharply and evenly while fitting closely; the crown must then be given a convex shape above the gingival crevice. The crown itself must have an occlusal support so it is not pushed beyond the preparation margin.

The coronal restorative material overlaps the tooth preparation. However, as it has to taper thinly, it may become frayed and bend upward. The artificial crowns have to be overcontoured at the preparation margin, thereby forming a step that encourages plaque accumulation.

The tangential finish line is easy to prepare and requires the least loss of dental substance. This preparation finish line is barely visible in the mouth and not at all visible on the working model. A precise crown margin cannot be created and

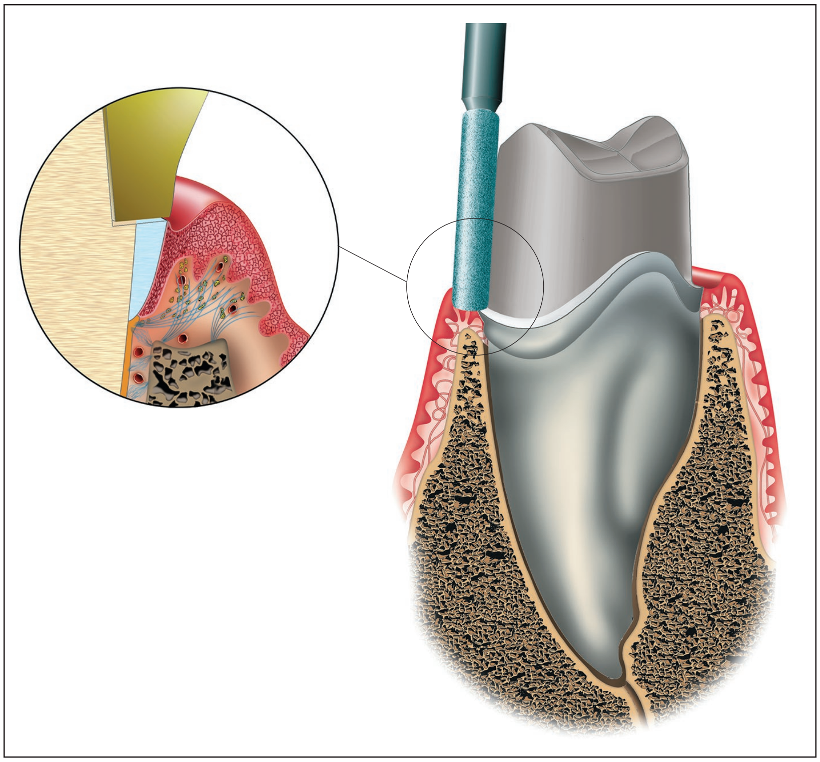


Fig 2-26 To sink the coronal restorative material into the tooth preparation, a shoulder is created for the preparation margin. The coronal restorative material ends flush with the tooth, usually in the depth of the gingival crevice. The crown margin does not occupy any more space than the natural dental substance. To ensure stability, the shoulder slopes slightly inward toward the tooth. If the crown is pressed onto the tooth by masticatory pressure, the crown material will slip inward like an inclined plane and will be pressed against the tooth.

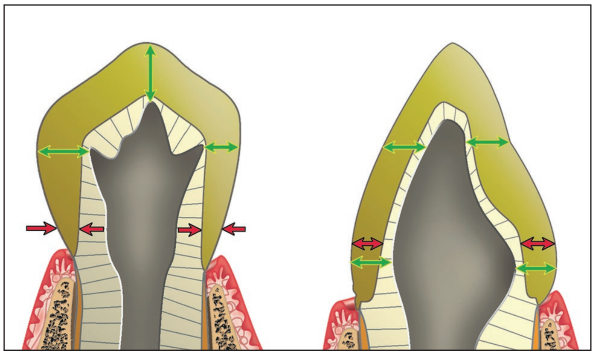


Fig 2-27 The thickness of dental hard tissue over the pulp of a canine. The dental tissue is considerably reduced by shoulder preparation, which can damage the pulp. In general, this means the tooth is mechanically weakened.

only happens by chance. This approach is used for young teeth with a large pulp chamber so that acrylic resin crowns can be made as temporary replacements.

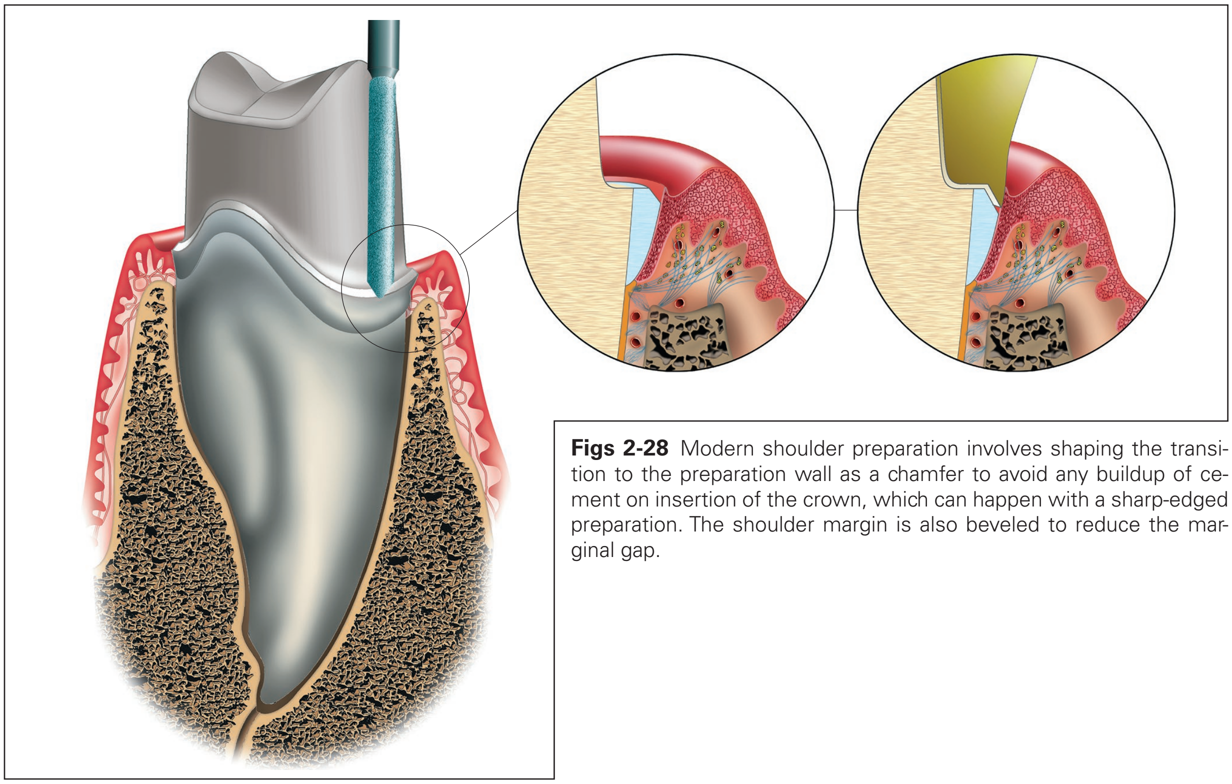
Owing to the lack of available space, this form of preparation is not suitable for metal-ceramic restorations, all-ceramic restorations, or for full-cast crowns. The tangential form of preparation cannot offer static support against occlusal forces.

Shoulder preparation forms a circular step around the conical tooth preparation. This offers static support to the coronal restorative material, which is particularly valuable for ceramic or acrylic resin crowns. The material for the artificial crown is sunk into the dental tissue and forms a flush transition between tooth and coronal restoration (Fig 2-26).

The preparation margin can be clearly seen on the model and thus allows for precise working. A shoulder preparation is easy to produce because the preparation tools have a cervical guide.

In the case of shoulder preparation, the tooth preparation becomes much smaller than the root cross section, and there is considerable loss of substance from the tooth. The stability of the tooth preparation may be reduced, putting the pulp at risk (Fig 2-27). To prevent a buildup of cement on insertion, the start of the shoulder is chamfered to the tooth preparation.

The edge of the shoulder can be beveled slightly to the gingival crevice to optimize the marginal



Figs 2-28 Modern shoulder preparation involves shaping the transition to the preparation wall as a chamfer to avoid any buildup of cement on insertion of the crown, which can happen with a sharp-edged preparation. The shoulder margin is also beveled to reduce the marginal gap.

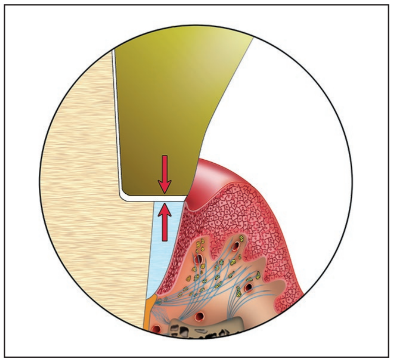


Fig 2-29 If a shoulder preparation is straight, a vertical marginal gap defect will occur because the crown cannot be lowered as far as the shoulder due to the thickness of the cement. The cement will also be washed out by normal teeth-cleaning in a horizontal shoulder arrangement.

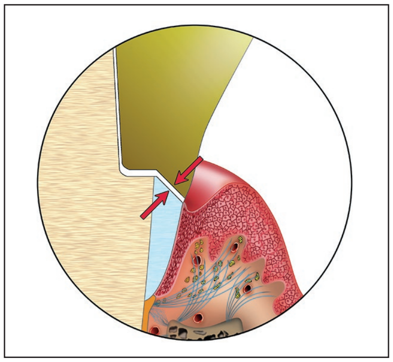


Fig 2-30 With a 45-degree bevel to the shoulder, the vertical marginal gap defect is markedly reduced, and the cement cannot be washed out as easily. This bevel is sufficiently identifiable in the mouth and is visible enough on the model so that the preparation margin can be readily exposed.

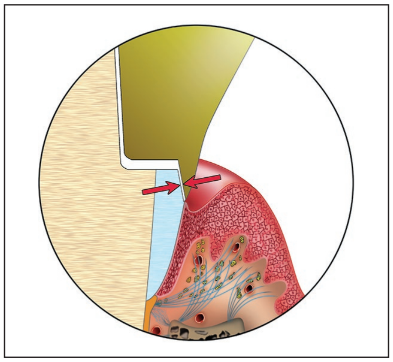


Fig 2-31 The vertical marginal gap defect is the smallest with a very steep bevel (more than 45 degrees). The exact path of the preparation margin of the bevel is very difficult to identify, similar to tangential preparation.

fit, reduce the interface between tooth preparation and crown, and move it out of the visible area (Figs 2-28 to 2-31). Preparation of the bevel is difficult and can blur the exact borderline on the model.

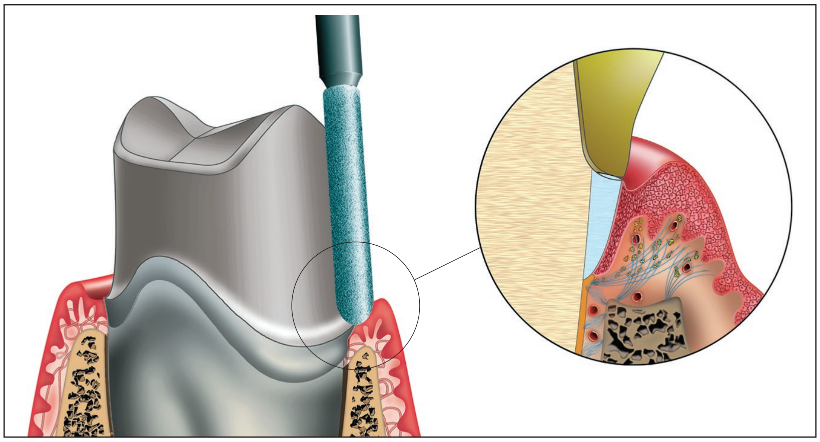


Fig 2-32 Chamfer preparation is a proven compromise between tangential and shoulder preparation. This form of preparation margin is used for full-cast crowns and veneer crowns, although the area to be veneered is prepared in a shoulder design. Chamfer preparation does not require as much substance loss as the shoulder form and produces a similarly precise marginal course that is clearly visible on the model and allows precise working.

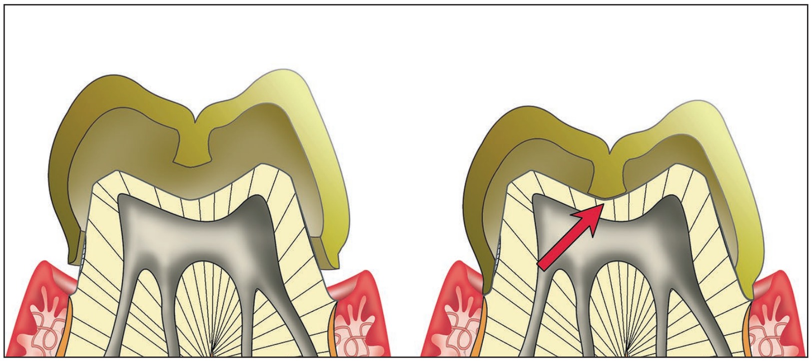


Fig 2-33 Chamfer preparation does not provide good static support to the crown over the crown margin and cannot prevent a reduced crown from sinking, so an occlusal stop is added for a reduced full-cast crown. This crown will not sag occlusally on loading.

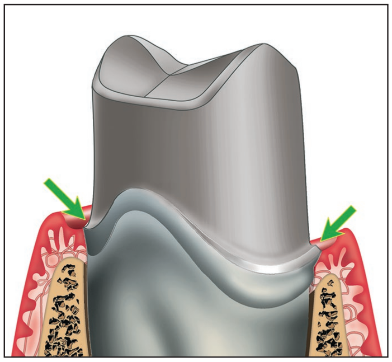
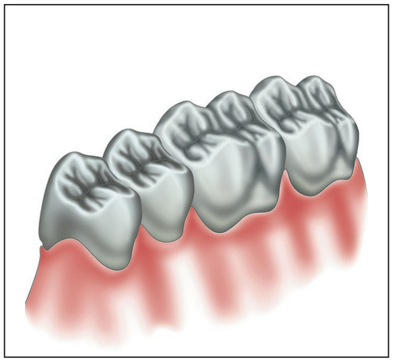
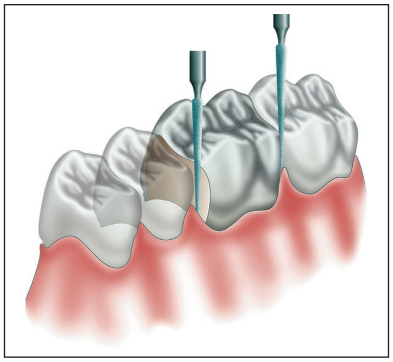


Fig 2-34 For veneer crowns, the tooth structure in the area of the veneer surfaces should be prepared with a shoulder that turns into a chamfer approximally and incorporates the lingual surfaces. As a result, less tooth substance is removed lingually, and the tooth preparation is more stable. This mixed form of chamfer and shoulder preparation is the usual approach for anterior and posterior teeth.

Shoulder preparation is generally necessary when jacket crowns are being fabricated from acrylic resin or ceramic. These materials need a specific minimum thickness at the crown margin for reasons of stability and color quality. Shoulder preparation is also appropriate for veneer crowns. The crown margin always ends flush with the shoulder, does not protrude horizontally, and does not sit too narrowly on the shoulder. Under no circumstances should the crown margin extend beyond the shoulder.

Chamfer preparation or veneer preparation happens when the conical tooth preparation is worked with suitably shaped abrasive tools so that a gentle circular chamfer is created (Figs 2-32 and 2-33). As a result, the coronal restorative material is moved into the tooth and ends flush. More dental substance is removed than with tangential preparation; consequently, the preparation finish line is clearly visible in the mouth and on the working model.

The chamfer offers adequate material thickness for metal frameworks, but there is not enough space for full crowns made of acrylic resin or ceramic. This preparation is suitable not only for veneer crowns—when a pronounced shoulder must be dispensed with because of the greater loss of substance—but also for full-cast crowns.

Figs 2-35 and 2-36 Preparation is done under water cooling, and the buccal and lingual vertical surfaces are prepared first.

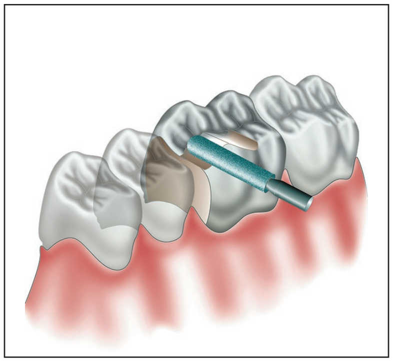


Fig 2-37 Separation: The approximal surfaces are prepared to obtain a gently conical tooth preparation. The adjacent teeth must not be damaged in the process.

The mixed form of chamfer and shoulder preparation results from a shoulder preparation that follows a vestibular course and turns into a chamfer approximally, which is then continued lingually (Fig 2-34). This method results in less loss of substance from the tooth preparation than with shoulder preparation alone. Mixed preparation is mainly used for veneer crowns to sink the material into the tooth in the visible vestibular region.

Phases of Tooth Preparation

Tooth preparation is not part of the work of a dental technician. The following description is for informational purposes only; it gives an overview of what a dentist does and should enhance understanding of the collaborative relationship between dentist and dental technician.

The tooth is prepared under water cooling with specially designed rotary instruments, usually diamond-tipped burs of varying grit size. Standardized preparation kits contain cylindric preparation tools with working parts approximately 4 to 8 mm long and special shapes such as pointed conical, needle-shaped separator, rounded bud-shaped, and ball-shaped burs. The instrument shafts are designed for micromotor-driven contra-angle handpieces or for ball-bearing or air-bearing turbines.

Preparation is done in the high-speed range (160,000 to 450,000 rpm), at which only minimal working pressure is required, no vibrations occur, and the treatment time can be very short. High-speed instruments require water-spray cooling. Use of a rotary instrument without water cooling would result in pulp damage due to friction heat. Even briefly exceeding a temperature of 51.6°C causes protein coagulation. Following is a brief outline of the phases of tooth preparation.

1. Preparation of the approximal surfaces

A needle diamond (separator) is used to separate the approximal surfaces. The purpose of this phase is to separate or clear a space around the tooth being prepared in the dental arch so that the adjacent teeth are not accidentally damaged during subsequent preparation (Figs 2-35 to 2-37).

2. Marking of depth

In order for the dentist to know how much dental substance to remove in subsequent phases of preparation without injuring the pulp, depth is marked with a groove-cutting or step bur. These instruments have a depth marking or a depth stop. They are used to create one or more 1-mm-deep grooves over the entire occlusal surface and onto the vestibular and lingual surfaces as far as the height of contour.

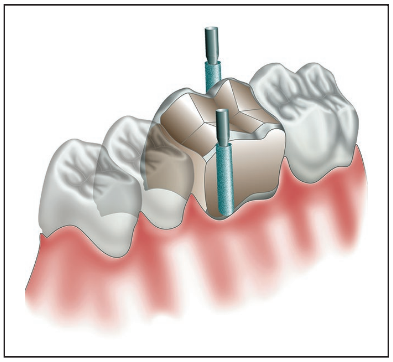


Fig 2-38 Occlusal preparation: The transitions between the occlusal and vertical surfaces are ground, creating an occlusal bevel.

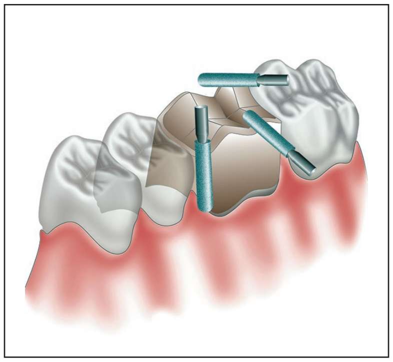


Fig 2-39 The occlusal surface is ground down. Adequate interocclusal rest space should be created and the angle of cuspal inclination maintained.

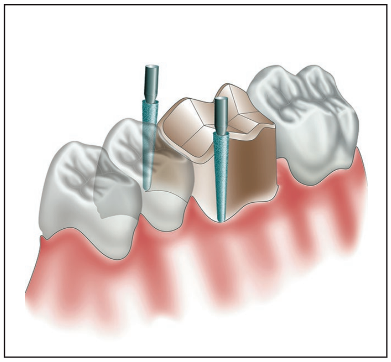


Fig 2-40 Lowering and precise regrinding of the path of the preparation margin is done with a suitable abrasive tool, in this case a tapered torpedo.

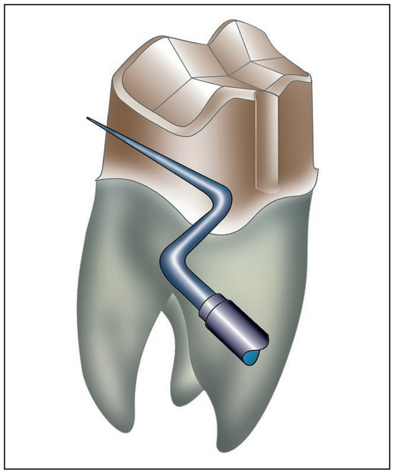
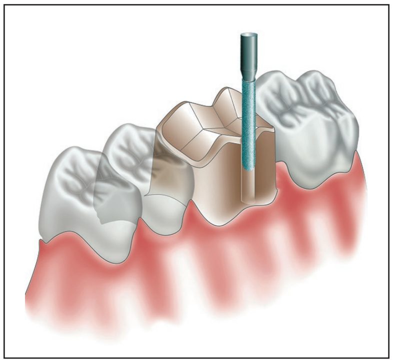


Fig 2-41 *(left)* The preparation target is checked with a probe. There must be no undercuts on the vertical surfaces. A conical preparation with a maximum preparation angle of 6 degrees is created.

Fig 2-42 *(right)* Insertion groove parallel to the path of insertion for clear-cut fixation of the crown on eventual insertion.



3. Preparation of the occlusal surface

The occlusal surface is removed as far as the depth marking without injuring the adjacent teeth (Figs 2-38 and 2-39). Depending on the design and the material used for the artificial crown, adequate interocclusal rest space should be created. The occlusal relief should retain its basic morphology (eg, cusp size, fissure configuration). The dental arches are checked in working and balancing positions to ensure that the preparation is adequate.

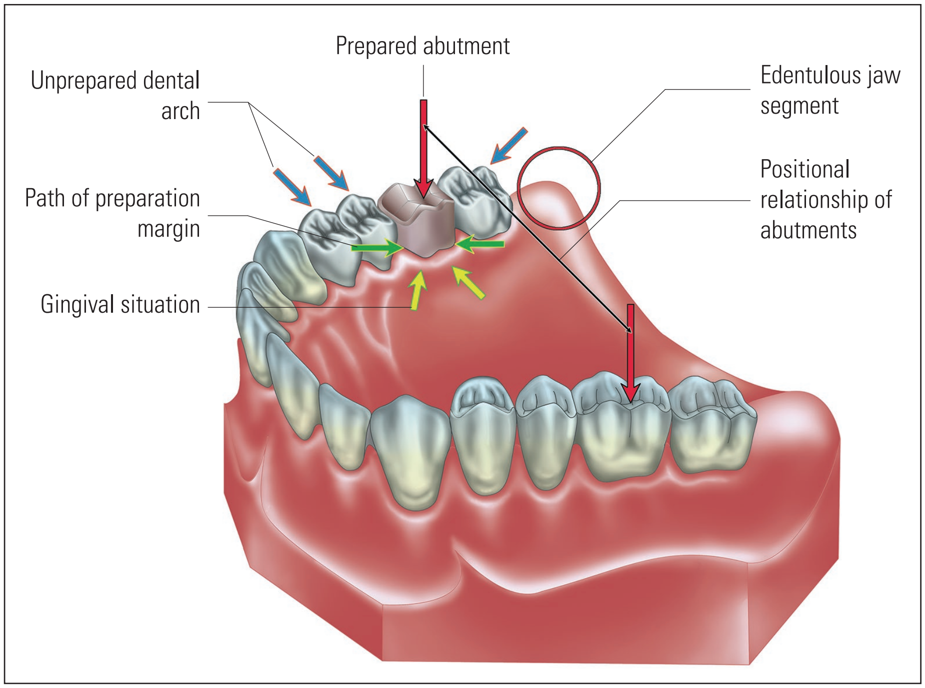
4. Preparation of buccal and oral surfaces

A cylindric bur that is angled or rounded at the tip is used for gentle conical reduction of the buccal and oral surfaces to just above the gingival crevice. This vertical circulatory preparation follows the curved path of the gingival attachment.

5. Preparation of the cusp bevel

The cusp bevel at the transitional surfaces to the vertical surfaces is prepared with special tapered

Fig 2-43 When a coronal restoration is produced, the impression needs to provide an accurate representation of the intraoral situation, and this must be reproduced in a working model. The impression and model must accurately depict the prepared abutments with the path of the preparation margin and the gingival situation as well as the unprepared dental arch, the positional relationship of the abutments, and the edentulous segments of the jaw.



instruments. This allows the cusp ridges, which have been displaced outward by the occlusal surface preparation, to be corrected into their proper position. Cusp ridges and cusp tips are moved toward the central fissure.

6. Preparation of the finish line

The finish line at the gingival margin is prepared with suitable instruments. For tangential preparation, the finish line is relocated into the floor of the gingival crevice with a pointed tapered abrasive (Fig 2-40). For chamfer preparation, a thicker conical tool (tapered torpedo) is used to create a clear finish line in the floor of the gingival crevice. The shoulder is mimicked with a rounded roller to create a chamfered transition to the vertical preparation surfaces and an almost horizontal step. In this phase, the gingival margin must be pushed back. Retraction cords have proved effective for this, or the pressure from the cooling water jet can also push back the gingival margin.

7. Smoothing of surfaces

The tooth preparation and transitions are smoothed using a cylindric finishing diamond with a very fine grit. The surface of the tooth preparation is checked for undercuts using a probe held crosswise (Fig 2-41). For safety, an insertion groove can be cut onto a vertical surface, allowing clear-cut fixing of the crown on insertion (Fig 2-42).

Impression of the Prepared Tooth

After preparation is completed, a check impression can be taken to produce a preparation check model. This allows the dentist to make an accurate check of the tooth preparation and identify any corrections needed.

An accurate model of the prepared tooth is required to fabricate artificial crowns (Fig 2-43). This means that a specific impression needs to be taken using a ring-supported single-preparation impression or an integrated complete impression, which is subdivided into single-phase (monophase) and dual-phase impression-taking.

Single-phase impression techniques use either one flowable material or two flowable materials simultaneously (double-mix technique). In dual-

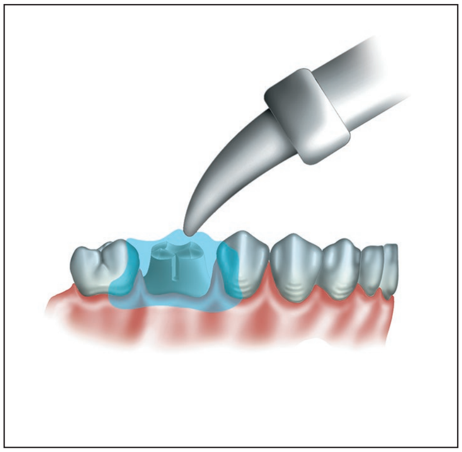


Fig 2-44 Taking an impression of a prepared tooth and the whole jaw is a precondition for an accurate working model. One method is a double-mix impression in which two materials are used to take an impression. Before taking the impression, a low-viscosity material is applied to the object from a disposable syringe. The gingival crevice is widened beforehand so that the impression material can reach the preparation margin.

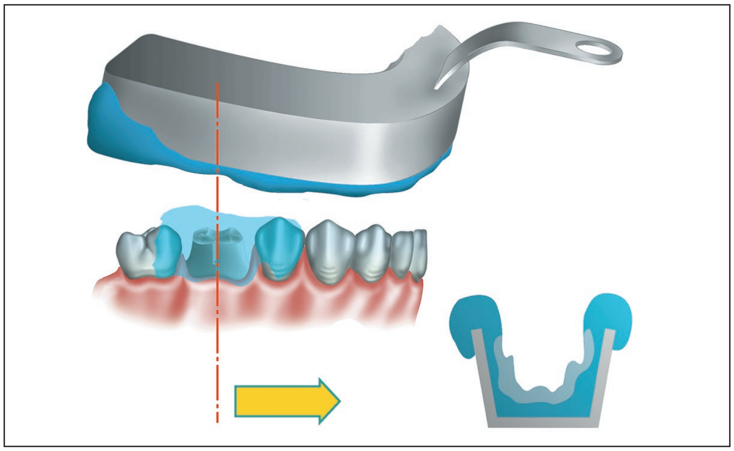


Fig 2-45 An impression tray is used to push the more solid second material over the low-viscosity material. Both materials set at the same time but have no effect on each other. The possibility of the impression materials warping is ruled out. This method is suitable for silicone and hydrocolloid materials.

phase impression-taking, an initial impression made of harder silicone is corrected with a low-viscosity second material (eg, correction impression, double impression). The entire occlusal area of the jaw and the antagonists are included.

A ring-supported impression is taken in two working phases:

1. The actual impression of the tooth preparation is taken with a copper-ring impression made of thermoplastic impression material or silicone, where the ring acts as a carrier for the impression material.
2. An impression of the entire jaw is taken with the ring in place in a combined impression with a prefabricated impression tray.

A matching ring is cut to fit the path of the cervical margin. Enough space for the impression material is left between the tooth preparation and the ring. When the cervical edge of the ring is adapted to the gingival contour, it is drawn in toward the prepared tooth. After a dry field is created and the prepared tooth is isolated, the ring is pushed as far as the preparation margin, and the heated plastic impression material is pressed occlusally as far as the edge of the ring. If low-viscosity silicone is used for the impression, the ring is sealed occlusally with wax, the impression material is poured in, and the ring is placed on the tooth preparation. A combined impression is usually taken with viscous silicone materials over the ring that is already in place. A ring-free impression is an integrated complete impression. It requires widening of the gingival crevice by suitable methods; otherwise, the impression material will not penetrate the gingival crevice. The gingival margin can be displaced by placing a retraction cord or elastic ring or by using a medication that reduces the tissue tension in the gingival margin.

A dual-phase correction impression first involves taking a primary impression out of viscous silicone; this takes on the function of a custom tray. The primary impression can be taken before preparation so that the pre-preparation space can be exploited to ensure tension-free reception of the low-viscosity correction material.

If the primary impression is taken after preparation in order to prevent compressive stresses from the primary material, the impression should be cut out slightly in the preparation area, and

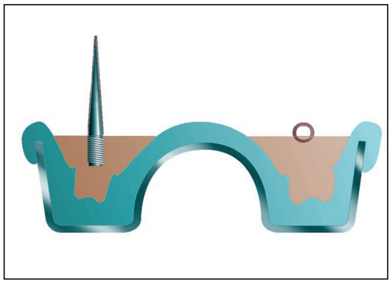


Fig 2-46 During impression-taking, the dental arch and part of the alveolar ridge (approximately 1.5 cm high) are cast. A dowel pin is placed precisely in the prepared tooth.

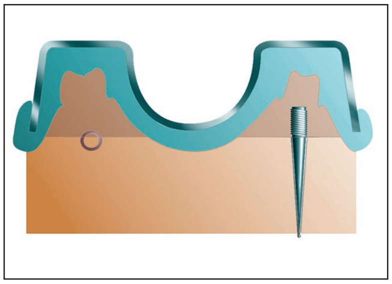


Fig 2-47 The other part of the dental arch is fitted with retention rings, the plaster is isolated, and the dental arch is based.

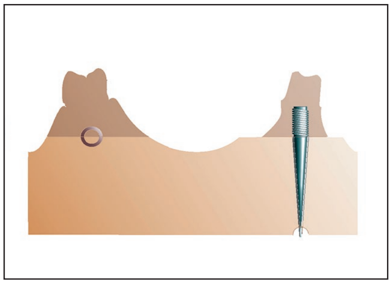


Fig 2-48 On the finished model, the tooth die is sawn out, and the preparation margin is exposed.

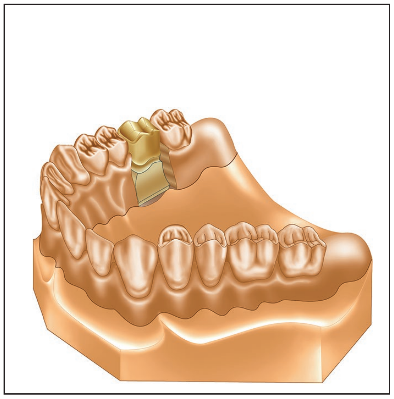


Fig 2-49 In a split model, a preparatory working step is to grind the preparation margin clear from the adjacent gingival area.

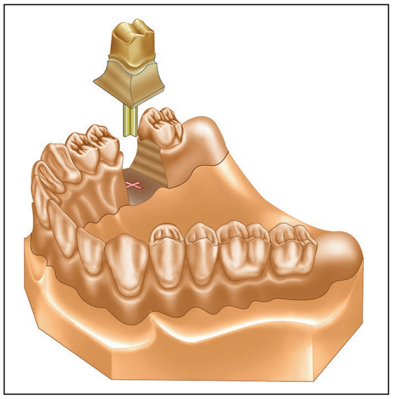


Fig 2-50 The saw cut should run parallel so that the sawn die can be smoothly taken out; the finish line of the gingiva on the adjacent teeth must remain visible.

drainage grooves should be created for the low-viscosity correction material. Only then is the low-viscosity correction material poured into the primary impression, which is briefly pushed over the prepared tooth under pressure but held in place without pressure until it sets. Under pressure, the secondary material may deform the primary material and distort the complete impression because of the latter's recovery properties.

In the double-mix impression technique, two impression materials are mixed at the same time: a low-viscosity material from a special impression syringe and a higher-viscosity second material for the impression tray (Fig 2-44). First the gingival crevice is filled throughout with the syringed material, then the impression tray with the high-viscosity silicone is immediately placed over it (Fig 2-45). The two materials set simultaneously without displacing each other; no elastoplastic stresses arise between the two materials. This working method is also used for hydrocolloid impression material.

A split model can be produced with the impression: The dental arch is cast in dental stone, and dowel pins are placed in the position of the prepared tooth (Fig 2-46) with the aid of a light point indicator (Pindex, Coltene). The dental arch is isolated, and a model base is fabricated from stone (Fig 2-47). After the plaster has set, the dies must be cut out and the saw cuts taken down to the plaster base (Fig 2-48). The separated die can be lifted off the model and placed back into the model by means of the dowel pin (Figs 2-49 and 2-50).

Figures 2-51 to 2-56 illustrate the steps of taking a ring impression. Figures 2-57 and 2-58 provide helpful hints for marking the dies.

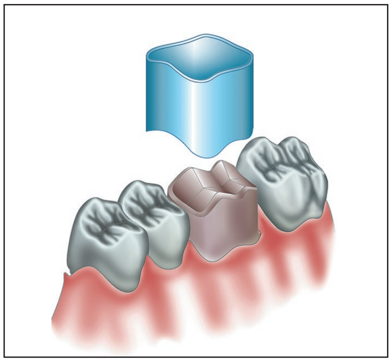


Fig 2-51 The principle of a ring impression: A prefabricated ring that fits the preparation circumference is adapted to the path of the preparation margin.

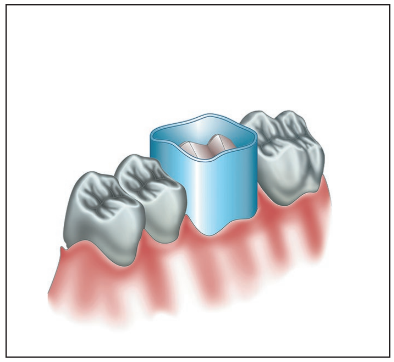


Fig 2-52 The ring is pushed slightly beyond the preparation margin below the gingiva; it lies close to the widest circumference of the preparation.

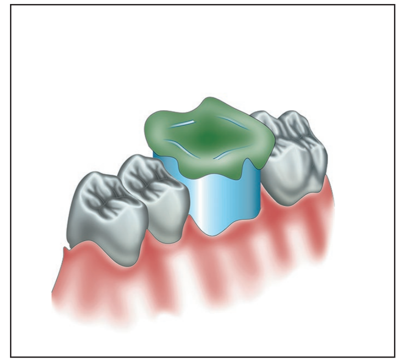


Fig 2-53 Thermoplastic impression material is pressed into the ring; the ring is removed, checked, reheated, and firmly put in place.

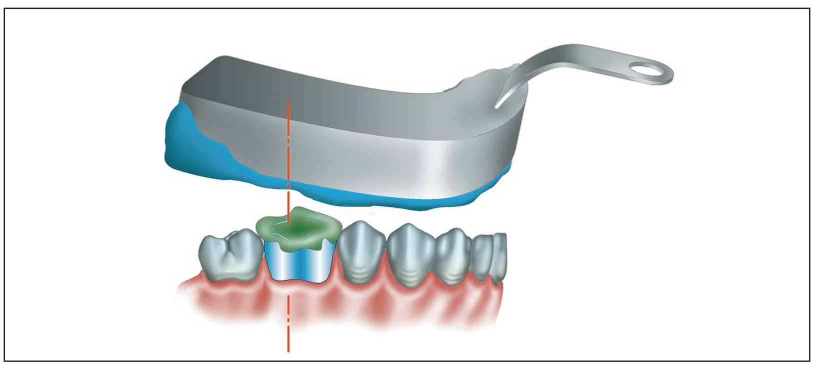


Fig 2-54 A combined impression is taken over the ring impression with silicone impression material in a prefabricated impression tray.

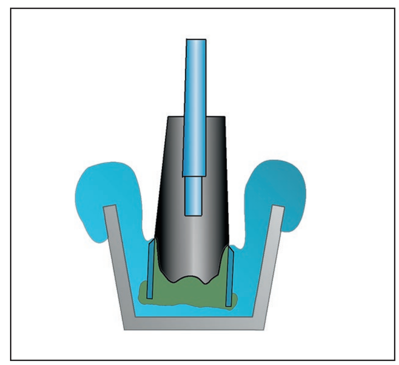


Fig 2-55 A multipart working model can be produced with a ring-supported impression. In what is known as a *die* (preparation model), the prepared tooth can be removed while the adjacent tissues remain unharmed.

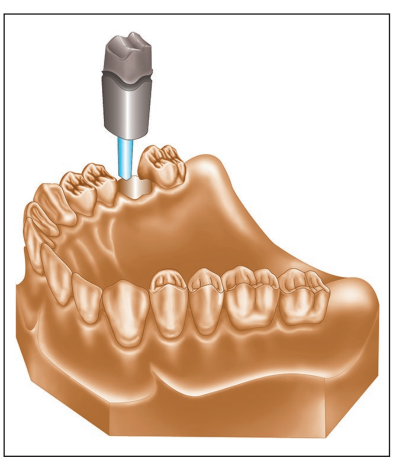
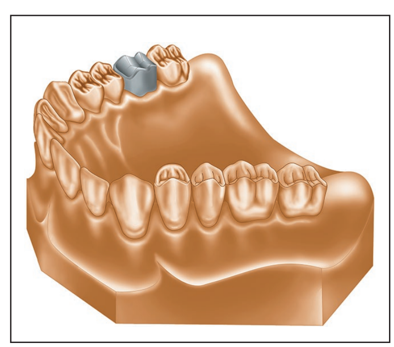


Fig 2-56 *(left)* In the ring impression, a tooth preparation with a conical root part and dowel pin is first prepared in modeling cement or dental stone. The preparation is isolated, and the combined impression is cast.

Fig 2-57 *(right)* Marking a die involves precisely depicting the path of the preparation margin and the spatial relationship to the gingival margin, which must not be ground free.



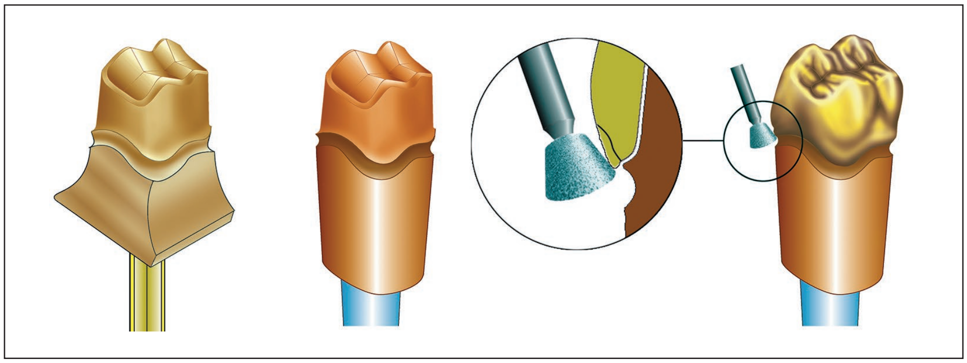


Fig 2-58 Placing a subgingival groove on a removable die and thereby marking the path of the preparation margin is recommended. This ensures that the preparation margin will be clearly identifiable, and the groove makes it possible to gently bevel the crown margin. The crown margin can be modeled to be slightly longer so that it can be subsequently polished on the model with a rubber polisher. For this reason, the die must be made of extremely hard modeling material.

Crown Margin and Marginal Periodontium

The marginal periodontium, the typical cellular seal of the mucosa to the oral cavity, can be altered in its structure by the crown margin and preparation work as soon as the preparation margin lies below the gingival crevice. This results in pathologic changes to the cellular structure in the marginal periodontium if the crown margin is pushed below the gingival margin (subgingival).

In exceptional cases, a crown margin (preparation margin) may be placed deep in the floor of the gingival crevice for caries prophylaxis (prevention) in a dentition highly prone to caries or for esthetic reasons. It is imperative that this margin be respected.

Foreign body irritation of the marginal periodontium may affect the success of a coronal restoration. Possible sources of foreign body irritation include the coronal restorative material, the general accuracy of fit, and defective shaping of the crown margin.

Irritation due to materials

All the materials used (metal, ceramic, acrylic resin) should be tissue compatible. The substance itself or the surface texture may be the source of irritation leading to chronic inflammation. Poorly polished metallic surfaces or roughly prepared ceramic surfaces lead to constant irritation if contaminants and deposits accumulate in grooves, pits, and other rough areas, which then leads to inflammatory changes.

High-glaze fired ceramic surfaces never cause tissue disorders, even when combined with metal frameworks. Acrylic resin surfaces occasionally display tissue incompatibility but also have condensed surfaces with no deposits or contamination. When processing acrylic resin, keep in mind that degradation of the acrylic resin is a continuous process; residual monomers can evaporate and subsequently cause irritation. Thus, acrylic resin veneers should always be kept clear of the periodontium.

Light-cured composites exhibit adequate tissue compatibility. However, veneering material for metal carries a risk (however small) of gap formation between metal and acrylic resin in which deposits become lodged and lead to irritation.

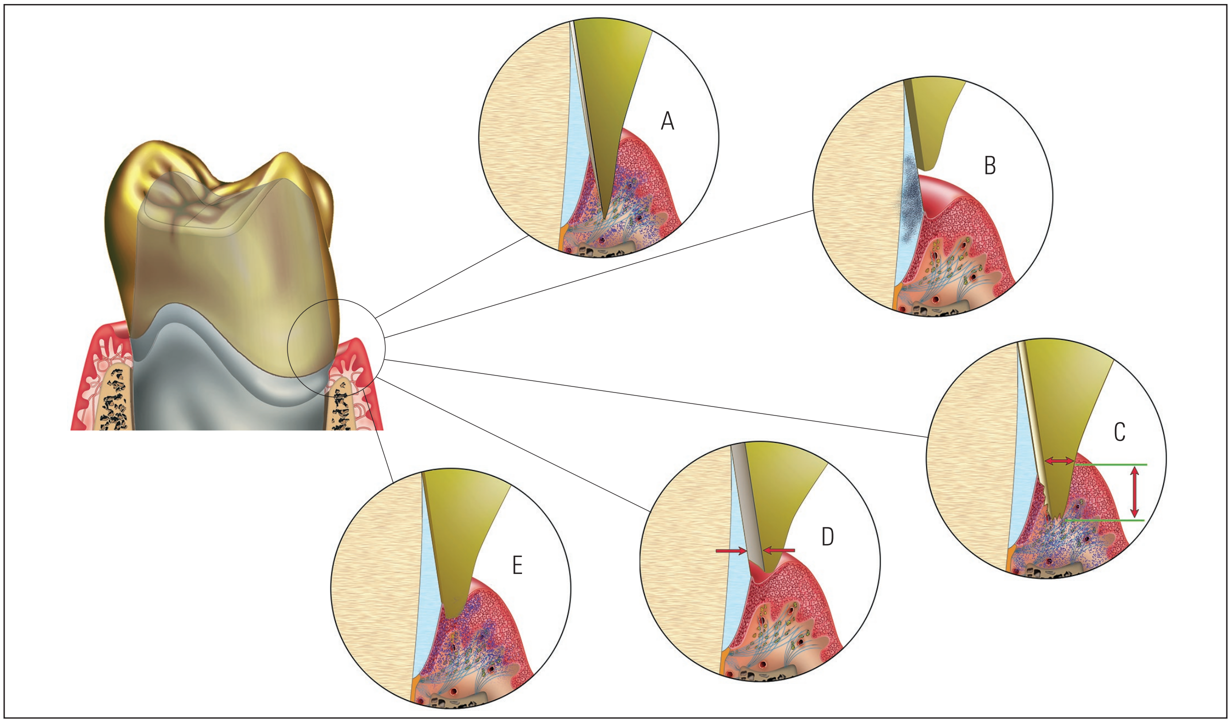


Fig 2-59 The most common mistakes when shaping the crown margin for a tooth preparation with tangential and chamfer preparation are the following: crown margin too long (A), crown margin too short (B), crown margin too thick (E), and crown margin sticking out (D). If a crown margin has several faults, such as an excessively thick, long, protruding, and frayed margin, extreme damage may ensue (C).

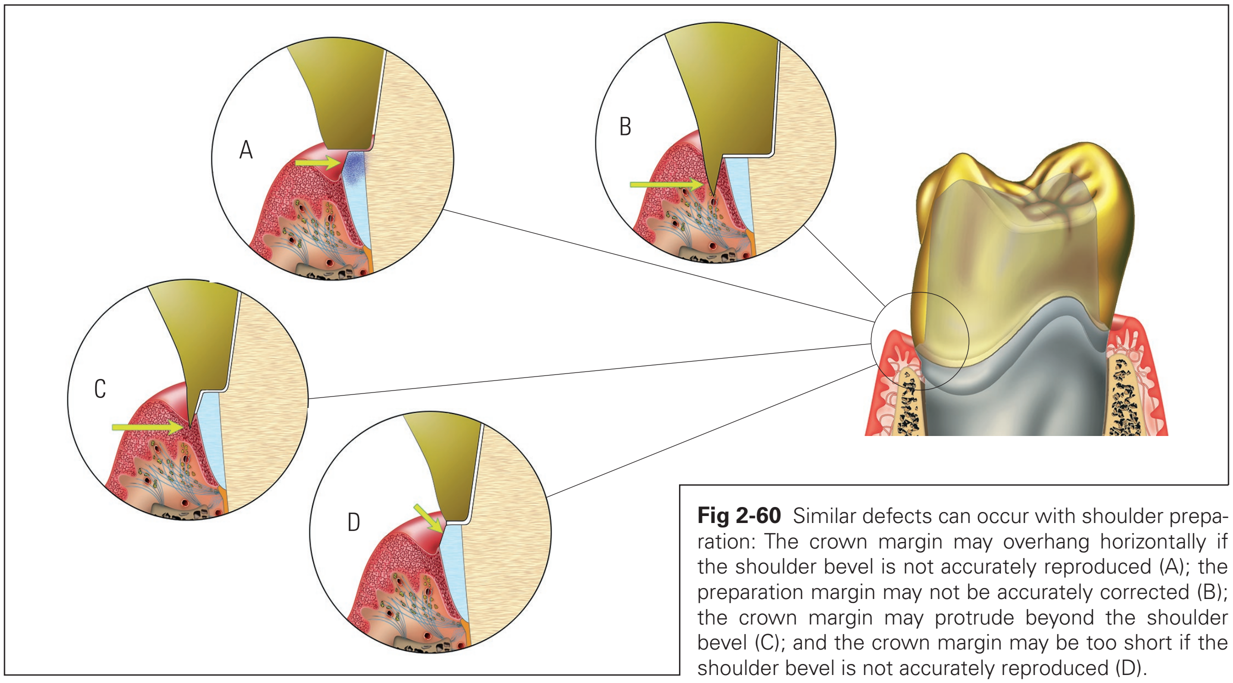


Fig 2-60 Similar defects can occur with shoulder preparation: The crown margin may overhang horizontally if the shoulder bevel is not accurately reproduced (A); the preparation margin may not be accurately corrected (B); the crown margin may protrude beyond the shoulder bevel (C); and the crown margin may be too short if the shoulder bevel is not accurately reproduced (D).

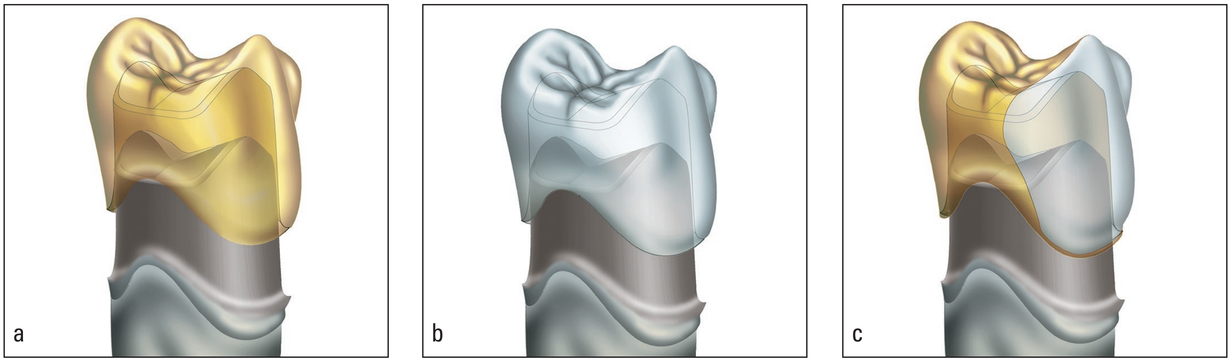


Fig 2-61 Full crowns completely cover the prepared tooth as far as the preparation margin. Full crowns can be made from one material or combinations of materials: *(a)* metal full-coverage crowns; *(b)* jacket crowns made of ceramic or acrylic resin; *(c)* veneer crowns made from a metal framework and a tooth-colored veneering layer in ceramic or acrylic resin.

Irritation due to inaccurate fit

If the artificial crown is sunk into the tooth as a result of accurate preparation, a microgap between the crown and the prepared tooth may be found on insertion that corresponds to the thickness of the cement. An absolutely smooth transition is not achievable. This accuracy of fit, however, can be kept within tolerances of 0.2 mm, which do not jeopardize the success of the coronal restoration. Inaccuracies above this level sooner or later lead to irritation because the gap can be washed clear of cement and provide an entry point for contaminant deposits.

Irritation due to defective shaping of the crown margin

A common error when shaping the crown margin is failure to respect the preparation margin. Although this rarely happens with shoulder and chamfer preparation, it is always encountered with tangential preparation (Fig 2-59). If the crown margin is too long, the marginal periodontium is torn and retracts.

If the crown margin is too short, the risk of caries cannot be ruled out. The crown in a tangential preparation must taper very thinly, usually giving rise to a ragged, frayed crown margin that is unstable and will damage the marginal periodontium as the margin bends and exposes some areas of the tooth preparation where caries will develop.

The coronal restoration must not occupy any more space in the crevice than the natural tooth did previously. Thus, the crown margin must not overhang or be too narrow in the case of shoulder or chamfer preparation (Fig 2-60). The trauma caused by pressure invariably leads to retraction of the periodontium and an excessively narrow margin that is prone to caries.

The causes of defective shaping of the crown margin can only be identified in each individual case. In most cases, however, the main cause is unsatisfactory fabrication of dies without a clearly visible preparation margin, which was either damaged or poorly created to begin with.

Full Crowns

A full crown covers the prepared tooth completely like a shell (full-coverage crown in metal) or a jacket (acrylic resin or ceramic jacket crown). Veneer crowns are full crowns made from different materials; these have a metal framework that is veneered with acrylic resin or ceramic. Every full crown exhibits the anatomical features and functional characteristics that are necessary to fulfill its functions (Fig 2-61).

A full crown is retained on the prepared tooth by static friction and gripping resistance; that is, adequate retention depends on the size and inclination of the contact surface: The steeper and taller the preparation, the more firmly a full crown will be seated.

Metal full-coverage crowns come in two fundamentally different designs: banded crowns and full-cast crowns. The full-cast crown is the more advanced construction and was developed because in banded crowns (collar crowns or prefabricated crowns) the margins of the crown shell damage the gingiva. In contrast, full-cast crowns have the following features:

- They are sufficiently stable against mechanical stresses.
- They fit completely to the prepared tooth without a thick layer of cement.
- They have a marginal fit that is clearly defined by the preparation margin.
- They require the least reduction of substance from the tooth because chamfer or tangential preparation is sufficient.
- They have almost unlimited durability.

Full-cast crowns cannot satisfy esthetic demands, however, and are therefore reserved for posterior teeth. Another drawback may be their weight in the case of large molar crowns, especially if large contact points need to be created or a positional correction becomes necessary because of crooked teeth.

To decrease the weight, a reduced full-cast crown can be fabricated by scraping out the upper part of the carved wax crown from the inside or by building up (blocking out) the tooth preparation before completing the wax-up. The scraping-out method is not recommended because of the high risk of error (scraping out may cause the crown to warp).

Heavily damaged tooth preparations are built up on the model or in the mouth with plastic filling material. It is important to ensure that occlusal support is created in the hollowed-out occlusal surface, which will prevent the crown from being inserted too deeply. To provide the necessary retention, the crown fits closely to the prepared tooth in the lower third, and the occlusal surface is carved thickly enough (a minimum of 0.5 mm) to prevent it from sagging or being damaged during mastication.

Reduced full-cast crowns can also be produced with prefabricated crown matrices made of wax or acrylic resin. In this case, the matrix is adapted and, at the preparation margin, fused onto the prepared tooth to a width of about 2 to 3 mm; an occlusal stop is also included. The advantages of this method are the calculable crown weight and time savings if the antagonists are favorable.

In adverse occlusal conditions, the matrix has to be reworked before casting because adjustment with a rotary instrument is not possible given the thickness of the material. There are fundamental drawbacks: The occlusal relief of prefabricated crowns will only be correct by chance in a few cases, including during articulation movements; as a result, the actual function of the artificial crown is not fulfilled.

The following steps should be followed to fabricate a full-coverage crown with semifinished parts (Fig 2-62):

1. Isolate the prepared tooth against wax.
2. Adapt the crown matrix (matrices are available in different crown designs and sizes) and trim the margin to match the path of the preparation margin.
3. Model the crown margin with casting wax precisely to the preparation margin and the form of preparation. Flood approximately 2 to 3 mm of the wax onto the die to guarantee adequate retention of the crown to the tooth preparation.
4. Flood the occlusal stop from the inside.
5. Invest and cast the crown as would be done normally.
6. Finish and polish the cast crown.

Fabrication of a full-cast crown

For a full-cast crown, the tooth is reduced to be slightly conical and with a chamfer preparation. The preparation margin is exposed on the removable die by means of a subgingival groove that starts precisely at the preparation margin. The margin is marked and its path traced with a red pen without applying pressure or scraping the preparation. A black or blue pen is unsuitable because if the casting wax is blue or green, the margin will cease to be visible later. The full-cast crown is carved out of a single piece of wax. The prepared tooth must be isolated against wax for this purpose.

The wax pattern is duplicated precisely by the investing and casting technique, so the finished cast can only be as good as the wax pattern. Errors such as faulty margins or parts of occlusal surfaces will reappear in the gold casting. Over-

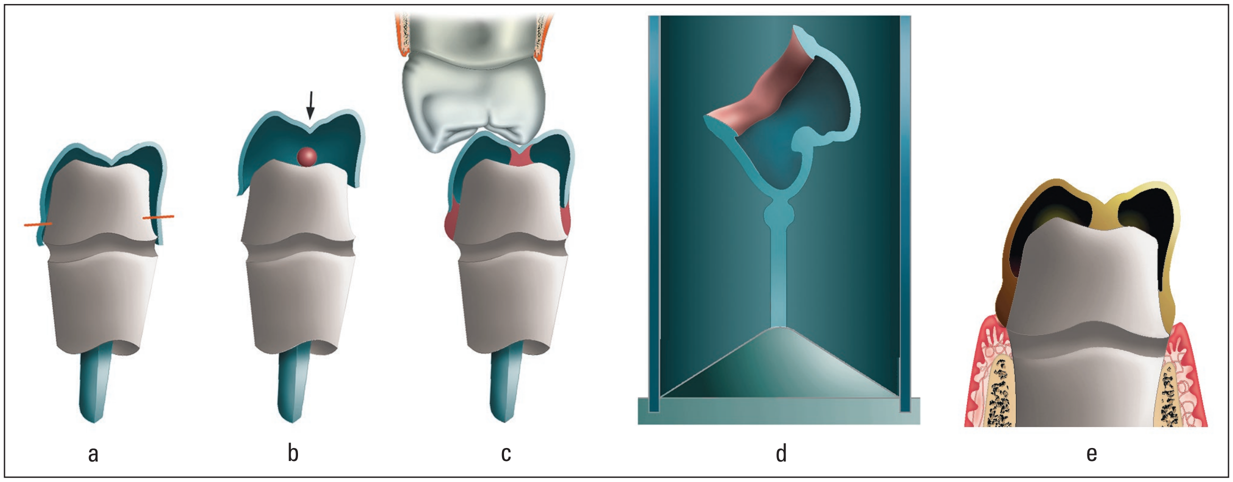


Fig 2-62 Principles of fabricating a reduced full-cast crown from semifinished parts: *(a)* The semifinished part is selected from a collection of different crown matrices and trimmed at the crown margin. *(b)* The semifinished part is fixed onto the isolated tooth preparation with a drop of wax; this fixation also acts as an occlusal stop. *(c)* The margin is marked to incorporate about a third of the preparation and clearly map the path of the preparation margin. *(d)* The waxed-up crown is fitted with a sprue and a reservoir in the casting and is normally invested, cast, and finished. *(e)* The finished crown requires only a small amount of metal, which is why the occlusal contacts cannot be reworked.

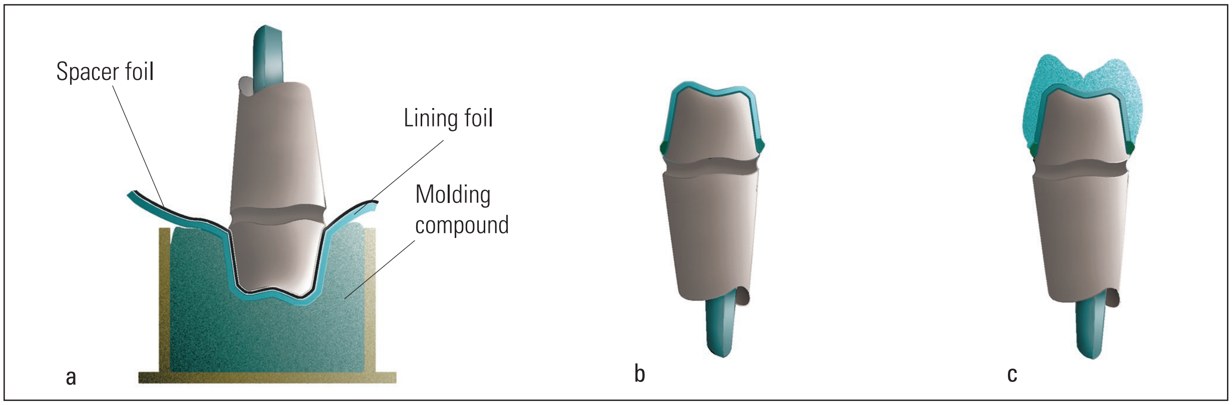


Fig 2-63 Using a foil lining as a basic framework for the crown wax-up offers several advantages: First, it is a rigid base for the wax pattern, which can be deformed with relative ease, and second, the thinness of the foil lining guarantees minimal thickness of the crown framework. A suitable thermoplastic foil with spacer foil is heated; the die is pressed into a molding compound *(a)* to beyond the preparation margin, so that the thermoplastic foil lining and spacer foil are pressed around the die. The spacer foil is then removed (the thermoplastic foil lining shrinks after cooling by about the thickness of the spacer foil), and the foil lining is trimmed to about 2 mm above the preparation margin. *(b)* The foil lining, without spacer foil, is placed back on the die, and the crown margin is quickly flooded with casting wax so that no flow lines are formed on the inside; any slight step that may occur between coping and the wax margin is carefully smoothed. *(c)* The actual crown framework is carved on the coping. The foil lining is sufficiently thick for the framework in the veneered area.

sized parts or carelessly carved occlusal surfaces would then have to be reworked, which would involve considerable loss of gold and time. As wax is easier and, above all, less expensive to work with than gold, a few more minutes spent on waxing up will save hours of corrective reduction and soldering.

Using specific wax-processing techniques to avoid stresses is advisable. It is important to ensure that the wax pattern is always machined on the die. Single crowns should be invested immediately after waxing up. Preparation of an underlining foil is a suitable option for preventing a single crown from warping in wax (Fig 2-63). The

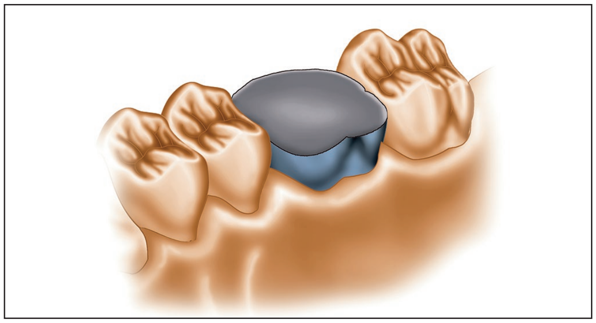


Fig 2-64 A full-cast crown is reconstructed by the systematic wax-up technique. The first step involves building up the occlusal surface outline by building up the vertical surfaces. The surfaces are convex above the gingiva; the overcontoured contact points lie on the approximal surfaces and are brought into precise contact by reworking and polishing.

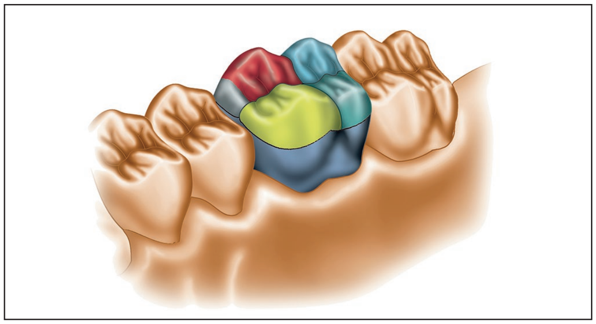


Fig 2-65 The occlusal surface can be built up with colored wax as far as the occlusal contacts. The finished wax pattern has all the morphologic features of the eventual metal crown. The more precise the wax-up, the less reworking will be needed later, which saves time and materials.

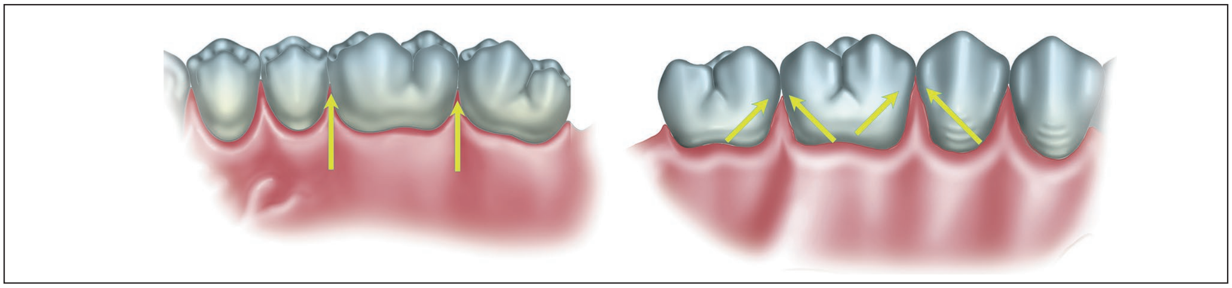


Fig 2-66 The surface elevations of the dental crown are shaped so that esthetic demands are satisfied, no niches are created where deposits could accumulate, and the marginal periodontium is protected. The approximal surfaces are shaped so that the contact points lie directly occlusally, in the depth of the interdental embrasures. The contact points must not lie too high or too deep to spare the interdental papilla.

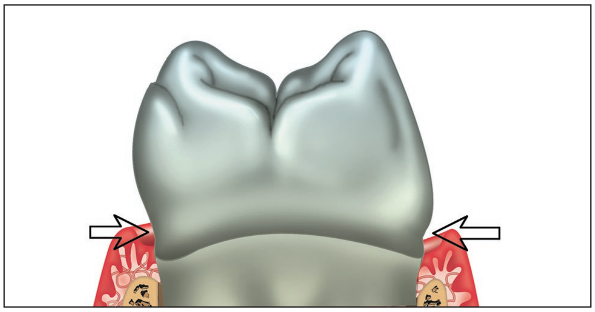


Fig 2-67 The vertical curvatures of the vestibular and lingual surfaces must be reproduced so that food is deflected away and the marginal periodontium is protected. These vertical curvatures are relatively slight; they should be reshaped in their natural thickness because excessively strong curvatures produce the opposite of what is intended: they create niches in which deposits will form and chronic inflammation can ensue. A die with an impression of the cervical margin will allow the dentist to check this.

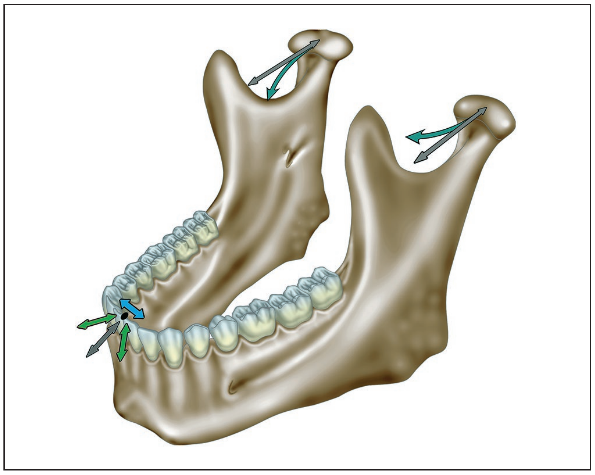


Fig 2-68 Active masticatory movements under tooth contact are sideways (lateral) or forward (protrusive). They can be projected onto the occlusal surfaces of the teeth as a regular movement pattern. This figure plots mediotrusion or laterotrusion *(blue)*, lateroprotrusion *(green)*, and protrusion *(gray)* at the mandibular incisal point. This movement pattern is often called the *occlusal compass* and can be transferred to each occlusal point.

Fig 2-69 Here the movement pattern (occlusal compass) of the mandibular incisal point has been transferred to the posterior teeth. The opposing cusp tips are represented as spheres in their contact fields. The protrusive movement is *gray*, the pure sideways movement (mediotrusion/laterotrusion) is *blue*, and the combined sideways/protrusive movements (lateroprotrusion) are shown in *red* and *yellow*. An appropriate clearance for these extrusive movements must be left when waxing up the occlusal surface.

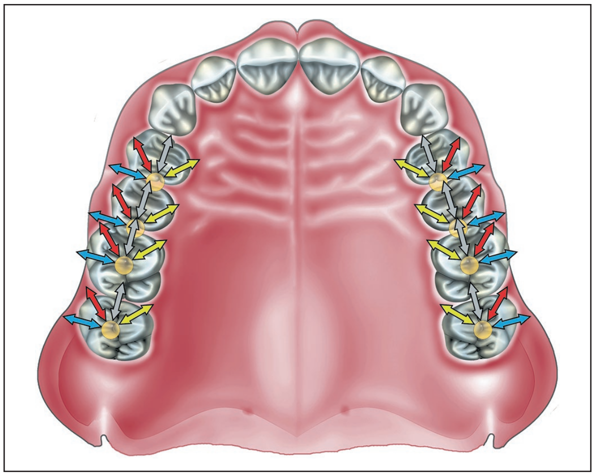


Fig 2-70 The movement paths of the opposing cusps on the maxillary posterior teeth show the opposite pattern. The opposing cusp tips are again shown as spheres in their contact fields. Protrusion is shown in *gray*, mediotrusion/laterotrusion in *blue*, and lateroprotrusive movements in *red* and *yellow*. Freedom of movement must be incorporated into the wax-up of the occlusal surfaces.

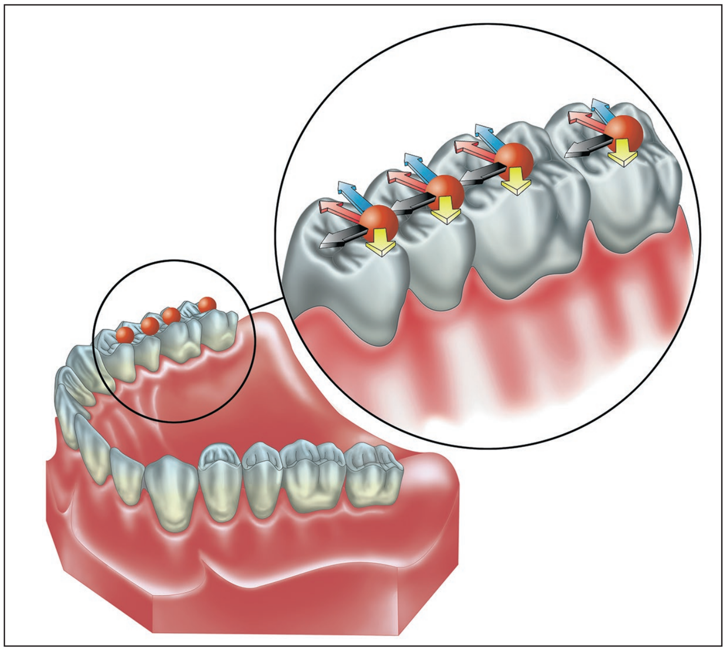


Fig 2-71 A perspective view of the maxillary posterior teeth shows the movement path of the opposing cusps in the occlusal relief. The functional clearance can be seen in the supplemental grooves and central fossae, on the triangular ridges of the cusps, and in the interdental embrasures. *Red* and *yellow* indicate lateroprotrusion; *gray*, protrusion; and *blue*, mediotrusion/laterotrusion.

actual waxing up can be done on the underlining foil. This then produces a warp-free crown framework and a minimal crown thickness because it avoids the risk of carving too thinly in places.

The occlusal surface is contoured according to the systematic wax-up technique (Figs 2-64 to 2-87). The highest elevations of the cusps are first established, then the individual enamel segments

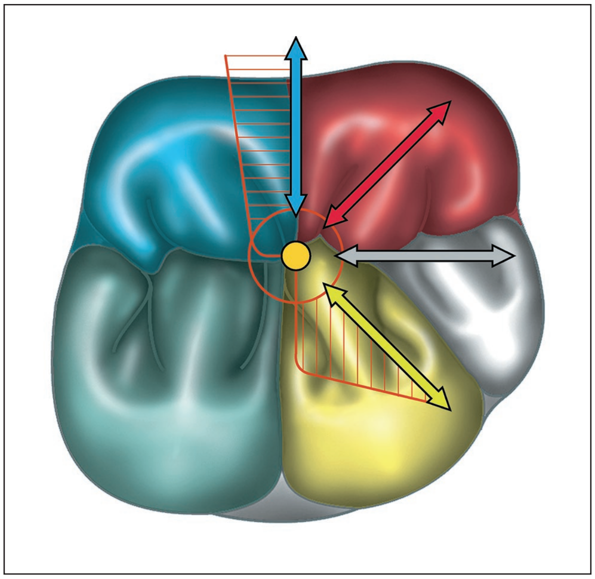


Fig 2-72 Projection of the movement pattern (occlusal compass) in a mandibular first molar shows the freedom of movement for the opposing cusps. The crosshatched area denotes the border region for backward (retrusive) movements of the opposing cusp.

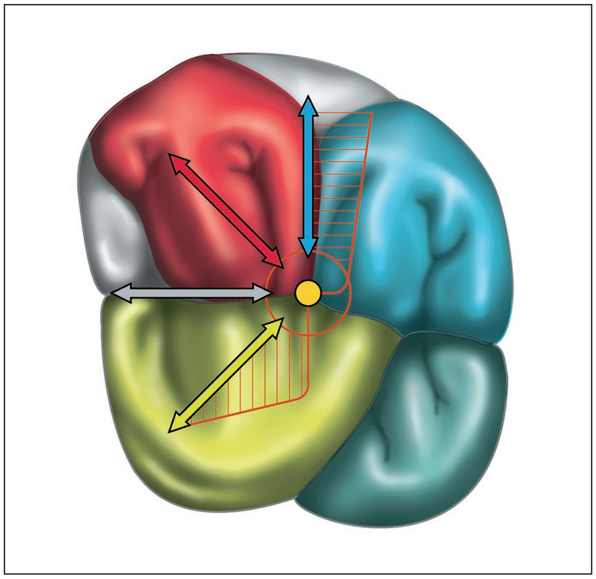


Fig 2-73 A corresponding movement pattern is shown on the maxillary first molar, radiating from the central fossa, to demonstrate freedom of movement. The movement pattern can also be projected onto the occluding cusp tips.

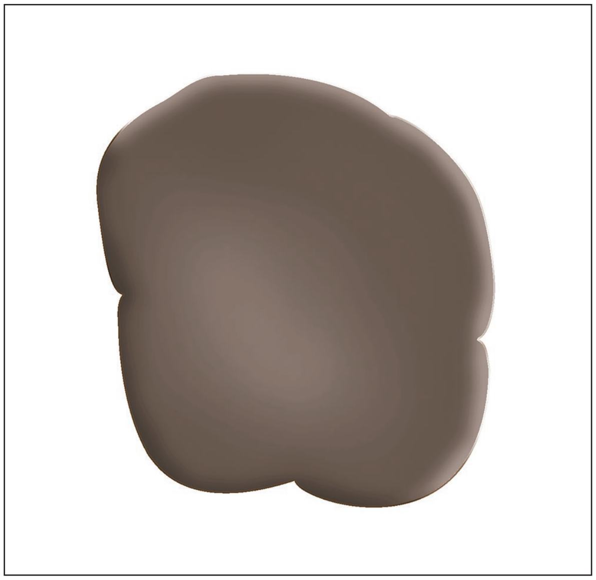


Fig 2-74 The first step in the systematic reconstruction of the tooth morphology is to create the outline of the occlusal surface. This is derived from the structure of the vertical tooth surfaces approximally, lingually, and buccally. The tooth proportions should be accurately produced during this working step.

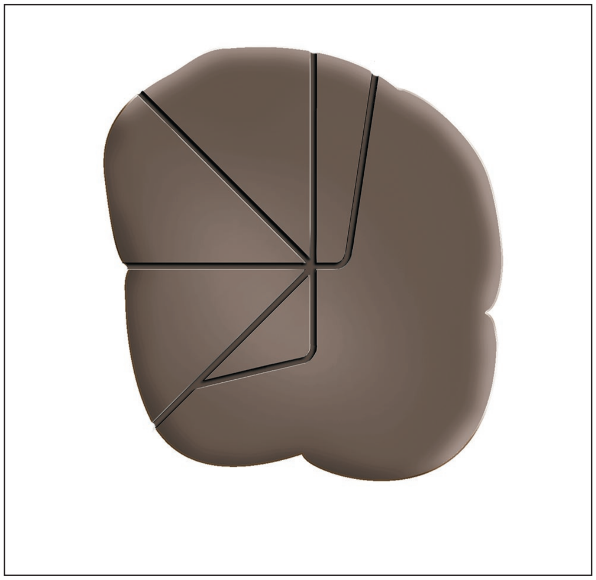


Fig 2-75 As a guide, the movement lines of the occlusal compass and the border region can be marked on the basic, flat occlusal surface; the cusp segments are placed on these lines. These orientation lines make it easier to determine the proportions of the different cusp segments.

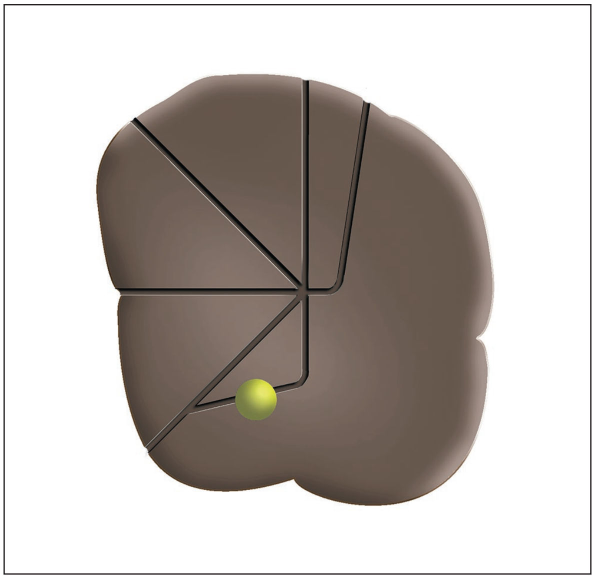


Fig 2-76 The cusp segments can be applied with different-colored wax. The cusp sphere for the mesiolingual cusp is placed on the curvature line of the border region.

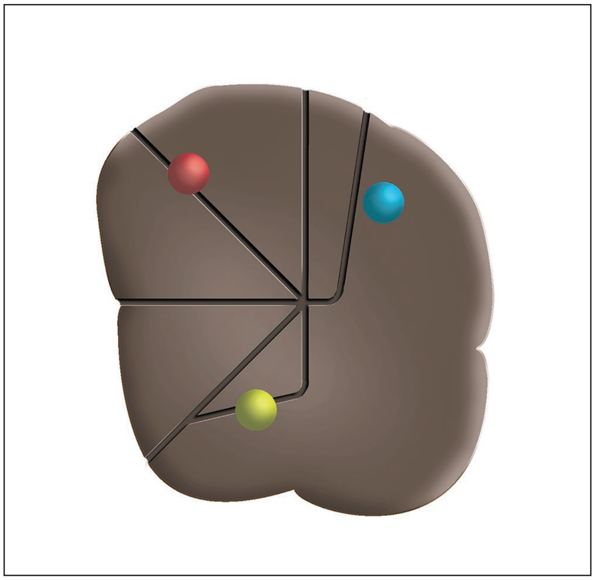


Fig 2-77 The mesiobuccal cusp sphere lies on the lateroprotrusion line toward the buccal region; the distobuccal cusp sphere lies behind the border region, slightly toward the middle of the tooth.

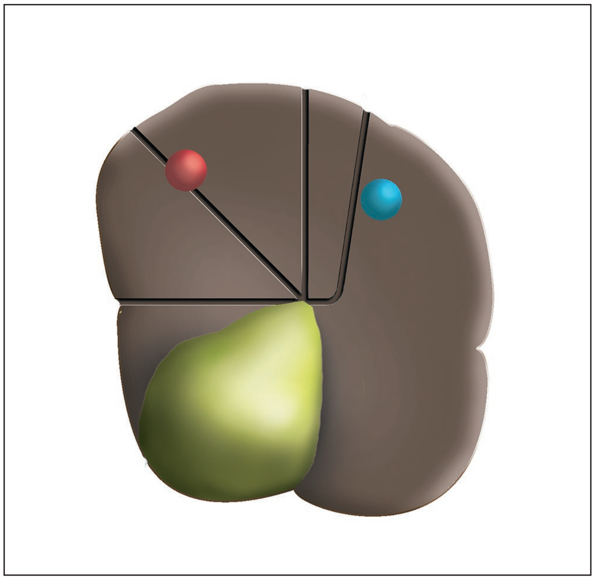


Fig 2-78 The mesiolingual cusp is built up until it comes into contact with the central fossa of its mandibular antagonist. The outer surface is adapted to the vertical curvature of the tooth surface. The rudimentary cusp shape extends to the middle of the tooth on the intersection of the movement lines.

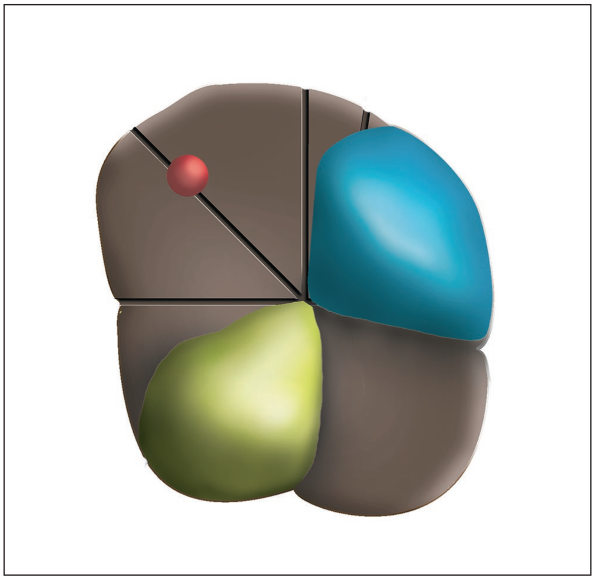


Fig 2-79 The distobuccal cusp sphere is applied in the same way. The vestibular surface curvature is matched to the tooth shape; the cusp extends as far as the intersection of the movement lines and broadens mesially to the laterotrusion line.

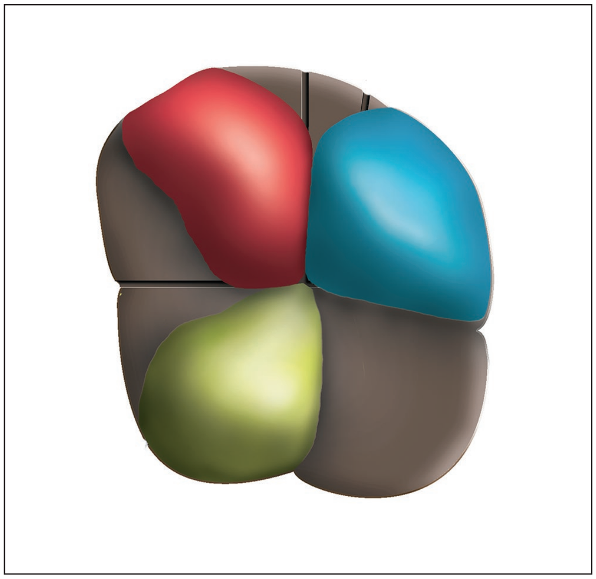


Fig 2-80 The sturdy mesiobuccal cusp sphere is placed between the protrusion and the laterotrusion line. The vestibular tooth surface curvature is reproduced so that the proportion of the molar is preserved. The distolingual cusp sphere is added later.

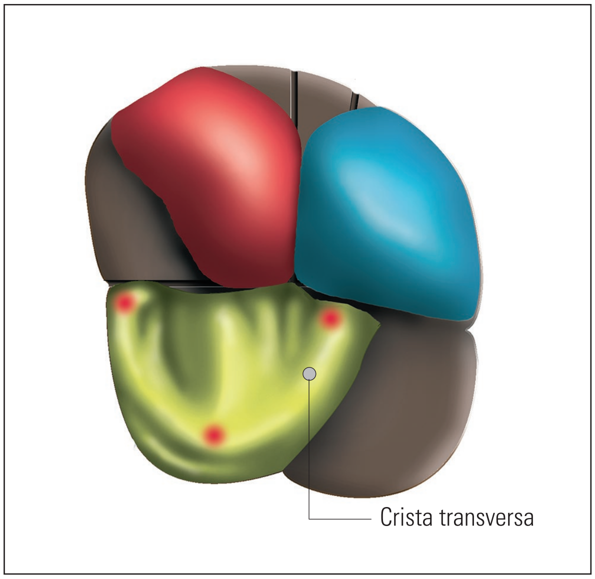


Fig 2-81 The next step is to shape the mesiolingual cusp. The central crest of the cusp is taken onto the mesiobuccal cusp, the cusp ridge is lengthened to the distobuccal cusp and forms the crista transversa, and the mesial approximal marginal ridge is built up. Occlusal points must be formed at the places marked.

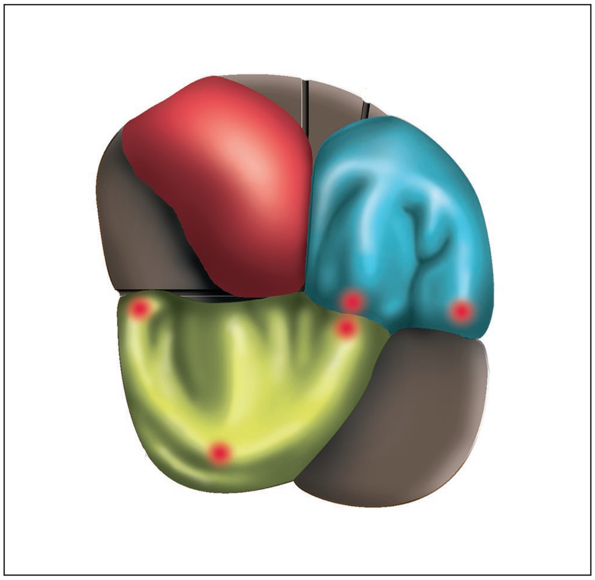


Fig 2-82 The distobuccal cusp is the next to be shaped; it forms the cusp crest and approximal marginal ridge with the respective occlusal points. The approximal marginal ridge is separated from the distal triangular ridge by a distinct supplemental groove.

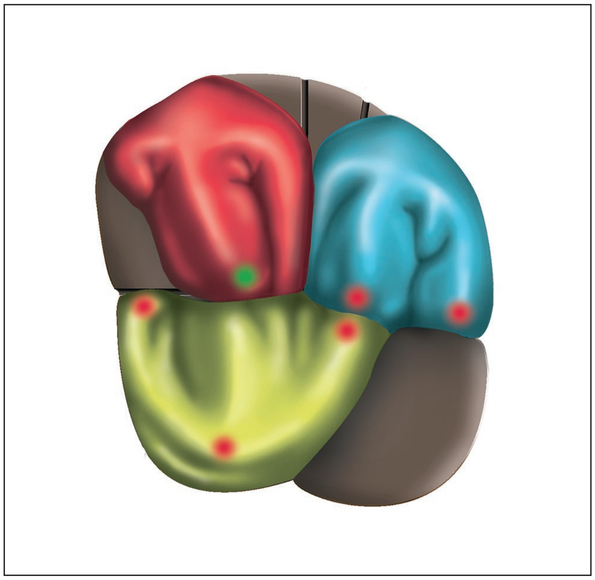


Fig 2-83 The mesiobuccal cusp has the following features: cusp crest, cusp ridge, supplemental groove, and triangular ridge. The occlusal point appears on the cusp crest facing the central fossa.

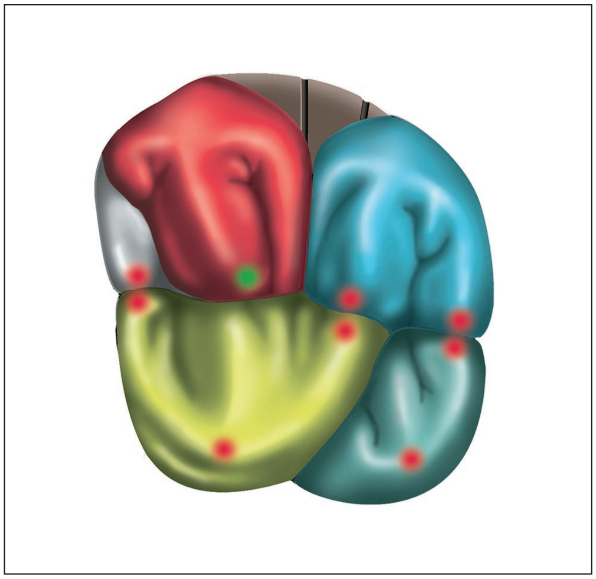


Fig 2-84 The distolingual and mesio-approximal marginal ridge is shaped and displays the marked occlusal points. The fissure paths and occlusal surface pits are traced, and if necessary, the occlusal contacts and approximal contact points are checked and reapplied.

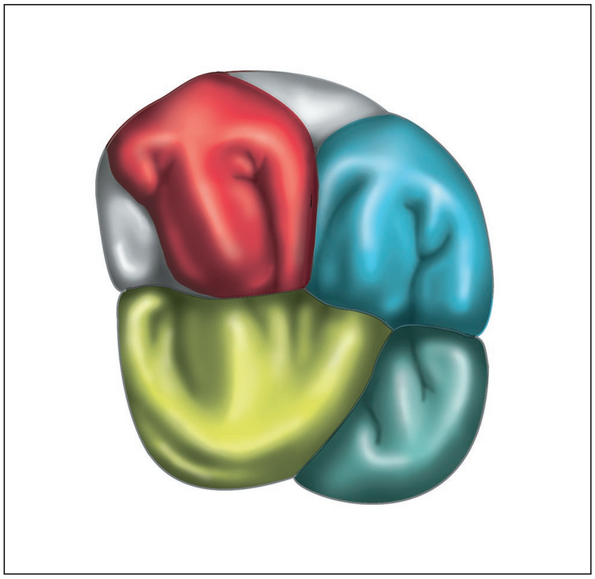
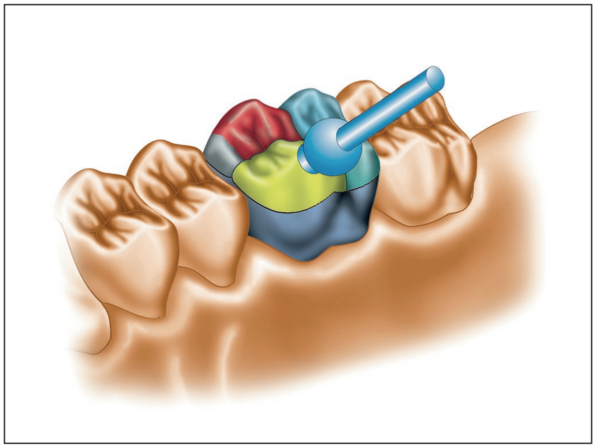
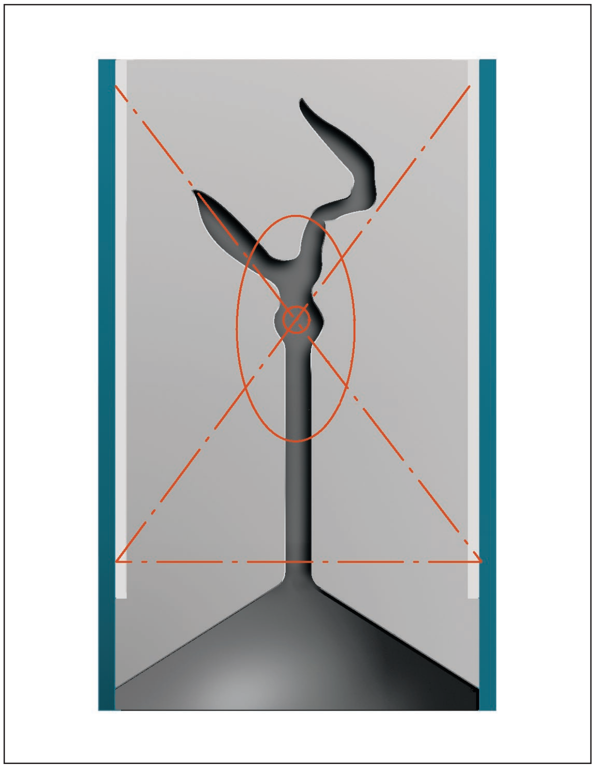


Fig 2-85 Carving of the occlusal surface is completed by closing the vestibular, lingual, and approximal surface curvatures. The wax pattern is then smoothed and degreased. The crown is lifted off the die, and the crown margins are checked. The sprue is then attached.





Figs 2-86 and 2-87 When attaching the sprue, the following applies: *(1)* The sprue attaches to the thickest part of the cast object. *(2)* The sprue has a minimum diameter of 1.5 mm and has a reservoir in the casting. A reservoir is not necessary for thicker sprues (3 mm and more). *(3)* The sprue should be long enough that the casting lies outside the heat center. *(4)* Molten metal should be injected without a change of flow direction and should flow from thick to thin cast parts. *(5)* The cervical opening of the crown should be upward when placed on the base socket mold former so that no undercuts are created that would allow bubbles to form during investment.

and marginal ridges are placed, and the fissures are traced. The circular surface bulges are then shaped. Checking the model in its working positions should reveal areas of occlusal relief that need to be corrected. The transitions of occlusal surface and vertical surfaces are then reworked. Finally, the crown margin is checked: Is the margin too long, too short, too thick, uneven, or sticking out? The following points should also be kept in mind:

- Overcontoured margins can break off.
- If margins are too short, they are extended to the finish line.
- The margin must be of even thickness but should be thinly tapered and entirely fill the preparation shape.
- The crown-preparation interface should be flush without a step.
- The surface of the crown is smoothed and cleaned with a wax stress-relieving spray. The use of spirits or alcohol is unsuitable because the resulting evaporative heat from these liquids is withdrawn from the wax and the crown warps.

Sprueing is done quickly to prevent increased transfer of heat to the wax-up. The wax pattern should not be altered when the sprue is being fitted.

The cast object is invested using precision investment material under vacuum. The flask is placed on the base socket mold former and lined with investment fleece (wet slightly) so that unimpeded setting and expansion of the investment material can take place and no pseudocontraction occurs. The investment material is then stirred and poured in under vacuum. About 20 minutes after investment, wax burnout is mandatory, even if casting will not take place until later. The flask is preheated to the necessary casting temperature, depending on the investment material. This is done according to the temperature guide for precise thorough heating of the flask. Casting in the specified equipment is performed without delay after the relevant process. Once the flask is cooled to room temperature in air, the cast object is divested. Airborne-particle abrasion is then performed with plastic beads.

Finishing involves smoothing machining marks from the surface of the wax pattern, surface grinding the sprue attachment, and removing any bubbles. Fine abrasives, rubber polishers, and fine burs are used for finishing. Tungsten carbide burs and cutters are recommended for reworking the fissures, and the resulting surface can usually be polished directly with handpiece brushes.

Banded Crowns

Full crowns made of metal include banded crowns made of sheet metal (gold, silver-palladium, or steel); these crowns used to be fabricated by a variety of methods but are now outdated. Following are the different types of banded crowns:

- *Collar crowns:* With this type of crown, the crown is soldered or cast onto a ring that is soldered to fit or seamlessly drawn. The crown holds the occlusal relief and is cast or punched out of sheet metal.
- *Prefabricated crowns:* These deep-drawn metal shells made of sheet metal (in different sizes and shapes) can be pushed over the tooth preparation, for which the margin must be suitably cut out cervically to the gingival margin. In the past, these crowns were used as provisional (temporary) crowns.
- *Deep-drawn crowns:* These are deep-drawn out of gold sheet over the prepared die in the dental laboratory.

These types of crown are outmoded because the benefit of material savings—these crowns are extremely lightweight—is outweighed by significant functional deficiencies. In principle, tangential preparation is used for these crowns. A closer look at collar crowns reveals the problems associated with banded crowns.

One of the advantages claimed for collar crowns is that the minimal (tangential) preparation needed for the tooth largely preserves the tooth substance and that the tight-fitting ground ring allows epithelial adhesion because rolled gold sheet delivers clean surfaces without pits or pores, thereby preventing deposits and contaminants at the margin. However, a major disadvantage of these crowns is the lack of stability, particularly because no occlusal stop can be incorporated, except in the case of cast crowns. The very thick layer of cement between the tooth preparation and the crown cannot handle the dynamic loading of masticatory pressure and thereby shatters. As a result, the crown slips in an apical direction and the crown margin bends so far that it lies on the alveolar bone. In addition to the traumatic changes to the tooth with the coronal restoration, the opposing tooth is also damaged as it follows the displacement of the replacement crown. In the process, irreparable periodontal damage is sustained.

With this method, the crown ring is usually trimmed in the mouth. In addition to the variation between the prefabricated ring and the circumference of the tooth preparation, another drawback is the inaccuracy of the marginal path because the crown margin is shaped by cutting with plate shears. The marginal finish of banded crowns is therefore always poor and leads to serious marginal damage.

Techniques for fabricating collar crowns with a cast crown are summarized here as an example of how banded crowns used to be produced. Following are the steps for fabricating a collar crown (Figs 2-88 to 2-95):

1. The sheet metal ring is prepared based on a specified ring size.
2. The ring is contoured according to the root cross section and cut according to the gingival margin.
3. The ring is anatomically contoured with contouring pliers.
4. The ring is trimmed to just below the occlusal level.
5. The prepared die is built up to the antagonists with modeling wax, and the edge of the ring is entirely exposed.
6. The occlusal surface of the crown is carved out of casting wax and fitted with a sprue.
7. Investing, casting, and divesting are done in the usual way.
8. The ring and crown are fitted together and joined with a little solder.
9. The sprue attachment and soldered joint are smoothed.
10. Polishing is done with felt wheels, short brushes, pastes, and high-luster buffs in the usual way. As the crowns are relatively thin, there is a risk of polishing through the crown.

There are other possible approaches to fabricating the occlusal surface of the crown—for example, modeling the surface slightly beyond the ring and investing it with the ring in order to join both parts by the casting-on technique. The crown surface can also be punched out of sheet metal and soldered to the ring; this delivers extremely light crowns that are even more unstable than normal collar crowns. In conclusion, banded crowns, including collar crowns, are entirely outdated prosthetic solutions!

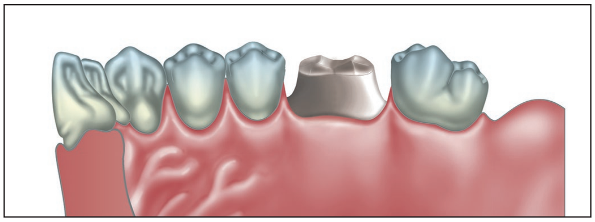


Fig 2-88 A collar crown is fabricated with a cast soldered-on occlusal surface following the working steps depicted here. First, the ring measurement is taken at the actual preparation margin.

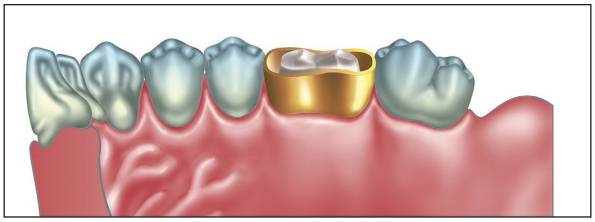


Fig 2-89 The ring is bent into an anatomical shape with suitable contouring pliers. It must have contact with contact points and overhang the gingival crevice.

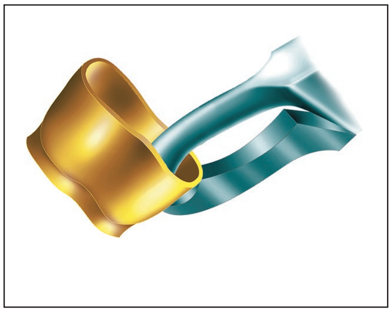


Fig 2-90 The ring is shaped in keeping with the die cross section. The edge of the ring is cut out to follow the path of the cervical margin and pushed about 1 mm below the gingival margin.

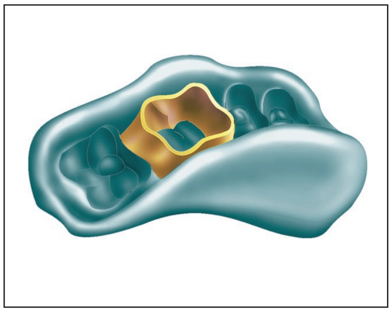


Fig 2-91 A (thermoplastic) stent impression is usually taken with the crown ring shaped in this way, in the form of a squash bite.

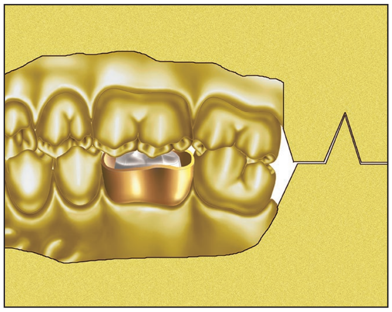


Fig 2-92 This impression is used to produce a cast fixator that shows the few teeth involved. Only terminal occlusion can be reconstructed with this cast.

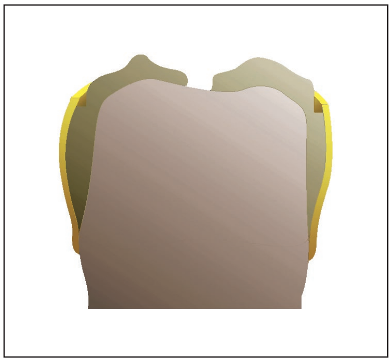


Fig 2-93 The ring is prepared, and the die is built up with wax until it is a uniform distance from the antagonist in order to achieve uniform material thickness and minimal weight.

Fig 2-94 The modeled occlusal surface is removed. It is essential to ensure that the edge of the ring is accurately marked in the occlusal surface margin and contains fixings that guarantee clear positioning of the ring in relation to the cap.

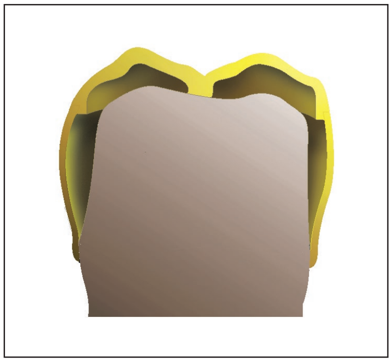


Fig 2-95 The cast occlusal surface is soldered to the ring. An occlusal stop is placed to avoid displacement of the crown.

Full Crowns Made of Tooth-Colored Material

These full crowns known as *jacket crowns* are made of ceramic or acrylic resin. The advantage of crowns without frameworks lies in their excellent esthetic effect. However, the materials require a minimum thickness of 1 mm, which means that shoulder preparation is always required (Figs 2-96 to 2-98).

Coronal restorative material is intended to be laid fully in the tooth to prevent irritation of the marginal periodontium due to pressure. For this purpose, the tooth preparation is ground to be slightly conical; to maintain stability, the preparation must not exceed three-quarters of the original length. For static support, an incisal plateau is prepared.

A circular or rounded shoulder approximately 1 mm wide is placed up to the epithelial fusion line. The inclination of the shoulder to the preparation should at least be at right angles, but a shoulder sloping down to the preparation would be better. If the shoulder slopes outward, the ceramic material is widened and will break in response to shear loading. Acrylic resin swells when absorbing water and is pressed outward by the sloping shoulder. A shoulder sloping inward compensates for shear forces in the ceramic crown and presses a swelling acrylic resin crown onto the tooth at the margin.

If tangential preparation were used, the crown margin—as with metal crowns—would have to taper thinly, and the ceramic crowns would break during placement. Although acrylic resin crowns could be placed because the material is capable of elastic deformation, fatigue would cause plastic deformation to occur after a short time, and the material would lift off the tooth.

In addition to the mechanical stress on the gingiva involving inflammatory processes, deposits and bacteria would become lodged under the margin, leading to traumatic changes to the entire periodontium. A chamfer preparation is inadvisable for precisely the same reasons.

The indication for these full crowns is determined by the material properties of the acrylic resin or the ceramic being used. For example, a porcelain crown (or an all-ceramic crown) has absolute color and dimensional stability and very good tissue compatibility. It is resistant to high compressive stress and abrasion but less resistant to shear forces. A material thickness of 0.8 mm is required, which means that shoulder preparation involves substantial reduction of the tooth; therefore, this type of crown is not an option if the pulp cavity is large. Veneer crowns can be fabricated by the metal-ceramic technique using chamfer preparation and offer similar esthetic advantages to porcelain crowns.

Acrylic resin crowns have elastic properties and sufficient abrasion resistance if light-cured composites are used; they are therefore well suited to long-term restorations. Acrylic resin often shows discolorations, and swelling of the material may cause a gap between the tooth and the crown. However, long-term studies have shown that composites are subject to only minor changes and thus remain dimensionally stable and color-stable for prolonged periods.

The advantage of acrylic resin crowns lies in their rapid, less complex, almost problem-free, and inexpensive fabrication. Today crowns can be produced from acrylic resins that are indistinguishable from a natural tooth or a porcelain crown in terms of shape and color. The elastic deformability and abrasion properties are other advantages because the tooth is not stressed as much during mastication as is the case with a rigid metal or porcelain crown.

Another advantage of an acrylic resin crown is its use as a temporary replacement for 1 to 2 years when a shoulderless preparation becomes necessary (in adolescents) because of the risk to the pulp. Once the pulp (possibly due to the irritation caused by grinding) has diminished, preparation for the definitive crown can then be carried out.

In principle, full crowns made of ceramic or acrylic resin are used for maxillary anterior teeth for esthetic reasons. In the mandible, jacket crowns are more difficult to fabricate because the necessary loss of substance weakens the mandibular anterior teeth too much, leaving insufficient retention.

Less plaque is deposited on ceramic crowns than on acrylic resin jacket crowns. Owing to the risk of fracture, acrylic resin jacket crowns are not indicated for posterior teeth; by contrast, ceramic crowns can be used for premolars, given favorable occlusal relationships.

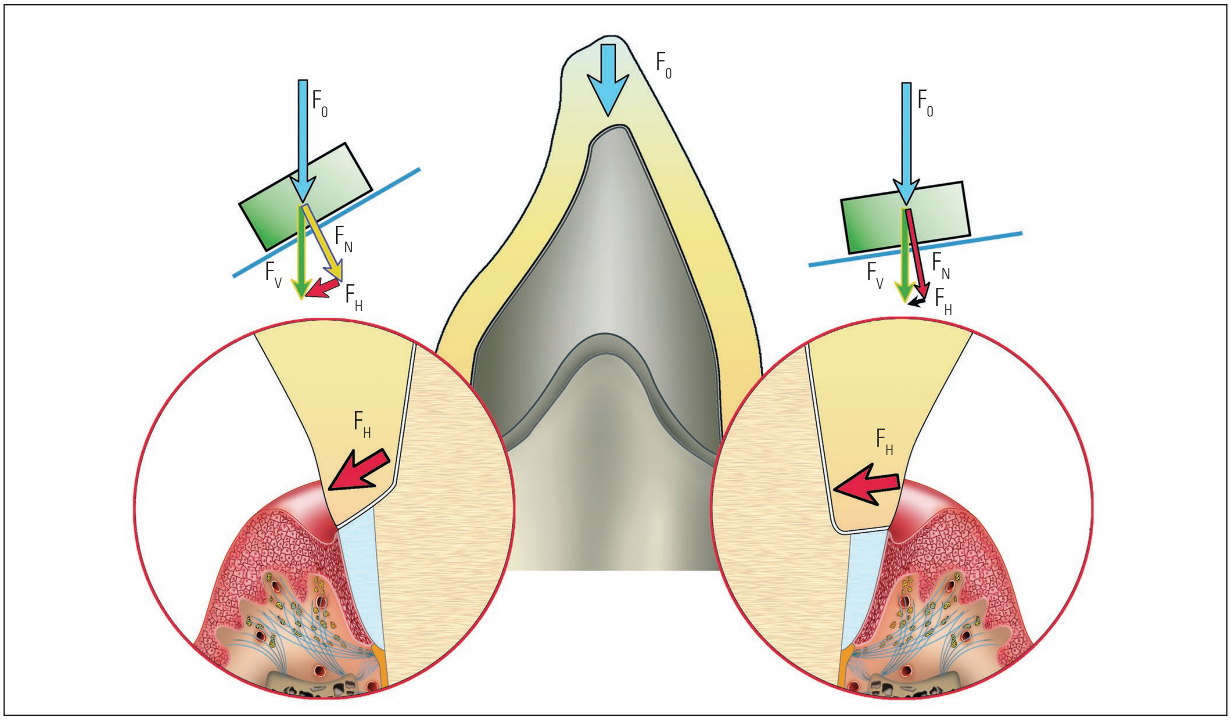


Fig 2-96 Jacket crowns must be prepared with a circular shoulder approximately 1 mm wide. The tooth is prepared to be slightly conical with a shoulder sloping inward. A shoulder sloping down to the preparation is an important requirement for stability. In response to compressive stress, the crown restoration material slips toward the preparation; the acrylic resin jacket crown widens if the shoulder slopes outward, and a porcelain crown may break. The advantage of an inward-sloping shoulder can be seen from the simple division of forces at an inclined plane.

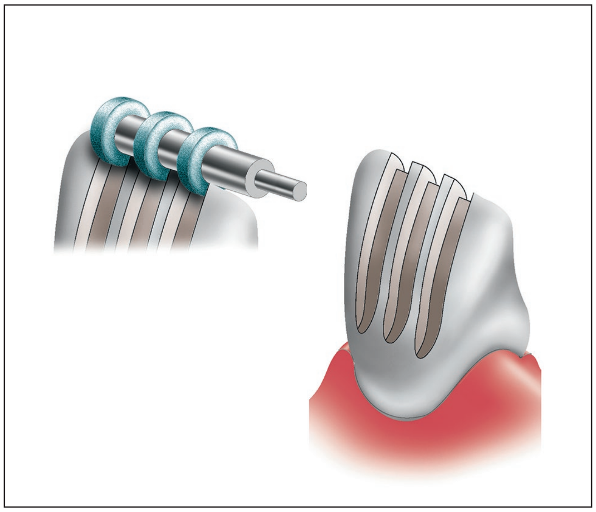


Fig 2-97 To get a better overview of preparation depth for anterior teeth, a groove is removed with a groove cutter. The amount of dental tissue removed depends on the depth of the groove.

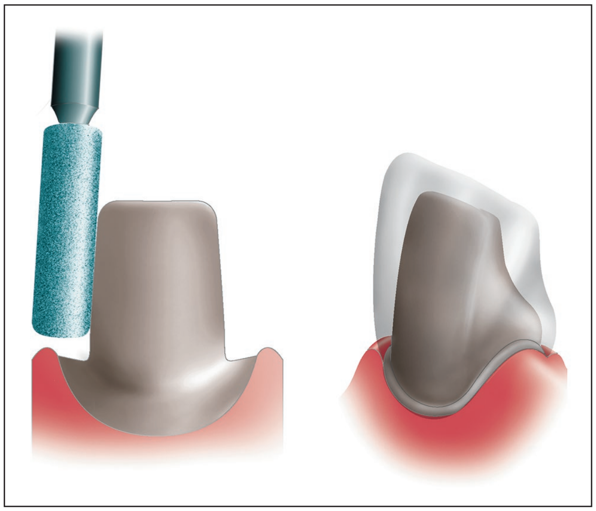


Fig 2-98 A conical preparation is created with a cylindric bur. At the same time, a shoulder sloping slightly inward toward the preparation is ground. Jacket crowns always require shoulder preparation, which demands considerable loss of dental tissue, particularly on anterior teeth.

Acrylic Resin Jacket Crown Fabrication

The working process for fabricating an acrylic resin jacket crown starts with the preparation of the die. Different acrylic resin materials require different processing methods, but there are two basic methods.

The first method involves carving the crown out of wax, then investing and pressing the acrylic resin into the resulting mold. This indirect molding technique is also used for ceramic crowns that are fabricated by the casting process (Dicor, Dentsply) or press technique (IPS Empress, Ivoclar). Fabricating acrylic resin crowns by the liquid resin press molding process, however, is an outdated technique and is only presented here to give a complete overview.

The second method involves applying the acrylic resin dough to the die layer by layer, carving it, and curing the individual layers in an ultraviolet light-curing device. This method resembles the classic fabrication of a porcelain crown in its working sequence and necessary manual skills. When processing acrylic resin, however, no platinum foil is drawn over the die. This is because material shrinkage does not need to be considered to the same extent as it does in porcelain firing.

The systematic waxing-up technique is relevant to the fabrication of jacket crowns and all-ceramic crowns. In addition to following the principles of wax processing to avoid stresses and warping of the wax crown, the following points should be noted when waxing up the crown:

- The tooth shape must match the original in all anatomical details. Any discrepancies will be particularly noticeable in the visible area. The adjacent teeth offer the best clue to finding the right shape.
- The length and width of the tooth must harmonize with those of the adjacent teeth.
- The mesial inclination should be determined from the vestibular view. The mesial inclination can be corrected most effectively if the marginal ridges of the vestibular surface are suitably emphasized: The mesial marginal ridge is more prominent, and the distal aspect is gently rounded in keeping with the curvature characteristic. The angle characteristic also reinforces the impression of the mesial inclination.
- The approximal inclination can be checked by comparing the position of the incisal area with the adjacent teeth and the position of the neck of the tooth; a recessed neck has a very unfavorable effect. The tooth must not protrude out of the arch or tip inward.
- The vertical curvature must match the anatomical pattern; hence, cervically the stronger curvature is needed to protect the marginal area.
- The crown must lie within the dental arch and not be twisted in a vestibular or inward direction in the dental arch.
- Occlusal contacts must be avoided in the terminal occlusion (Fig 2-99). The sagittal distance between the anterior teeth must be maintained.
- The approximal contacts should fit closely in the right place, that is, in the upper third of the crown. They can be slightly thickened before investing to make up for the loss of material during finishing.
- The precise surface form of the approximal surface must be respected. The contact point is not a bulge that is specially added, but the tooth widens steadily from the cervical margin to the

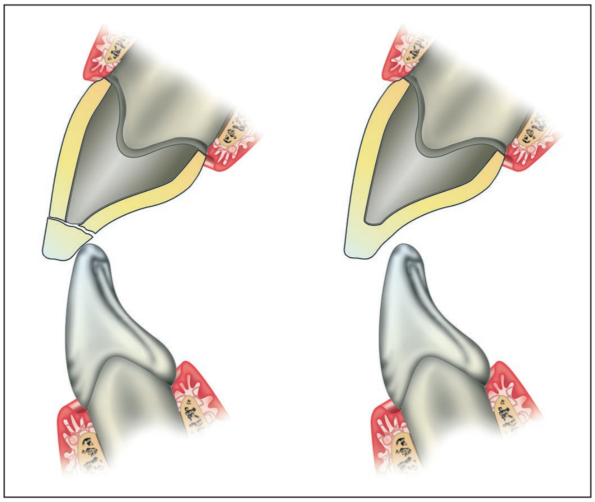


Fig 2-99 The occlusal contacts on jacket crowns are problematic. If contact on an anterior tooth in terminal occlusion lies too far incisally and is too pronounced, the artificial crown may fracture. Therefore, it is advisable to omit occlusal contacts on anterior crowns; even slight gliding contacts should be avoided.

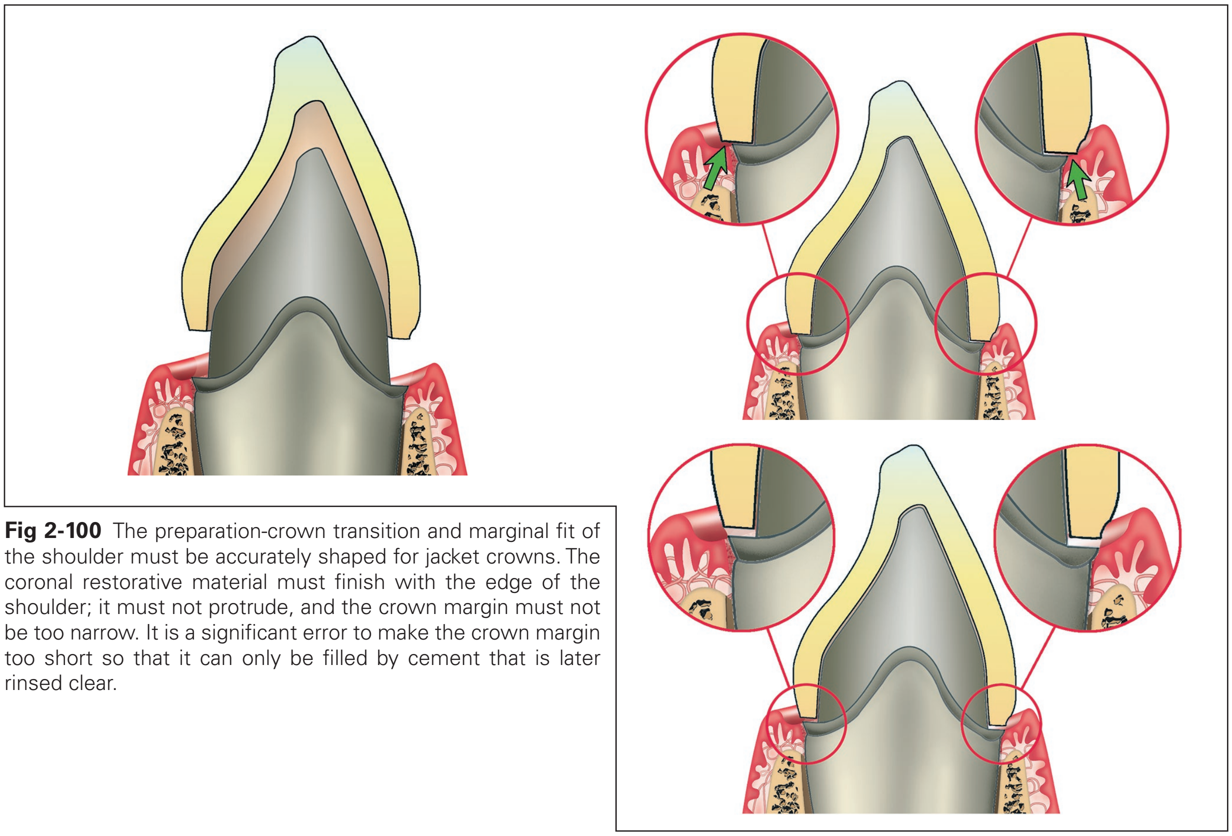


Fig 2-100 The preparation-crown transition and marginal fit of the shoulder must be accurately shaped for jacket crowns. The coronal restorative material must finish with the edge of the shoulder; it must not protrude, and the crown margin must not be too narrow. It is a significant error to make the crown margin too short so that it can only be filled by cement that is later rinsed clear.

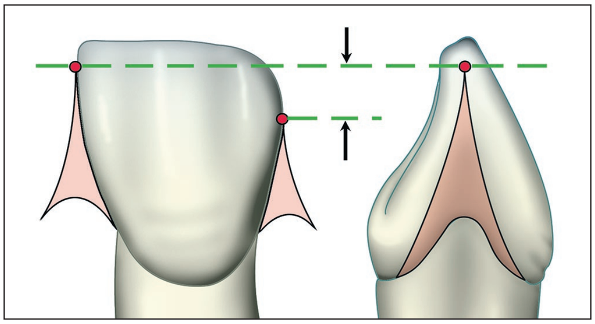


Fig 2-101 On maxillary incisors, the mesial contact point is higher than the distal contact point. If an anterior tooth appears too wide because of shaping of the contact, the tooth can be worked to look narrower by emphasizing the mesial and distal marginal ridges, which are pushed slightly toward the middle of the tooth.

approximal contact; the interdental papilla must not be squashed.

- The transition from crown to preparation should be flush (Figs 2-100 and 2-101). The crown must neither protrude beyond the shoulder width nor be narrower.
- The shoulder must be marked accurately in the wax crown.
- The inside of the crown must be smooth and reproduce the precise contour of the tooth preparation.

Again, it should be noted that the more precise the wax pattern, the fewer corrections will be necessary at the finishing stage. Once the wax crown has been relaxed and corrected, the crown can be invested.

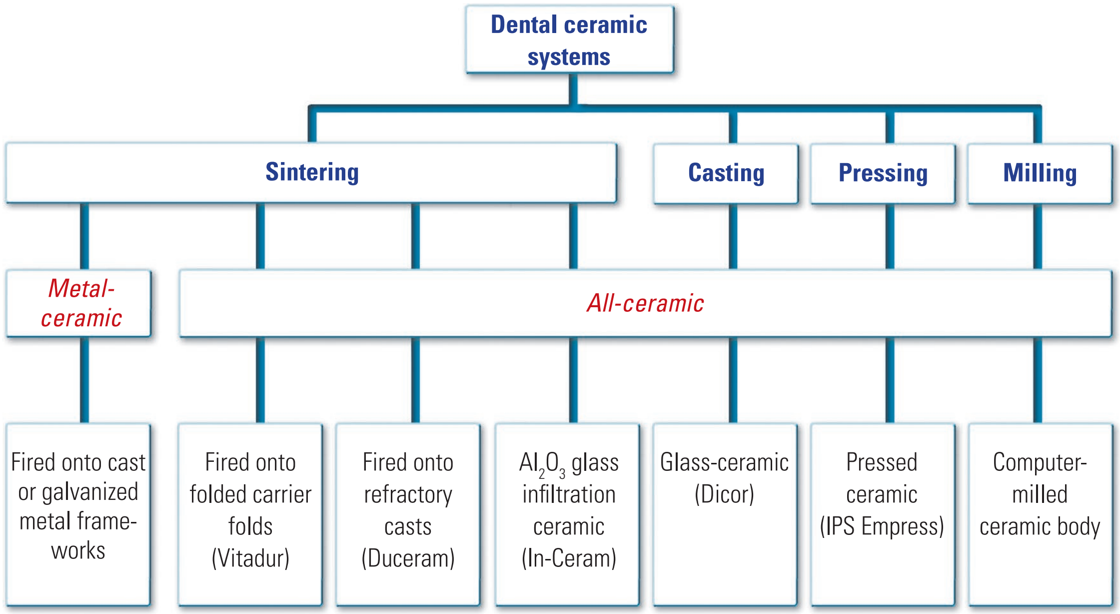


Fig 2-102 Diagram of dental ceramic systems.

Ceramic Crown Fabrication

The same indications for acrylic resin jacket crowns apply to full crowns made from ceramic. Optimal color matches can be made with suitable layer thicknesses (at least 1 mm). Because tissue incompatibility is not an issue with mineral materials, ceramic crowns are the best solution for this situation. Figure 2-102 outlines the different types of dental ceramic systems.

The classic approach to fabricating a porcelain crown allows for free layering of the ceramic materials. The individual layers are applied and fired separately. For this purpose, a folded platinum cone is produced as a coping over the tooth preparation. The platinum foil is placed closely over the preparation and is intended to act as a carrier for the ceramics during firing and to compensate for material shrinkage as a spacer (Fig 2-103).

Application of materials and the firing sequence, including any corrections, take place in a succession of working steps. Ceramic powders dyed with metallic oxides are mixed with distilled water to a paste that can be modeled.

Shrinkage (drying shrinkage and sintering) of the mineral material on firing is approximately 20% to 25% and is compensated for by enlarging the shape during modeling. The ceramic is fired in a furnace under vacuum. Only then is the core material applied and fired (core firing). The dentin and incisal materials are then built up and fired. In the process, the relatively squarely applied materials merge into rounded surface contours as a result of sintering.

The ceramic materials should be mixed and applied without bubbles; excess fluid must be removed by suction before firing, and the materials must be applied in even layers before drying. On firing, the ceramic always shrinks down to the thickest part so that thinner parts are under stress and may tear.

The final shaping is done by corrective grinding and application of correction materials in a separate firing. The final firing process is the glaze firing, during which the surface of the crown is glazed. Finally, the platinum foil is removed.

Note that the described process of fabricating a jacket crown is an outdated technique, which is

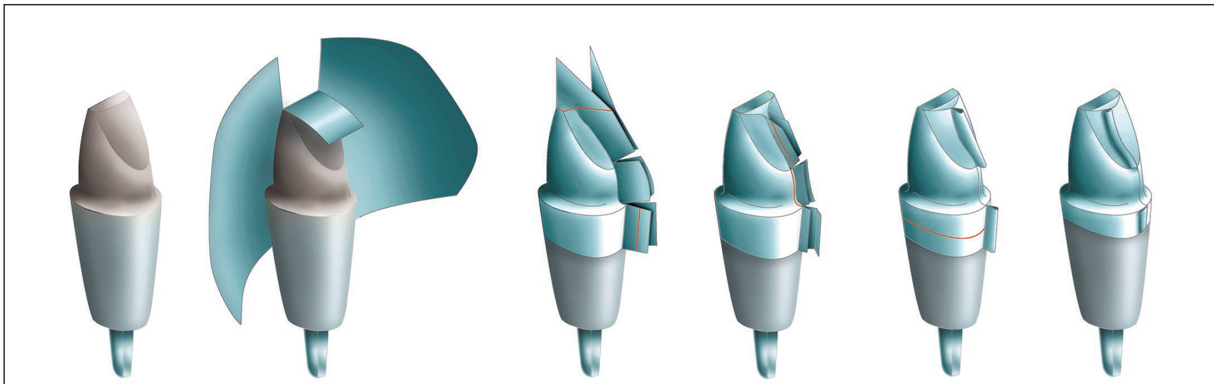


Fig 2-103 The foil is squeezed around the die. Notches the width of the die are made at the incisal edge, and the foil is bent lingually. The first cut is made level with the shoulder. *(1)* Below the shoulder, the foil is trimmed to 2 mm on one side. *(2)* The second cut is made level with the tubercle. *(3)* The third cut shortens the points of the foil up to the incisal edge. The long part of the foil below the shoulder is flattened and pressed on. *(4)* The foil is cut off parallel to the die from the tubercle to the shoulder. Above the tubercle, part of the foil is trimmed to 2 mm, then flattened. *(5)* The long part of the foil above the tubercle is bent into a U shape and pressed onto the die. The same is done with the portion of foil below the shoulder. The foil is then trimmed to about 2 mm below the preparation margin. The foil must lie firmly in place and must not be crinkled. The platinum cone must be relatively easy to remove.

why no error analysis is presented. A number of all-ceramic systems are available, such as glass infiltration ceramic (In-Ceram, Vita), pressed ceramic (IPS Empress), and cast glass (Dicor), for which crystal-reinforced ceramics are used. These materials are usually strengthened with leucite or aluminum oxide. In the Duceram (Vita) technique, the ceramic is applied layer by layer onto a platinum carrier foil (or onto a refractory die) in the classic form and fired layer by layer.

Vita's In-Ceram and Hi-Ceram methods are hard-core systems for all-ceramic crowns and fixed partial dentures. These methods involve working with glass-infiltrated aluminum oxide ceramic that is reinforced with zirconium oxide. The porous Al_2O_3 hard-core crown sintered at 1,120°C is infiltrated with lanthanum glass melted in a special glass infiltration firing at 1,100°C. The hard core then forms the frame to carry the actual ceramic layering. This technique does not result in any marginal defects, such as those found where the platinum foil is folded in the conventional technique.

Interspace varnish (approximately 45 µm) is applied to the tooth preparation of the master cast before the die is duplicated with special stone. A slip of fine-grain Al_2O_3 and mixing fluid are applied to the plaster die to form a thin framework crown that is dry-sintered for 2 hours in a sinter firing (wet sintering should not be used). This results in minimal shrinkage, which is aided by expansion of the stone die. A thin suspension of special glass powder and distilled water (glass-infiltration material) is applied to the extremely brittle coping and fired at 1,100°C for 4 hours. In the process, the coping is infiltrated by the melted glass and hardens.

The finished coping can be reworked with diamond burs and coated with sintered ceramic (mainly Vitadur N, Vita). The inside of the finished ceramic crown is silanized by tribochemical coating for adhesive fixation in the mouth and is inserted with composite.

Cerestore (Coors Biomedical) is a castable, shrinkage-free ceramic in which the core (mixed with silicone) is cast into a mold in the injection molding process at 180°C. After a 12-hour firing process (1,300°C), the material sinters and forms spinel crystals.

The IPS Empress technique involves carving the crown (inlay) in wax and investing it in phosphate-bound investment material (Fig 2-104). The flask is heated to 900°C so that a precerammed glass material infiltrated with leucite crystals, heated in

Fig 2-104 In the IPS Empress system, the wax objects are placed on a special base socket mold former with sturdy sprues. (Courtesy of Ivoclar Vivadent.)

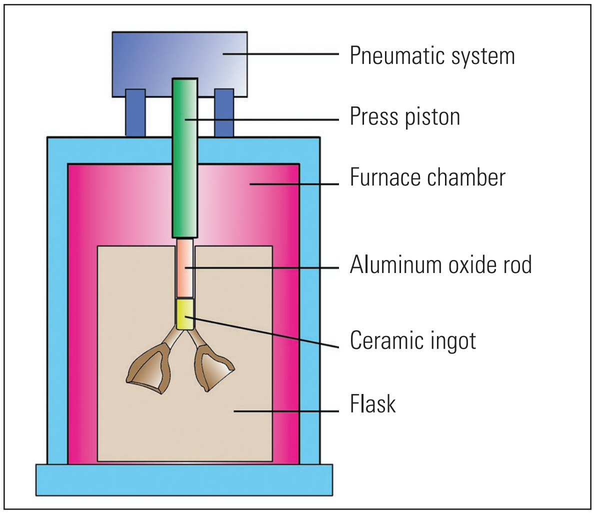


Fig 2-105 In the IPS Empress press furnace, the preceramed glass mass with leucite crystals is pressed into the mold at 1,100°C with the aid of an aluminum piston. Leucite crystals grow during the approximately 15 to 30 minutes allowed for the pressing process. (Courtesy of Ivoclar Vivadent.)

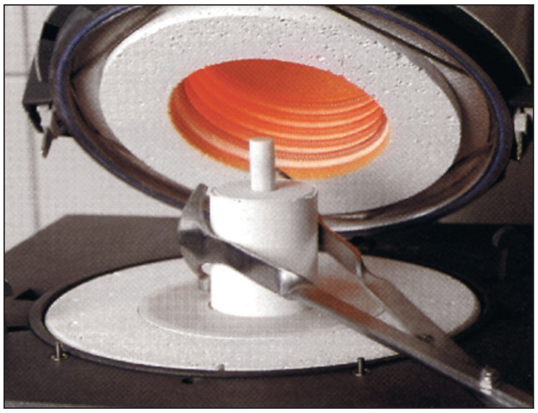


Fig 2-106 The preheated flask is loaded with the preheated ceramic ingot and the aluminum oxide rod and placed in the press furnace; the furnace chamber is closed, and the press piston is hydraulically pulled out. The pressing process lasts up to half an hour, depending on the size of the object. (Courtesy of Ivoclar Vivadent.)

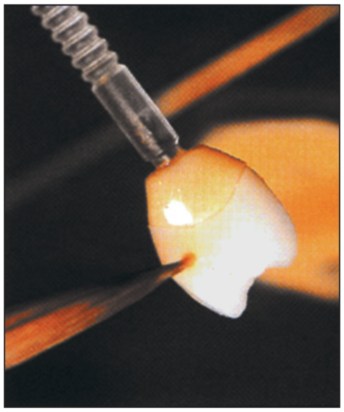


Fig 2-107 The pressed ceramic object can be stained with mineral stains, then fired. Color matching can also be done by subsequent layering. Stains are fired in additional firing runs, during which more leucite crystals are formed. (Courtesy of Ivoclar Vivadent.)

a pressing furnace at 1,100°C, is pressed into the mold (Figs 2-105 and 2-106). For a 15- to 30-minute pressing process, the pressed ceramic has a consistency like glass during glass-blowing. Leucite crystals will grow during the pressing process. The glass ingot is carefully divested, the sprue is separated, and shape corrections are reground. Color matching is done by staining with mineral stain or by subsequent layering with the system's own sinter ceramic (Fig 2-107).

In the case of cast glass (Dicor technique), the crown is also carved in wax and invested in phosphate-bound material. The flask is heated to 900°C, and the glass is poured in the centrifugal casting technique. In the casting centrifuge, the flask is heated to the casting temperature of 1,110°C. In a disposable casting crucible made of zirconium oxide, the glass mass is melted and becomes more viscous than molten metal. For this purpose, the centrifuge must spin for 4 to 5 minutes. The cast glass object is carefully divested and abraded with Al_2O_3, then coated with special ceramming investment and cerammed at 1,075°C according to a set program, which results in crystallization of mica glass. Color matching is done by staining with mineral stains that are baked in at 950°C without vacuum. The color layer can be abraded and reapplied. Corrections, such as contact points, can be subsequently applied with a ceramic from the same product range and fired on.

A foil crown is a metal-ceramic crown with a metallic carrier framework made of multilayered rolled precious metal foil approximately 0.1 mm thick. In terms of construction, the foil crown lies between all-ceramic crowns and metal-ceramic crowns. To exploit the esthetic depth of the ceramic, the die of the prepared tooth is encased in a very thin prefabricated part made of precious metal foil, without creasing, and the ceramic is fired on. This means that the entire preparation space is used for the ceramic crown. The same depth of color is achieved as with an all-ceramic crown, and the stability is similar to that of a metal-ceramic crown.

The foil technique involves adapting a five-layer pure precious metal foil (Ultralite foil, Ulbrich) to the die and pressing it in a pressure chamber filled with plasticine (die stamp) in a cold plastic state. The cavities caused by folding are then closed over an open flame by diffusion melting. Ceramic bonding is supported by a 30-mm-thick, fired-on pure gold mesh that is applied with a brush in the form of pure gold granules and fused at 900°C. The ceramic modeling is done by the usual layering technique.

The different precious metal layers of the foil have excellent thermal constancy because of the bimetal effect, so that remarkably good crown margin accuracy is achieved even after several ceramic firings. For esthetic reasons, however, and to avoid any tissue contact between the metal and the gingiva, the foil can be trimmed to about 1 mm above the preparation margin and the crown margin fired in ceramic.

Fabrication of a galvano (electroformed) gold coping is another way of layering and firing the ceramic tooth mold onto a very thin carrier coping. The metal carrier framework is produced by a galvanoplastic method: The surface of the tooth preparation is rendered electroconductive, and galvanic metal plating takes place with the aid of direct current out of a saline solution containing the plating metal. The tooth preparation acts as the cathode (negative pole), and a plate of the metal being deposited serves as the anode. The electrolysis conditions are selected so that a smooth, uniform deposit is produced on the mold.

Computer-aided design/computer-assisted manufacturing (CAD/CAM) technology offers computerized fabrication of ceramic inlays, onlays, and half-shells in which the molded part is fabricated directly with the aid of computer-controlled milling machines. This is done after an optical impression has been taken with a measuring camera and after the preparation margins have been defined on a monitor. Using a construction program, the computer builds the molded part out of the available dental data and the plotted construction lines. With minimal loss of dental tissue, this method provides metal-free restorations made from tooth-colored ceramic that have properties similar to those of dental enamel. The molded parts are adhesively cemented with composite.

Veneer Crowns

Veneer crowns are full crowns that combine the mechanical stability of full-cast crowns with the esthetic benefits of acrylic resin or ceramic crowns. With this type of crown, a stable metal framework forms the functional parts, such as occlusal and approximal contacts, preparation coverage, and the crown margin, and tooth-colored veneering material forms the visible covering and matches the anatomical surface curvatures (Fig 2-108).

Veneer crowns are indicated for all tooth shapes in which the preparations can be adequately prepared; this usually applies to all maxillary ante-

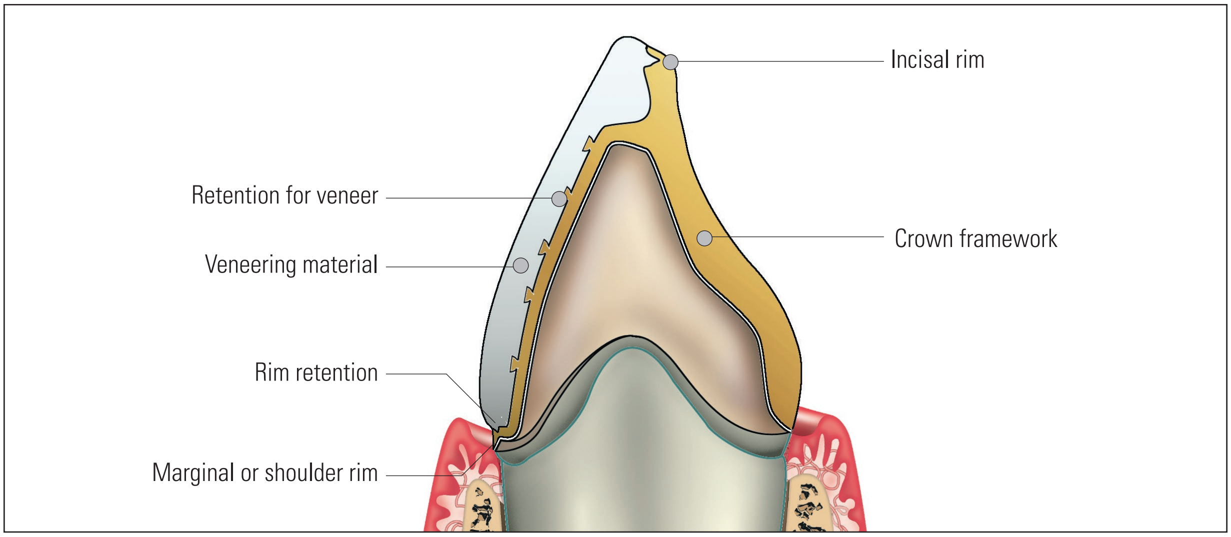
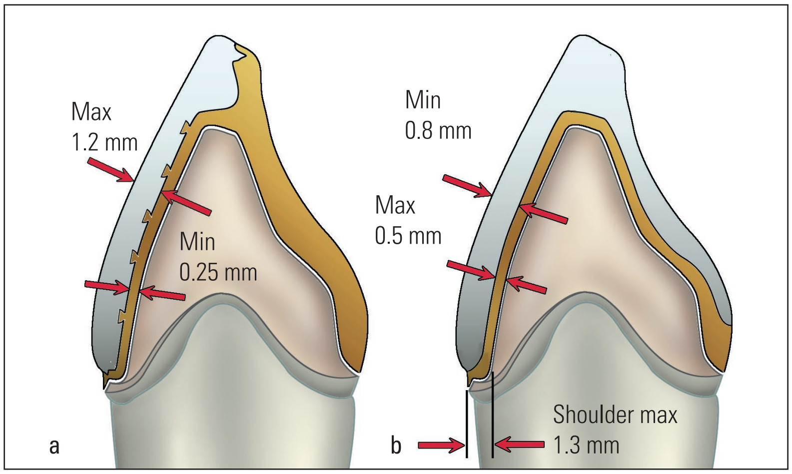


Fig 2-108 The veneer crown comprises a metal framework and a tooth-colored veneer.

Fig 2-109 The minimum material thicknesses in a veneer crown are as follows: *(a)* An acrylic resin veneer crown should have a crown framework 0.25 to 0.4 mm thick and veneering acrylic resin at least 0.8 mm thick. *(b)* A ceramic veneer crown should have a crown framework 0.35 to 0.5 mm thick and veneering ceramic at least 0.8 mm thick. The crown frameworks must be worked to be more stable if the veneer crowns are being used as fixed partial denture abutments. Splinted veneer crowns should also have more stable crown frameworks.



rior and posterior teeth and mandibular canines and posterior teeth. Use of the metal-ceramic technique can also be extended to molars with occlusal surface veneering. The parts of a veneer crown are the crown coping, margin or shoulder, veneer retention, shoulder retention, and ceramic or acrylic resin veneering material.

The crown framework should have a minimum thickness of 0.35 to 0.5 mm for ceramic and 0.25 to 0.4 mm for acrylic resin (Fig 2-109). In addition, the veneering material should have a minimal thickness of 0.8 to 1.2 mm. Thinner layers of metal impair stability, and excessively thin veneers result in color discrepancies. Stability is a primary concern in veneer crown frameworks for fixed partial denture abutments.

The frameworks of crowns veneered with acrylic resin must be designed as a retention surface in order to create a proper bond between acrylic resin and metal (Figs 2-110 and 2-111). The acrylic resin must not come into contact with the mucosa; the aim is to extend the veneer into the

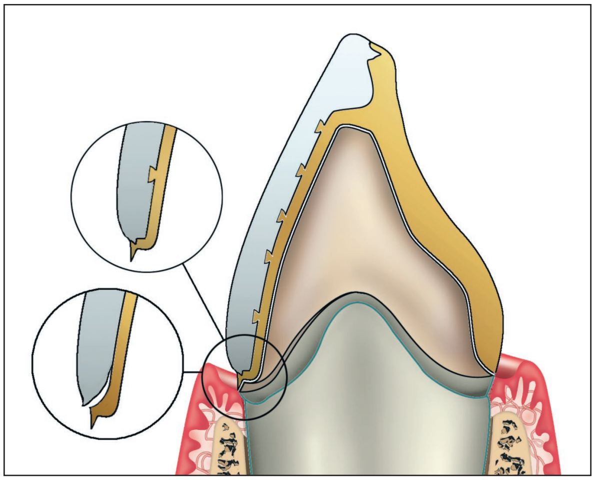


Fig 2-110 The metal framework is made to match the form of the preparation margin and creates the undercut "watch-glass notch" to the veneer surface that holds the acrylic resin. If the veneer surface is worked without a rim, the veneer acrylic resin will taper thinly and may lift off due to swelling and form a crack for plaque to become lodged. Even when chemical bonds are involved, the acrylic resin may lift off in the marginal area so that a rim retention also needs to be shaped here.

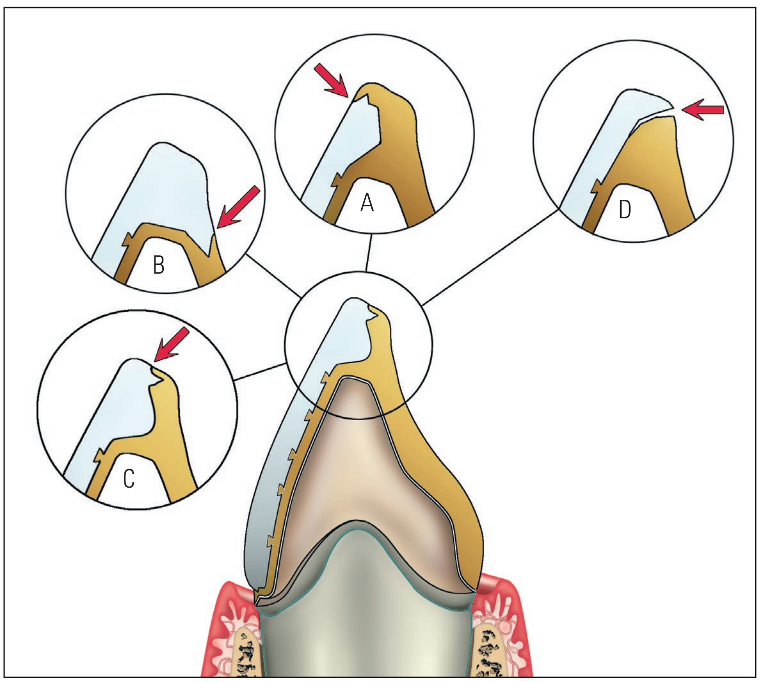


Fig 2-111 The retention surface for an acrylic resin veneer crown is worked as a rim retention, which is undercut all the way around. For esthetic reasons, the transition can be moved lingually in the area of the incisal edge (B), although stability suffers as a result. The transition shown in A is extremely stable but not esthetically attractive. A good compromise is to place the transition incisally (C). The transparency of the cutting edge does suffer somewhat, but the rim is stable enough. Overlapping the acrylic resin over the rim should be avoided because the acrylic resin will lift off (D).

approximal area so that no metal can be seen. When creating a metal-acrylic resin bond, the metal framework is fabricated with box retention and additional retentions. The chemical metal-to-acrylic resin bond is stable enough with a chemical bonding layer (silane layer) (Fig 2-112), but box retention and (small) additional retentions have also proved effective.

Preparation for veneer crowns requires substantial reduction of dental tissue wherever two materials overlap each other. A shoulder is mandatory in the vestibular visual area and must measure between 0.95 and 1.3 mm.

Acrylic resin veneers are mainly used with telescopic crowns, less commonly for stand-alone crowns or fixed partial denture abutments. The

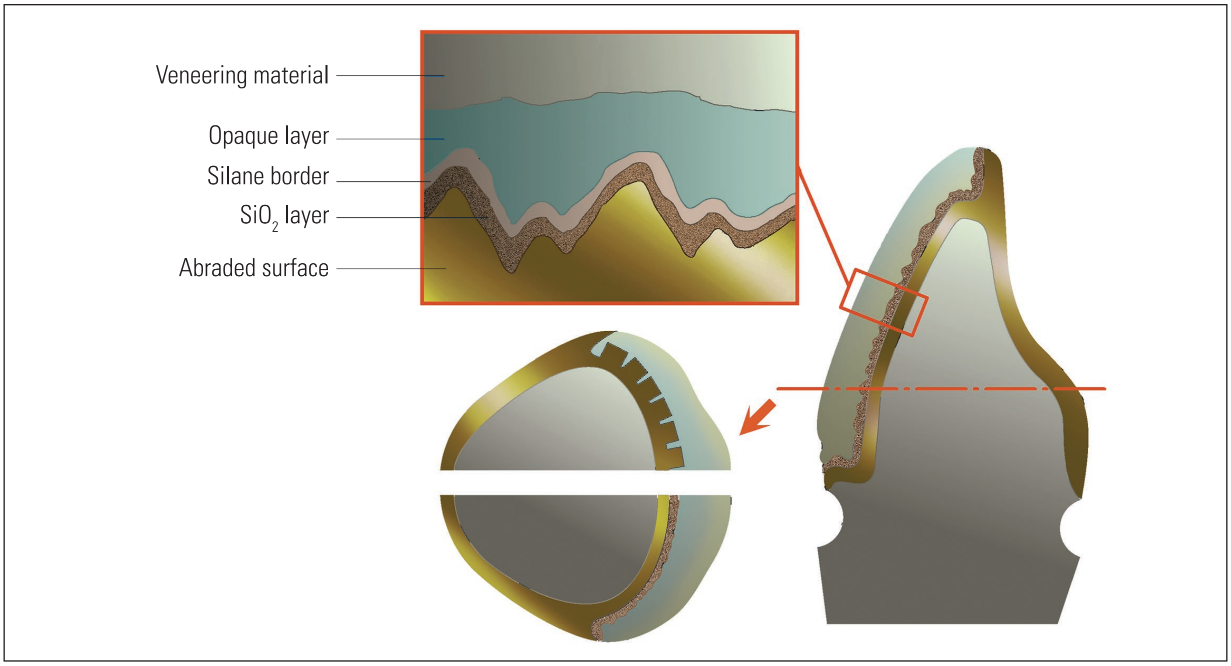


Fig 2-112 Schematic diagram of the layer buildup of a crown veneered by the silanization method. With a chemical adhesive bond between metal framework and acrylic resin, the acrylic can be cured onto an organic intermediate layer of silane. The metal surface is roughened and enlarged by airborne-particle abrasion, the SiO_2 layer (silane) is applied by tribochemical coating, and a silane bonder is applied to provide surface conditioning to allow polymerization on the veneering acrylic resin. The comparison of mechanical and chemical bonding of the veneer material shows the space required by mechanical retentions.

first acrylic resin veneers were characterized by low wear resistance, thermal expansion in the bond to metal, and faster aging. The development of microfilled, abrasion-resistant acrylic resins (composites) and adhesive bonding to silanized metal surfaces has largely overcome these drawbacks. The latest veneer crowns have adequate mechanical quality and durability, have the best color effect and color-fastness, and measure up to ceramic veneers in esthetics.

The metal framework is the supporting part in acrylic resin veneer crowns. It absorbs masticatory pressure and holds and supports the veneer, so it is essential to achieve absolutely closed containment of the tooth preparation. Incisal edge protection may be created for stability reasons. In principle, the veneer is rimmed by metal, but the veneer metal must have no contact with the mucosa.

The rim itself defines the size of the veneer. The aim is to produce an extensive veneer with approximal spread and veneering of the incisal edge (or the occlusal edges in the case of premolars). A full veneer, such as those produced with porcelain, can also be created using modern composites.

The retention areas must offer good enough mechanical anchorage, which is achieved with a roughened, wettable surface. Box retention and microretention beads on the veneer surface work well. As noted, the gingival margins should be formed out of metal because the mucosa should not have any contact with the acrylic resin.

An undercut box retention that surrounds the veneer should also be formed in the case of an adhesive bond (silanization) between metal and composite. Any overlapping of the acrylic resin from the box retention to the crown framework should be avoided because polymerization shrinkage will cause the edges to feather and lift off, and cracks will form in which deposits may become lodged.

Figure 2-113 shows a multiple-unit metal framework for acrylic resin veneer crowns supported by two preparations.

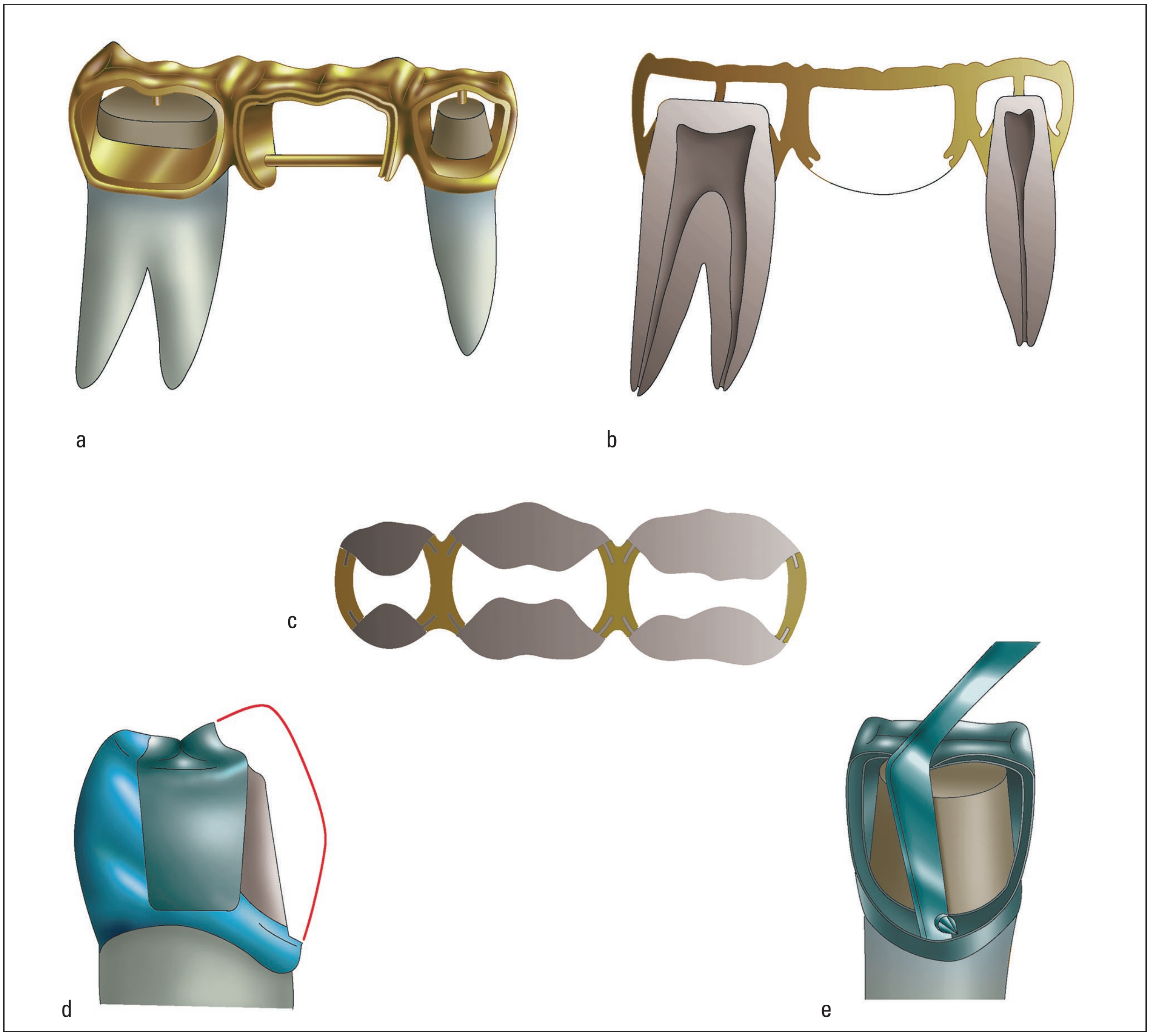


Fig 2-113 There have been repeated attempts to optimize acrylic resin veneer crowns by special framework designs. In the following system, a delicate open-metal framework was formed for the veneer material, whereby the acrylic resin lay directly on the tooth preparation. The metal framework undertook all the functional tasks expected from a veneer crown framework: transfer of masticatory forces to the tooth preparation, marginal fit at the shoulder, approximal contacts, and occlusal contacts. Prefabricated masticatory bars in the form of mesio-occlusodistal inlays were used, which were supported by an occlusal stop on the tooth. The crown margin was shaped like a "watch-glass notch" to secure the acrylic resin and was completed by the dental technician. The masticatory bar of the system could also be used as a partial denture pontic, for which a reinforcing wire had to be inserted in the lower third to create the necessary stability. The prefabricated blanks were calculated for maximum masticatory force. *(a)* Three-unit metal framework supported by two preparations, with a reinforcing bar in the middle. *(b)* Framework in cross section. *(c)* Occlusal view. *(d)* The framework for a veneer crown can be closed lingually. *(e)* The framework has a "watch-glass notch" that holds the acrylic resin.

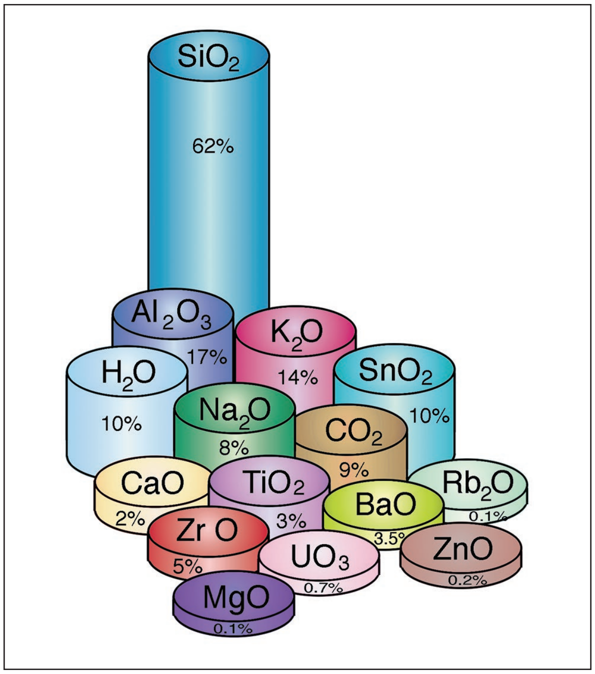


Fig 2-114 Dental ceramic materials consist of 70% to 80% feldspar (potash/sodium feldspar) and 10% to 20% quartz; they contain only minute quantities of kaolin. Bonding oxides, binders, expansive additives, and flux (2% to 4%; potassium phosphate, potassium carbonate, sodium carbonate, borax, lead oxide, potassium oxide, and manganese oxide) are also added. The dyes are made of heat-resistant metal oxides and salts. The percentages shown here indicate the maximum levels.

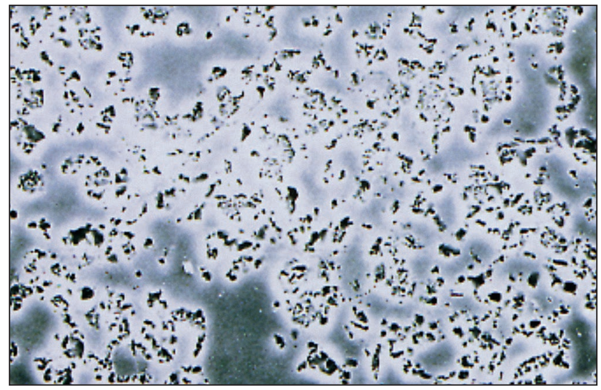


Fig 2-115 Magnification shows leucite crystals in the fine-particle ceramic Omega 2000 from Vita. The leucite crystals are cubic tetrahedron–shaped crystals that are formed in potash feldspar at 1,170°C. The leucite crystals will not soften and give the ceramic stability during firing.

Ceramic Veneer

In terms of mechanical strength and esthetic advantages, a ceramic (or porcelain) veneer is the safest solution for providing a fixed replacement. The term *metal-ceramic* refers to metal frameworks covered with fired-on ceramic material as well as to the technique in which ceramic materials are fired on directly. The composition and properties of the alloys and materials used in this technique have been specifically developed for bonding upon firing; therefore, other types of materials may not be substituted.

The ceramic materials for the metal-ceramic technique differ chemically from porcelain, which is made up of kaolin, feldspar, and quartz and forms what are known as *multicrystals*. Ceramics contain no kaolin, but their main constituent is feldspar, and they form leucite crystals (Figs 2-114 and 2-115). Firing produces a feldspar glass that can be classified between hard porcelain and ordinary glass based on its properties and composition.

In its melted state (at a minimum of 1,160°C), feldspar disperses large amounts of quartz. If the resulting feldspar glass is heated again, it will melt at a lower temperature (approximately 1,000°C). This is why potash feldspar, which has a high degree of purity, is used as a constituent of the ceramic materials. For the metal-ceramic technique, additives (flux) of potassium phosphate, potassium carbonate, and sodium carbonate are used to reduce the softening temperature.

Colored metal oxides are added to create tooth shades (Fig 2-116). Organic dyes help to distinguish layers before firing. For plastic formability during layering, the powder (ground prefritted ceramics) contains added organic substances (eg, sugar, starch). When mixed with distilled water, these provide cohesion for layering. During fir-

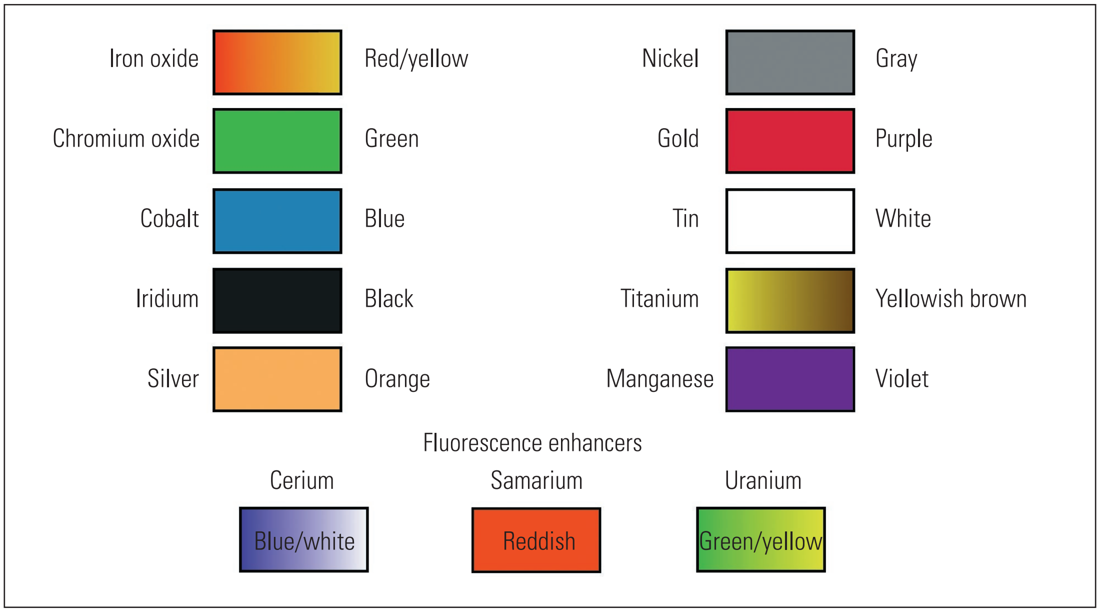


Fig 2-116 Inorganic dyes for dental ceramics are heat-resistant metallic oxides and salts that produce a variety of color shades.

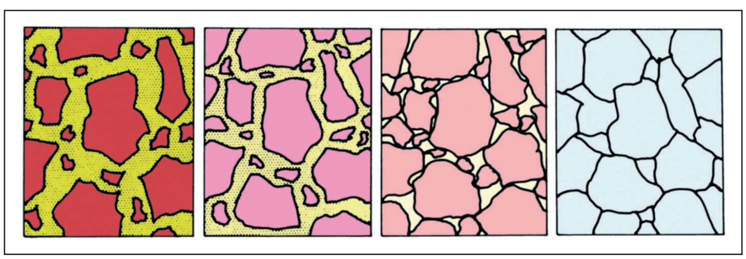


Fig 2-117 Sintering gives rise to firing shrinkage. On firing, the surface energy of the ceramic particles decreases, and without melting, the surfaces of the particles react with each other; they fuse and the spaces between them decrease. The firing temperature is well below the melting temperature of the ceramic particles; only the components with the lowest melting point flow around the other materials.

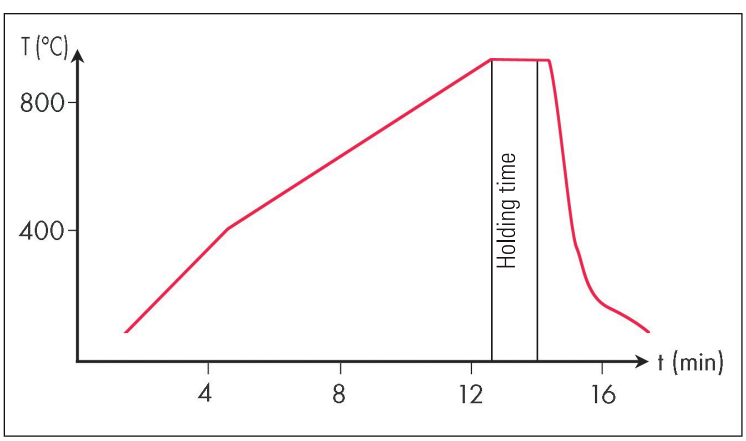


Fig 2-118 Firing is performed in three phases: predrying, firing, and cooling. Predrying evaporates the mixing fluid and oxidizes the dyes and binding agents. During firing, the material is placed in a furnace, and a vacuum is drawn. The temperature is increased over a period of about 4 minutes, after which the firing temperature remains constant throughout the holding time. Cooling is then performed slowly and gently.

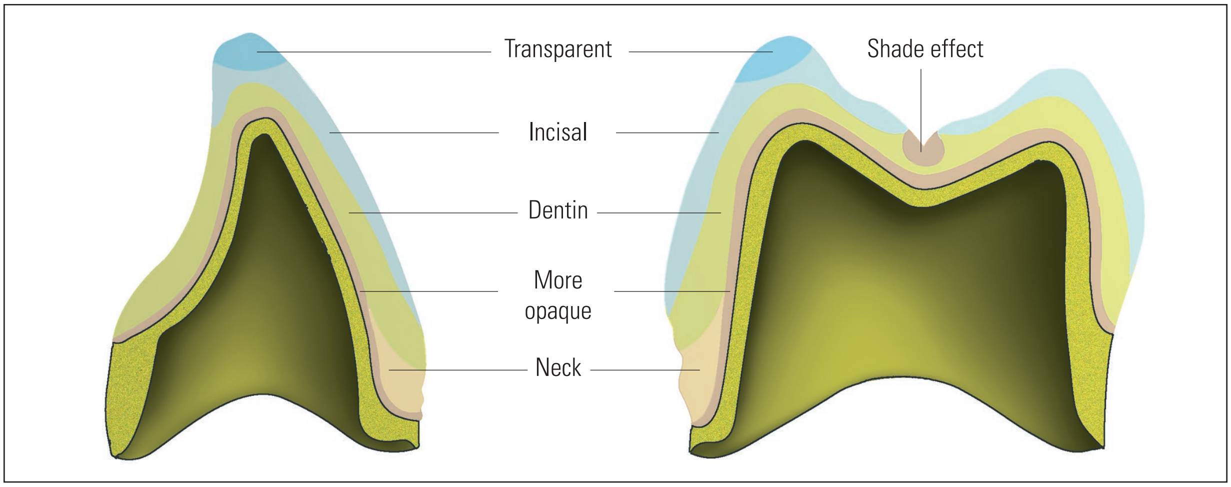


Fig 2-119 The schematic structure of a metal-ceramic veneer crown shows the distribution of the individual materials, which create the subtle coloring of the veneer.

ing, these constituents gasify; thus, vacuum firing has proved advantageous.

On firing, the volume changes from drying shrinkage and sintering of the ceramic materials (Fig 2-117). On drying, the liquid evaporates from the mix, and the organic dyes and binding agents gasify (Fig 2-118). During firing, the powder grains on the surface melt and sinter (Fig 2-119).

The volume change is between 25% and 35% and always occurs in the direction of the greatest mass because the cohesive forces between the powder parts tend to reduce surface tension. For this reason, practitioners should follow these processing principles:

- Before layering, the mass must be intensely condensed. The more it is condensed, the smaller the volume change will be.
- Firing temperature and time must be adhered to. If they are exceeded, the internal friction of the vitrified material decreases, the thickest part of the mass shrinks, and surface contours are lost.
- Layer thickness should be consistent over the entire veneer. Thin areas will shrink the most and will be drawn to the thick parts.

The alloys for metal-ceramic crowns are matched to the strength and thermal behavior of the ceramic materials. The properties required of the gold-platinum group for firing purposes are the following:

- A high melting range is required in which the solidus point of the alloy is higher than the temperature at which the ceramics are fired on. The firing temperature of the ceramics is between 950°C and 1,000°C, and the melting range of the alloys is a maximum of 1,300°C.
- The heat resistance ensures that the alloys remain firm on firing and are not deformed by intrinsic weight.
- The thermal expansion of the metal-ceramic alloy and the ceramics must be virtually the same so that the ceramic does not come under tension when cooling after firing.
- The alloys must harden so that their mechanical values can be increased by the annealing process.
- High-yield strength and a high modulus of elasticity account for the high flexural strength of the alloy so that the framework will not be deformed by masticatory forces in the mouth.
- Alloys for metal-ceramic crowns must tolerate intraoral conditions as effectively as previous metals.

Retention of ceramics onto the metal framework can be attributed to three mechanisms:

1. Mechanical surface interlocking occurs when the ceramic material is wet and shrinks on the surface so that compressive forces ensue. Roughened surfaces offer good microretention.
2. Intermolecular forces (van der Waals) form the second retention mechanism; the molecules of the interlayer become dipoles and therefore attract. Overlapping of the molecular orbitals then occurs.
3. The chemical bond strength of bonding oxides is attributed to the increased concentration of nonprecious metal atoms at the boundary layer between ceramic and metal. During oxidation annealing, the nonprecious metal atoms migrate along the grain boundaries of the structure at the alloy surface and oxidize there. During the firing process, the bonding oxides diffuse into the ceramic mass and bond to the silicone oxides.

Bonding via the oxygen bridges of the bonding oxides and the silicone requires sufficient metal oxides in the boundary layer. Bonding oxides should therefore be formed to a moderate extent during correct oxidation annealing.

Framework Design for Ceramic-Fused-to-Metal Crowns

The design of the metal framework for ceramic-fused-to-metal crowns is extremely important. The function and structural balance of the framework determine the success of the restoration.

The minimum thickness of the crown wall after finishing should be at least 0.3 mm for a single crown and 0.4 to 0.5 mm for a fixed partial denture, depending on its span length.

The modeled crown and fixed partial denture frameworks should allow for a consistent veneer layer thickness (Figs 2-120 and 2-121). Relatively thin ceramic layers, fired onto a rigid metal framework, are the most stable. The veneer layer should be no less than 0.8 mm thick to ensure color fastness (Fig 2-122). The best layer thickness (for color and stability) is 1.0 to 1.2 mm.

A consistent layer thickness is best achieved if the framework compensates for deformations of the tooth preparation and the surfaces being veneered are given the anatomical shape of the tooth on a reduced scale (ie, contoured 1 mm smaller). Varying layer thicknesses cause unwanted color shifts and stresses because the thinner parts are pulled away from their base toward the thicker layers as a result of shrinkage.

If a full veneer is to be constructed for esthetic reasons, the veneer must be seated on the framework like a crown. The transitions between metal and ceramic are not placed in the area of an occlusal contact because the ductile metal may flow as a result of masticatory forces, leading to cracking and fracturing of the veneer. The functional area is therefore shaped entirely in the metal or entirely in the ceramic. The incisal area should in any case be worked without an incisal wrapover for esthetic considerations.

Occlusal contacts can be made of metal for stability reasons because the ceramic is protected against harmful shear stresses and because natural antagonists abrade less than is the case with ceramic occlusal surfaces. The crown margin for the preparation border is fully fashioned in metal. In principle, therefore, ceramic veneered crowns can be fabricated for any form of preparation.

Shoulder preparation is a good approach because it provides excellent support to the metal framework and elastic deformation cannot occur. The preparation is fully encased in metal as far as the shoulder. The veneer surface is hollowed out toward the crown margin, leaving a very thin metal margin visible. However, where there is a shoulder, this metal is concealed by the gingival margin in the floor of the gingival crevice.

The mixed form of shoulder and chamfer preparation is ideal in terms of stability and reduction of tooth substance (Fig 2-123). The tooth preparation obviously needs to be wrapped as far as the preparation margin. On the vestibular side, the shoulder is covered by a metal chamfer that merges lingually into a wider metallic edge. It is stable enough to prevent flexural stresses on the ceramic.

Fig 2-120 Fixed partial dentures for ceramic veneers have to be shaped to ensure that the veneers have a consistent material thickness so that color shifts and stresses do not occur in the veneering material. The crown framework must therefore compensate for an uneven preparation.

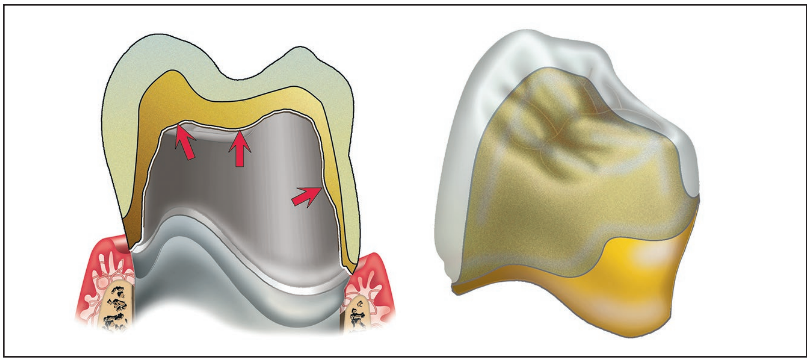
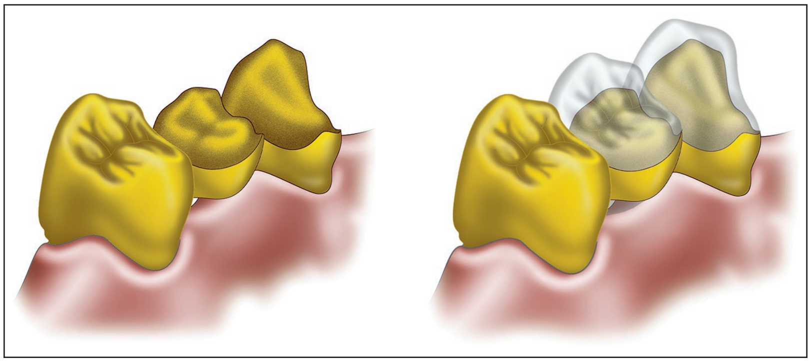


Fig 2-121 In the case of fixed partial dentures, a consistent veneer thickness must be obtained. The ceramic veneer must not entirely surround (wrap around) the fixed partial denture because the veneering material shrinks so much during firing that it would rupture. It is possible, however, to bring the veneering material in contact with the mucosa because ceramic is compatible with the mucosa.



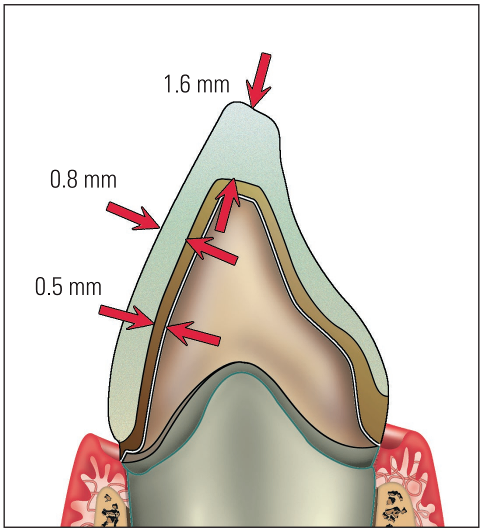


Fig 2-122 The minimum layer thicknesses of the metal framework and the veneer are given. The incisal area should have no metal wrapover and can be up to 1.6 mm thick.

Chamfer preparation requires a slightly thicker metal edge than a circular shoulder for reasons of stability (Figs 2-124 and 2-125). This metallic border might become visible if the chamfer is not placed low enough (Fig 2-126). If the metallic crown margin tapers thinly, the ceramic material may flake off due to elastic deformation. It is also inadvisable to let the metal framework end before the chamfer or to shape the preparation margin with ceramic. The crown margin cannot

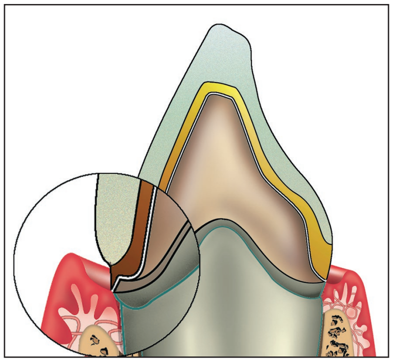


Fig 2-123 The combination of shoulder and chamfer preparation is suitable for ceramic veneers because it allows veneering of the lingual surface.

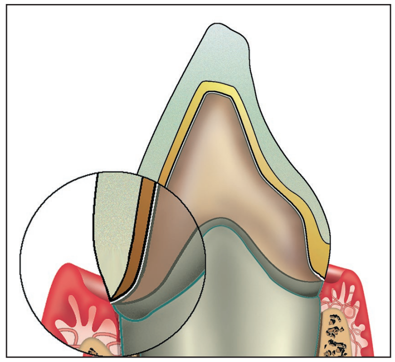


Fig 2-124 Chamfer preparation is well suited to ceramic veneered crowns. The metal framework can be thinly tapered at the preparation margin so that no metal border is visible in the mouth.

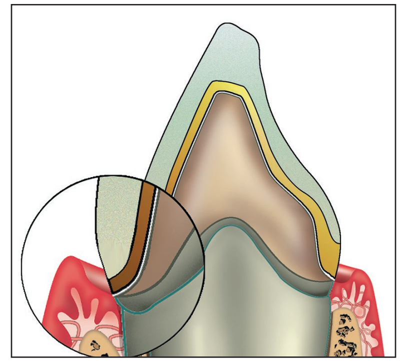


Fig 2-125 Even if normal thickness of the crown margin is maintained at the preparation margin for stability reasons, the metallic border may be concealed by the gingiva.

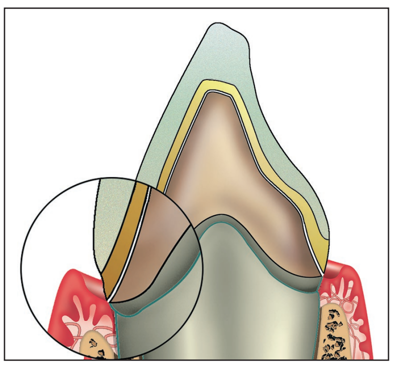


Fig 2-126 If a ceramic veneer is to be applied to a tooth with tangential preparation, a wide cervical metallic edge will become visible.

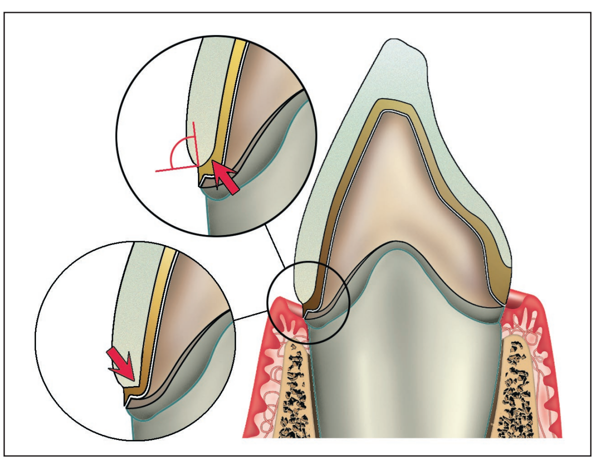


Fig 2-127 The transitions from metal to ceramic must never have sharp-edged grooves, recesses, or undercuts. The transitional areas have convex contours, and the outer join ends flush at right angles. This is necessary because ceramic undergoes severe shrinkage during firing and cannot compensate for tensile and shear stresses. These kinds of stresses occur in recesses, grooves, and undercut areas.

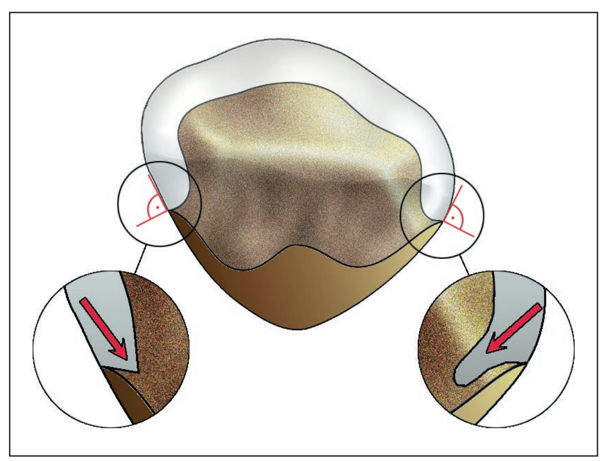


Fig 2-128 The metal-to-ceramic transitions must be rounded in the approximal area, and the outer transition should be right-angled and flush. Undercut areas, as used for framework retention, should be avoided because the veneer will rupture. Sharp-edged corners in the retention surface lead to stresses and tears.

be shaped as accurately with fused-on ceramic as with metal. Furthermore, a crown margin made of ceramic is unstable and can easily break off.

It is imperative to avoid sharp edges, grooves, recesses, or undercuts—such as those required for retention of acrylic resin veneers—on ceramic veneer surfaces (Figs 2-127 and 2-128). The transitional areas between metal and ceramic must be convex, and the joint must always run perpendicular so that:

- An adequate layer thickness is created in this area, just as it is on the entire veneer surface.
- No stresses can occur as a result of shrinkage of the ceramic at the enclosed areas.
- No air is trapped when the materials are applied.
- No contaminants (grease or particle-abrasion dust) become lodged, because these gasify during firing and, because they are so deeply embedded, cannot be fully removed by suction even during vacuum firing.

Design of Lingual Surfaces on Anterior Teeth

The more stable the metal framework, the more resistant the overall structure. The success of the overall construction must not be jeopardized and the framework weakened for the benefit of esthetics. In eugnathic bite relationships, when antagonist contact is relieved via canine guidance, the entire crown surface can be veneered.

In dysgnathic bite relationships (deep overbite, overbite less than 2 mm) or in the case of canine guidance, it is essential to fashion the functional surfaces on canines out of metal. The transitions between metal and ceramic lie at least 2.5 mm away from centric contacts (Fig 2-129).

If the vertical overbite of the maxillary anterior teeth is small, the transition must be placed cervically. Incisal edge protection is inappropriate because it impairs the transparency of the cutting edge if the incisal layer of ceramic becomes too thin and too unstable and the thin metal edge offers no support. To address severe additional antagonist loading, the incisal layer thickness must be 1.2 mm and placed out of contact in terminal occlusion.

The shape of the veneer surface can be influenced by a property of ceramic that causes it to shrink in the direction of gravity. This has no influence on partial vestibular veneers, but in the case of full veneers, the position of the object during firing can have an impact. The influence of gravity is minimal, however, if the thickness is uniform.

Design of the framework for posterior teeth

In principle, crowns on the posterior teeth can always be fully veneered with ceramics, provided the following:

- The patient's occlusal relationships and movement are clinically normal.
- An adequate interocclusal rest space of at least 1.4 mm has been created in the preparation stage.
- The framework can be placed without any difficulty and fits closely. (Note: In this case, a framework try-in is essential because stresses can lead to fracture even at the cementation stage; furthermore, stresses caused by fit inaccuracies may add to those caused by chewing.)
- The occlusal contacts can be accurately reconstructed. (This condition is difficult to satisfy, however, so occlusal veneering becomes a decision of general principle.)

A very smooth, polished occlusal surface will not abrade the antagonists any more than a natural tooth, but a ceramic veneer may have inaccurate contacts with the antagonist in the occlusal area. This can lead to excessive abrasion where there are faulty contacts with the antagonist; traumatic stresses may also arise, thereby affecting the periodontal tissue surrounding the antagonist and the crown tooth.

To avoid this situation, a full veneer on the occlusal surfaces needs to be ground back in a fully adjustable articulator, then a glaze firing should be performed (Fig 2-130). Yet even if performed with total concentration and accuracy, the end result will always be second class when measured against the accuracy of sculpted metallic occlusal surfaces. From a functional point of view, however, veneering of occlusal surfaces should not be sanctioned uncritically. The esthetic quality is

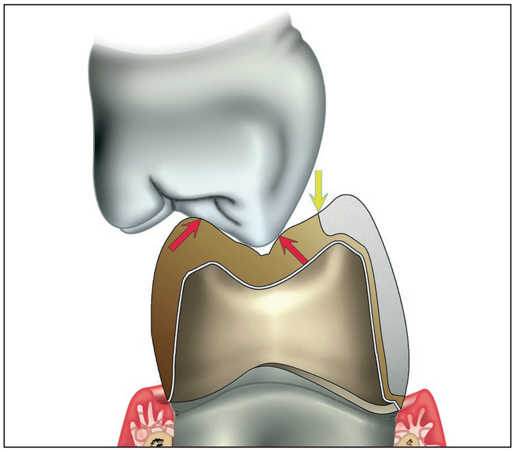


Fig 2-129 In teeth with occlusal surfaces, the transitions between metal and ceramic should be at least 2.5 mm away from the antagonist contact. One possible method is to veneer the entire occlusal surface as far as the lingual surface. The ceramic is loaded under pressure if all hindrances to gliding movements are eliminated.

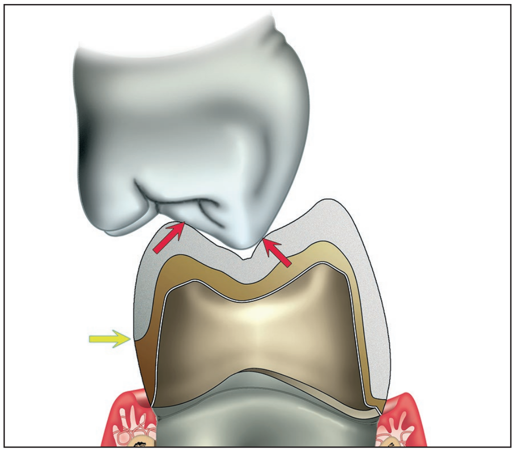


Fig 2-130 A functional occlusal surface has punctate occlusal contacts that lie correctly in relation to the temporomandibular joints. Grinding to create punctate occlusal contacts and smoothing them with a glaze firing will produce good results but is technically demanding.

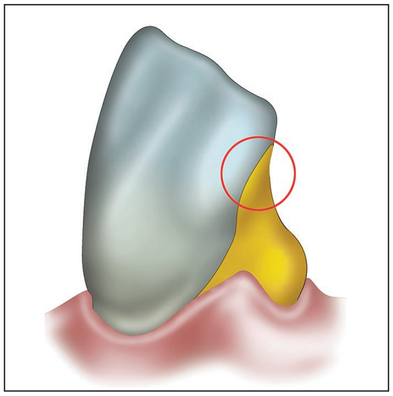


Fig 2-131 The approximal surfaces can be fully veneered. In the case of veneer crowns that are to be soldered, an approximal surface must be fabricated from metal. The soldering area must be at least 3 mm^2. From the vestibular aspect, the veneer will conceal the soldering surface that lies interdentally.

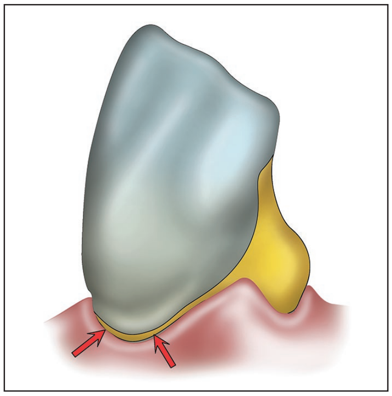


Fig 2-132 A complete vestibular veneer is the goal. Depending on the form of preparation margin (eg, chamfer), it may be necessary to fashion a crown margin out of metal that is wide enough to stand out above the crevice and be visible.

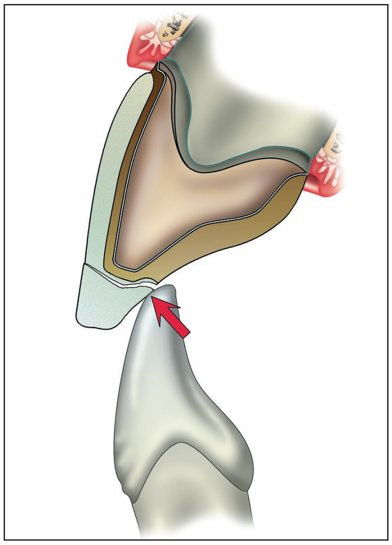


Fig 2-133 In dysgnathic bite relationships (eg, a deep overbite), the functional surfaces should be made from metal. If the metal-to-ceramic transition lies in the area of the antagonist contact, the ceramic will be subject to bending and will break because of the ductility of the metal.

optimal, provided the color match is successful. If metallic occlusal surfaces are preferred for functional reasons, it is important to ensure that the functional contacts are at least 2 mm away from the metal-to-ceramic transition.

Design of approximal contacts

Antagonist contacts are made entirely of metal or entirely of ceramic to protect the ceramic against bending stress. If the approximal contacts are fashioned from ceramic, they can be corrected at any time by grinding and refiring. To enhance the esthetic impression, the contacts on the anterior teeth and mesial contacts on the posterior teeth are shaped out of ceramic veneering material. All the basic principles governing the contouring of approximal surfaces apply here. The contact point lies in the occlusal third and must not displace the interdental papilla.

If individual teeth are being soldered for splinting, the contact areas are obviously fabricated in metal (Figs 2-131 to 2-133). They need to be large enough—an area of 3 mm^2 is sufficient—and the veneer should conceal the soldered surface interdentally. In such cases, an oral metal wall helps to secure the stability of the unit.

Partial Crowns

Partial crowns are crowns cast from metal that do not enclose the tooth on all sides but leave a substantial part of the natural tooth visible from the vestibular aspect. The other surfaces are ground back, which means the crown can be classified according to the amount of ground surface (Fig 2-134):

- A half crown (open-face crown) for the anterior region covers the tooth lingually as far as the incisal edge and up to half of the approximal surface (Fig 2-135).
- A three-quarter crown for the posterior region covers the tooth occlusally up to the buccal cusp and approximally entirely; only the buccal surface remains uncovered (Fig 2-136).
- A four-fifths crown for the posterior region encloses the tooth with a pronounced retention and covers the buccal surface at the margins.
- A seven-eighths crown for the maxillary molar covers the distal portion of the buccal surface. The mesiobuccal part of the vestibular surface forms the veneer (Fig 2-137).

The preparation surfaces are covered with metal and form an open ring that gains its support and retention from ground-in channels and pins as well as cervical shoulders. The basic idea behind using a partial crown is to preserve the natural veneering of the tooth.

In patients with extensive caries lesions, a mesio-occlusodistal filling is not provided if it would mean the narrow lingual tooth wall would have to be ground back too thinly. The cusps would need to be enclosed to prevent a fracture. Restoration with a full crown requires loss of more tooth substance and covers the intact vestibular surface. An extensive mesio-occlusodistal filling, including treatment of approximal defects, calls for a relatively thick, central masticatory bar, which means the tooth would be greatly weakened from the occlusal.

Partial crowns offer the advantages of multiple-surface fillings, reduce the risk of fracture of weakened dental tissue, and provide considerable strengthening of the residual tooth. Following are the advantages of a partial crown:

- A good esthetic effect is provided by the natural tooth color because the vestibular part of the crown is spared.
- There is minimal loss of tooth substance.
- Considerable reinforcement is provided for the restored tooth.
- The tooth remains accessible to subsequent pulp testing.
- The crown margins are easy to check and keep clean.
- Occlusal and approximal contacts can be built up in the same way as for a full crown.
- They are suitable as fixed partial denture abutments or to receive attachment components for a partial denture.

A partial crown is contraindicated in the following circumstances:

- The tooth is susceptible to caries.
- The tooth is short, thereby offering insufficient retention.
- The tooth is nonvital and discolored.

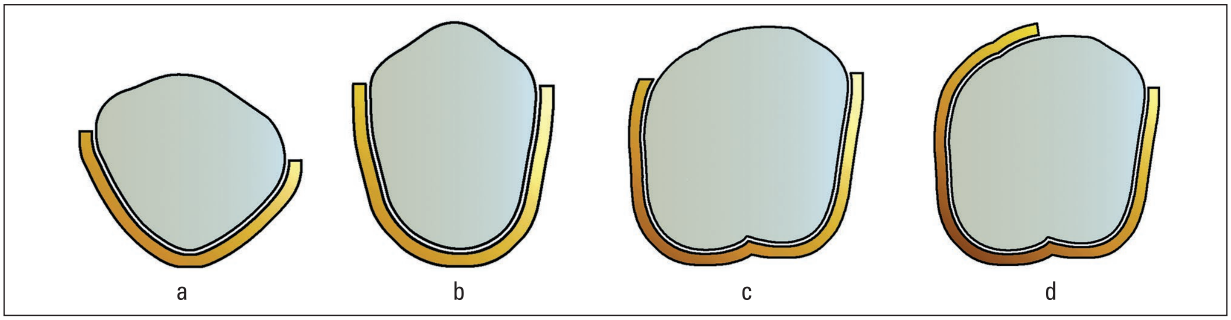


Fig 2-134 Partial crowns can be classified according to the amount of tooth enclosed. They are divided into *(a)* half crowns, used primarily for anterior teeth; *(b)* three-quarter crowns, used primarily for premolars; *(c)* four-fifths crowns; and *(d)* seven-eighths crowns for molars.

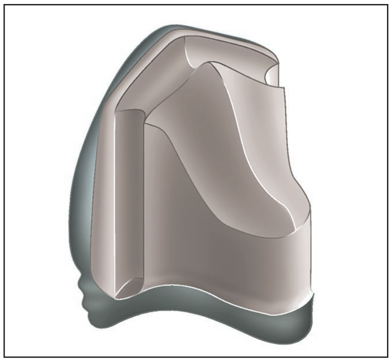


Fig 2-135 Retention of partial crowns is dependent on how far the tooth preparation is enclosed. Half crowns for anterior teeth encase the lingual surface, small parts of the approximal surfaces, and the approximal stabilization channels.

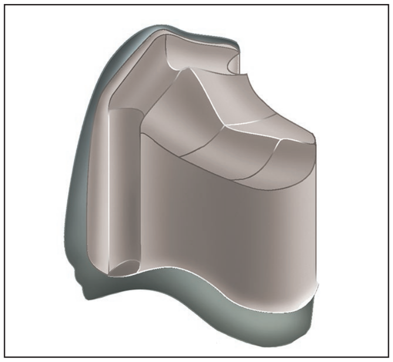


Fig 2-136 Retention of three-quarter crowns for premolars is achieved by parallel channels created in the retentive surfaces. The stability of a half-ring, as represented by a partial crown, is increased by extending the partial crown and continuing the channels onto the occlusal surface.

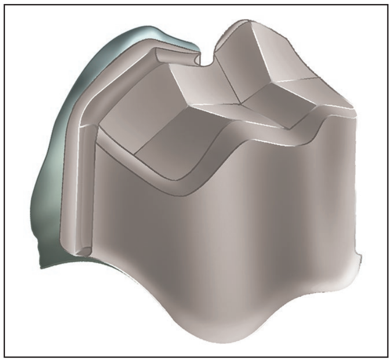


Fig 2-137 The greatest coverage of a tooth is provided by a seven-eighths crown for molars, in which only the mesiobuccal part of the vestibular surface remains uncovered. The marginal area to the vestibular window is again stabilized by preparation of channels.

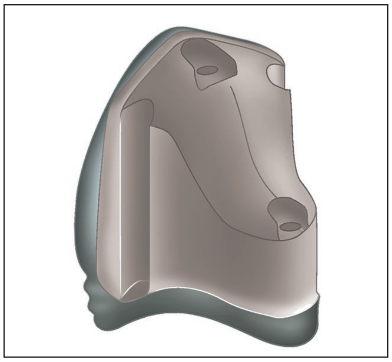


Fig 2-138 A channel-and-pin preparation on an anterior tooth displays parallel walls approximally and lingually that contain the parallel channels and the occlusal shoulder channel. The cervical shoulder is often omitted because the tooth would have to be weakened too much in the area of the tubercle. Incisal edge protection—that is, beveling of the incisal areas—must not be omitted on anterior teeth, even though it creates an unfavorable esthetic impression.

Partial crowns can be classified according to the nature of their retention:

- Window crowns are sheet-metal sleeves that are pushed over the tooth and leave the labial surface clear and the cervical margin enclosed. Window crowns are obsolete and are no longer made because they do not meet modern demands in terms of functional quality.
- Carmichael crowns are cast partial crowns that gain their mechanical retention from lateral enclosure of the prepared tooth and approximal grooves.
- The obsolete Vest's or claw crown is similar to the Carmichael crown; it has a clawlike enclosure down toward the root but has no approximal ridges or shoulders.
- Partial crowns with channel-shoulder-pin preparation are cast partial crowns in which parallel channels approximally and crosswise channels occlusally are prepared on the normal preparation surface, as is a cervical shoulder (Fig 2-138). In addition, they may also incorporate parapulpal pin fixation.

All partial crowns are prepared according to this principle today. They offer the strongest retention to the tooth preparation and good inherent stability, so they can also be used as fixed partial denture abutments.

After an impression of the prepared tooth has been taken, a die is made from dental stone and the partial crown is waxed up. Waxing up of the occlusal surfaces and vertical surfaces is done according to well-known principles. The crown margin should be molded to precisely follow the preparation margin so that it can be finished intraorally.

Statics of Channel-Shoulder-Pin Retention

A partial crown is not as stable as a full crown against pull-off forces from the transverse and occlusal directions (Fig 2-139). Additional retentive structures therefore have to be created to counter forces from various directions. The same problem occurs with milled attachment fittings, which are pushed over a partial crown in the form of a half-ring.

Retention against occlusal pull-off forces

The ideal basic preparation for a full crown is considered to be a cylindric preparation, which offers the greatest static friction because of its parallel surfaces but is difficult to produce and displays a piston effect upon placement. This effect does not apply with a partial crown. The pull-off forces in an occlusal direction can therefore be compensated for by parallel retentive surfaces with high static friction.

The vestibular surface is left clear and cannot be used for retention. This must be offset by enlarging the retentive surfaces with channels and pins. The channels and pins parallel the retentive surfaces.

Poor retention would be provided by undercut cribs in the cervical area (after Vest) because these would bend apart on placement and would have to spring back by means of elastic restoring force. It would be necessary to determine the spring constant and spring travel, but this is too inaccurate owing to processing errors.

Retention against lingual pull-off forces

If a partial crown, such as a half-ring, is pushed occlusally over the tooth preparation, this half-ring can be pulled off with application of minimal force. Apart from the adhesive forces of the cement, there is no mechanical retention acting in this direction. Channels and pins, which are created approximally in the retentive surfaces and run parallel to them, secure the crown's position against this direction of force (Fig 2-140).

The half-ring can extend beyond half the circumference like a ferrule and thus be braced against lingual pull-off forces. For this structure to be pulled off lingually, the half-ring would have to bend open so that it could slip over the ferrule. This is why the half-ring needs to be braced against being bent open.

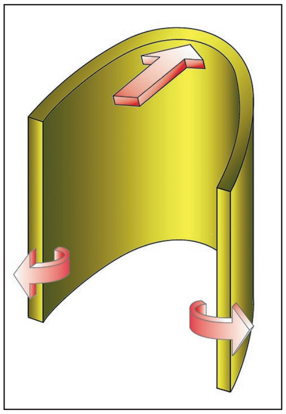


Fig 2-139 Retention of a partial crown must be effective against occlusal and lingual pull-off forces. A half-ring on a tooth preparation gains its adhesive force from the parallel walls by means of static friction, but static friction of the parallel walls is insufficient to withstand transversally directed forces.

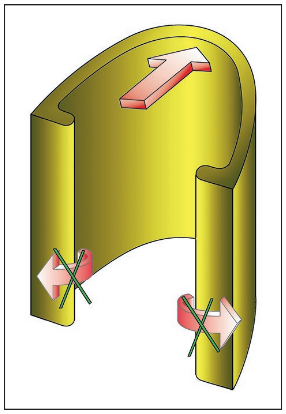


Fig 2-140 Channels milled parallel to the path of insertion offer the best retention against lingually directly forces. Some bracing against bending open is necessary because only slight bending open will loosen the crown. A special design is therefore needed.

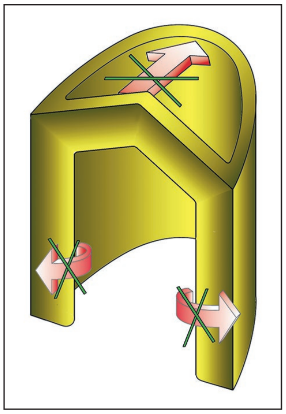


Fig 2-141 Vertical channels are joined by one channel running occlusally, giving rise to a frame that resists bending in the cervical area.

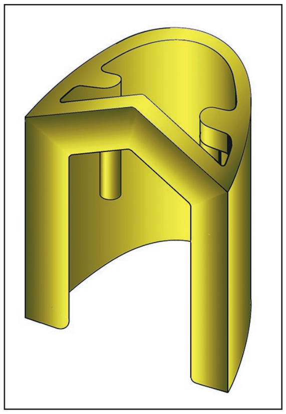


Fig 2-142 Flexural rigidity is increased by placing additional parallel pins alongside the channels. Additional retention against pull-off forces and bending open is achieved with the channels.

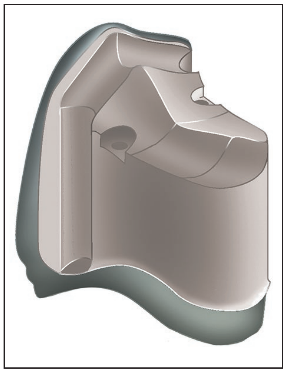


Fig 2-143 Channel-and-pin anchorage secures the crown against all forces that may arise. In this design, the half-ring can be prevented from bending open by a cervical step or shoulder. This step can be shaped sloping down to the tooth. In the incisal area, edge protection is created to protect against masticatory forces.

Retention against bending open

If a partial crown is used as a fixed partial denture abutment or to hold an anchor for a removable restoration, forces acting approximally and lingually as well as torsional forces can bend the half-ring open.

Rigidity to prevent its being bent open cannot be achieved by vertical channels. The channel profile must continue at the crown margin, both cervically as a shoulder and occlusally, in order to produce a rigid frame (Fig 2-141). This frame in the form of channels is easy to create and extremely stable because a round profile in every direction shows the same amount of resistance against possible bending.

A circular shoulder resembles shoulder preparation and provides material reinforcement of the half-ring, static support against occlusal forces, and retention against bending open. Furthermore, a shoulder preparation accurately establishes the crown margin.

Parapulpal pin retentions are prepared parallel to channels and offer additional bracing against bending open and against occlusal and lingual pull-off forces (Fig 2-142).

Preparation with a special retentive structure comprising parallel surfaces, channels running in the same direction, parapulpal pins, and shoulder preparation, as well as channels that merge occlusally, constitutes the typical channel-shoulder-pin retention with a defined path of insertion. The partial crown is thus secured against these forces but particularly against twisting (torsional forces).

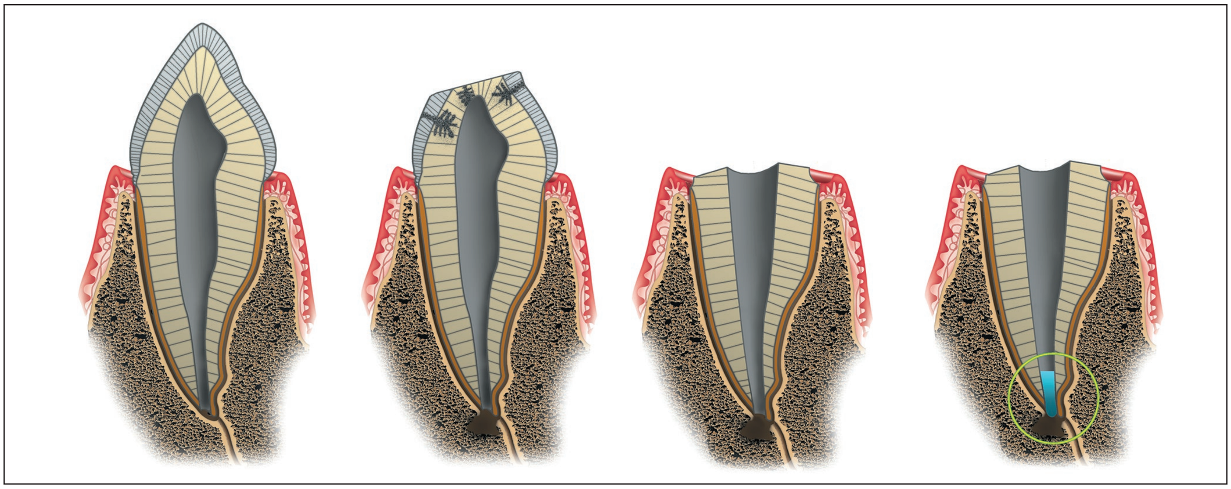


Fig 2-144 Devitalized teeth can be restored with technical constructions, provided the periodontium is intact. A tooth that is almost entirely destroyed by caries is ground back as far as the cervical margin, and the pulp is removed. If necessary, the root apex may be resected (apicectomy), and the tooth is sealed at the root apex with a filling. A metal post can be placed in the root canal as a form of retention for a replacement tooth.

Retention against masticatory forces

Though the described preparation protects the partial crown against pull-off forces and offers similar stability to a full crown, both the tooth and the crown are inadequately secured against dynamic masticatory forces. The incisal or vestibular transitions from crown material to tooth are particularly at risk from masticatory forces. A thin metallic base is usually insufficient because the ductile metal can undergo plastic deformation by masticatory forces. As a result, the vestibular enamel surfaces may break away. Therefore, incisal and/or cuspal enclosure become necessary, to which a grinding edge is added, this being beveled in the vestibular direction and giving rise to a metal edge about 0.5 mm thick (Fig 2-143).

Post Crowns

In the case of devitalized teeth, the coronal restoration can be retained with a post sunk into the prepared root canal (Fig 2-144). Unlike full-coverage crowns, which are pushed over a dentin core, post crowns involve placing a cast or prefabricated post in the root canal and fixing the coronal restoration to the upper end of the post.

Devitalized prepared teeth tend to have brittle dentin, and the preparation can break. An accurately fitting metal post is inserted to provide stability. Accuracy of fit is crucial to the stability of this root and post unit.

Post crowns are mainly indicated in the maxillary anterior and premolar area where the roots are sturdy enough. Mandibular anterior teeth cannot generally be restored with pivot teeth because their roots are too short and often stunted. In principle, multiple-rooted molars can also be treated with pivot teeth provided the root canals follow the same direction. As this is rarely the case, however, other designs are more appropriate.

A distinction should be made between post crowns, in which the post and the crown are fabricated in combination, and post and core crowns, in which an accurately fitting endodontic post and a metal buildup are inserted as an artificial tooth preparation (Fig 2-145). This core buildup has the same dimensions as a prepared tooth and can be fitted with any possible form of crown.

The post and crown unit is more stable than a post and core crown; with the post and core, the post and crown can be separated again and the coronal restoration can be replaced or integrat-

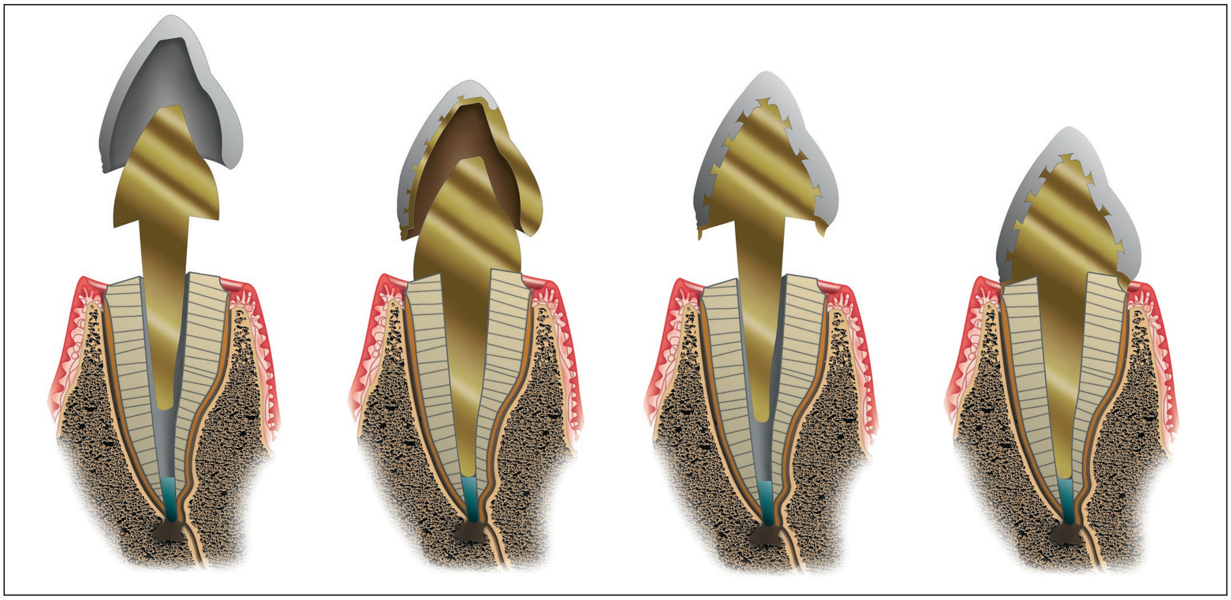


Fig 2-145 There are two possible forms of restoration with post crowns: in a post and core, the root preparation is fitted with a post to which an artificial core is fixed; a post and core can be fitted with any type of crown, including one within a fixed partial denture. In a classic post crown, the root preparation is fitted with a post to which the replacement tooth is fixed.

ed into a fixed partial denture unit. In very rare cases, the root canal coincides with other abutment teeth in its path of insertion. Furthermore, the post is difficult to remove without damaging the root. Therefore, it is better to construct a post and core that does not differ in shape from other prepared teeth.

Statics of post retention

The root of the prepared tooth must be prepared to allow for absorption of forces and the special stresses on the post. As a rule, the devitalized tooth is ground down to a 2-mm-tall preparation; the root canal is then cleaned, widened slightly, and closed apically with a root filling.

In terms of absorption of forces, the post is stressed via the crown in three different ways: bending (flexion), compression, and twisting (torsion) (Fig 2-146). The vertical compressive forces must be transferred vertically to the surface of the root preparation, which requires a suitably large surface contact between the post and the preparation (Fig 2-147). If this contact is absent or inadequate, the post is pressed into the root canal, and the wedge effect will fracture the root.

The horizontal bending forces stress the root on one side from the vestibular direction via the aforementioned surface contact; as a result, the post may bend out of shape (Fig 2-148). In extreme cases, wedge-shaped chipping may occur at the root on the vestibular side. The root preparation is therefore given a vestibular, roof-shaped bevel, and the post is worked appropriately (ie, its thickness) to provide stability. The root preparation is then given a chamfer preparation.

In the case of post crowns, torsional stresses may loosen and separate the post. The rooflike bevel of the preparation provides minimal resistance to such torsion; complete torsional rigidity is achieved by creating an auxiliary cavity in the form of a second post arranged in parallel, eccentric widening of the post, and a lateral groove on the preparation.

Torsional stresses are compensated for if a nonround root preparation is fitted with a crown or ring enclosure. There are three types of posts: conical, cylindric, and threaded (Fig 2-149).

A conical post can be easily and clearly prepared in the root canal because it follows the natural shape of the root canal. The post can be easily fitted but, owing to its shape, produces a wedge effect and may fracture the root.

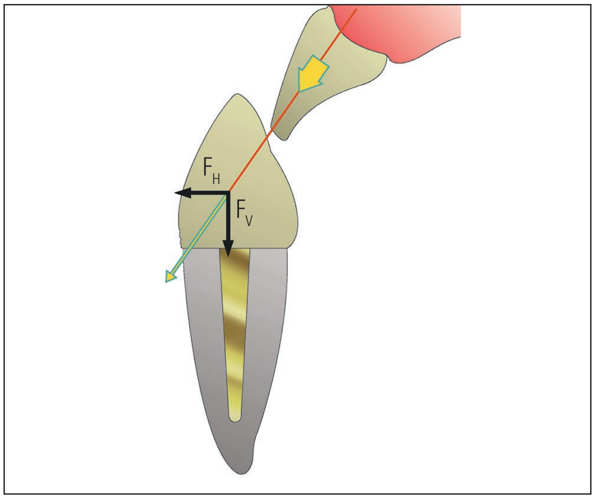


Fig 2-146 A post crown is loaded by masticatory forces just like a natural tooth. In the process, the post retention is stressed in three different ways: the masticatory forces can be divided by a forces parallelogram into vertical (F_V) and horizontal (F_H) masticatory force components. The third stress arises from masticatory forces that act laterally on the tooth and twist it.

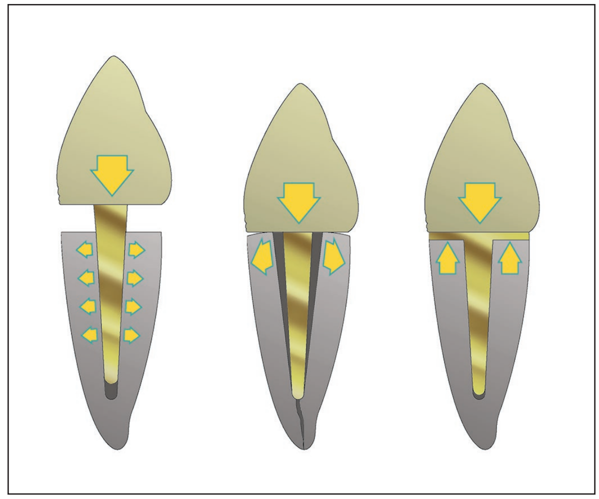


Fig 2-147 The vertical masticatory force component applies compression to the post retention, but the post cannot transfer this force to the tooth because it would fracture the root. For the vertical force component, post crowns must have a horizontal, flat support on the root preparation. The contact area is not for retention but serves to absorb forces.

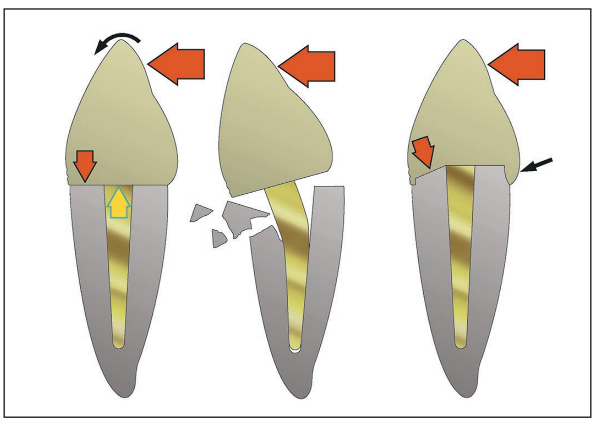


Fig 2-148 The horizontal masticatory force component bends the post. The horizontal force can pull the post retention like a nail out of a wall, where the labial wall of the root preparation breaks off. If the labial part of the root preparation is given a rooflike bevel, the horizontal force component is well absorbed. The ring-shaped enclosure of the root preparation also anchors the post against bending forces.

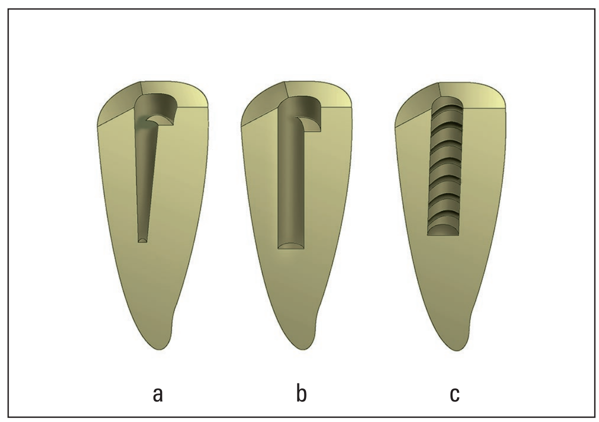


Fig 2-149 Three different forms of retention post are identified: *(a)* A conical post is easy to fabricate but has a tendency to a wedge effect, and hence fracture of the root is possible. *(b)* A cylindric post is difficult to fabricate and has excellent retention because of the parallel walls. *(c)* A threaded post must be prepared precisely, can easily result in fractures, and is not secured against twisting.

A cylindric post requires a parallel-walled root canal, which is difficult to create. If the accuracy of fit is good, it provides excellent retention because of the static frictional resistance of the parallel walls.

A threaded post requires a thread in the root canal, which has to be cut with a thread cutter. This can easily lead to fractures. A prefabricated root post is screwed in place and fitted with a form of retention for the coronal restoration.

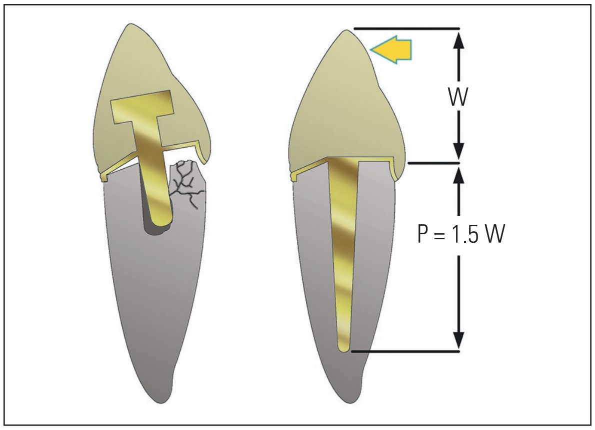


Fig 2-150 The stability of the post anchorage depends on the length of the post in the root canal. The aim is a minimum post length that corresponds to crown height. The crown height is the work arm (W), and the post length in the root canal is the power arm (P). If the power arm is too short, the root will break on loading. A power arm length 1.5 times the work arm length is ideal. The post should therefore be longer than the crown length.

Post Crown Designs

Post and core crown

A root post is prepared—cast or as a prefabricated threaded post—and fitted with a metallic pseudopreparation. This post can be divided into a power arm and a work arm according to its loading: The part that extends into the root is the power arm, and the part that extends into the replacement crown is the work arm. Hence the longer the power arm and the shorter the work arm, the more rigid the retention (Fig 2-150).

The length of the coronal restoration is taken to be the minimum length of the post anchored in the root. However, the retention post (power arm) should be at least two-thirds the length of the root canal.

Stability is further influenced by the thickness of the retention post and the size and position of the auxiliary cavities. The post should have a diameter of 1.3 to 1.8 mm. When taking the impression, special emphasis should be placed on ensuring that a precise impression is taken of the root canal and that the surface of the root preparation with auxiliary cavities and gingival crevice is precisely reproduced. A ring-retained impression is most suitable, where the root canal impression is taken with a post surrounded by thermoplastic material.

In a cast post and core crown, the post is fitted with a core buildup that exactly overlaps the root preparation and fills the auxiliary cavity but that leaves the chamfer preparation clear. The post is cemented in place so that a root preparation treated in this way forms the basis for fabrication of any type of coronal restoration.

Fabrication of a custom-made post

On the die, the root canal is isolated and filled with casting wax. A castable metal post is then heated and carefully pushed as far as the floor of the canal. The root preparation cover and the auxiliary cavity are filled. The core buildup is modeled in the same way as a prepared tooth: slightly conical on the vestibular and lingual sides and almost parallel approximally (Figs 2-151 and 2-152). The coronal restoration should have a consistent minimum thickness.

To ensure that the castable post adheres in the investment material, it can be cleaned of wax to about a 1-mm height at the root apex. Investing, casting, and finishing are performed following the usual procedure. Casting is typically done in gold, but other materials are permissible if color problems (eg, with acrylic resin jacket crowns) are likely. For better retention of the replacement crown, the core buildup is not polished.

According to Richmond, dowel crowns were produced as a unit comprising root post, core cover, and crown framework, then veneered. The classic Richmond crown encases the root prepa-

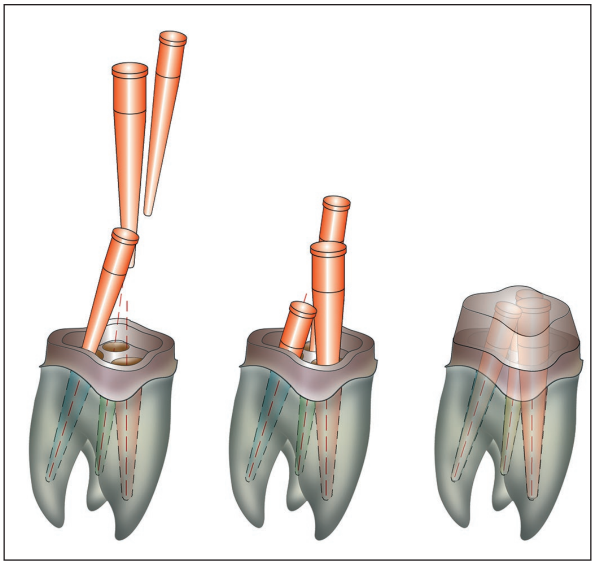


Fig 2-151 Post cores in multiple-rooted teeth are necessary if the natural coronal dentin core has been lost due to massive caries lesions but the external enamel wall appears mechanically strong. A buildup with plastic filling material is only strong enough if posts are let into the root canals and embraced as a unit by the buildup. Two-rooted teeth can be fitted with a central post in the longest and most readily accessible root canal, and a short safety post to counter twisting forces can be inserted into another canal parallel to the first.

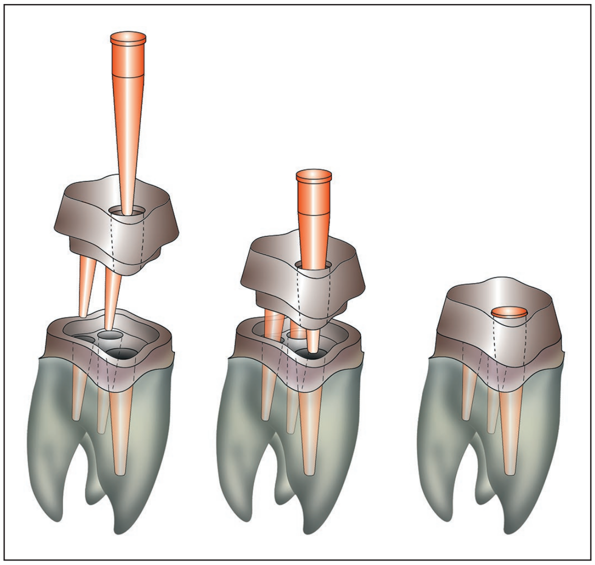


Fig 2-152 Three-rooted maxillary molars with diverging root canal axes can be restored with divided post cores. For this purpose, the buccal root canals are made parallel, and shorter pins with a primary core are inserted. The longer secondary post is placed in the palatal root and pushed through the primary core like a sliding attachment. In terms of preparation, as much hard dental tissue as possible should be preserved, and the subsequent finish of the crown margin should be moved into the dental tissue to prevent corrosive processes that occur when different metals come into constant contact in the oral cavity.

ration with a sheet-metal crown to which a prefabricated post is soldered. The veneer consists of a long pivot tooth made of porcelain, which is riveted into a back protection plate that is cast and soldered onto the crown. This type of crown is now obsolete.

In the case of an occlusal crown, the root post, the core cover, and the crown framework are cast in a single piece. The core cover (post cap) is accurately seated on and encompasses the root preparation. The occlusal margin is also the crown margin and ends with the preparation border. Owing to the good placement accuracy and precise path of the crown margin, the occlusal crown provides excellent protection against caries, the necessary stabilization of the root preparation against fractures, and good protection of the marginal tissue.

If vestibular coverage of the preparation is very short, the lingual coverage is kept very high to compensate; this leaves a good esthetic impression because only a narrow metallic edge remains, and this is often covered by the gingival margin. In occlusal crowns, the oral surface made of metal can be fashioned as a back protection without incisal coverage and fully veneered with acrylic resin or ceramic in the vestibular area.

The choice of veneering material and the material for the palatal occlusal surface depends on the stability of the remaining root preparation. It is preferable to use acrylic resin as the veneering and occlusal material because of its favorable abrasion characteristics in preventing periodontal damage.

Simple post crowns are suitable as temporary solutions to the long treatment phases for fixed partial dentures. For this purpose, prefabricated conical root posts are fitted into a root canal, and a solid acrylic resin crown is polymerized onto the prepared retentions. This means the acrylic resin encases the root preparation on all sides like an acrylic resin jacket crown.

3

Features of Partial Dentures

Definition and Indications

When the periodontal tissue is used to support replacement teeth via rigid connection to the residual dentition, this approach belongs to the area of partial prosthodontics. Partial edentulousness is treated with a prosthetic structure in which the artificial teeth are firmly connected to some of the residual teeth, and the masticatory forces acting on the tooth replacement are absorbed entirely by the periodontium of the residual teeth involved. These structures are known as *partial dentures*. Figure 3-1 provides an overview of the various components of partial dentures.

When a partial denture is fitted, the edentulous jaw segments are not loaded by masticatory pressure. Rigidly connecting several or all residual teeth by means of a partial denture produces a functional unit in which all the stresses of the unit act equally on all the involved teeth.

The tooth that is prepared to receive a partial denture is known as an *abutment tooth*. A crown that is fixed onto an abutment is called an *anchor*; it is the retaining part of the partial denture. The term *pontic* refers to the individual tooth replaced by the partial denture body; a partial denture between the canine and first molar therefore contains two anchors and one body that consists of two pontics. The functional unit of this partial denture structure consists of the periodontal tissues of the abutment teeth (canine and first molar), the abutment teeth themselves, and the pontic teeth (premolars) as the partial denture body (Figs 3-2 to 3-4). Owing to the rigid construction, the replaced teeth are supported entirely by the periodontium.

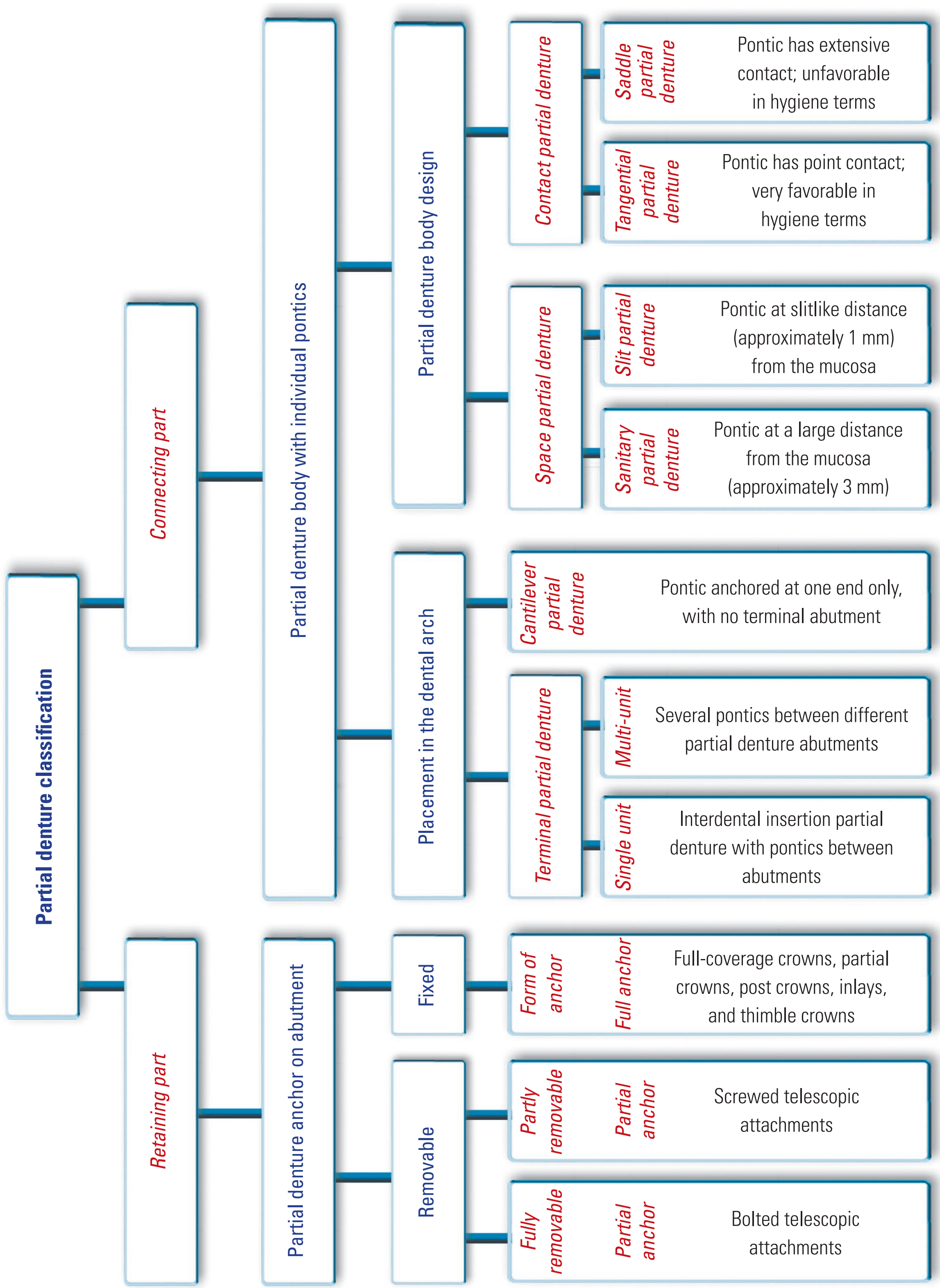


Fig 3-1 Partial denture components.

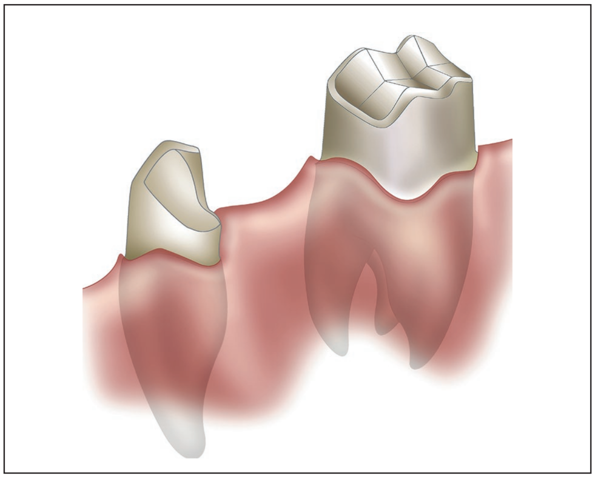


Fig 3-2 An edentulous space can be closed with a fixed partial denture. The teeth bordering the space are first prepared by corrective reduction. Together with their periodontal tissues, they form the abutments.

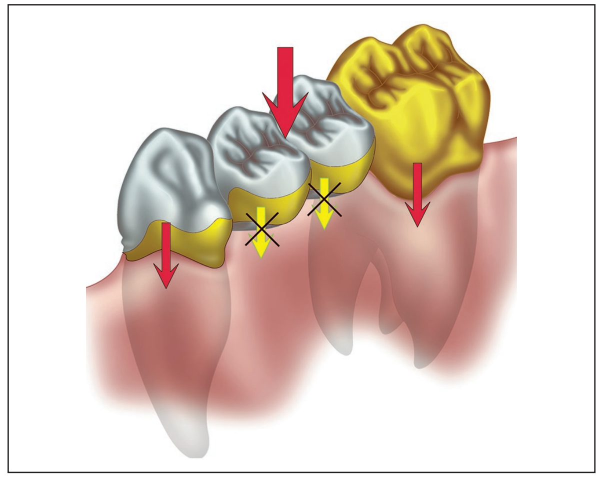


Fig 3-3 The partial denture forms a functional unit between the periodontal tissues of the prepared teeth, the crowns, and the pontics, which form the partial denture body.

Partial dentures are indicated if missing teeth have to be replaced to restore the statics and function within a closed dental arch. Masticatory function is restored (therapeutic function), and the adjacent teeth and antagonists are prevented from migrating into the space. This is the only way to avoid malocclusions and temporomandibular joint (TMJ) changes and to reduce shrinkage of the edentulous parts of the arch. Remedying an unsightly change to the face caused by visible loss of teeth is an important indication for a partial denture (regulative function).

The periodontium of abutment teeth needs to meet certain requirements; if the tooth replacement is supported entirely on the periodontium, the abutment teeth have to bear additional stresses apart from the masticatory pressure directed onto them. Ideally, abutment teeth should be vital. Teeth that have undergone endodontic treatment may only be used as abutments if they have healthy and noninflamed periodontium (Fig 3-5).

The root shape of the abutment teeth is also important: Cylindric, round roots are less suitable than flattened ones. Multirooted teeth with splayed roots offer greater security than fused, convergent roots (Fig 3-6). Curved irregular roots are also more suitable than completely conical roots.

The abutment teeth should be firmly anchored in the jaw and should not have a short or wide

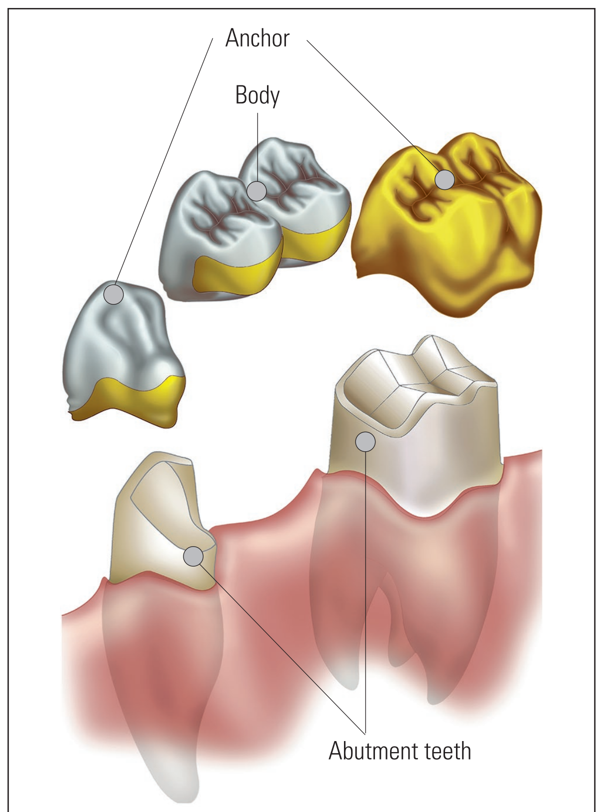


Fig 3-4 The parts of a partial denture are the anchors (retainer), the abutment teeth, and the body, which consists of the pontics and the connector between the abutments and the pontics.

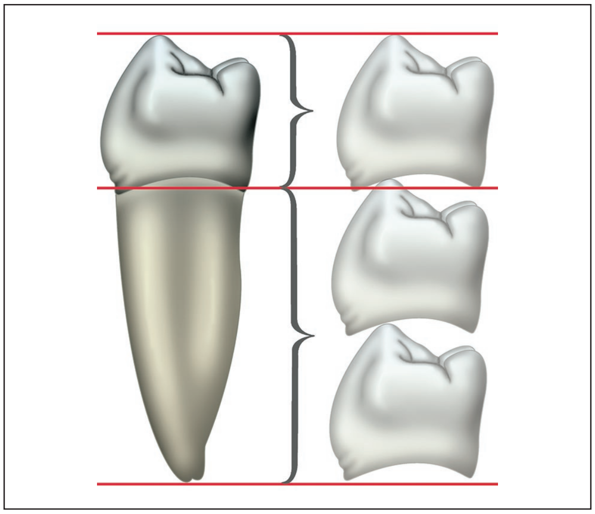


Fig 3-5 A partial denture is a periodontally supported tooth replacement, which is why the periodontal tissues of the abutment teeth have to meet certain requirements. Vital teeth are the ideal abutments, but above all, the periodontium must be healthy and not inflamed. The usability of a tooth can be determined by the ratio of root length to crown length: Ideally the root should be twice as long as the crown.

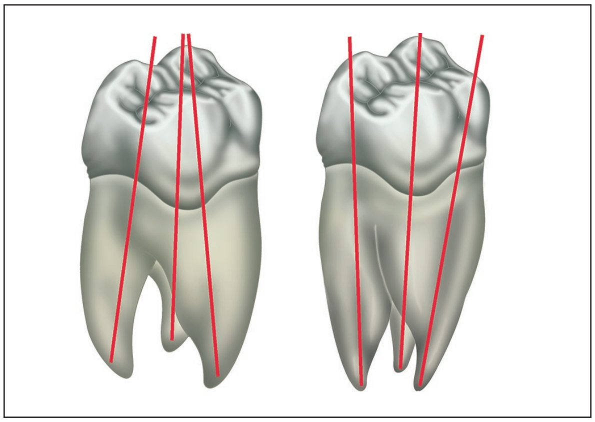


Fig 3-6 The shape of the root is another measure of a tooth's usability as an abutment. Flattened, splayed roots in multirooted teeth are better suited than round roots that are close together.

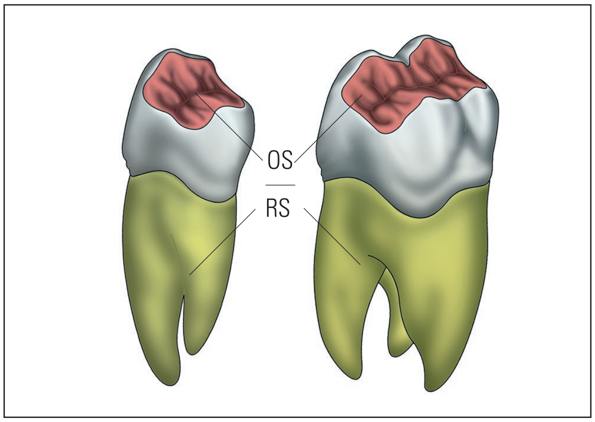


Fig 3-7 A good measure of the usability of a tooth as an abutment is the ratio of the area of its occlusal surface (OS) to the area of its root surface (RS); the root surface area should be five times that of the occlusal surface.

periodontium. Two abutment teeth can usually bear two pontics. Another relationship explains this better: The root surface area (periodontal surface area) of the abutment teeth must be as big as or bigger than the root surface area of the teeth being replaced (Figs 3-7 and 3-8).

A partial denture is contraindicated if two abutment teeth have to bear more than two pontics; in this situation, an implant to help fill the gap may become necessary. A fixed partial denture is also contraindicated if several adjacent teeth need to be replaced but there is no terminal abutment. A removable partial denture can be used for this purpose. A fixed partial denture is also not appropriate if the pontics cannot be easily shaped because of severe shrinkage of the alveolar processes (ie, if parts of the alveolar ridge have to be replaced by the fixed partial denture and thus become uncleanable). A removable partial denture may be considered in these circumstances.

The assessment of whether abutment teeth will withstand the loading caused by the pontics should take into consideration that the periodontal tissues of abutment teeth have limited adaptability to increased stress. In this connection, an increase in Sharpey fibers may be observed in the

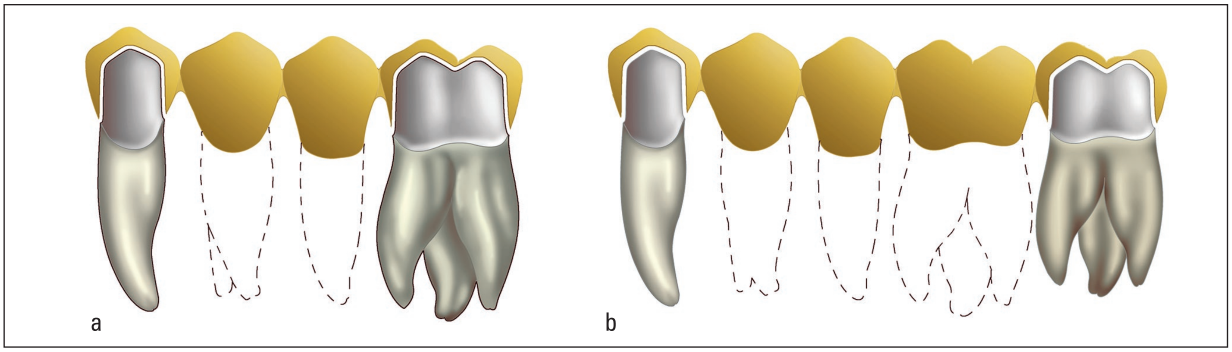


Fig 3-8 The choice of an abutment tooth depends primarily on how many pontics it has to bear. As a rule of thumb, one abutment tooth can receive one pontic. To put it another way, the root surface area of the abutment teeth should be as large or larger than the root surface area of the teeth being replaced. *(a)* The common situation in which the two premolars are being replaced and are borne by the canine and the first molar is very good because the root surface area of the abutments is more than twice that of the teeth being replaced. *(b)* If the missing teeth are to be borne by a canine and a second molar, the solution is inadequate.

periodontal space. An abutment tooth is therefore secured by the partial denture if the partial denture is constructed accurately.

Function of Partial Dentures

Restoration of a complete dental arch with a fixed partial denture restores full masticatory function and thereby contributes to the patient's well-being. Sagittal support within the dental arch can be restored by a partial denture when an existing edentulous space is closed. In an interrupted dental arch, horizontal force components cannot be transferred via approximal contact points, which means potential overloading of individual teeth. A partial denture therefore takes on the supporting function for the entire dental arch.

The rigid partial denture structure is intended to have a therapeutic action. In a periodontally damaged residual dentition, the therapeutic action involves rigidly connecting the remaining teeth to each other and limiting pathologic tooth mobility. This rigid connection between residual teeth is known as *splinting*. Above all, horizontal force components acting on the alveolar periodontal tissue are reduced in this way. In terms of splinting, a distinction is made between *primary splinting*, which is done by splinting the residual teeth with fixed constructions such as partial dentures and bar connectors, and *secondary splinting*, which involves a rigidly anchored removable structure (Fig 3-9).

Primary splinting is achieved with fixed partial dentures using several abutments and pontics, so that the splinting can encompass the entire dental arch. Secondary splinting can be done with removable partial dentures or partial dentures in which the splinting is achieved via telescopic anchors or precision attachments (Fig 3-10). The splinting effect is the same for both forms, but secondary splinting has the advantage of better oral hygiene maintenance. Partial splinting means rigidly connecting single teeth or groups of teeth; full splinting involves rigidly connecting all the teeth, for example, by a 14-part partial denture or a rigidly anchored partial prosthesis.

The edentulous parts of the jaw are protected against mechanical masticatory influences by a partial denture. This applies mainly to the marginal periodontium in tooth spaces. Resorption of edentulous jaw segments is alleviated by contact partial dentures and is stable over prolonged periods.

The closed occlusal field of a partial denture not only provides sagittal support for the dental arch in which it is located but also delivers the necessary occlusal support for the opposing dental arch. When there is a gap between the teeth,

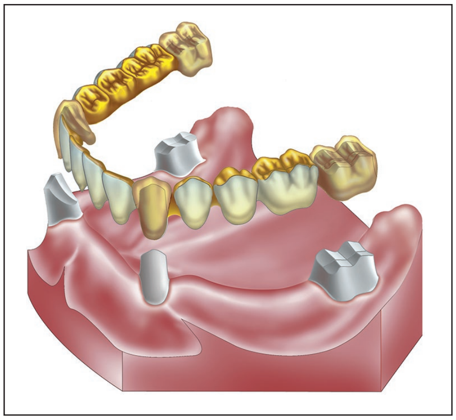


Fig 3-9 An excellent splinting effect is achieved with a partial denture. As a result of the rigid connection, all the teeth absorb the masticatory pressure that arises. Periodontally damaged dentition can be therapeutically treated by splinting structures. Primary splinting occurs if a fixed partial denture is cemented in place; secondary splinting is achieved by a removable partial denture.

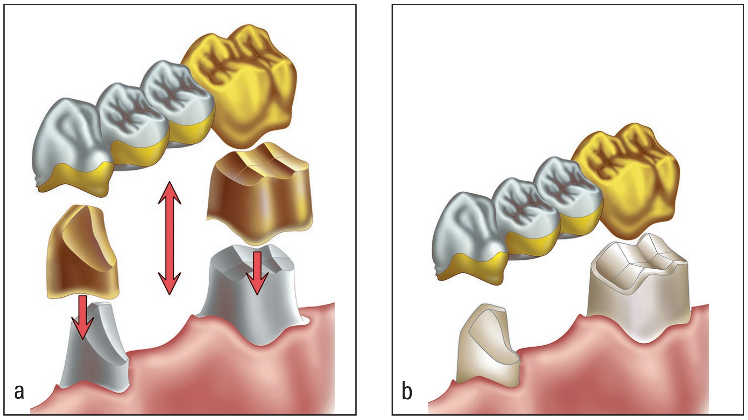


Fig 3-10 There is a difference between fixed and removable partial dentures. *(a)* In removable partial dentures, abutments have a double-crown structure, for example, telescopic crowns or tapered crowns; the subcrowns are fixed, and the actual prosthesis with outer crowns is removable. *(b)* A fixed partial denture consists of a block and is firmly inserted.

the adjacent teeth incline into the space; a partial denture will prevent this. The antagonists would also supererupt into the gap if they do not have an opposing occlusal force. In extreme cases, these teeth erupt until they come into contact with the opposing jaw. The resulting malocclusions are so severe that such a tooth usually has to be pulled into position during prosthodontic work.

Supereruption (lengthening) of individual antagonists can be prevented by promptly fabricating a partial denture, which will thus provide support to the opposing dental arch. An overerupted tooth means severe loosening for a dental arch because the approximal contacts are lost. It is almost as if there were a gap in the opposing dental arch too.

A gap within a dental arch means that chewing efficiency is greatly impaired. The patient will usually chew on the undamaged side, which causes overloading on that side, not only for the teeth and their supporting structures but also for the TMJ, and one-sided loading of the muscles of mastication. Uniform and balanced loading of the masticatory system is therefore prevented. As functional adaptation of the tissue ensues, deformation of the TMJ and changes to the neuromuscular system will occur. The space must be closed with a partial denture so that the patient feels no impediment when speaking. Spaces between anterior teeth greatly interfere with speech, especially the pronunciation of consonants (c, d, s, t, and z). A partial denture needs to accurately close this kind of space, including space in the interdental area, because small interdental spaces due to an artificial interdental papilla cause the patient to spit unintentionally when speaking. A partial denture must therefore take into account speech function achieved with the closed dental arch.

Characteristics of Partial Dentures

Different types of partial dentures are required for different topographic situations in a partially edentulous dentition. For instance, the following types of partial dentures are identified according to their placement in the dental arch (Fig 3-11):

- Unilateral interdental insertion partial denture (posterior on one side)

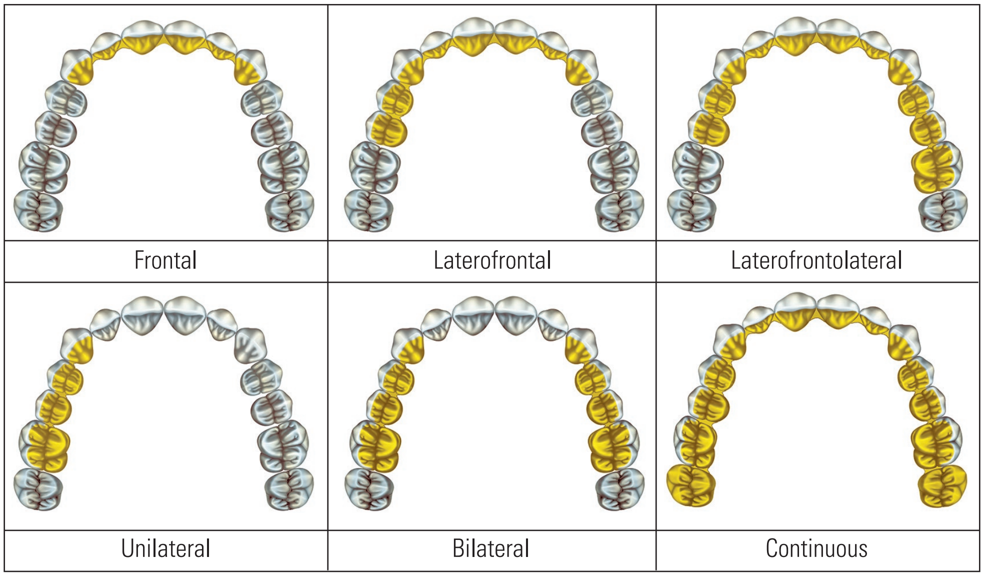


Fig 3-11 Classification of partial dentures based on placement in the dental arch.

- Bilateral interdental insertion partial denture (posterior on both sides)
- Frontal interdental insertion partial denture (anterior)
- Laterofrontal interdental insertion partial denture with abutment blocks (joined anterior and posterior)
- Laterofrontolateral interdental insertion partial denture (continuous single partial denture comprising a posterior area extending over the anterior teeth to the posterior teeth)
- Laterofrontal interdental insertion partial denture (three single partial dentures over an entire dental arch)
- Laterofrontal interdental insertion partial denture combined with a removable free-end saddle
- Continuous partial denture over the entire dental arch

In addition, fixed and removable partial dentures have different characteristics. Fixed partial dentures are cemented onto the abutment teeth and therefore cannot be removed for cleaning. They offer patients a feeling of security as they provide an intact dental arch, and patients do not have to constantly confront their mutilated dentition when they take out the appliance. Hygiene conditions with fixed partial dentures are often poor, which not only leads to unpleasant breath odor but also means damage to the residual dentition or mucosa underneath the restoration.

Fully removable partial dentures are better for periodontal hygiene and often have a denture saddle that serves as an alveolar ridge replacement. One advantage of a removable partial denture is that the entire structure does not become unusable if an abutment tooth is lost. In the case of a fixed restoration, the loss of an abutment tooth usually means loss of the entire appliance. Furthermore, the marginal periodontal tissues are more readily accessible for further dental treatment in the case of removable partial dentures. Partly removable dentures (or detachable dentures) are screw retained on primary crowns and can only be taken out by a dentist.

Interdental insertion partial dentures are used in a tooth space where the teeth bordering the gap serve as the abutment teeth. They are also called *terminal partial dentures* because the pontics are bordered by abutments. If the partial denture is mounted between the abutments without interruption, this is known as a *single-span terminal partial denture*. If several pontics are mounted between different abutments in several regions, this structure may be called a *multispan terminal fixed partial denture* (Fig 3-12). Multispan terminal

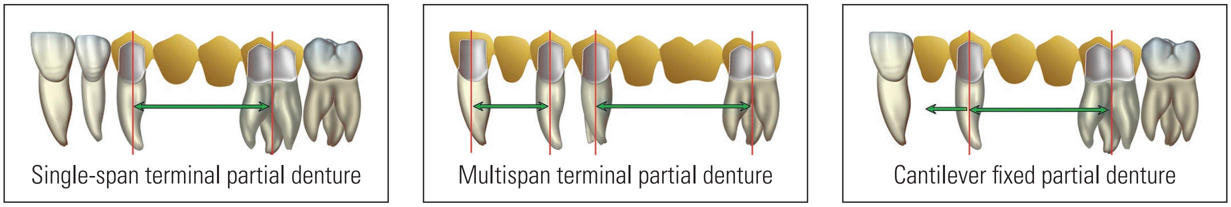


Fig 3-12 If a prosthesis unit is mounted between the abutments without interruption, this is known as a *single-span partial denture*; if several pontics are mounted between several abutments, the structure is known as a *multispan terminal partial denture* in reference to the terminal abutments between which the pontics are mounted. A multispan partial denture therefore closes several edentulous gaps, which is why the term *alternating interdental insertion partial denture with one or more central abutments* is more accurate. It is possible to retain a prosthesis unit on an abutment on one side so that the replacement tooth is cantilevered. This is called a *cantilever fixed partial denture*.

partial dentures close several edentulous gaps, which is why the term *alternating interdental insertion partial denture with one or more central abutments* can also be used.

Cantilever fixed partial dentures are structures in which one pontic is anchored to an abutment on one side and the replacement tooth is cantilevered to close an edentulous gap; cantilever fixed partial dentures can also be used to complete shortened dental arches.

A terminal partial denture may be fixed onto normal interdental insertion partial dentures and combine both forms of partial dentures. Anchoring a cantilever pontic to an abutment tooth is not advised because this cantilever pontic always represents a lever arm, leading to nonphysiologic tipping and rotation of the abutment tooth. The longer the lever arm, the greater the nonphysiologic loading, which leads to loosening and loss of the abutment tooth.

Installation of a cantilever fixed partial denture is possible if the terminal pontic is suspended on two splinted crowns or an interdental insertion partial denture. In both cases, however, the cantilever pontic should not be wider than a premolar. For longer-span free-end gaps, a terminal implant is necessary as a terminal abutment.

Characteristics of Partial Denture Abutments

Full crowns made of metal, veneer crowns, post crowns, thimble crowns, and jacket crowns can be used as partial denture abutments. Three-surface inlays can only be used to anchor prostheses in exceptional cases (Fig 3-13).

A metal full crown is ideal for anchoring the partial denture. It offers the greatest mechanical strength and highest anchoring force because, compared with other types of crowns, it has the most compact structure. Full crowns entirely encompass the abutment teeth without the loss of a great deal of dental tissue from corrective reduction. A full crown offers the greatest stability, even in the case of weakened and damaged dental crowns.

The protective function of a full crown against caries and the precise shaping of the crown margin offer advantages in terms of partial denture anchorage. Outside the visible area, full-cast crowns are preferable to any other type of crown as abutments; in the visible sections of the dental arch, veneer crowns are preferred for anchoring the appliance. Acrylic resin and ceramic veneers are the available options.

The advantage of an acrylic resin veneer is that, if dislodged, veneers can be repaired in the mouth if necessary; the partial denture does not have to be removed and become unusable for a time. Modern composites are sufficiently abrasion resistant and hence unproblematic in the occlusal or incisal area. Acrylic resins swell and age, which leads to increased deposition of contaminants, discoloration of the material, and signs of mucosal inflammation.

Ceramic veneers are abrasion resistant and have the best color effect under all lighting conditions. Ceramic veneers are also suitable for full veneers when the occlusal circumstances are

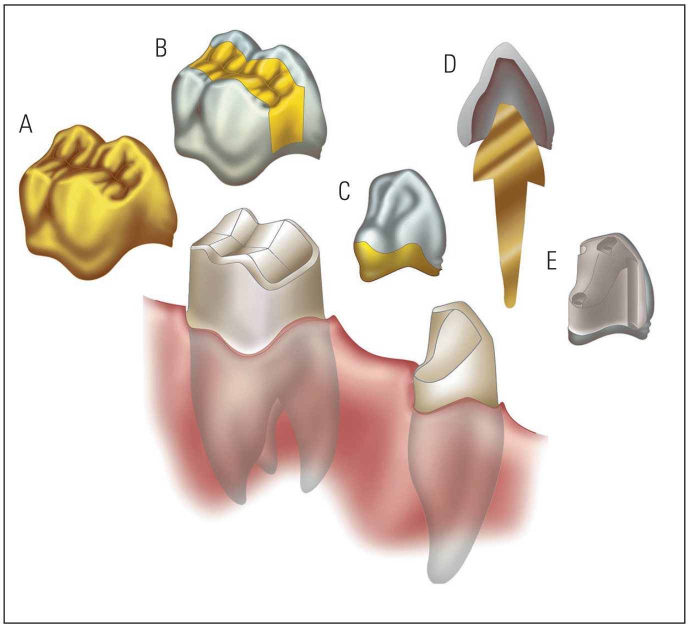


Fig 3-13 All types of coronal restorations are suitable as abutments. (A) A full-cast crown is the most stable but has the disadvantage of being esthetically unsatisfactory. (B) In exceptional cases, multisurface inlays may also be used as a form of anchorage. (C) In the visible area, a veneer crown structure is appropriate. (D) Pivot teeth have only limited use as abutments because the abutment tooth is devitalized. (E) Partial crowns are safe abutments, provided adequate retentions for the crowns are available.

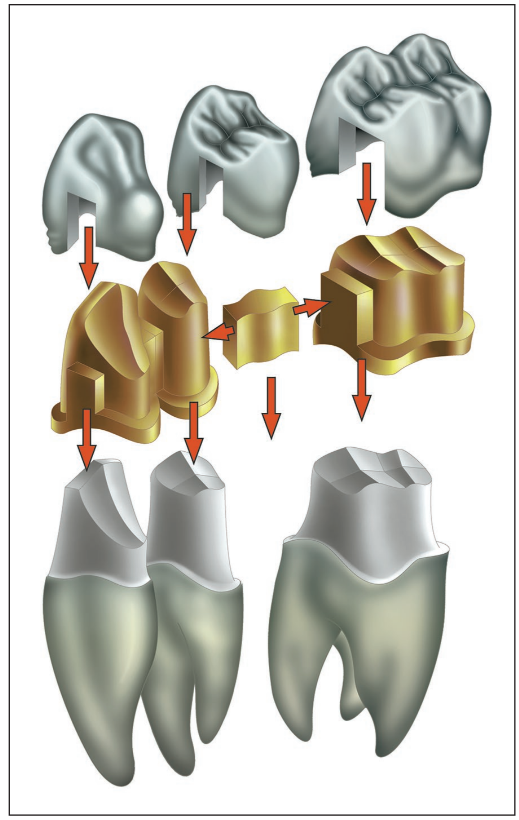


Fig 3-14 Thimble crowns are a special form of abutment with a cervical shoulder; they are cemented onto the prepared teeth. In addition, these crowns are joined together by narrow bars. For the pontics, bars are also fitted between the thimble crowns. The prepared teeth are protected by a thin layer of metal and can be covered with any crown design. If the pontics and crowns are fabricated and fitted individually, the individual components can easily be replaced. Relatively soft acrylic resin crowns can be placed, and these can be replaced after a short wearing period if they become discolored or are severely abraded.

straightforward. Compared with full-metal crowns, veneer crowns have the following disadvantages as partial denture abutments: The crown framework is unstable, the tooth has to be reduced more extensively, and the fabrication of veneer crowns is more prone to error.

Thimble crowns are especially suitable for partial dentures (Fig 3-14). Thimble-like metal crowns are cemented onto teeth that have undergone extensive preparation; the metal crown encases the preparation like a full crown and thereby stabilizes it. Externally, the thimble crown has a tapered shape. Between these crowns, the pontics are soldered in place or cast in a single piece. The pontics may have the same tapered shape as the thimble crowns. The size of the approximal connector is reduced to the minimum dimensions necessary.

Jacket crowns are used as the veneer for thimble crowns. The relatively compact thimble partial denture framework bears the individual crowns. The advantage of this is that defective crowns can easily be replaced. The disadvantage of thimble constructions in general is the considerable loss of tooth substance because of the extensive corrective reduction required.

Partial crowns are used as abutments in the visual area of the dental arches for esthetic reasons, though extensive inlays can also be integrated. Poor stability, risk of caries development, and the time-consuming and error-prone method of fabrication are drawbacks of such abutments. Precise channel-shoulder-pin retention is required for partial crowns as abutments.

Because post crowns can only be fitted to devitalized teeth, they have very limited use as abutments. Only the maxillary canines may be considered as terminal abutments; the maxillary central incisors and mandibular canines are possible as central abutments. The holes on post crowns rarely coincide with the path of insertion of the other abutments, which is why in such cases a core crown should be prepared (ie, a separate root post with core buildups that is coordinated with the insertion path of the other abutments and cemented in place separately).

Acrylic resin crowns can be used as abutments for large acrylic resin partial dentures for a maximum of three-unit anterior interdental insertion partial dentures. All-ceramic crowns (eg, IPS Empress, Ivoclar; In-Ceram, Vita) are also suitable as abutments for small edentulous gaps in the anterior region.

Resin-bonded partial dentures are indicated for anterior single-tooth edentulous gaps. For this purpose, a veneered metal framework with two lingual wings is bonded onto the abutments bordering the gap using the acid-etch technique. For better guidance, the lingual wings can easily be extended into the enamel without the dentin being exposed.

Bonded Partial Dentures

Minimally invasive restorations, which can be produced without substance-abrading preparation or surgery on the bone, can be achieved with metal or all-ceramic bonded partial dentures. According to the current state of the art, a single-wing all-ceramic bonded partial denture with a framework of zirconia-ceramic is the classic form of restoration for single-tooth spaces in the anterior region. Metal-ceramic bonded partial dentures became known internationally as *Maryland bridges* as early as 1970; more commonly known today as *resin-bonded prostheses*, these are electrolytically etched, double-wing, metal-ceramic bonded partial dentures (Figs 3-15 and 3-16).

Bonded partial dentures are used to treat single-tooth gaps between posterior teeth in the maxilla and mandible as well as the maxillary anterior region. They are placed on neighboring teeth that border the gap and are free of caries or fillings. Bonded partial dentures are also indicated in the case of congenitally missing maxillary lateral incisors, the gap having been widened and the required sagittal space created beforehand by orthodontic treatment so that removal of dental hard tissue is minimal.

Bonded partial dentures for posterior teeth are preferably made from a ceramic-veneered metal framework; for anterior teeth, they are all-ceramic. Nonprecious-metal fire-on alloys based on cobalt-chrome and nickel-chrome have a high modulus of elasticity and can be cemented more successfully than precious-metal alloys. High-strength framework ceramics, such as glass-infiltrated aluminum oxide ceramic or zirconia-ceramic, are esthetically better for anterior partial dentures.

The success rates of metal-ceramic bonded partial dentures are roughly equivalent to those of conventional partial dentures; even single-wing bonded partial dentures have proved successful. The advantages of bonded partial dentures include the following:

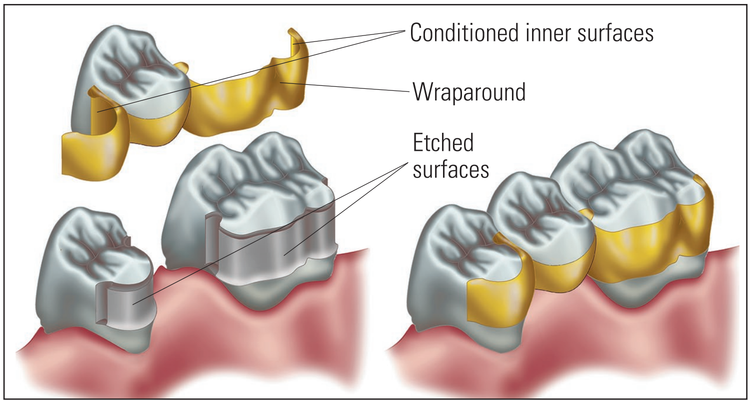
- They are minimally invasive; that is, only a small amount of natural tooth substance is removed.
- They do not cause pulp irritation.
- The costs are relatively low.
- Anesthesia is not required.
- They do not rule out alternative restorative options.

Single-wing bonded partial dentures have additional advantages: *(1)* No nonphysiologic splinting is required. *(2)* Preparation is simpler because abutment teeth do not have to be parallelized.

The disadvantages of cemented joints are the following:

- Extensive treatment is required because of the difficult enamel-bordered tooth preparation.
- Cementation is time-consuming.
- The cemented bond is prone to failure.

Fig 3-15 Bonded prostheses can be designed with lingual wraparounds as retainer wings. The prepared surfaces on the teeth are edged with end grooves and pre-etched; the inner surfaces of the wraparounds are conditioned so that a silane layer can be applied. The cemented joint between the components and the abutments is achieved with composite.



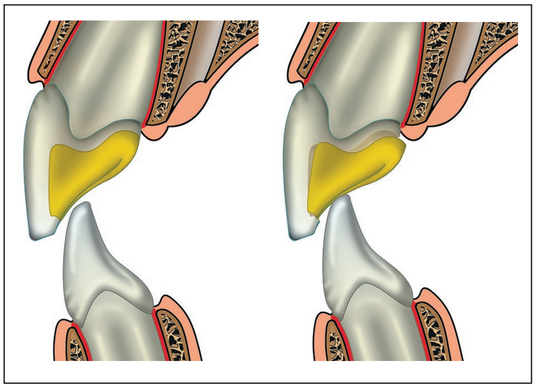


Fig 3-16 The retention surfaces or retainer wings must lie so that there are no parafunctional occlusal contacts that would tear apart the cemented joint on loading. In the case of double-wing bonded prostheses, one wing might become detached without being noticed, creating a gap under which caries lesions will form. Preparation of the retention surface must therefore create enough space to guarantee the minimum material thickness of the retainer wing and cement layer and provide space for adequate freeway.

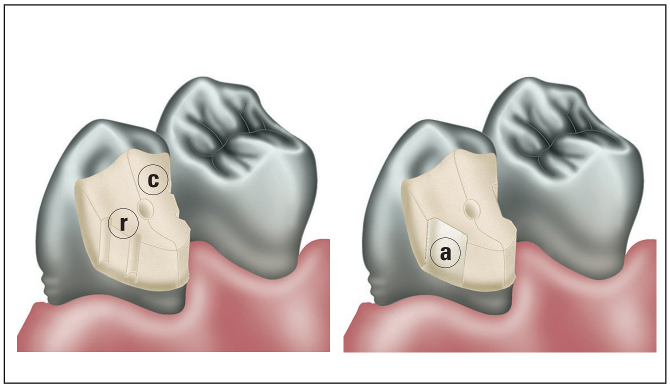


Fig 3-17 For metal frameworks, parallel, approximal retention grooves (r) need to be placed in the enamel, which requires use of an intraoral parallelometer. For all-ceramic frameworks, it is enough to mill an approximal box (a) 0.5 mm deep. A chamfer (c) for a central nub makes it easier to position the retainer wings.

The space required for the framework and cemented joint—about 0.8 mm—has to be prepared; a retentive preparation design greatly increases the stability of the cemented bond. The retainer wings should have a minimum material thickness of 0.7 mm for adequate rigidity in the case of metal frameworks or sufficient strength in the case of ceramic components.

Preparation of the abutment teeth involves creating usable bonding surfaces with mechanical retentions by making narrow grooves in the enamel, which also serve as retentive reinforcement against bending and peeling of the metallic retainer wings. The rigid ceramic retainer wings require no retentive preparation on abutment teeth, only shallow depressions for clear positioning of the partial denture. Narrow approximal retention channels are prepared with slightly tapered separating diamonds in the enamel only; an intraoral parallelometer makes it easier to prepare parallel channels. In addition, creation of a shallow approximal box (approximately 0.5 mm deep and 2 × 2 mm wide) toward the pontic can strengthen the framework at critical points (Fig 3-17).

If a bonded partial denture debonds, it may be swallowed or inhaled. Therefore, a checkup every 6 to 12 months is absolutely essential. Furthermore, caries damage may occur under a detached retainer wing. Patients should be advised about the risk of swallowing or aspirating the appliance if it becomes detached.

Adhesive retention in a mechanochemical bond by means of corundum blasting, application of a silane coupling agent, and cementation with special monomer cements requires acid etching of the dental enamel. Opaque cements are used for metal-ceramic bonded partial dentures, whereas all-ceramic partial dentures are fixed with tooth-colored cements. The retentive surface of the tooth is etched with 37% orthophosphoric acid, thoroughly sprayed with water, and air dried. After application of a composite cement to the retention surfaces of the bonded partial denture and the tooth, the appliance is held in position until the cement sets.

Bonded attachments can be used to retain partial prostheses as an alternative to cast clasps, double crowns, or attachments integrated into crowns. With bonded attachments, the cement joint acts as a predetermined breaking point upon overloading; tooth fractures do not occur because usually only the retainer wings become detached. The retainer wings of bonded attachments made of cobalt-chromium alloys should be at least 0.7 mm thick to provide adequate rigidity. They bear extracoronal slide attachments with a replaceable resin matrix. Approximally to the prosthesis saddle, retainer wings have a recessed rest area or a parallel contact plate for the secondary structure; an additional oral encircling catch can be milled to secure the attachment position.

Partial Denture Body Design

Fixed partial dentures must be designed to create favorable hygiene conditions and a natural appearance. Fixed partial dentures are categorized based on the nature of the spatial relationship to the edentulous dental arch: Contact appliances have mucosal contact, and space partial dentures do not. Contact fixed partial dentures can also be differentiated by the amount of mucosal contact (Fig 3-18).

In tangential partial dentures, the unit is lingually drawn inward toward the mucosa until the body touches the round alveolar ridge tangentially. The contact is without pressure and punctate. To ensure that the partial denture can be rinsed through, the interdental areas between the pontics and abutments are left clear. However, this only applies to the posterior region. In the anterior dentition, this kind of clearance cannot be created because the natural appearance—and certainly phonetics—might suffer. A broader rest area is required in the anterior region.

The tangential contact of the partial denture is shifted vestibularly. This means that the vestibular tooth shape can be extended to its natural length. The partial denture body must be brought steeply toward the alveolar ridge so there are no niches where contaminants could accumulate. The contact with the mucosa must not be made of acrylic resin or else a dense coating of shed, dead mucosal cells will form on the resin, which has a tendency to swell, leading to severe inflammation of the mucosa. A narrow metal strip at the cervical margin of the partial denture pontics cannot be avoided because the retention for the acrylic resin requires a box-shaped design.

With ceramic-veneered pontics, tangential mucosal contact can be achieved with the ceramic fired to a high glaze. However, the contact must still be punctate and pressure free. It is also important to ensure that the partial denture body can be thoroughly rinsed, avoiding the interdental papilla in the posterior region and the lingual surface of the partial denture sloping steeply toward the tangential contact.

A saddle is a type of partial denture body that has extensive contact with the mucosa, almost overlying it like a base. In special cases, a root extension can be sunk into the socket of the extracted teeth. This design should be rejected, however, because appliances seated over a broad area are impossible to clean. Furthermore, they prevent mucosal cells from being shed underneath the saddle. This and the hygiene problems lead to chronic inflammation and even tumorlike tissue changes.

In the anterior region, a broader rest area is required for esthetic and phonetic reasons. However, a saddle structure should also be rejected here. The rest area is designed to be linear and to

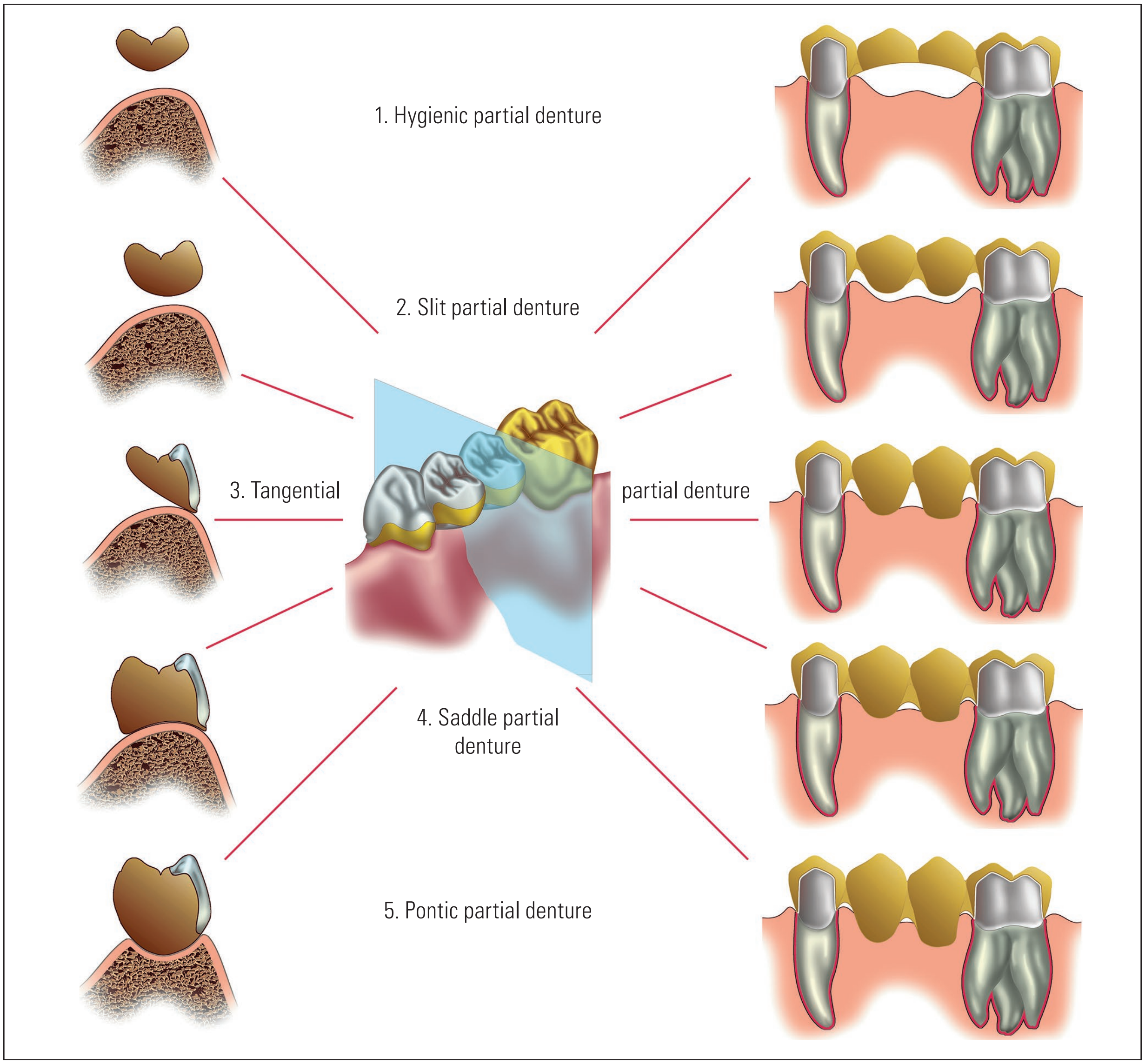


Fig 3-18 In terms of body design, there is a difference between hygienic and contact prostheses. This refers to the relationship between the pontic and the alveolar ridge. Five possibilities can be identified: *(1)* A hygienic (or sanitary) partial denture is classified as a supramucous partial denture; that is, it has no contact with the mucosa. *(2)* A slit partial denture has no direct contact with the mucosa but is about 1 mm from the mucosa. *(3)* A tangential partial denture as a contramucous partial denture has only point contact with the alveolar ridge; as a result, niches can develop where contaminants may accumulate. *(4)* A saddle partial denture has extensive mucosal contact, which is extremely unfavorable in terms of hygiene for a long-term restoration. *(5)* Pontic partial dentures or intramucous partial dentures have a root extension that has extremely broad contact with the jaw. Fixed partial dentures should not have broad, extensive mucosal contact. If a broad rest area is necessary for esthetic reasons, the partial denture should be removable.

have a maximum width of 3 mm. If this still does not satisfy the esthetic demands, a removable partial denture construction with a broad rest area may be the solution. If an extensive rest area cannot be avoided with an anterior fixed partial denture, the better salivary flow, more favorable cleanability, and suction effect during chewing will make it less likely that inflammation will develop. Hence, the rejection of a saddle should be weighed against these issues.

As a result of the pressure-free, point contact of the partial denture body, masticatory loading initiates a stimulus on the mucosa and jaw bone via axial tooth mobility. This halts the progressive shrinkage of edentulous sections of the dental arch.

Space partial dentures have no contact with the jaw mucosa. For esthetic reasons, such designs can only be used in the posterior region and only then in the mandible. Such devices are available in two types: slit and sanitary or hygienic types.

A hygienic pontic has a heart-shaped cross section with a minimum height of 3 mm. This cross section offers adequate rigidity against bending and enhances cleanability. The appliance can be thoroughly rinsed with a minimum gap of 3 mm to the alveolar ridge. If the gap is smaller, there is a risk that food particles will become lodged. The span width of hygienic pontics should not exceed a molar's width to guarantee adequate flexural rigidity and ensure that the alveolar process is not reduced by the massaging effect of tongue and cheek.

The gap between the mucosa and a slit partial denture is about 1 mm. Slit partial dentures are more difficult to clean but are necessary if the minimum thickness of the sanitary pontic could not otherwise be achieved or if the esthetic impression would suffer.

Connection Between the Partial Denture Body and the Anchor

High-quality casting techniques involved in metal processing make it possible to cast any partial denture design in a single piece. This provides a homogenous, rigid connection between abutments and the partial denture body. It is reasonable to assume that impression materials and methods give equally accurate models, making it unnecessary to do a framework try-in with divided partial denture structures.

An undivided, rigid partial denture framework with at least two abutments can only be inserted in a defined path, so the teeth must be prepared so that they are parallel to each other. If the abutment teeth are severely tipped, making the prepared teeth parallel is only possible with substantial loss of dental tissue. Loss of tooth substance also puts the pulp at risk.

If corrective reduction cannot be performed in parallel for the abutment teeth, especially in multi-span partial dentures, the partial denture can be divided into individual components or into a complete assembly of partial components that are assembled in the mouth to form a rigid connection (Figs 3-19 and 3-20). If the plan is to extend the partial denture, the division is made at an abutment where this extension is expected to take place. A large variety of prefabricated connector components are available for this prospective planning so that the appliance can later be extended into combined prostheses.

Division by means of an attachment to a weakened abutment tooth can relieve that abutment if the attachment allows slight movement corresponding to axial tooth mobility. The dentist decides where and when the division of a partial denture structure is necessary, because dividing the appliance is not straightforward. For instance, the splinting effect may be lost, or slight mobile connections may exert a lever effect on the abutment teeth.

Hand-fabricated or prefabricated attachments are available as divided slide attachments. It is important to ensure that the path of insertion for the attachment coincides with that of the abutment to which the pontic is firmly connected.

Precision attachments have a limited range of use as dividing members because they do not have a rigid connection and permit movement within the path of insertion. This also applies to the possibility of covering an abutment tooth with a telescopic double crown. In this case, the path of insertion of the outer crown must match that of the other abutment teeth.

A rigid connection can only be created if the divided partial denture parts are screwed together (Fig 3-21). In this case, an extension to an abutment will engage in the pontic. A drill hole is placed through the pontic and extension, which bears the thread in the extension part. The two parts are then joined and firmly screwed together intraorally. A precisely rigid connection is produced if the extension engages in the pontic like an attachment.

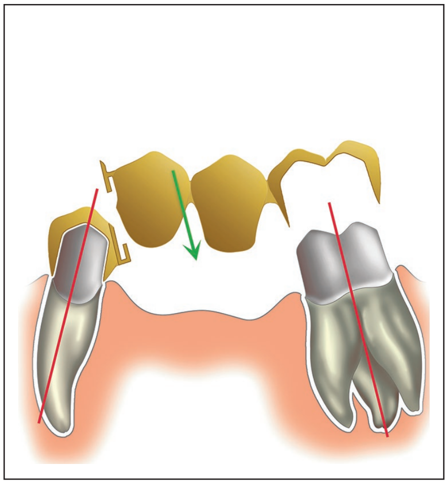


Fig 3-19 If the axes of the abutment teeth greatly converge, a rigid, undivided framework cannot be inserted. In this case, the framework can be divided and joined together intraorally. The framework is joined using a dividing attachment that is placed parallel along the path of insertion of an abutment; the abutments are cemented onto the abutment teeth so that the divided partial denture forms a closed block in the mouth.

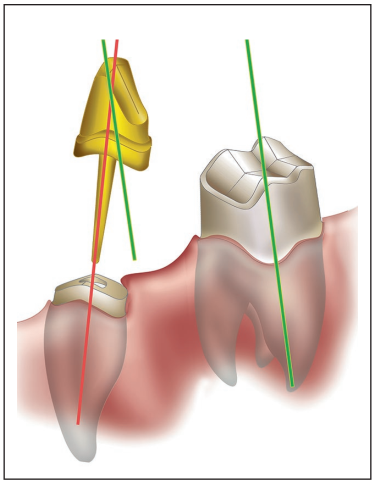


Fig 3-20 Where abutments are divergent, post crowns in the form of core crowns can be fabricated based on the direction of inclination of the abutments. A rigid structure can easily be inserted. The loading capacity of a pivot tooth is limited compared with that of a healthy abutment tooth. If the direction of loading in relation to the periodontium of the pivot tooth is altered by the coronal axis, the loading may be too great for the pivot tooth.

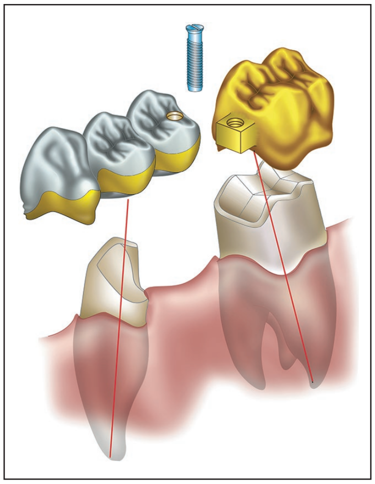


Fig 3-21 Division may become necessary if the individual abutments are significantly inclined toward each other. In this case, a screw connection provides the necessary rigid join between pontic and anchor.

It is advantageous to place the screw guidance lingually to buccally; a screw connection directed occlusally should be covered with veneer material to prevent contamination. The threaded portion and screw are prefabricated components that can be cast on and allow the connection to be detached at any time; hence, the divided partial denture can be replaced or expanded. The technical working method of fabricating abutments and bodies separately, veneering (with ceramic), and soldering the parts in the final working step does not constitute a divided partial denture but equates to a one-piece cast partial denture.

For a multispan partial denture, it may be advantageous to fabricate the prosthesis in separate parts, fire on ceramic, then solder the parts together (Fig 3-22). This avoids stresses in the framework that occur as a result of waxing up during casting and especially during firing. This technical trick is strongly recommended for multispan partial dentures.

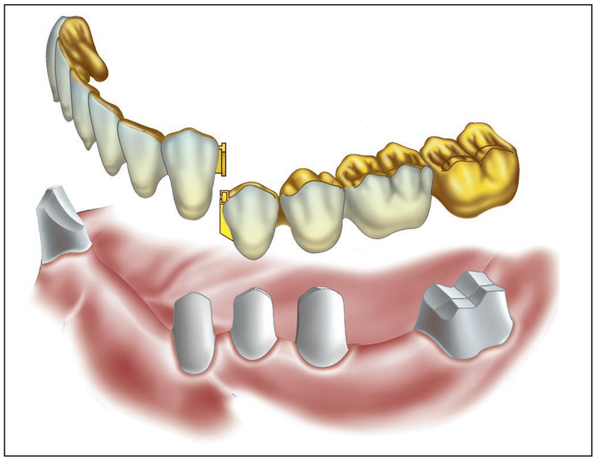


Fig 3-22 For ceramic-veneered multispan prostheses, it is advisable to fabricate the partial denture in several parts and join them together intraorally. This division can be achieved with a dividing attachment that permits relative movement of the partial denture parts. Stresses arising from masticatory forces and those caused by processing inaccuracies are offset by division of a multispan partial denture.

Acrylic resin–veneered partial dentures are soldered together after a framework try-in. A precision impression is taken of the framework parts in their correct relationship to each other; the framework parts can be fixed and soldered together on the correction model. A further advantage is that stresses are compensated for. The veneer is obviously not applied until after the soldering stage.

Removable Partial Dentures

The major drawback to fixed partial dentures lies in the adverse hygiene conditions they create. This can be compensated for by the construction of a removable partial denture, which is a periodontally supported tooth replacement, except that the anchors are divided so that the actual partial denture framework can be reduced (Figs 3-23 and 3-24).

Removable partial dentures are being used increasingly and, based on their construction, could be classified as partial prostheses. However, they do not have a prosthesis framework and differ very little from fixed partial dentures in their basic construction. This is why they fall into the same category.

Unlike the described abutments for fixed partial dentures, the anchors for removable partial dentures have several components:

- Primary anchors are firmly cemented onto the prepared tooth. These may be subcrowns for a telescopic or tapered (conical) crown or full crowns with an attachment matrix.
- Secondary anchors are firmly attached to the prosthesis. These may be outer crowns for telescopic or tapered crowns or the secondary attachment components.
- Tertiary anchors are additional anchorage components that rigidly connect to the aforementioned partial anchors. These can be latches, bolts, screws, or springs.

There is a technical fit between the primary and secondary anchors. The design of tertiary anchors for a removable restoration is dependent on whether the prosthesis is partly or fully removable.

Partly removable (eg, screw-retained) restorations can only be removed by a dentist. These designs resemble a divided prosthesis but have the advantage that parts can be replaced or the appliance can be extended outside the mouth. Because partly removable restorations can only be removed at long time intervals, the bodies should be designed as for a fixed restoration. Partly removable restorations therefore have only tangential contact with the mucosa of the jaw in the area of the pontics, which gives them the quality of a divided fixed restoration.

Fully removable partial dentures can be taken out by patients themselves because they are connected using latch designs. Fully removable partial dentures are the real alternative to a fixed replacement. The hygiene conditions are extremely favorable, and the appliances can be extended, which allows for repairs and relining outside the mouth.

Jaw segments can be replaced with fully removable partial dentures if there is severe shrinkage of the alveolar ridge. Rests can be created on the jawbone, as in fixed partial dentures. For example, removable partial dentures can also be combined with mucosa-borne cantilever parts. Another advantage is that the individual abutments do not have to share a common path of insertion. This is produced by the primary anchors for the framework.

One disadvantage of removable partial dentures is that more extensive preparation of the abutment teeth is required for double crowns than for full anchors on fixed restorations. If veneered abutments are also required, the critical limit for preparation is usually exceeded. All of the reported drawbacks of parallel fits also apply to this kind of restoration. The technical effort involved in complex designs is not in reasonable proportion to the outcome. An equally good restoration could probably be achieved with a less time-consuming partial prosthesis.

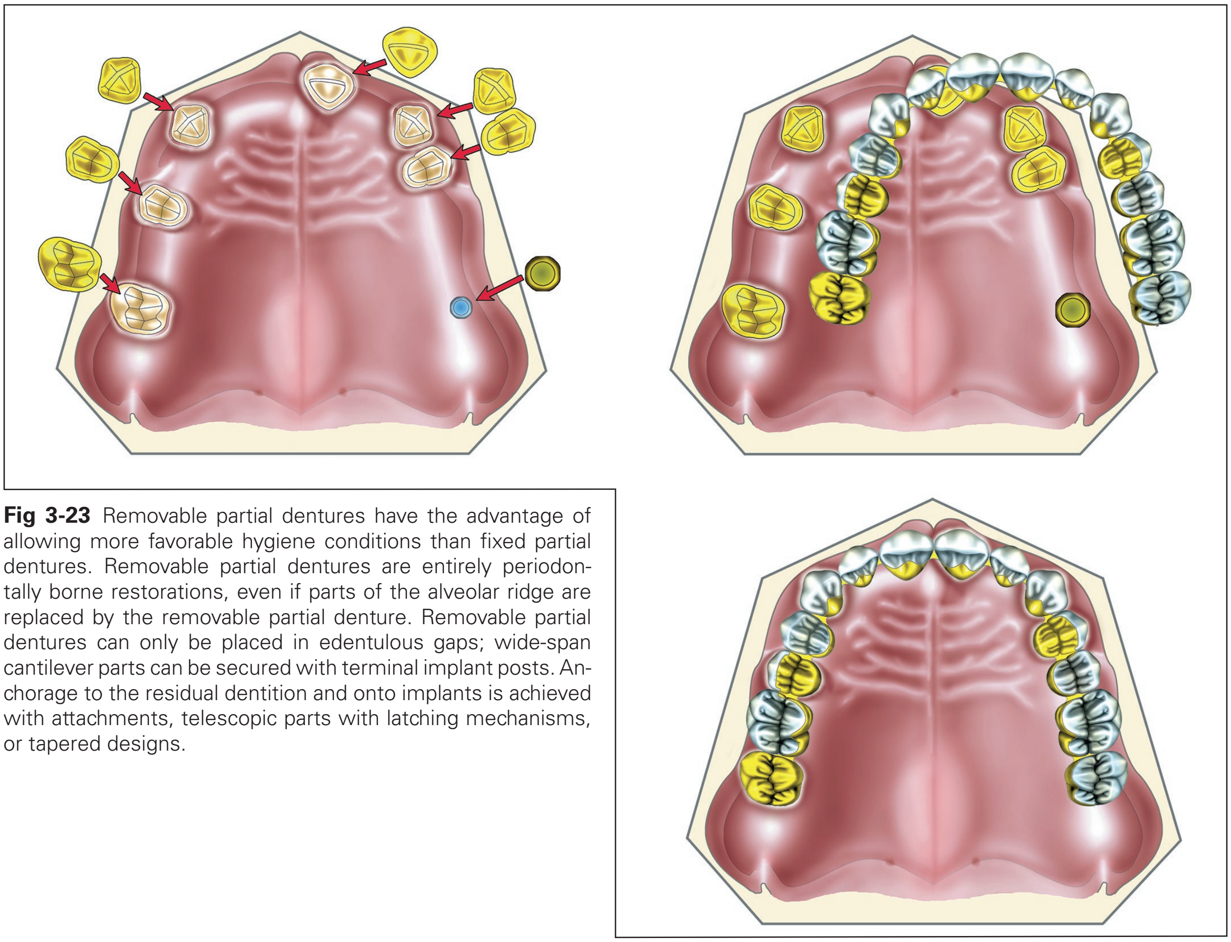


Fig 3-23 Removable partial dentures have the advantage of allowing more favorable hygiene conditions than fixed partial dentures. Removable partial dentures are entirely periodontally borne restorations, even if parts of the alveolar ridge are replaced by the removable partial denture. Removable partial dentures can only be placed in edentulous gaps; wide-span cantilever parts can be secured with terminal implant posts. Anchorage to the residual dentition and onto implants is achieved with attachments, telescopic parts with latching mechanisms, or tapered designs.

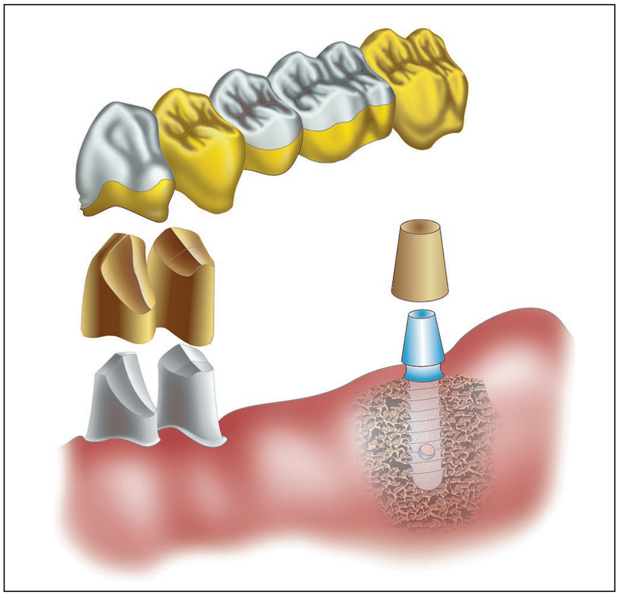


Fig 3-24 If a large-span free-end gap is to be restored with a removable partial denture, the free-end gap can be fitted with one or more implants on which the prosthesis is supported. The mixed support from periodontal and bony tissue may negatively affect the implant, however, so attempts have been made to relieve the implant with resilient mesostructures (intramobile elements).

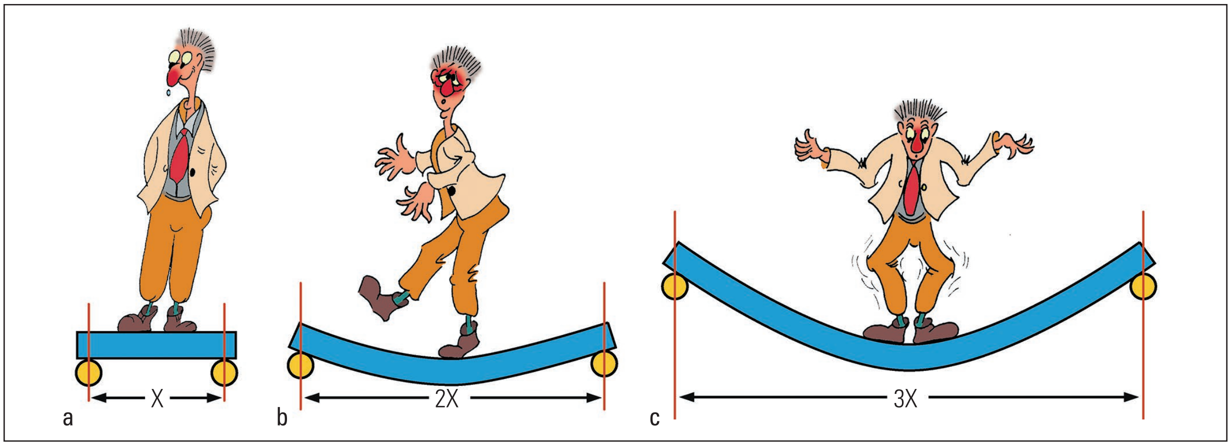


Fig 3-25 The deflection of a partial denture can cause extreme loading of abutments and therefore must be discussed as a function of its cross section and length. *(a)* A thick, short beam will hardly bend at all because of the small weight load. *(b)* A beam that is twice as long but has the same cross section will bend eight times as much. *(c)* For the same cross section but three times the length, the beam deflects exactly 27 times as much.

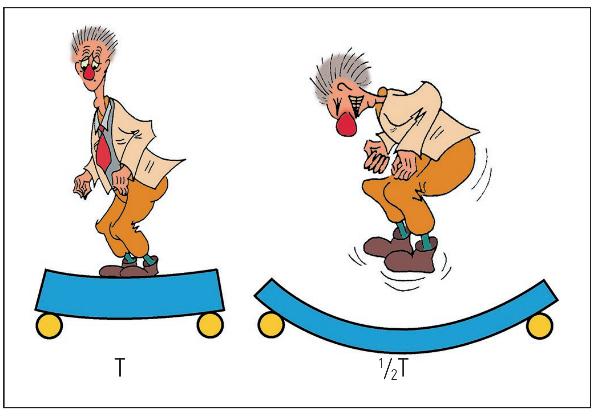


Fig 3-26 The deflection depends on the thickness of the material. A beam of a specified length and thickness (T) bends only slightly as a result of the weight placed upon it. If the beam has the same length but only half the original thickness (½T), this beam will deflect exactly eight times as much.

Partial Denture Statics

The design of periodontally supported restorations must not place excessive strain on the loading capacity of the abutments. Otherwise, constantly changing forces from different directions will destroy the tissues supporting the teeth. A *partial denture* must therefore be worked so that all horizontally acting (ie, not axial) stresses on the abutments are largely avoided; excessive axial stresses on the abutment teeth must be ruled out. The loading of a restoration is influenced by the following:

- The length and dimensions of the body
- The position (inclination) of the abutment teeth
- The shaping of the occlusal surfaces
- The path of the body

The length and dimensions of the restoration body depend on its span length. Long units are not as rigid as short ones because they might bend. The degree of bending (deflection) of a body with a fixed cross section increases to the power of three as a function of its length. To put it another way, if a 1-m-long bar bends by a fixed amount under loading, a bar of twice that length

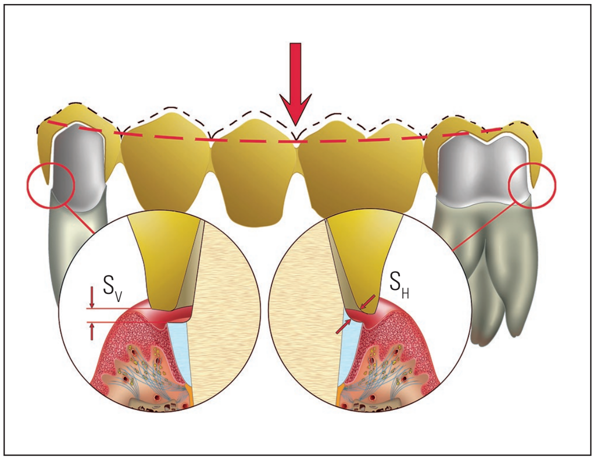


Fig 3-27 If a partial denture span is too long, deflection can cause two problems: tipping of the abutments and formation of a gap at the surfaces of terminal abutments facing away from the prosthesis. A gap of varying size will develop, depending on the shape of the preparation margin. A small horizontal gap will form (S_H) in the case of a chamfer preparation; given the same deflection of the partial denture body, shoulder preparation will result in a vertical gap (S_V).

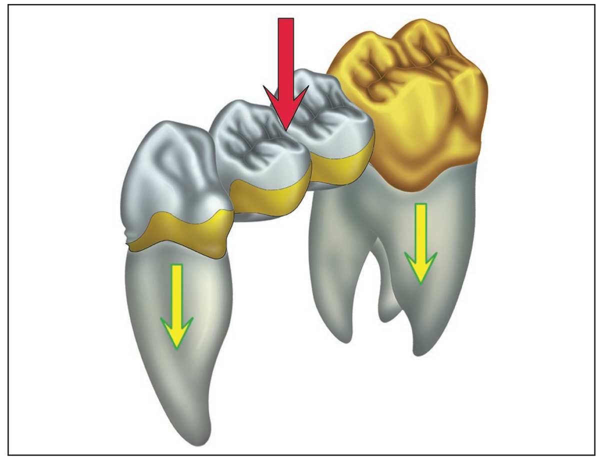


Fig 3-28 If a partial denture is loaded exactly in the middle, the resulting load on the abutments will also be exactly in the middle. Each abutment will bear the same load, which may mean overloading for an anterior tooth serving as the anchor for a posterior partial denture.

will bend under the same load not twice as much but exactly eight times as much; for three times the span length (3 m), deflection is 27 times as high (Fig 3-25).

The cross-section dimensions (height and width) have a similar influence on the deflection of the restoration body. The amount of deflection increases eightfold if the span length is the same but the cross section of the body is halved; a thin board will bend more than a thick one (Fig 3-26).

The deflection of a body that rests on two supports is dependent on the shape of its cross section; that is, a board bends much more if it is laid flat but hardly yields at all if placed on its edge. Applying that principle to the restoration body, the cross section of a unit can be reduced to the shape of a T-beam, which has very high bending stiffness (flexural rigidity). Given the high-quality materials used, a pontic with a thickness of at least 3 mm has sufficient flexural rigidity.

For multispan bodies, however, a cross section dimension of approximately 5 mm^2 should be set to ensure adequate rigidity. Appliances with poor dimensions will bend, and the abutment teeth will tip toward the body and sustain axial loading (Fig 3-27).

The foundations of a structural prosthesis may be assumed to stand firm, whereas the foundations (abutment teeth) of a dental prosthesis move under load. To simplify the comparison, a pontic can be seen as suspended between two pillars (abutments). If a force acts in the middle of the structure, both abutments are equally loaded; that is, they are pressed into the sockets until the periodontium stops the movement and produces a counterforce (Fig 3-28). If the force does not act in the middle but is shifted toward one abutment, the loading is greater on that abutment and smaller on the more distant abutment. By extension, this means that if the force acts exactly over one abutment, this will absorb the full force while the other abutment apparently remains unloaded. However, appearances can be deceptive.

Torque (torque = force applied × lever arm) works by means of the forces acting on each structure. The force applied acts with a lever arm (length of the prosthesis span) around the more distant abutment. A counterforce in the periodontium of the first abutment produces an opposing torque with the span length of the prosthesis. However, the torques are not equal in size because the force applied presses on the abutment

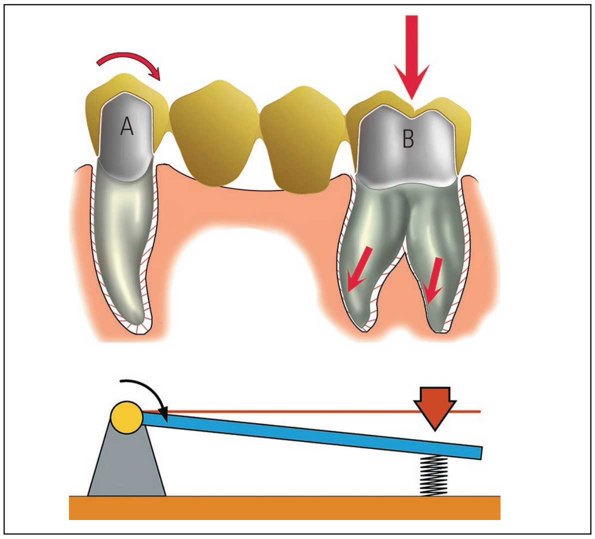


Fig 3-29 If the load on the same partial denture is unilaterally shifted to one end of the partial denture body, the load distribution for the individual abutments will also be shifted. One abutment tooth (B) has to bear the main masticatory pressure, and the partial denture rotates around the other abutment tooth (A) with a torque comprised of masticatory force and prosthesis length. The amount of rotation depends on how far the abutment tooth (B) can be sunk into its socket.

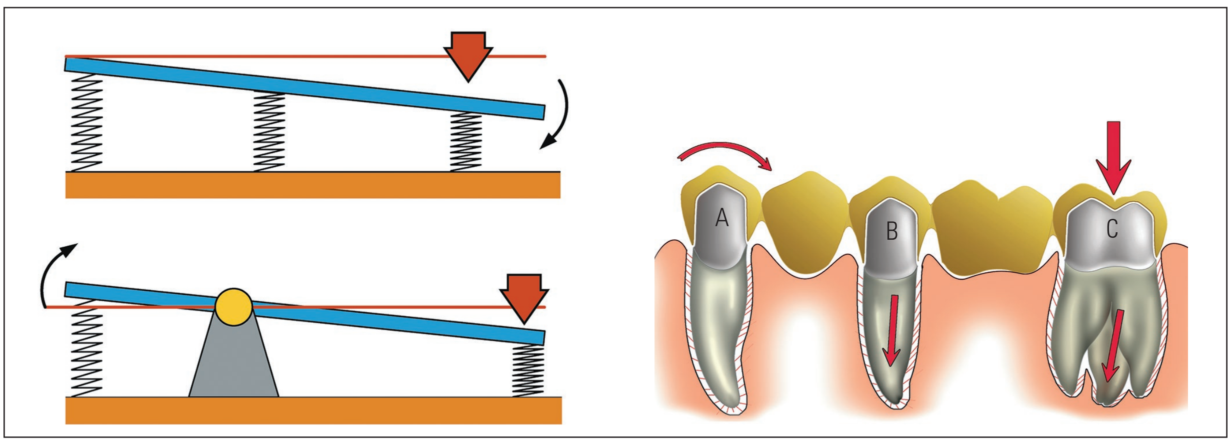


Fig 3-30 A system involving three abutments can be compared with a beam supported on three springs, which rotates around the opposite abutment when loaded on one side. It is wrong to assume that the beam would rotate around abutment B. It could only do that if abutment B were jointed but rigidly supported. A multispan partial denture has relatively stable support because rotations around an abutment cannot exceed the amount to which the other abutments can be pressed into their periodontal tissues. In a multispan partial denture, the loading relations for abutment C do not change if masticatory force acts exactly on that abutment. In addition, the basic loading does not change for the terminal abutment (A) at the other end. However, it is weakened by force being absorbed by abutment B.

so that it sinks into the socket, and the prosthesis is rotated by exactly this amount of sinking and tips the distant abutment into its socket (Figs 3-29 and 3-30).

Tipping is dependent on the length of the whole structure. The amount of rotation can never be greater than the amount to which the abutments can be pressed into their sockets. If one abutment sinks into the socket as far as the limit of its loading capacity, the other abutment can only be tipped up to the limit of its loading. This applies only to forces acting in parallel to the abutment axes. Only very minimal rotation is produced in a long prosthesis, while a short partial denture, in which the loaded abutment is pressed into its socket, will tip the distant abutment more markedly.

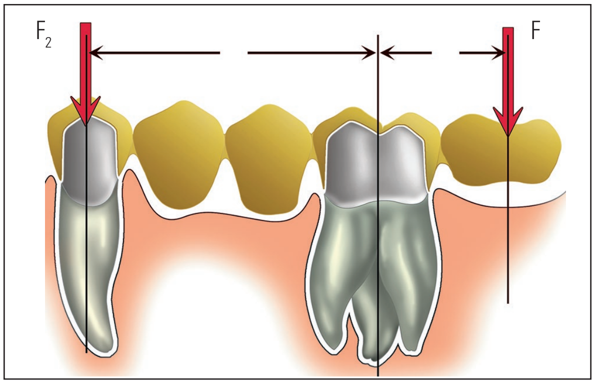


Fig 3-31 Loading of a partial denture and its abutments is adversely affected by a cantilever pontic. Because of a force (F) on the cantilever pontic, the prosthesis is loaded with a torque that must be counteracted by a torque with force F_2. The possible rotation takes place via the abutment next to the cantilever pontic. Deflection of the middle pontic is not ruled out.

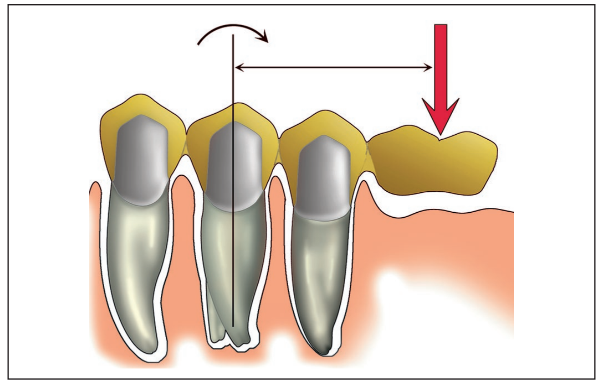


Fig 3-32 If several teeth are splinted and a cantilever pontic is attached to them, torques will load the structures via this pontic. Rotation happens at the middle abutment, while the abutment at the cantilever pontic is subjected to pressure and the opposite abutment to tensile stress. The loading is nonphysiologic for all the teeth involved.

Path of the Partial Denture Body

The path, length, and shape of the occlusal surfaces influence loading of the abutment teeth. It is advisable to keep the body straight to reduce the effects of tipping forces. Generally speaking, two abutments should bear only two pontics so that axial overloading is avoided.

If two abutments linked by a restoration unit also bear a cantilever pontic, a torque acts on the structure with a lever arm that is equivalent to the length of the cantilever pontic. The torque acts around the abutment that is nearest to the cantilever pontic. Torque also arises in the opposite direction around that abutment with the lever arm, equating to the length of the unit between the abutments. The force for this has to be produced by the periodontal tissue of the distant abutment because this abutment is put under tensile stress.

In terms of the geometric relationships, the longer the pontic, the less opposing force is necessary because torque follows the first principle of levers: force exerted on the cantilever pontic × cantilever length. However, this makes it clear that, for a cantilever partial denture with only one abutment (crown with cantilever extension), the total torque acts on the abutment. Therefore, such designs should be avoided (Figs 3-31 to 3-35).

Because the teeth are always arranged in the form of an arch, a long-span restoration must follow the path of that arch; this becomes clear with a terminal abutment prosthesis in the anterior region: The abutments would be the canines, and the pontics would be the incisors, following the path of the dental arch. If a force then acts in parallel to the abutment axes precisely in the middle of the prosthesis body, torque is produced around the abutments. The lever arm is the distance between a straight line connecting the canines and the height of the dental arch. In reality, this distance can be greater than 10 mm. In this case, the arched body acts like a cantilever partial denture.

Two basic principles therefore emerge: *(1)* The body of the partial denture must run straight between the abutments. *(2)* If possible, additional abutment teeth should be used (increasing abutments). The additional anchorage must be at the same distance from the torque axis as the (possible) force being exerted. In a model case, the first two premolars would be sufficient as additional anchors.

During mandibular movements, the antagonistic occlusal surfaces move against each other horizontally. As a result, horizontal loading can arise

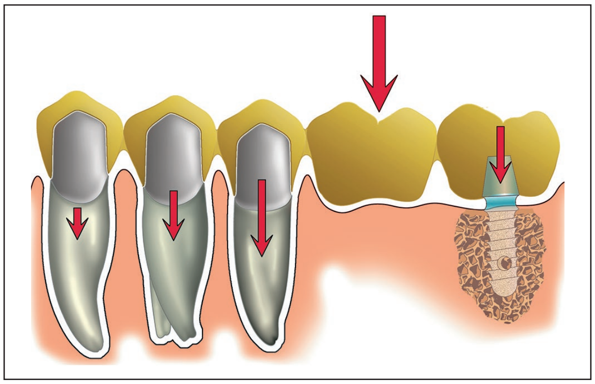


Fig 3-33 Several cantilever pontics can be secured with an implant that supports the gap. This structure behaves like a terminal abutment in which the whole masticatory load is transferred to the abutment teeth—and here to an implant as well.

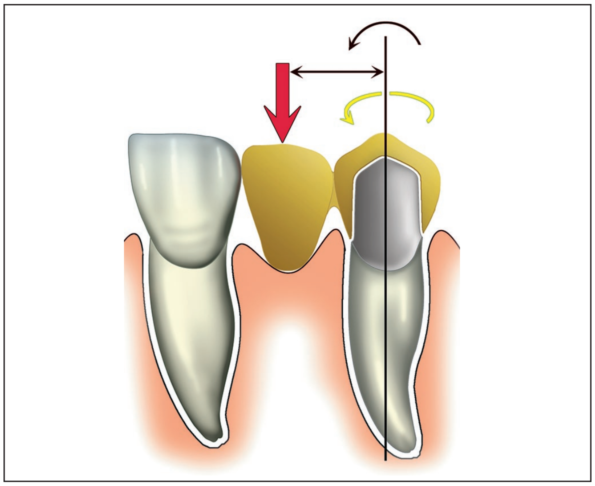


Fig 3-34 The case in which an abutment tooth is covered by a cantilever pontic is particularly unfavorable. A crown with cantilever extension subjects the abutment tooth to so much tipping that this design rarely lasts long. If the cantilever pontic is also a tooth with occlusal surfaces and the abutment is an anterior tooth, the life span of this restoration is likely to be very limited. The case in which a canine is occupied by a cantilever pontic (a small incisor, in fact) is relatively common. In this case, the canine is preferentially subjected to rotation around the vertical axis. This results in tooth migration and means that often the canine can no longer be used for further prosthodontics.

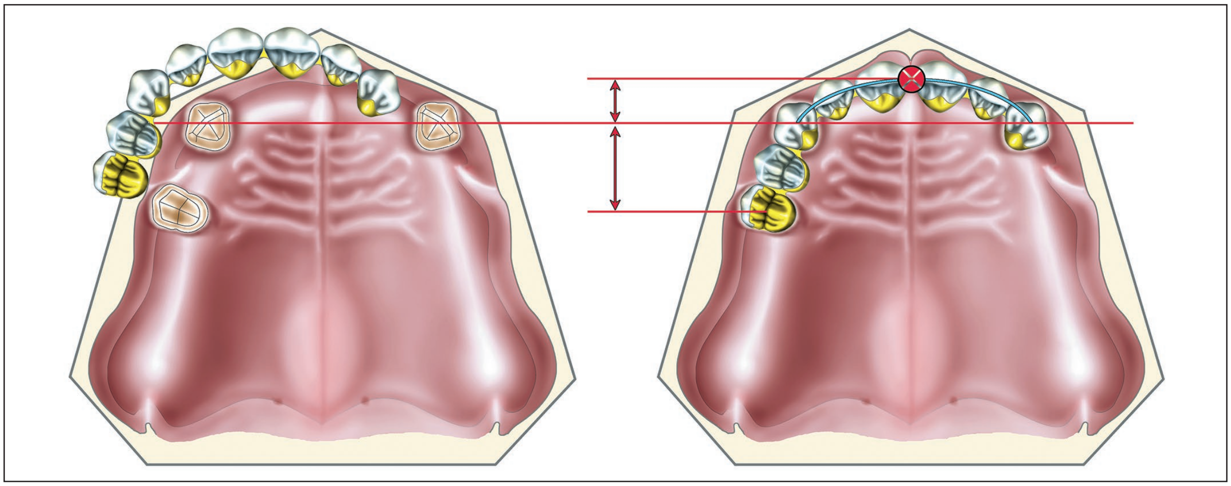


Fig 3-35 When examining the torques in the case of cantilever pontics, it is clear that the arched arrangement of the teeth can become a problem when restoring with long-span partial dentures. In an anterior partial denture from canine to canine, the anterior teeth run labially in a wide arch. The possible rotation axis moves linearly from canine to canine. When the anterior teeth are loaded, a torque acts in the distance from the canine connecting line as far as the point of force application in the horizontal. Hence, there is a requirement for a prosthesis to run straight between the abutments. In the case of a maxillary anterior partial denture, lateral abutments must be used for support. The further the lateral partial denture abutment is from the rotation axis, the better it can counteract the torque.

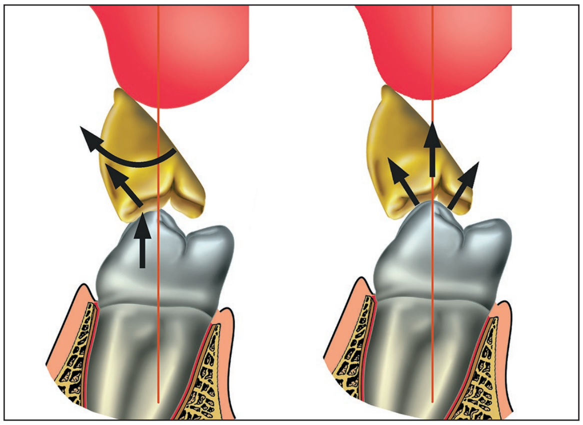


Fig 3-36 Loading of the pontics is unfavorable if the occlusal surfaces are incorrectly shaped. If the cusps are too high, the pontic will be subject to tipping during lateral excursions of the mandible. The requirements that the prosthesis unit must be straight and the width of the replacement tooth must be smaller make it difficult to shape the occlusal contact correctly, which is why special, careful checks are needed.

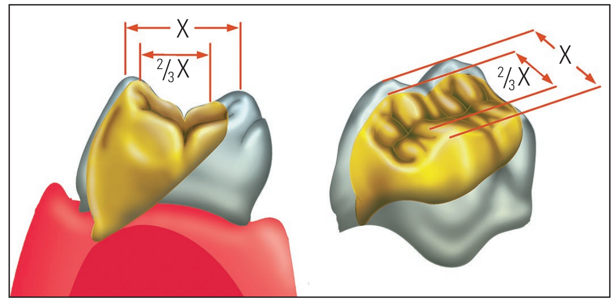


Fig 3-37 In the posterior region, the replacement teeth (pontics) are modeled to be two-thirds the width of a normal tooth. This does not mean that masticatory pressure on the pontics is reduced but that periodontal hygiene is considerably better.

for the partial denture and hence for the abutments. The size of the load depends on whether the cusps are worked in keeping with TMJ guidance or only adapted to centric occlusion. Steep, tall cusps produce greater horizontal loading than flat ones; the cuspal inclination of the adjacent teeth is a useful support. Horizontal loads are limited if antagonist contact occurs in exact intercuspation with multipoint contact where the occlusal patterns have been adapted to the patient's individual movement pattern (Fig 3-36).

A decrease in horizontal and axial loading is achieved if the pontic is roughly two-thirds the normal width of the tooth being replaced (Fig 3-37). Once again, higher and more effective surface pressure can be produced for the same masticatory force if the occlusal surface is narrow. Furthermore, in the posterior region, a pontic is easier to shape for tangential mucosal contact if the occlusal surface is reduced by the specified amount.

The position and inclination of the abutments also influence abutment loading. Whether an abutment tooth is loaded horizontally or axially depends on what inclination the tooth has in relation to the force striking it. Extremely inclined (displaced) teeth are less suitable as abutments than straight, upright teeth. If a tooth space has remained unrestored for a long time, the teeth bordering the gap—the potential abutment teeth—may already have inclined markedly into the space.

The disadvantage is clear: Much tooth substance has to be removed to make the teeth roughly parallel. On normal loading, however, the abutment teeth will never absorb the pressure truly axially (centrally) to their periodontium but always eccentrically. In exceptional cases, it will be necessary to upright the teeth again by suitable orthodontic measures.

4

Removable Partial Dentures

Classification of Partially Edentulous Arches

As the dentition deteriorates from a fully dentate masticatory system to a fully edentulous jaw, various edentulous situations arise that demand different solutions when planning prosthodontic treatment. Note, however, that there is a difference between edentulous spaces and shortened dental arches. *Edentulous space* denotes the situation where one or more teeth are missing within a dental arch and the gap is bounded by natural teeth. A shortened dental arch or free-end gap refers to the situation where tooth loss occurs at the end of the dental arch. Following is a simple description of the types of partially edentulous dental arches (Wild's classification) without specifying the number of missing teeth (Fig 4-1):

- Interrupted dental arch
- Shortened dental arch
- Interrupted and simultaneously shortened dental arch

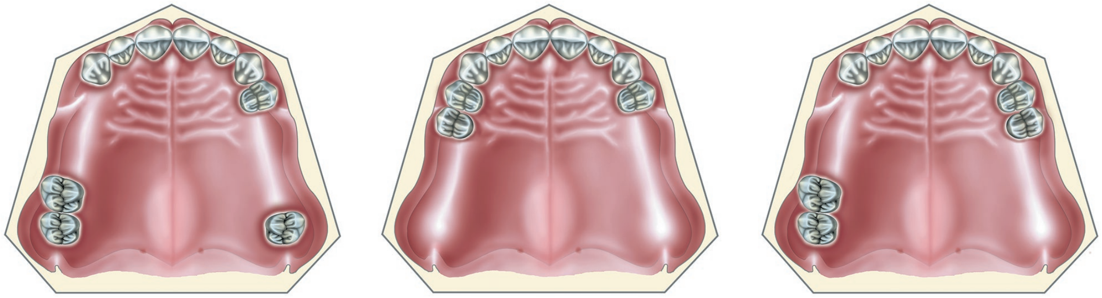


Fig 4-1 Wild's classification of partially edentulous arches differentiates between edentulous space and a shortened dental arch as well as a combination of edentulous situations.

Types of partially edentulous arches can also be grouped into comparable dentition situations. Two fundamental classifications are based on the topography of the residual dentition and the biostatic conditions.

The Kennedy topographic (or morphologic) classification describes the dentition of the individual jaws, so it can be used equally for the maxilla and the mandible. Four basic classes are identified (Fig 4-2):

1. Bilaterally shortened dental arch
2. Unilaterally shortened dental arch
3. Posterior edentulous space
4. Anterior edentulous space

This classification is further divided into various subcategories:

- Residual dentition is interrupted by one other space
- Residual dentition is interrupted by several spaces
- Only minimal residual dentition remains

This morphologic classification can be used to assess the statics of a denture during design planning for the individual jaws and to select the abutments for a rigid construction or for the rest seats that will support the denture.

Assessment of the functional state in a partially edentulous arch is not possible with such a classification, making it difficult to plan the optimal denture design. When assessing the damage to the dentition, it is important to know how many teeth are missing and where they are missing. For example, the function of the masticatory system is not disrupted if all four third molars are missing, yet functional impairment occurs if the maxillary incisors have all been lost. In addition to the poor esthetic impression, speech and biting function are impeded. Or if four posterior teeth are missing on one side of the jaw, masticatory function is greatly impaired.

The criterion used in the Eichner classification to describe the functional level of the residual dentition is to name the antagonistic groups of teeth in the jaw (Fig 4-3). The classification is based on the biostatic condition of the dentition and describes antagonist contact in four support areas (Fig 4-4):

1. Premolars on the left side
2. Premolars on the right side
3. Molars on the left side
4. Molars on the right side

The support function of such an area is dependent on whether a clearly defined occlusal contact exists in the area (Figs 4-5 to 4-7). For this to be the case, it is not necessary for all the teeth to be present. Complete contact exists, for instance, if the mandible still bears the two second premo-

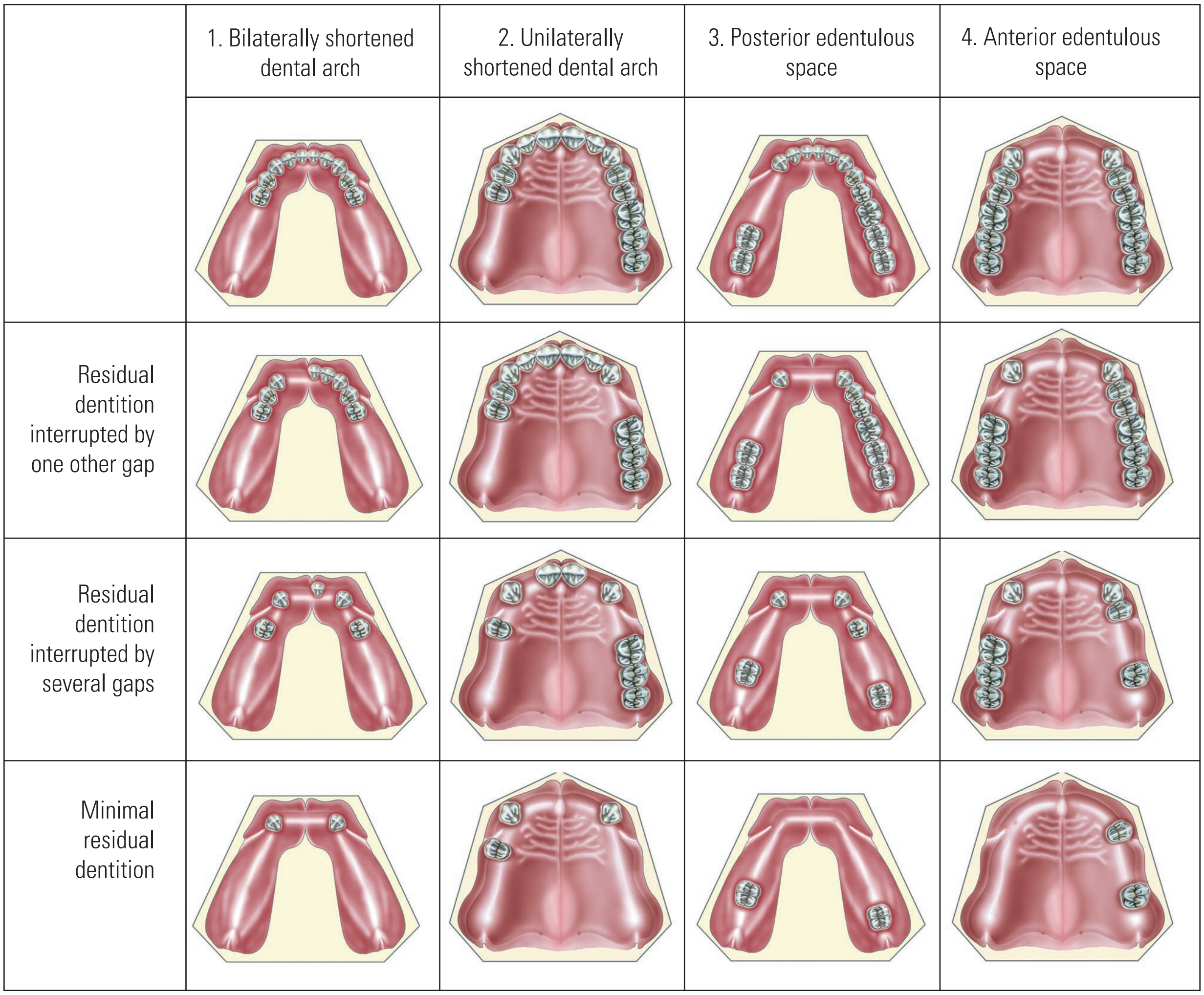


Fig 4-2 The Kennedy topographic classification describes the distribution of spaces, which is categorized into four classes and three subgroups.

lars and the second molars and the corresponding main and secondary antagonists are still present in the maxilla. Canines and incisors are disregarded in terms of the support areas.

Depending on an edentulous situation resulting in the loss of one or more support areas, different stresses will affect the temporomandibular joints, the muscles of mastication, and the periodontal tissue of the remaining teeth. The Eichner classification of the partially edentulous arch categorizes antagonist contact in the four support areas into three classes, each with three subgroups (Fig 4-8). During denture planning, the Eichner classification can provide information about antagonistic loading conditions, while topographic classification identifies the abutments for a partial denture.

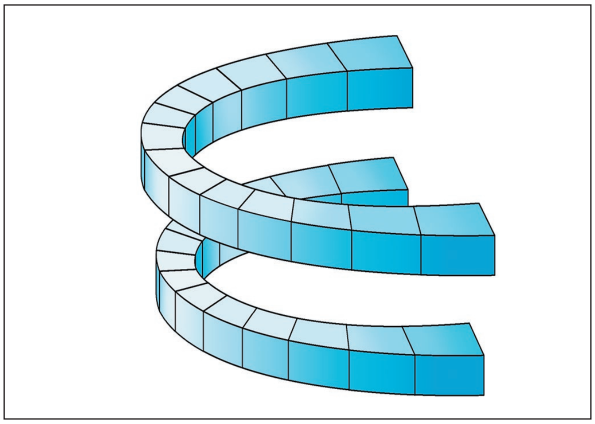


Fig 4-3 The functional level of a partially edentulous dental arch can be described by recording the antagonistic pairs of teeth. This figure shows a schematic representation of two antagonistic dental arches. Complete supporting function in the dentition only exists if there is antagonist contact throughout.

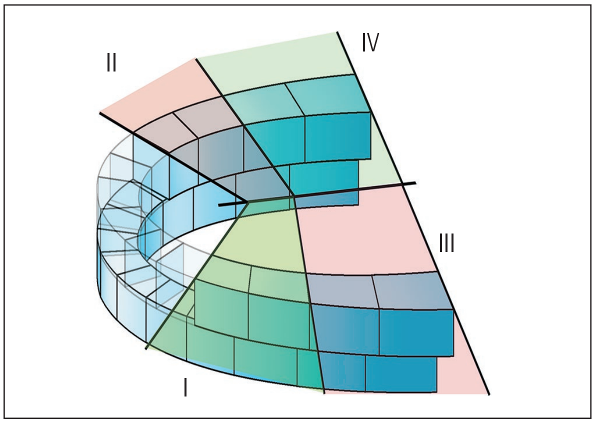


Fig 4-4 Classification of the dental arches into four support areas: (I) premolars on the left side, (II) premolars on the right side, (III) molars on the left side, and (IV) molars on the right side.

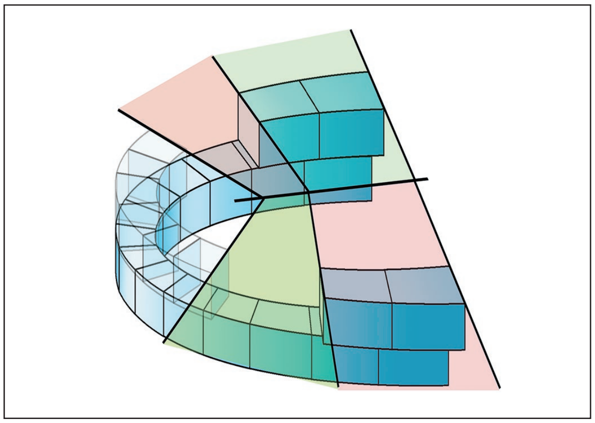


Fig 4-5 The biostatic status of the dentition is inadequate if antagonist contact is not present in all of the support areas. When there are four missing teeth, two support areas are without contact.

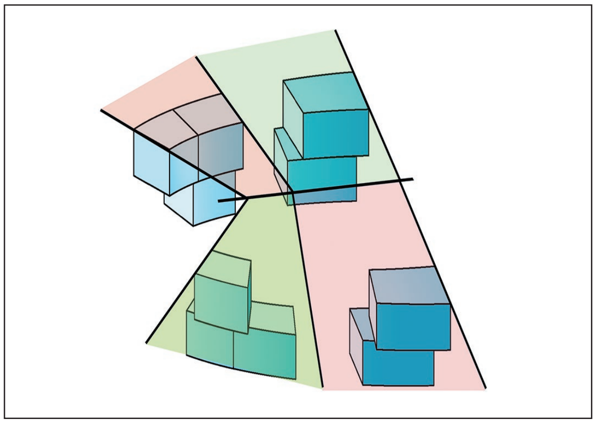


Fig 4-6 Biostatic balance may still exist in a greatly reduced residual dentition if, as shown here for a case of 10 residual teeth, antagonist contact is present in all four support areas.

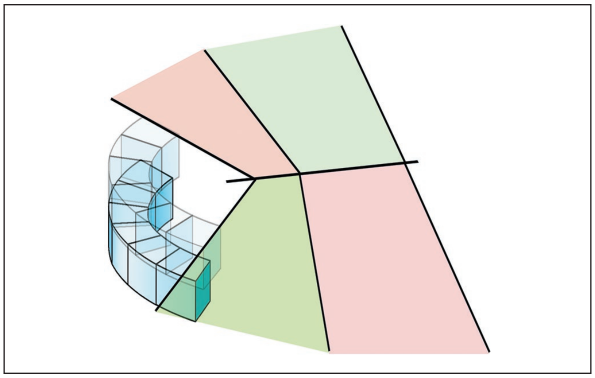


Fig 4-7 Biostatic balance is totally disrupted if only the anterior teeth remain. This partially edentulous dentition has no support area contact and reflects the same biostatic condition as complete tooth loss.

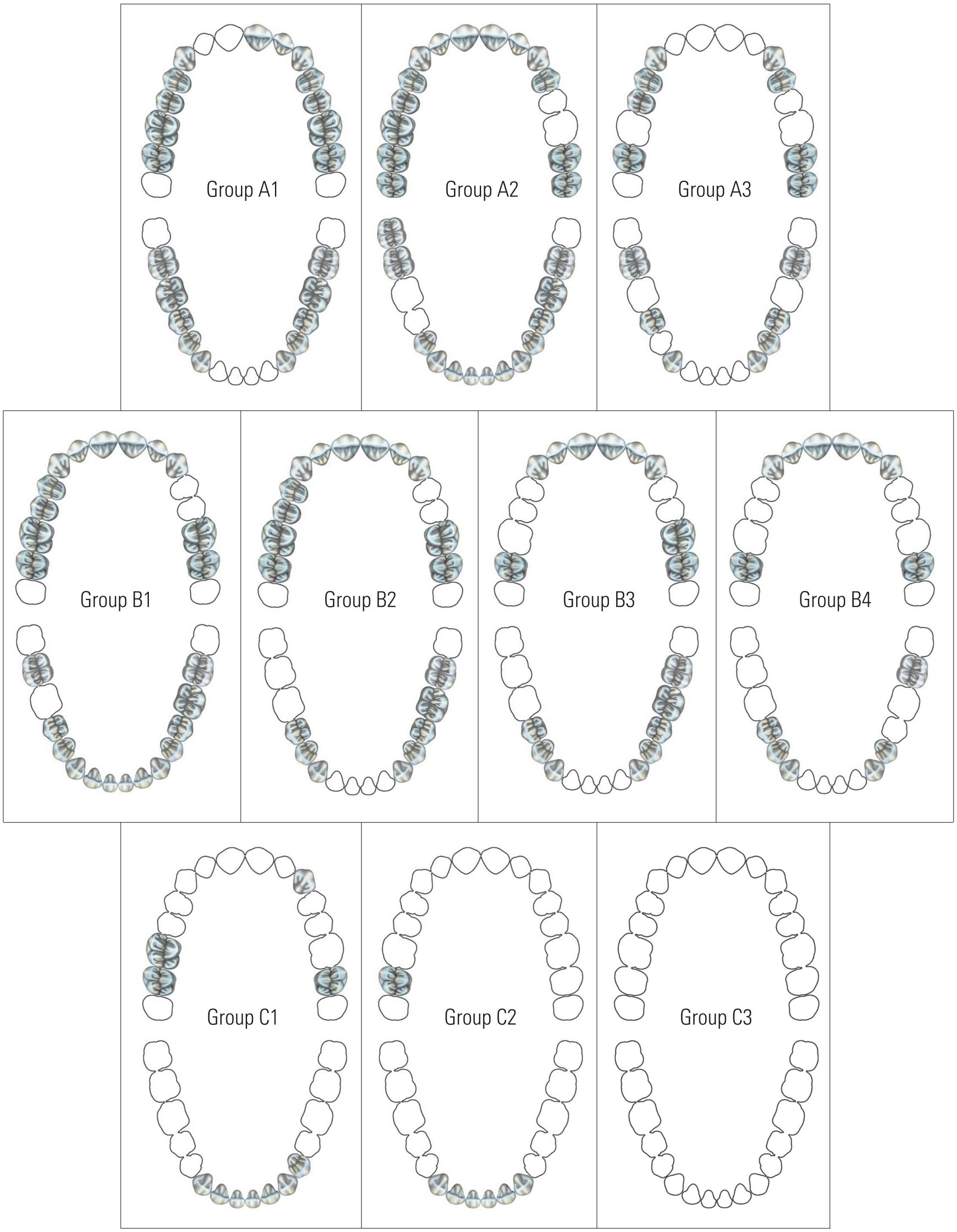


Fig 4-8 The Eichner classification categorizes support area contacts into three groups: Groups A1 through A3 show antagonist contact in all four support areas, groups B1 through B4 show antagonist contact but not in all support areas, and groups C1 through C3 show no antagonist contact.

Classification of Partial Dentures

Partial dentures can be classified according to the nature of tissue loading or the topography of the partially edentulous arch (Fig 4-9).

Classification according to tissue loading

Classification according to tissue loading takes into account the functional level of the denture. The basic categories are periodontally supported, mucosa-borne, or bone-supported tooth restorations.

A periodontally supported prosthesis is a physiologic design because masticatory pressure is transferred solely to the periodontium of the remaining teeth via symmetrically arranged abutments. The denture contacts the edentulous alveolar ridge but does not put any load on it. The design is similar to a partial denture construction. Where the abutments are asymmetrically arranged, the restoration is supported on the residual dentition, but the denture also rests on the mucosa.

A mucosa-borne prosthesis without support on the residual dentition transfers masticatory pressure to the mucosa. In relation to partial dentures, such structures can be used as interim solutions. Because there is considerable loading of the margin with this kind of prosthesis, the area resting on the mucosa should be very large, though the marginal periodontium should be avoided. A full denture is a mucosa-borne restoration that has an extended prosthesis base.

Prostheses with mixed support are used for shortened dental arches in the form of cantilever fixed partial prostheses. The dentures rest on the alveolar ridge and are supported periodontally at one end only. These structures are statically indeterminate systems because the mucosal support can only absorb masticatory forces to a limited extent and can hardly absorb transverse forces at all, while the periodontal support takes on all masticatory forces depending on the quality of the retentive component. The periodontal support is usually overloaded and loosened because of the unstable mucosal support.

Support on implants is another method of seating partial dentures. The denture body is fixed symmetrically onto implants that are inserted into the jawbone and bear the prosthesis. The denture is then a bone-supported restoration.

Mixed support, in which the denture is supported simultaneously on the residual dentition, mucosa, and implants, is statically indeterminate because of the variable resilience of the rest areas involved. The result is variable loading of the involved rest areas.

Classification according to edentulous topography

Classification according to edentulous topography provides a precise description of the form of the denture based on the distribution of gaps across the dental arches. Interdental insertion prostheses replace teeth within a dental arch. They are essentially supported on the remaining teeth, which means that insertion dentures belong to the group of periodontally borne or supported restorations. Following are types of insertion dentures:

- Unilateral interdental insertion prostheses on one half of the jaw are supported on both halves of the jaw; the supporting components are joined by a denture framework.
- Bilateral interdental insertion prostheses on both halves of the jaw are joined by means of a denture framework. Large arch-shaped interdental segments are possible for patients with a small anterior residual dentition but terminal molars.
- Anterior interdental insertion prostheses replace missing anterior teeth. If a long, arched path extends to the premolars, this denture acts as a cantilever fixed partial prosthesis.
- Alternating interdental insertion prostheses replace single teeth in several small edentulous spaces over the entire dental arch.

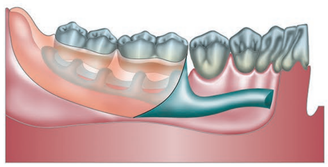
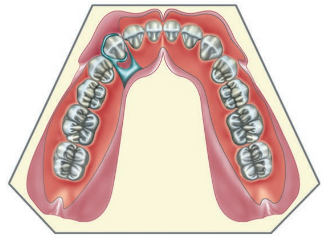
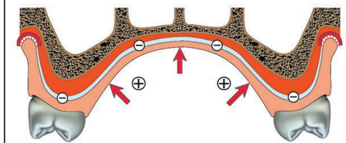
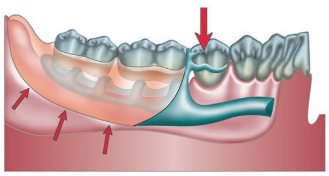
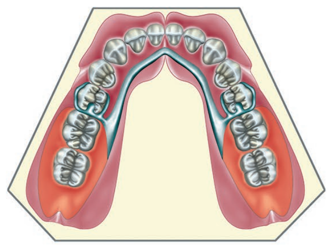
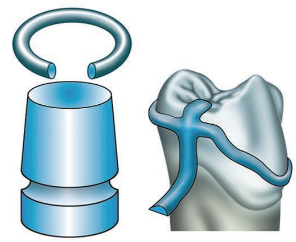
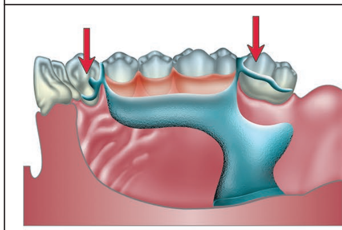
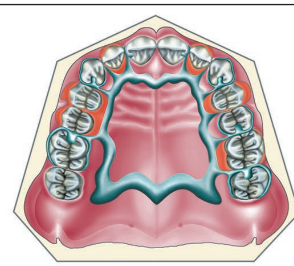
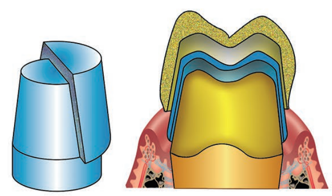
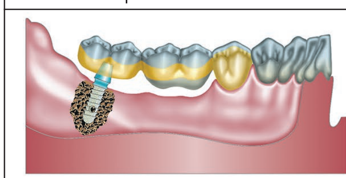
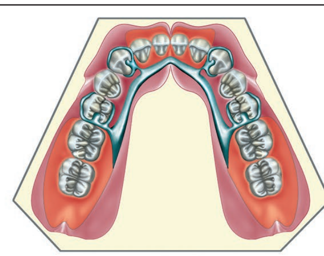
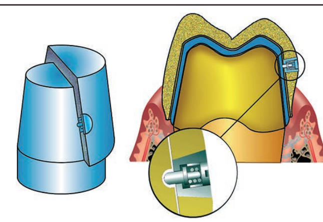
Based on the type of tissue loading	Based on the topography of the partially edentulous dentition	Based on the type of anchorage to the residual dentition
 Mucosa-borne dentures transfer the masticatory load to the mucosa alone	 Minimal residual dentition requires almost complete dentures	 Suction, adhesive, and cohesive effects are of minor importance to partial dentures
 Dentures with mixed support transfer the masticatory load to the mucosa and periodontium	 Cantilever fixed partial dentures are used for unilateral, bilateral, or arched free-end gaps	 Anchorage with spring components such as clasps or spring anchors
 Periodontally supported dentures transfer the masticatory load to the periodontium alone	 Interdental insertion dentures are used for posterior, anterior, or alternating edentulous spaces	 Anchors via telescopic components are retained due to resistance to static friction
 Bone-supported dentures transfer the masticatory load directly to the bone	 Combination of interdental insertion and cantilever fixed partial dentures is used for appropriate gaps	 Latch systems for telescopic anchorage

Fig 4-9 Classification of partial dentures.

Following are types of cantilever fixed partial prostheses, a type that replaces teeth in shortened dental arches:

- Unilateral cantilever fixed partial prostheses in a unilaterally shortened dental arch
- Bilateral cantilever fixed partial prostheses to replace posterior teeth
- Arched cantilever fixed partial prostheses as almost-complete dentures in which a few terminal molars remain on one side only

Combinations of cantilever fixed partial and interdental insertion prostheses are used when there is a unilateral edentulous space with a unilateral shortened dental arch and an anterior edentulous gap. Each form of partially edentulous dentition requires a specific solution with a particular form of denture and the necessary retentive components.

Structural Features

In principle, a removable partial denture is made of four structural sections, each of which has different functional tasks (Fig 4-10):

- Saddle
- Framework or major connector
- Anchoring elements
- Supporting elements

The denture saddle rests on edentulous jaw segments and bears the replacement teeth. To avoid pressure points, the denture saddle needs to fit precisely to the alveolar ridge. High accuracy of fit also prevents movement of the saddle relative to the jaw. In this type of prosthesis, the denture saddle is adapted to its function; specifically, the three sections of the denture saddle have the following functions (Fig 4-11):

- The denture base, which has direct mucosal contact, is designed to cover an extensive area as defined by the adjacent, mobile mucosal areas. It must be possible to reline the area of the denture base.
- The denture body forms the replacement for the resorbed alveolar ridge; it carries the artificial teeth and provides buccal and lingual support. The basic principle is to reproduce the anatomical form, especially in its spatial dimensions.
- Replacement teeth are the substitute for the occlusal field, masticatory function being restored by the artificial teeth. Therefore, it is necessary to give the replacement teeth a functional anatomical form while enhancing the esthetic impression.

The denture framework or the large connector represents the mechanical join between the denture saddles and the anchoring and supporting elements. These connectors can be fabricated from metal or acrylic resin. An acrylic resin plate is usually constructed as a full plate or as a sectioned and partial plate; for stability reasons, the edge of the plate fits closely to the residual teeth. This results in encystment and inflammation of the marginal periodontium, not to mention the mechanical effects of the plate edges on this gingival region. Therefore, acrylic resin structures are only used for interim dentures; they are largely avoided for partial dentures and have been replaced by model cast dentures. Metal constructions can be shaped as reduced plates, skeleton parts, or narrow straplike connectors owing to the stability of the material.

The anchoring elements secure the denture to the residual dentition and take on the function of retention. The supporting elements should support the artificial occlusal field on the remaining teeth in order to transfer the masticatory forces periodontally. Anchoring and supporting elements generally form a unit and create the linkage between the denture and the residual dentition. Depending on their design, they may take on a splinting function. The residual dentition is reinforced via rigid anchoring elements or splinted by resilient connectors. As a result, uniform distribution of forces to all the residual teeth can be achieved, and periodontally damaged teeth can be favorably supported by means of splinting.

Mechanical fittings are used as anchoring and supporting elements on the residual dentition; they are differentiated as follows:

- Fabrication of manually produced components (eg, clasps and telescopic crowns) and prefabricated (industrially produced) components (eg, attachments and anchors)

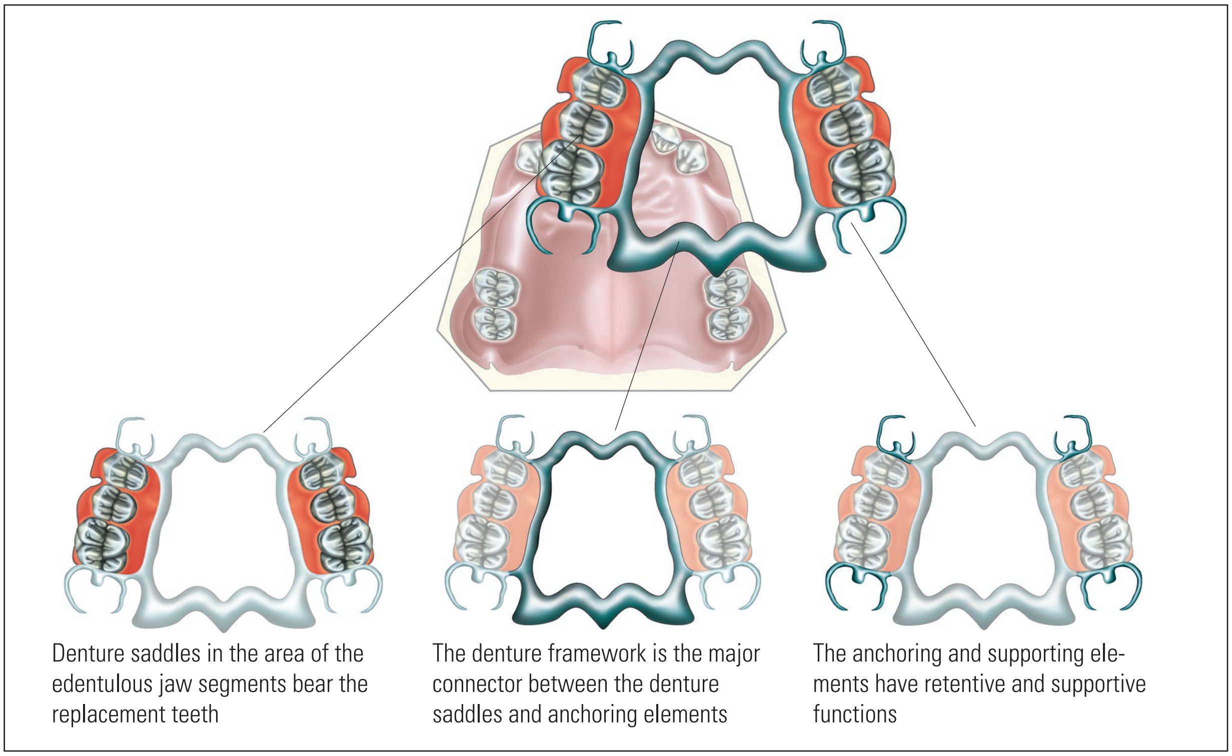


Fig 4-10 The structural features of a partial denture reflect their assigned functions.

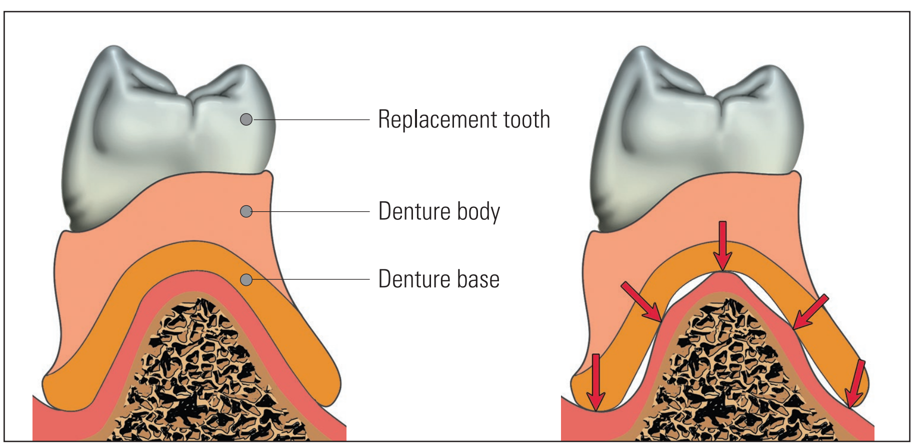


Fig 4-11 The denture saddle comes in contact with the mucosa and bears the replacement teeth; it should fit accurately against the jaw to avoid pressure points and prevent movement. The denture saddle has three functional parts: *(1)* Replacement teeth constitute the actual replacement of the occlusal field and are anatomically shaped to meet esthetic and functional requirements. *(2)* The denture body replaces the resorbed alveolar ridge and bears the replacement teeth. The denture body is anatomically shaped to provide support to the cheek and the tongue. It must not impede the tongue or restrict the patient's speech function. *(3)* The denture base lies against the mucosa over an extensive area and is relinable; the edges are trimmed in the area of mobile mucosa.

- Coupling between the denture and the residual dentition with rigid, semirigid, resilient, and articulated structural elements
- Physical and technical design or retentive action, in which the spring fittings are in the form of clasps that anchor by spring forces, and telescopic components in the form of parallel or conical fittings (eg, telescopic crowns that anchor by means of friction resistance)

Anchorage by means of implants in conjunction with these types of fittings is always a possibility. The implant embedded in the bone serves to carry the primary fitting part. Anchorage achieved by the retentive effect of suction, adhesive, and cohesive forces is of limited importance to partial dentures. This is the main form of anchorage for complete dentures because insufficient mechanical retentions are available.

Design Principles for Denture Saddles

The design of denture saddles in model cast prostheses allows for the possibility of relining (Fig 4-12). The denture base should be relinable in the saddle area, where particularly severe tissue shrinkage occurs. This applies generally to the alveolar ridges, and this area should be interpreted as broadly as possible. It is not enough to make the vestibular part of the ridge relinable, but the possibility of relining should extend just as far lingually.

The relinability of dentures is necessary mainly because the edentulous parts of the jaw will shrink in response to pressure loading (or a total lack of loading). If the mucosal support atrophies after a certain period of denture wearing, the poor accuracy of fit has to be compensated for by relining. Inaccuracies in the fit of the denture saddle lead to horizontal transverse stresses on the jaw segment and hence to increased tissue resorption.

Free-end saddles are designed as extension saddles and are always entirely relinable. These saddles are extended onto the largest possible mucosal surface in order to enlarge the support surface and improve distribution of masticatory forces (the snowshoe principle). The saddle encompasses the maxillary tuberosity in the maxilla and the alveolar tuberosity in the mandible.

An extended saddle must be scalloped to avoid ligaments, muscle attachments, and bony ridges, as the need for saddle reduction dictates. The vestibular parts of the saddle should not be applied too thickly, in the same way as for lingual parts, so that the space for the tongue is not restricted and the cheeks and lips are not displaced; a valve-type margin, as with complete dentures, is not attempted.

An alginate impression is taken of the saddle surface while pronounced functional movements are performed to determine the entire surface area of the edentulous section that will be necessary for denture wear. An extended alginate impression is taken of the sublingual space by the mucostatic impression technique to ensure that sufficient space is allowed for the sublingual bar.

Moderate pressure loading on the mucosa by the denture saddle can have a positive or stimulating effect on the tissue. It has been observed that unloaded mucosal areas or bony segments undergo inactivity atrophy, whereas alveolar bone that has been loaded with normal pressure by accurately fitting denture saddles are not subject to anywhere near as much shrinkage (Fig 4-13).

The degree of loading and progression of shrinkage are related, but the relationship cannot be detected in every case. It is very clear, however, that a jaw that was instantly loaded with an immediate prosthesis after extraction of a number of teeth will display less shrinkage than a jaw that was not fitted with a long-term prosthesis until weeks after healing. In particular, this illustrates the prophylactic value of an immediate restoration while, generally speaking, pointing to some conclusions about the shrinkage process under denture saddles.

The resilience of the periodontium allows a supported prosthesis to sink as far as required for it to stimulate the mucosa. With an accurately fitting, regularly relined denture, edentulous jaw segments can be sustained for long periods without any appreciable tissue breakdown. If a complete denture is later fitted, the shape of the alveolar ridge is crucial for the retention of such a restoration; therefore, a well-preserved ridge is always valuable.

The tooth-prosthesis interface is the transitional region between denture saddle and abutment tooth, which is particularly at risk in terms of

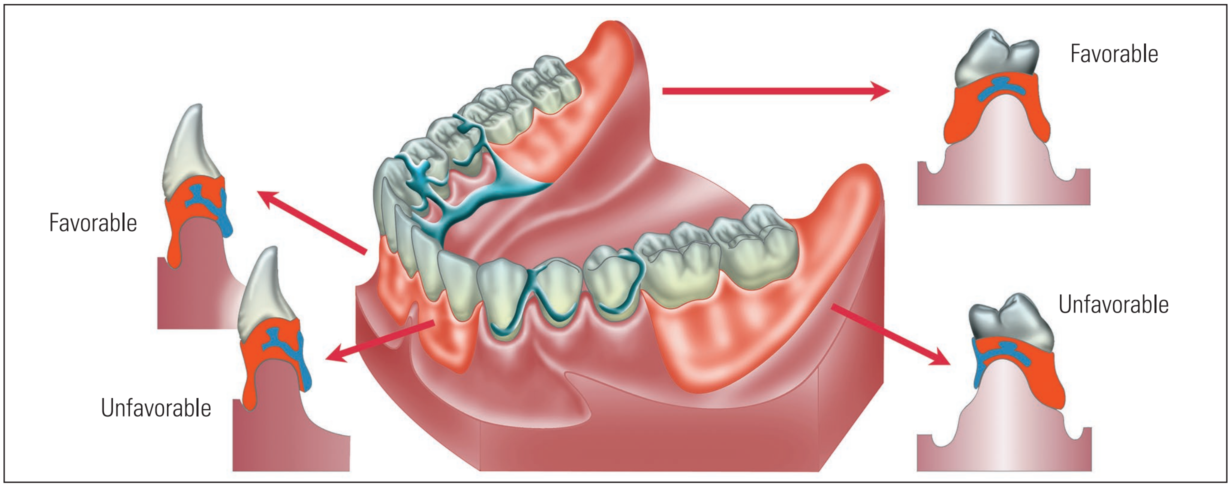


Fig 4-12 Denture saddles must be designed so they can be relined; that is, after a certain wearing period, the dentist must be able to rework the area of the denture with acrylic resin where the alveolar ridge has shrunk. The metal frameworks must be designed so that only a small part of the jaw is covered with metal. In the posterior region, only one retention is laid on the middle of the ridge, and the framework parts should not touch the jaw. The more extensively a denture saddle can be relined, the better the construction. In the anterior region, however, it may be necessary to place a bar relatively high to guarantee the denture's stability. Starting from the bar, retentions and a collar can be fitted to the replacement teeth. A lingual plate in the area of a replacement tooth, which is fully relinable, is the best construction. A chemical metal-acrylic resin bond makes more delicate retention designs possible; the relinability of a denture framework is essentially guaranteed by silanization of the framework because the acrylic resin can be directly polymerized onto the organophilic silanization layer.

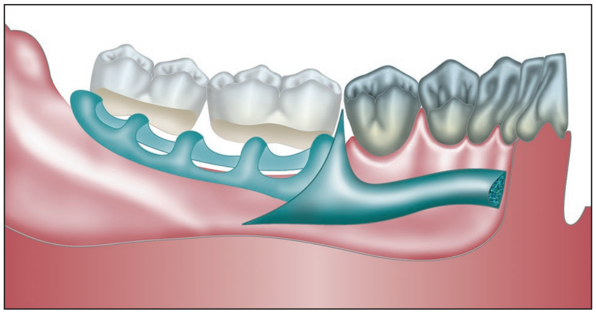


Fig 4-13 Saddle retentions are placed in the middle of the alveolar ridge, approximately 1 mm from the mucosa; they must not show through from the vestibular side. The border to the abutment tooth adjacent to the gap is kept clear of the periodontium and must not provide an edge where deposits can become lodged.

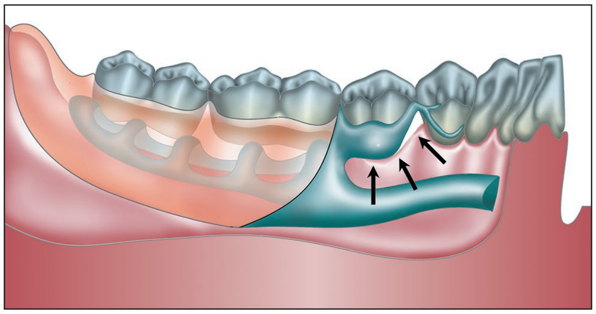


Fig 4-14 The closed-saddle framework arrangement has a smooth metal surface without acrylic resin covering the border to the abutment tooth adjacent to the gap. The metal is polished smoothly so that plaque cannot build up. The replacement tooth is prepared from the vestibular side and looks like a pontic.

periodontal prophylaxis. Saddle contact with the gingival margin in the tooth-prosthesis interface should be avoided to prevent the gingival margin from being squeezed when loaded by the saddle; nevertheless, no retention space should be created where plaque can accumulate.

To this end, the saddle region can be shaped to form a tooth-prosthesis interface from metal framework to anchoring element, without acrylic coverage, which is referred to as a *closed-saddle framework* or *clasp stem arrangement* (Fig 4-14).

The saddle retention forms the mechanically firm connection between the denture body and the denture framework; it is at a distance from the alveolar ridge so that a uniform denture base can be shaped out of acrylic resin. The saddle retention also leaves enough space occlusally for the replacement teeth, under which it is placed centrally. The saddle retention must not show through the saddle acrylic resin vestibularly for esthetic reasons.

Design Principles for Denture Frameworks

Frameworks for partial dentures can be made from acrylic resin or metal (chromium-nickel, cobalt-chromium, or gold-platinum alloys). The decision regarding which material to use depends on a few fundamental considerations.

Acrylic resin frameworks are inexpensive and relatively simple to fabricate. They have to be shaped so that they are thick and cover a large area to ensure adequate stability. For the same reasons, an acrylic resin framework should always fit residual teeth closely like a collar, which is problematic in terms of periodontal hygiene. A large framework surface evenly transfers masticatory forces to the underlying mucosal support. In a severely reduced partially edentulous dentition, in which adequate periodontal support is impossible and an extended base is in any case required, an acrylic resin framework is an option. Acrylic resin dentures are fully relinable. However, their drawbacks are poor stability, especially in the area where clasps are attached, and a large, thick shape that makes them unpleasant for patients to wear. Acrylic resin frameworks are therefore only used for interim prostheses.

Model cast dentures made of chromium-nickel alloys are preferable to any acrylic resin denture in terms of functional quality. The metal frameworks can be worked to be very thin and delicate because of the high material strength; narrow connectors or transverse bands are often sufficient. The individual clasps are joined together rigidly enough by the metallic structure, so that adequate splinting of the residual dentition can be achieved.

Patients prefer metal frameworks because they are more comfortable to wear, even if the greater heat conductivity of the metal may have an unpleasant effect when they eat hot food. Metal frameworks provide better accuracy of fit than acrylic resin dentures. Prostheses with metal frameworks can always be relined with acrylic resin in the area of the alveolar ridges and in other areas of the framework after fitting of retention components or after application of a silane layer.

The delicate metal frameworks are particularly advantageous in the mandible because unfavorable spatial relationships often prevail there. Even given the small space available, sufficiently stable connectors can be placed that can also be satisfactorily sited in terms of periodontal hygiene. When constructing model cast dentures, the framework parts should meet the following fundamental requirements (Fig 4-15):

- Stable and torsion resistant
- Sufficiently delicate
- Clear of the periodontium
- Largely clear of the tongue

Stability can be achieved by enlarging or strengthening the profile of the framework parts. It is important to find a practical compromise between the necessary stability and the smallest possible size of framework parts; stable yet delicate is the watchword.

For sublingual bars in the mandible, prefabricated wax profiles with adequate dimensions are suitable for waxing up. It is different in the maxilla, where there are several design options for framework parts. These have to be strengthened by suitable moldings so that adequate resistance to deformation is achieved. Deformation resistance is only adequate if the framework does not warp in response to normal stresses during chewing.

The width of a framework part that rests on the mucosa should not exceed 10 mm to avoid deposits. Such a narrow band needs to be reinforced to 1.5 mm by a molding in the middle to achieve torsion resistance. The wider the band, the smaller the reinforcement needs to be.

Periodontal clearance relates to periodontal hygiene. For this purpose, the edge of the denture framework must be a minimum of 4 mm from the marginal periodontium of the remaining teeth (Fig 4-16). The transition from the framework to the denture saddle should also be fashioned to ensure periodontal hygiene. The tooth-prosthesis interface is kept clear of the periodontium as the framework parts are brought close to the denture saddle in a wide arch, which is mainly necessary at the transition to the anchoring elements (Fig 4-17).

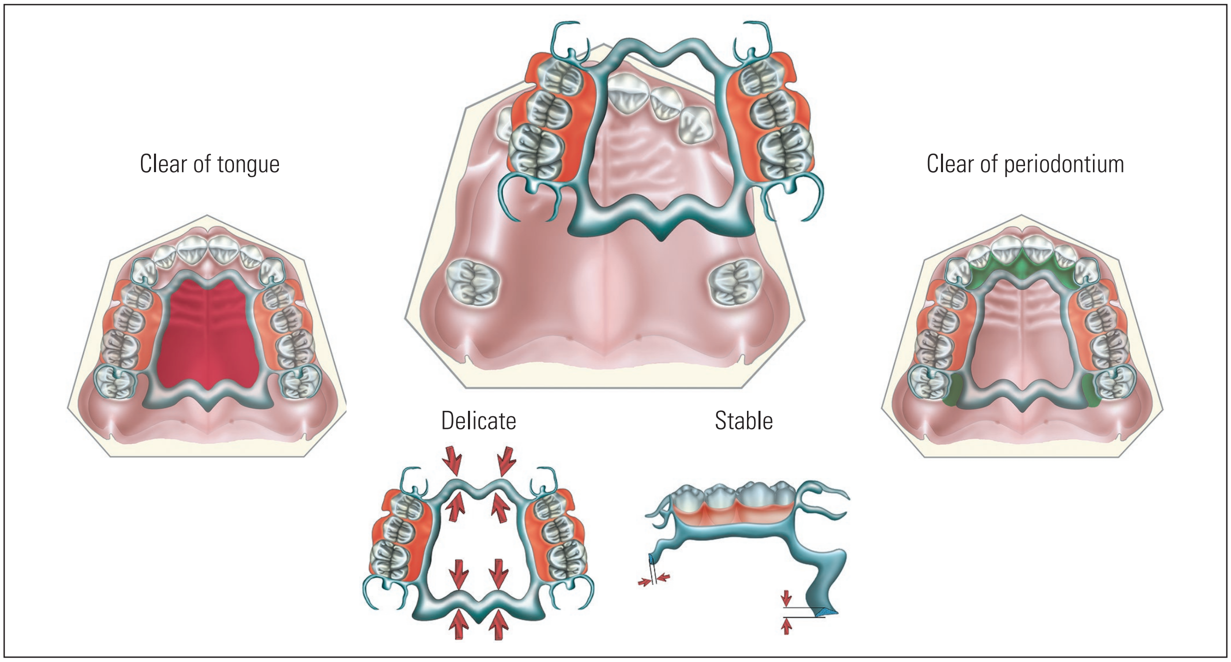


Fig 4-15 Denture frameworks should be stable and torsion resistant. They also must allow self-cleaning as they are kept clear of the periodontium at a minimum distance from the marginal periodontium. And they must be shaped so delicately that they do not impede tongue activity and are comfortable to wear.

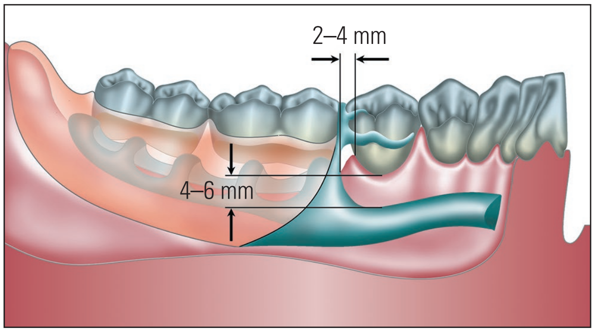


Fig 4-16 To avoid the marginal periodontium of the abutment teeth and the residual dentition, framework parts should be placed so that in the tooth-prosthesis interface the marginal areas cannot be damaged by mechanical stress or coverings. Denture frameworks, like the sublingual bar shown here, should be placed a minimum of 4 to 6 mm from the gingival margin. The minor connectors in the tooth-prosthesis interface should leave a gap that allows for rinsing.

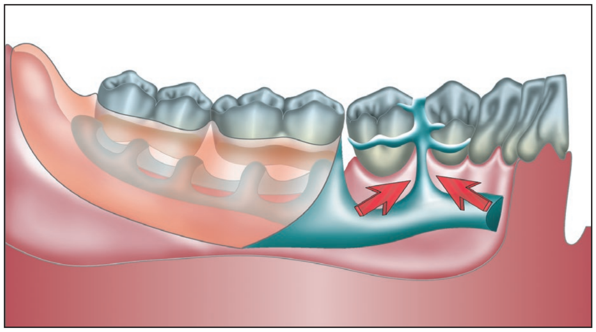


Fig 4-17 Minor connectors of the framework parts for the closed dental arch (eg, Bonwill clasps) should also be clear of the periodontium. The minor connector must be at a minimum distance from the alveolar ridge and should not impede the tongue; if the connector sticks out too much, it will interfere with speech function.

Tongue clearance is achieved by delicate shaping of the framework parts; thin plate components overlying the mucosa are better than thick bar profiles placed at some distance from the alveolar ridge. Framework parts should largely be laid outside the range of activity of the tongue, which is the area of the palatine rugae (pressure and fricative field) in the maxilla and the entire sublingual area in the mandible.

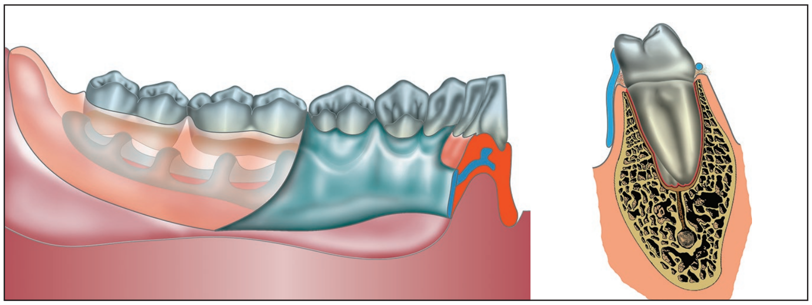


Fig 4-18 Lingual plates should be rejected in principle because they cause encapsulation at the marginal periodontium. To avoid a mechanical impact on the periodontium, the edge of the plate is trimmed slightly, which gives rise to niches in which deposits will form. As self-cleaning is prevented, chronic inflammation develops, deep gingival pockets are formed, and complete destruction of the tissues supporting the teeth and loss of the teeth may occur.

Denture Frameworks in the Mandible

Denture frameworks in the mandible are shaped like sublingual bars. The alternatives would be full plates covering the lingual area of the alveolar ridge and raised along the teeth in the form of a collar.

Lingual plates should be rejected as unsuitable (Fig 4-18). Even though these structures achieve an excellent splinting effect and can thereby stabilize the residual teeth, these benefits are outweighed by drawbacks in terms of periodontal hygiene. If a denture flange extends as far as the tooth, it results in dynamic, mechanical irritation of the marginal periodontium; at the same time, this gingival area becomes encapsulated, preventing the necessary self-cleaning. The consequences are chronic inflammation and the formation of deep gingival pockets, which can lead to complete destruction of the periodontium and loss of the tooth. A lingual bar is easy to extend, although admittedly its extension very soon becomes a necessity.

A sublingual bar for mandibular dentures has a rounded, drop-shaped profile; the tip of the drop is fitted to the incline of the alveolar ridge and points upward. It must be placed clear of the periodontium and tongue and should be worked so it is stable and torsion-resistant but also delicate enough to ensure that it is pleasant to wear. It can be carved out of prefabricated wax profile wires that are 4-mm high and 2.5-mm thick. In contrast to the framework parts that lie against the mucosa, a sublingual bar must be polished (ie, smooth) in the area facing the mucosa.

Owing to the periodontal clearance and clearance of the tongue, a sublingual bar is placed as deeply as possible; the marginal-periodontal safety distance is 4 to 6 mm (Fig 4-19). In the anterior region, the bar must lie a horizontal distance of 0.2 mm from the alveolar ridge and therefore must not touch the mucosa (Fig 4-20). If the posterior alveolar ridge area is inclined in the lingual direction or the inclination of the posterior teeth is very pronounced, the horizontal distance may be increased to as much as 1 mm. If free-end saddles sink under masticatory loading, the sublingual bar is pressed forward onto the alveolar ridge. Therefore, freedom of movement becomes necessary so that the vertical alveolar ridge surface is not loaded and the bar does not become embedded.

The mobile floor of the mouth must not be displaced. The average depth of the floor of the mouth is approximately 3 mm at the incisors, though it may be less at the attachment of the lingual frenum and about 6 mm at the premolars. The bar must pass around the lingual frenum so that movement of the frenum and the tongue is not impeded. This makes it difficult to place the bar clear of the periodontium in this area.

If the lingual frenum attaches too high or the floor of the mouth lies too high, so that the sublingual bar does not maintain the minimum distance from the marginal periodontium, a reasonable distance might be achieved by changing the position of the bar, that is, horizontal displacement under the tongue (Fig 4-21). A supracoronal transverse connector may also be placed that runs along the dental crowns of the groups of residual teeth, or the framework could be placed as a vestibular connector in the oral vestibule.

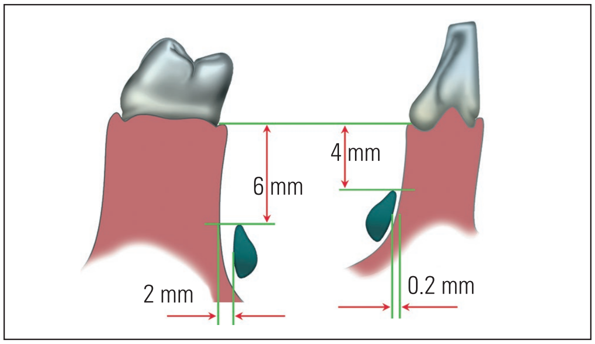


Fig 4-19 In the mandible, a sublingual bar should run approximately 0.2 mm from the alveolar ridge. This distance may be increased to around 2 mm in the posterior region if the bar cannot be taken out because of the inclination of the alveolar ridges and teeth. The vertical safety distance from the marginal periodontium is 4 mm in the anterior region and 6 mm in the posterior region.

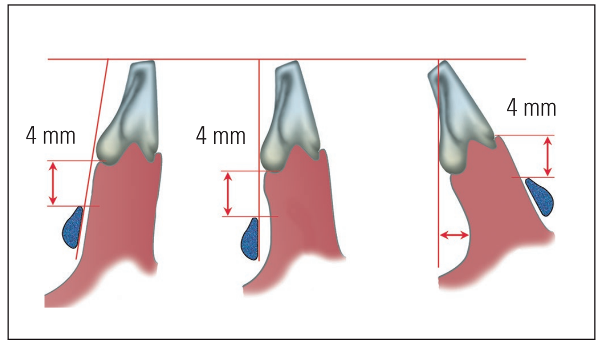


Fig 4-20 The sublingual bar is drop shaped. The minimum distance from the alveolar ridge is 0.2 mm. If the alveolar ridge is upright, the bar can be taken out without being obstructed. If the alveolar ridge is inclined lingually, the horizontal distance is increased; the bar can be shifted to the vestibular aspect if the inclination of the alveolar ridge is extreme.

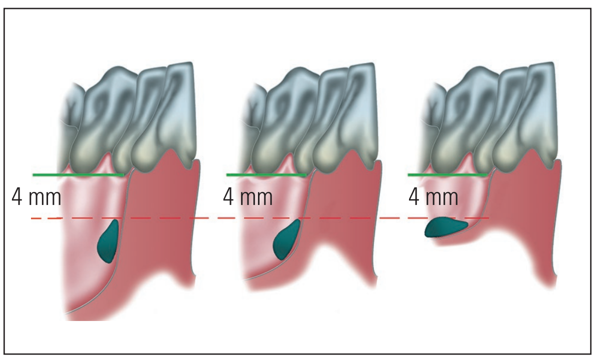


Fig 4-21 To achieve an adequate safety distance from the marginal periodontium, the bar can be placed horizontally under the tongue if the floor of the mouth is too high.

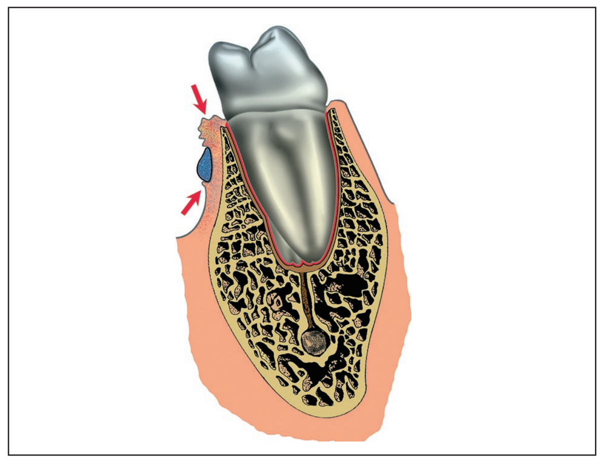


Fig 4-22 If the safety distance from the periodontium is not observed, self-cleaning is prevented and deposits will form. If a sublingual bar becomes embedded, the mucosa will be squeezed, swell up, and become inflamed.

The minor connectors to the anchoring and supporting elements also have to be constructed so that a minimum distance of approximately 4 mm from the periodontium is achieved in order to allow for self-cleaning (Fig 4-22). If minor connectors from the denture framework to clasp structures are prepared, problems of periodontal hygiene may arise.

With these structures, it is important to ensure that the horizontal distance is not less than 5 mm from the saddle and that the difference between two connector parts is the same amount. A structure in which continuous splinting is combined with a bar connector—always in the approximal areas—should be rejected if this means the bar would still run at a distance of 2 mm from the marginal periodontium. This structure is only exceeded by a lingual plate in its deleterious effect.

Denture Frameworks in the Maxilla

Denture frameworks in the maxilla need to be shaped to ensure clearance from the periodontium, tongue, and palate as well as stability and torsion resistance (Fig 4-23); they have to be delicate to make them pleasant to wear.

A full plate, as prepared for acrylic resin dentures, can be used for complete dentures. For a partial prosthesis, a full plate is only necessary in a reduced form if one or two residual teeth are still present. In this case, the extensive mucosal support is intended to absorb the masticatory forces; for this purpose, supporting elements in the form of resilient anchors are usually prepared. Starting from a full plate covering the whole palate, three types of framework can be derived:

- Anterior palatal strap
- Posterior palatal strap
- Skeleton plate

An anterior palatal strap is also known as a *horseshoe connector* or a *sectioned plate*. The framework is modeled out of 0.5- to 0.8-mm-thick grained wax, and the curved posterior edge of the strap can retain a prepared reinforcement approximately 0.2 mm deep; the width is between 15 and 20 mm, depending on the size of the teeth being replaced and the thickness of the strap. The torsion resistance of an anterior palatal strap is adequate at these dimensions.

A horseshoe design is indicated if both anterior and posterior teeth have to be replaced. When only the posterior teeth are missing, a horseshoe connector may be necessary if the palate in the posterior area has an excessively pronounced palatine suture or a sturdy palatine torus. A horseshoe connector can be prepared for an arch with missing posterior teeth in such a way that extensions can be made later if anterior teeth become inadequate.

The pressure and fricative field of the palate is covered by an anterior palatal strap (Fig 4-24). This impedes the function of the tongue in terms of speaking as well as turning and insalivating food. The wearing properties are therefore unfavorable.

A posterior palatal strap, which may also be called a *transverse strap* or *transpalatal bar*, lies in the posterior area of the palate approximately 3 mm in front of the palatal vibrating line. The thickness of a posterior palatal strap depends on the length and path of the strap. If a pointed, high palate has to be restored, the transverse connector must be thicker and fashioned over a broad area. For a flat, narrow palate, the transverse connector can be relatively thin. The width ranges between 12 and 18 mm; it is modeled out of 0.5- to 0.8-mm-thick grained wax and reinforced in the middle with a 0.8-mm-thick inlaid strip like the ridge of a roof; as a result, this palatal strap is sufficiently torsion resistant and does not become embedded.

A posterior palatal strap is indicated if posterior edentulous spaces have to be treated; to restore a posterior edentulous gap and a free-end gap, the palatal strap must be wider and thicker so that masticatory forces can be transmitted to the mucosal support.

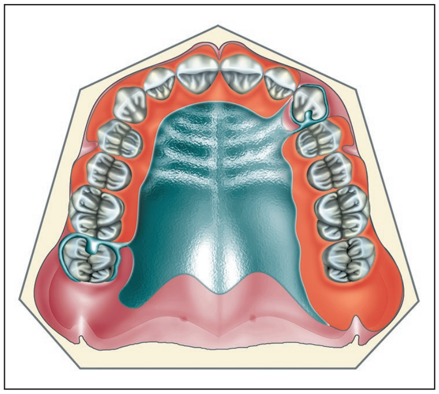
The tongue is left clear because the whole pressure and fricative field is uncovered (Fig 4-25); thus, the posterior palatal strap has the best wearing properties. However, this type of framework is not suitable for extensions in the anterior region.

A skeleton plate (ring-shaped connector) comprises two slender palatal straps in the posterior and anterior area of the palate (Fig 4-26). The thin bars must have a certain minimum width (5 to 10 mm) and minimum thickness (profile strip in the middle that is 1 to 3 mm). This kind of denture framework has the best torsion resistance.

A skeleton plate is indicated for alternating edentulous gaps when a periodontally supported interdental insertion prosthesis needs to be fabricated. No forces can be transferred to the mucosal support with skeletal frameworks. Therefore, they are only suitable for cantilever fixed partial prostheses if the posterior palatal band is widened, and in that case, this type of framework can be used universally.

In terms of framework dimensions, a framework can be kept smaller the more extensive the periodontal support of the denture. In other words: The fewer residual teeth that are available as abutments, the larger the area the denture base (the framework) has to cover. A skeleton plate covers little of the natural palatal surface, tongue function is only slightly restricted, and wearing properties are very favorable.

Fig 4-23 There are three basic requirements when shaping the framework parts for model cast dentures: stability, periodontal clearance, and tongue clearance. In the maxilla, adequately stable framework parts can be reduced from a full plate to create three different forms: anterior palatal strap, reduced anteriorly; posterior palatal strap, reduced posteriorly; and skeleton plate, reduced from the middle.



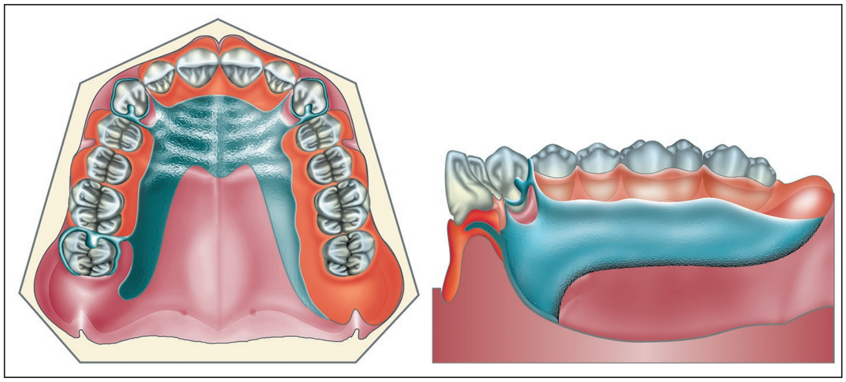


Fig 4-24 An anterior palatal strap (or horseshoe connector) lies in the anterior part of the palate and covers the pressure and fricative field. Interdental and free-end saddles can be connected with a horseshoe connector.

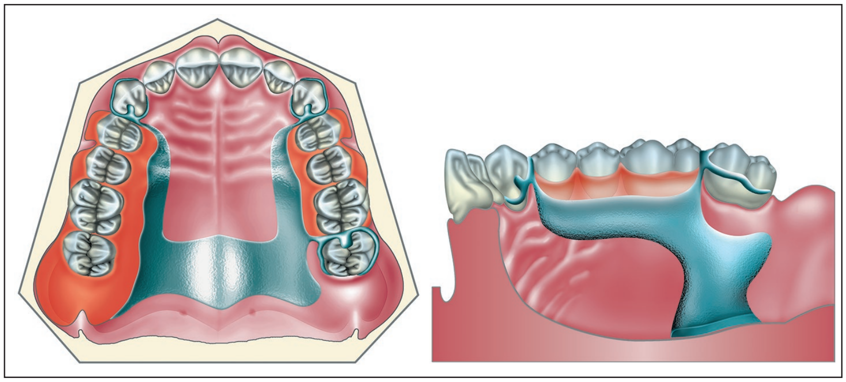


Fig 4-25 A posterior palatal strap connects two denture saddles in the halves of the dental arch in the posterior part of the palate and leaves the pressure and fricative field clear.

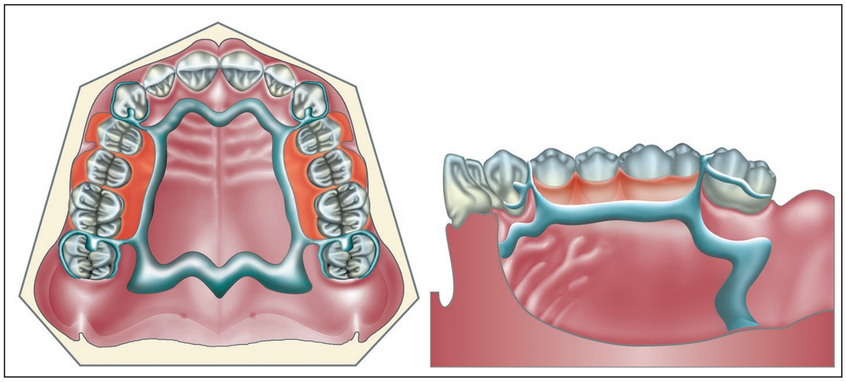


Fig 4-26 A skeleton plate made of slender, profiled palatal straps leaves wide areas of the palate uncovered. The delicately sectioned plate is only used for interdental saddles.

Anchoring and Supporting Elements

Removable partial dentures belong to the group of fully removable tooth replacements and are therefore anchored to the residual dentition with detachable connectors. The anchoring elements also provide support on the residual dentition, forming integrated anchoring and supporting elements that are described as a unit.

Mechanical fittings are used as anchoring and supporting elements. There are two types based on their functional principle: *(1)* resilient (or elastic) and *(2)* telescopic designs, which can be fashioned by hand or industrially (prefabricated components).

Resilient structural elements anchor by means of spring forces and are used in the following types of designs (Fig 4-27):

- Hand-fabricated
- Bent-wire clasp
- Cast onlay clasp
- Industrially fabricated
- Resilient circumferential anchor (eg, Rothermann attachment)
- Stud anchor with spring sleeve
- Stud anchor with spring head
- Resilient bars (eg, Dolder bar)

The functional value of resilient anchoring elements is defined by their splinting effect; resilient components offer semirigid connections that produce statically indeterminate systems depending on design.

The principle of a spring fit is demonstrated by an elastic ring that is open on one side and corresponds to the basic structure of a double-arm clasp. Such a ring widens with the pitch of the cone when it is pushed over a conical shaft. The restoring force of the widened ring resists being pushed onto the cone. The ring springs back into its original shape when, for example, a matching groove is set into the cone or when the clasp is pushed over the widest circumference of the tooth into the undercut area.

The retentive or extraction force of a resilient structural component arises when the spring element is bent apart on an inclined plane; the spring force does not act in parallel to the direction in which the spring element is withdrawn but occurs as slope force and frictional force on the inclined plane.

Telescopic anchors are precision structural components in the form of parallel or conical fittings that gain their joining and separating forces or retentive and extraction forces from static and dynamic friction resistance. The following types are common:

- Hand-fabricated
- Telescopic crowns
- Channel-shoulder(-pin) attachments
- Circular notch with shear distribution arm
- Milled parallel bars
- Bolts
- Industrially fabricated
- Precision attachments
- Bar attachments
- Bolt attachments

These structural elements have two components: the primary part and the secondary part. The primary part is fixed to the residual dentition as a subcrown (in the case of telescopic and tapered crowns) or as the primary matched part of an attachment soldered or cast onto an abutment crown. The secondary part, either the telescopic or tapered crown or the secondary attachment component, is located on the removable restoration.

Prefabricated matched components, produced by computerized manufacturing methods with specialized tools from high-quality materials with high precision and within defined tolerances, fulfill the different functional requirements within technically defined tolerances, depending on the design. Prefabricated components are engaged in normal-size anatomically shaped crowns or fitted interproximally. Extracoronal components are questionable in terms of periodontal hygiene; they can cause mucosal irritation due to plaque, suction, and the compressive effects of the floating denture parts.

In the case of manually fabricated components, the primary part is produced by the milling process and the secondary part is waxed up and cast with fitting tolerances that cannot be calculated. Fabrication of the secondary part by the galvanoplastic technique yields higher accuracy of fit. To ensure the defined retention, interlocking com-

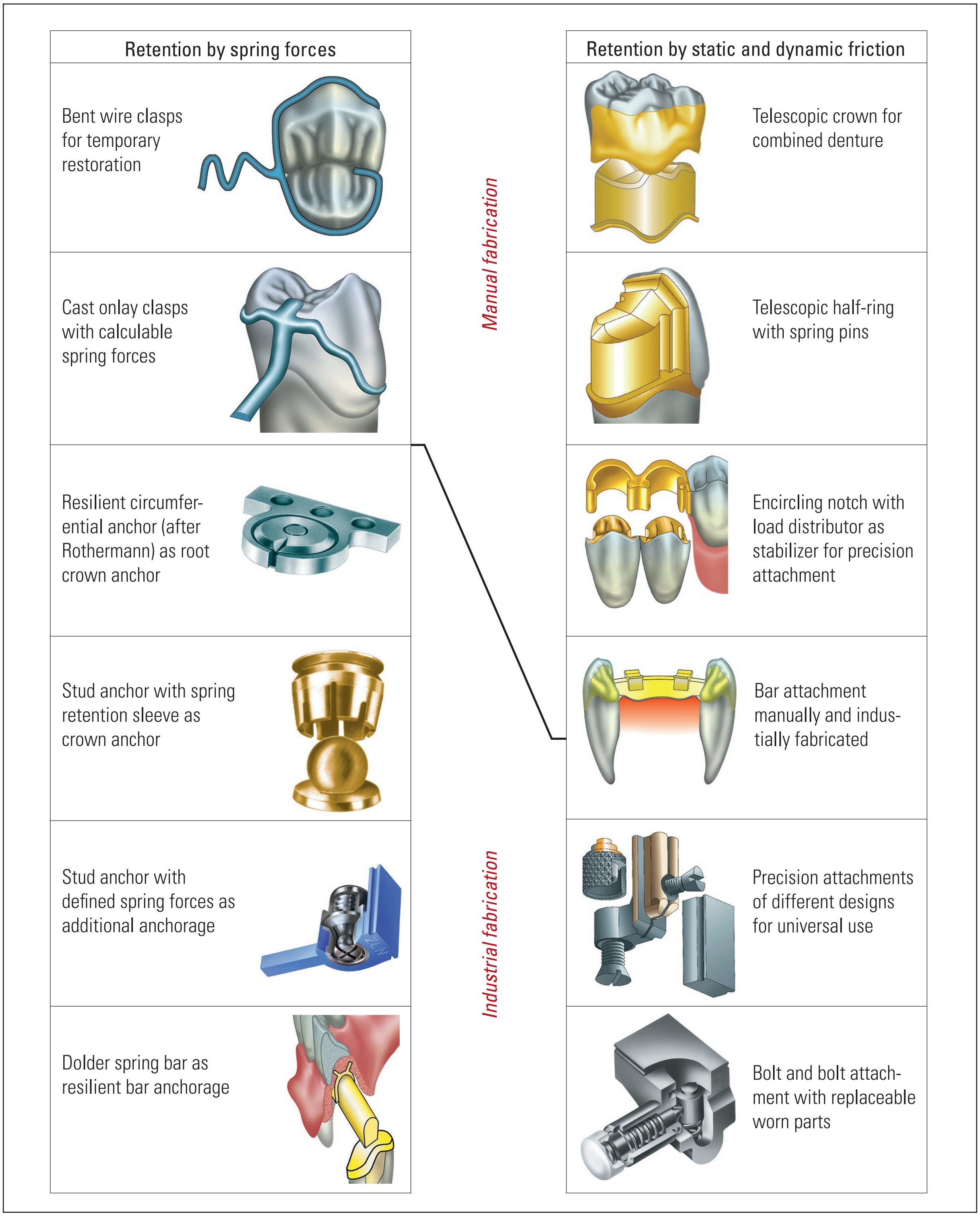


Fig 4-27 Types of anchoring and supporting elements.

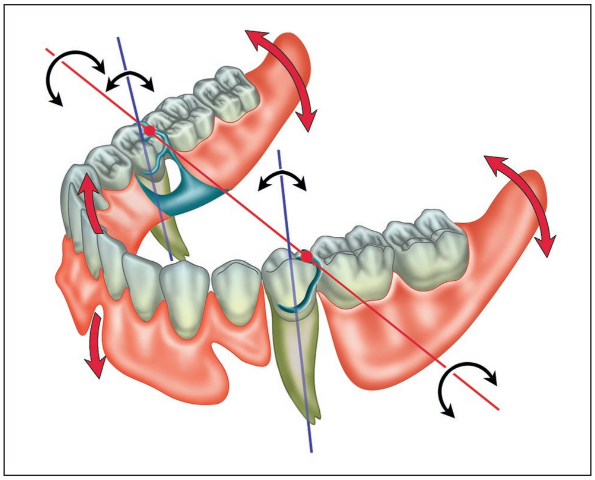


Fig 4-28 A support line that intersects the denture body becomes the axis of rotation of the denture; the denture will always rock. In the process, the remaining teeth are moved to and fro so that they are soon lost.

ponents can be inserted that lock the telescopic components in the resting position.

Function of Anchoring and Supporting Elements

Anchoring and supporting elements must anchor the denture securely during speaking and chewing and must transfer the functional forces, in a largely tissue-protective way, to the denture rest area comprising the periodontium and mucosal support. Anchoring and supporting elements need to meet the following requirements:

- Fulfill a retentive function
- Secure the vertical position
- Secure the horizontal position
- Brace the residual dentition
- Ensure periodontal hygiene

Retentive function means securing the denture against extraction forces during functioning, which can occur due to sticky foods, the denture's own weight, and tongue and cheek movements when speaking. The extraction forces must be periodontally tolerable and must not exceed a maximum of 10 N.

Securing the vertical position concerns the periodontal support, whereby functional forces acting on the denture are distributed centrically to the periodontal tissues. Eccentric loading of abutment teeth must be avoided because this can cause faulty loading of the abutment periodontium and give rise to uncontrolled detachment of the denture from the residual denture, which nonphysiologically loads the mucosa.

The occlusal rests secure the vertical position when cast claps are used. In the case of milled components, occlusal or cervical shoulder milling fulfills this function. Prefabricated components have depth stops to limit vertical movement.

Securing the horizontal position involves absorbing sagittal and transverse thrusts. The denture can be shifted, twisted, or tilted by functional forces on the mucosal support (Fig 4-28). These denture movements are supposed to be absorbed by anchoring and supporting elements and transferred to the abutment teeth. Securing the position against horizontal thrusts produces eccentric loading on the abutment teeth.

There is an interaction between mandibular movement under tooth contact and the thrust moments on the denture. When the mandible moves forward, a maxillary prosthesis is pulled in the same direction, and a mandibular denture is pushed distally.

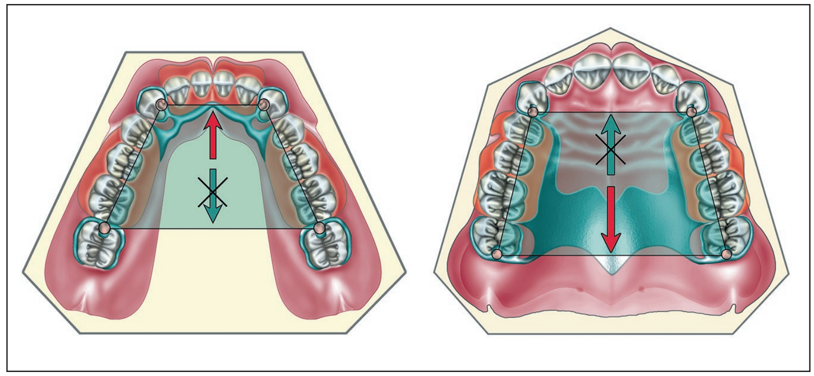


Fig 4-29 The enclosure provided by clasps is effective at bracing the denture against horizontal forces; the lower arms of the clasp are inadequate for counteracting these forces. If all the clasps in the maxilla are opened mesially, the denture is not secured against distally directed thrusts. This applies to a mandibular denture in which all the clasps are opened distally, which means mesially directed thrusts cannot be absorbed.

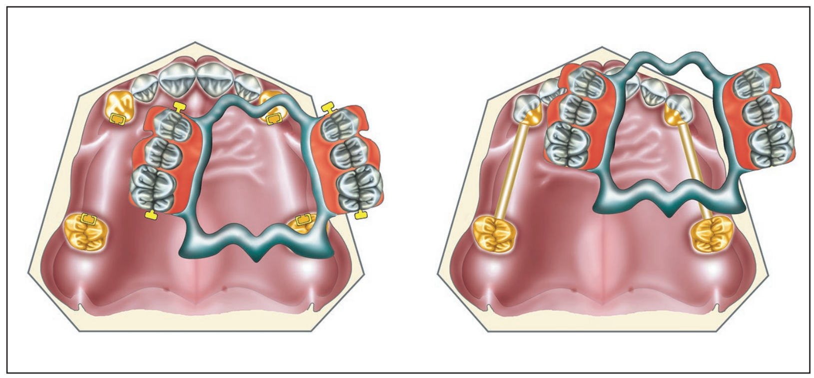


Fig 4-30 When splinted (interlocked), all of the involved teeth are combined by the denture structure to form a resistance block. In this rigid connection, all of the teeth absorb the masticatory pressure applied. Periodontally damaged dental arches can be therapeutically treated by splinting structures. A distinction is made between primary splinting, in which the interlocking effect is achieved by a bar construction, and secondary splinting, in which the rigid connection is achieved by a partial denture anchored with telescopic supporting elements.

In the case of clasp anchors, the horizontal position is secured by the rigid enclosing parts (clasp body and clasp bracing section). In telescopic designs, the rigid connector braces against horizontal thrust; spring anchors, on the other hand, will secure position inadequately (Fig 4-29).

Bracing the residual dentition concerns the aspect of stabilizing the residual dentition that has been rendered unstable due to reduction, as anchoring and supporting elements distribute the vertical and horizontal loads evenly to the residual dentition and prevent eccentric movements of the abutments. The residual dentition is braced when the remaining teeth are splinted by groups of clasps or by rigid telescopic components. This fulfills the therapeutic function of the restoration.

Splinting by enclosing the teeth in groups of clasps is elastic and still permits abutment tipping. The elastic splinting effects allow approximate tooth movements as they are required in the closed dental arch for forces to be uniformly distributed.

The abutments are interlocked with telescopic components that absorb all stresses as a closed unit. Rigid interlocking moves all the abutments at the same time when loaded; all the abutment periodontal tissues form a resistance block (Fig 4-30).

The prophylactic function of prosthodontics should ensure periodontal hygiene. The anchoring and supporting elements must attach to the abutment teeth without causing mechanical damage or nonphysiologic loading.

Cast clasps lie relatively broadly on the tooth surface and abrade dental tissue during functioning; they form retention sites for plaque and promote caries lesions. With their minor connectors, they cover the gingival margin, possibly irritating it mechanically or leading to encapsulation.

Connecting the Denture to the Residual Dentition

A removable partial denture should allow full chewing function while transmitting the masticatory forces to the residual dentition and bases of the dental arch, yet largely sparing the denture rest area. The resilient edentulous jaw segments are less suitable for absorbing masticatory forces than the remaining teeth because of the periodontal ligament's low tolerance of movement. If, in addition, the mucosa is compressed by intermittent denture movements, the result will be progressive resorptive atrophy of the alveolar bony tissue.

The anchoring and supporting elements must join or couple the denture to the residual dentition on a tissue foundation in such a way that the denture gains adequate positional stability and physiologic transfer of masticatory forces to the periodontium and tegument is ensured. Following are the four states of coupling between the denture and the residual dentition:

- Rigid coupling
- Semirigid coupling
- Articulated coupling
- Decoupling

Rigid coupling with telescopic or locking anchoring and supporting elements completely secures the vertical and horizontal position of the prosthesis (Fig 4-31). Rigid coupling is statically determinate, can transfer all the masticatory forces to the abutment teeth, and will not load the mucosa and the bony foundation. To achieve this, as many abutment teeth as possible must be incorporated into the coupling; the more residual teeth are connected by rigid anchoring—thus, the more extensive the fixed denture support—the better the coupling state.

Rigid coupling cannot be implemented on a clasp prosthesis. Instead, rigid telescopic anchors are needed. These include not only prefabricated attachments but also handmade telescopic or tapered crowns and their modifications; combinations of prefabricated and handmade structural components also provide the intended coupling.

If the residual dentition is insufficient for complete periodontal support, conditionally rigid coupling can be achieved with resilient attachments. These telescopic components have a defined depth stop that allows the denture to lie in the resting position, initially on the mucosa. Not until the resilience of the mucosa is exhausted by exposure to masticatory pressure, and the denture has sunk onto the depth stop, will axially directed forces be absorbed by the periodontium of the abutment tooth.

Semirigid coupling arises with prostheses that are fixed to the residual dentition with cast onlay clasps (Fig 4-32). The horizontal and vertical positions are not fully secured with clasps, and masticatory forces are transferred to the periodontal tissues of the abutment teeth and to the mucosa. Interdental insertion prostheses will secure the position effectively because all the saddles can be periodontally supported and the abutment teeth can be splinted (Fig 4-33). Cantilever fixed partial dentures must be supported on the remaining teeth, but equally on the mucosa.

Mixed seating of cantilever fixed partial dentures is statically indeterminate because the periodontal rest area is rather rigid and the mucosal support is very yielding. True distribution of load between the periodontium and the mucosa cannot be achieved; and in addition to uneven loading of the resilient mucosa, nonphysiologic loading of the periodontium occurs. To reduce the load on the mucosa, groups of clasps are extended onto the residual dentition. If the free-end saddle sinks in response to masticatory loading, the entire clasp unit will counteract this sinking.

Articulated coupling exists in a cantilever fixed partial denture that is supported with proper joints or spring connecting parts (Fig 4-34). Such a system also has the static indeterminacy of a mixed seating, in which the periodontal rest area can be viewed as rigid and the mucosal support as a resilient rest. Furthermore, the mucosal rest area is loaded considerably at its distal end but not at all under the joint, thus lying in the pressure shadow.

Decoupling happens in a denture without anchoring and supporting elements on the residual dentition. This kind of prosthesis rests on the mucosa, which absorbs all the compressive, tensile, shearing, and tipping forces. The denture may

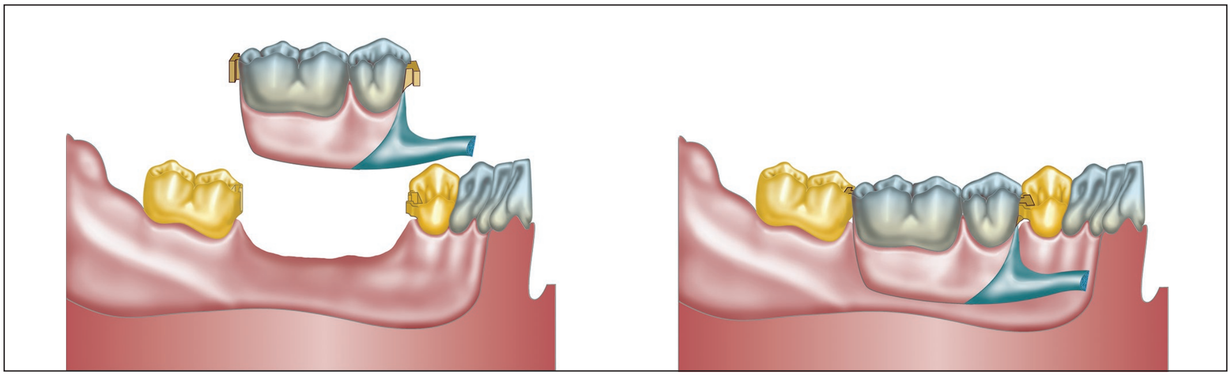


Fig 4-31 Rigid coupling between the denture and the residual dentition can be produced with rigid attachments; secondary splinting of the involved abutment teeth ensues.

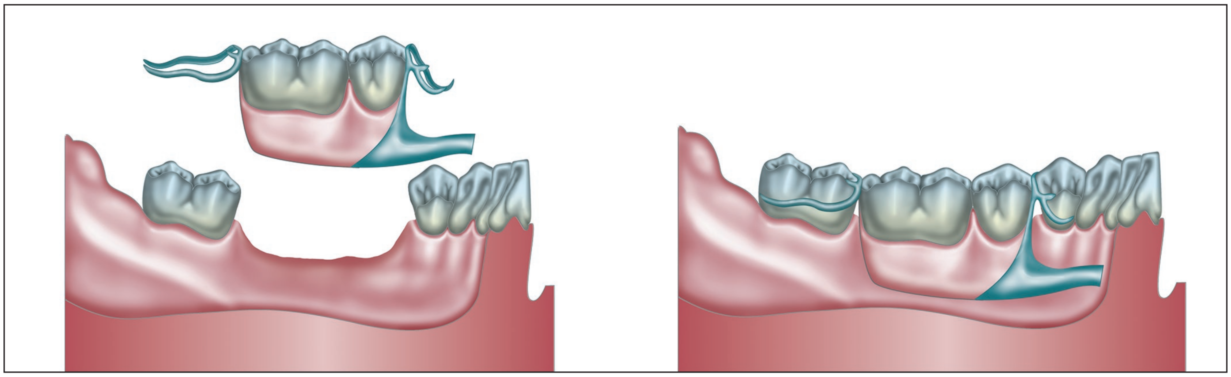


Fig 4-32 Physically encompassing the rigid clasp parts of double-arm clasps with onlays in the case of interdental saddles offers only semirigid coupling; this produces splinting effects for teeth with clasps.

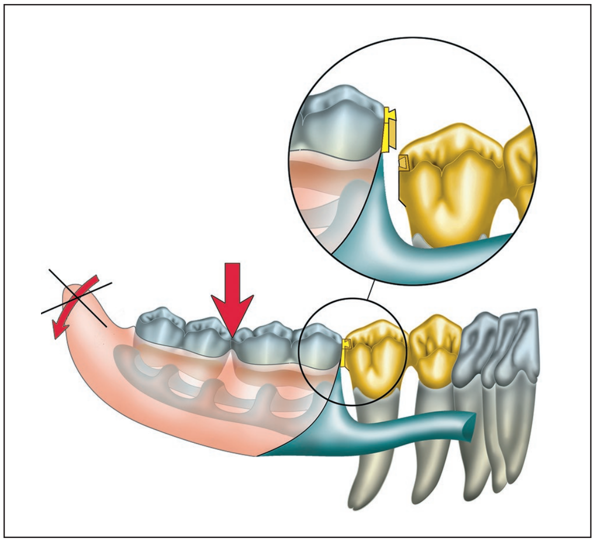


Fig 4-33 If a free-end saddle is joined to the residual dental arch via rigid connectors, rigid coupling occurs, by which the vertical and horizontal positions are fully secured. Joining several teeth to the rigid connecting element via splinting can fully compensate for masticatory forces. The abutment teeth are axially loaded and slightly tipped.

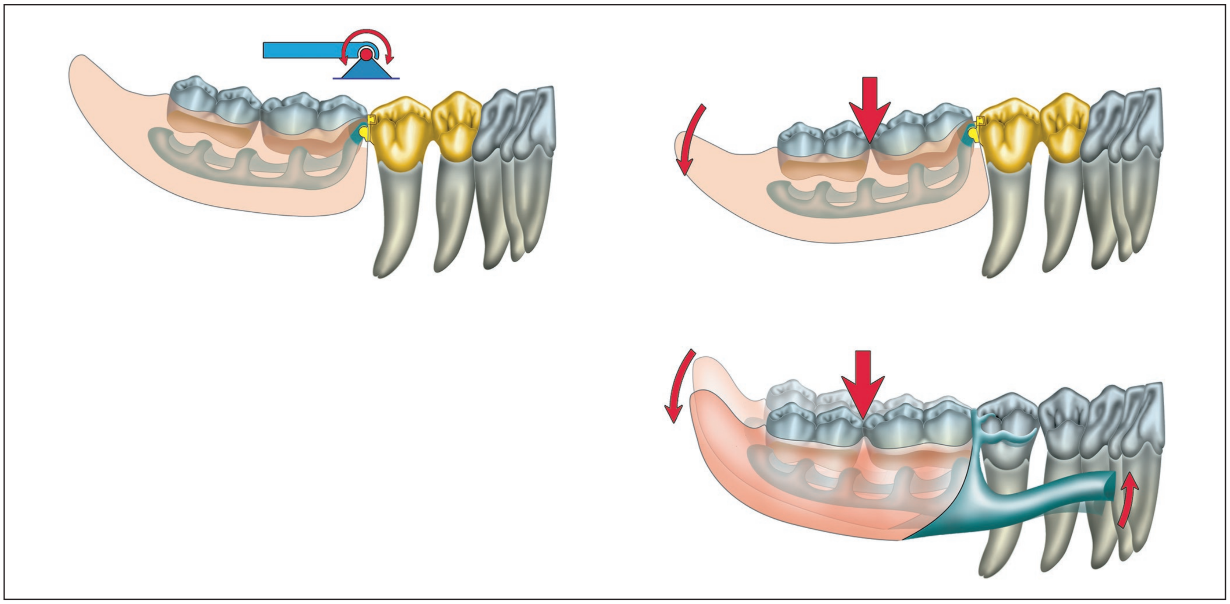


Fig 4-34 Articulated coupling between a free-end saddle and the residual dentition can be achieved by proper hinge joints, which results in extremely uneven loading of the mucosa. Similar conditions prevail with elastic coupling achieved with a double-arm clasp with onlay. Once again the mucosa is loaded extremely unevenly.

tilt, twist, shift, or tip because no bracing of the horizontal and vertical position is provided. Positional stability has to be achieved by tooth position and extension of the base, as in complete dentures, and bar connectors cover the marginal periodontium and broad mucosal areas and lead to tissue irritation due to encapsulation, plaque, suction, and compressive effects. Certain technical instructions for anchoring and supporting elements and criteria for assessing their quality can be deduced systematically from the general requirements.

5

Telescopic Anchoring and Supporting Elements

Precision Fittings

The detachable anchoring and supporting elements for partial dentures are invariably precision fittings, such as spring ring, parallel, conical, and thread fits (Fig 5-1). Artificial crowns are constructed to carry these fittings. In principle, every replacement crown is suitable as an anchoring element for extensive partial restorations—as a partial denture abutment, as a double crown for removable partial dentures and dentures, as a carrier for attachment parts, or as a crowned clasp tooth. When used in such forms, the restored tooth is loaded more than a single crown within a closed dental arch. The physiologic conditions remain intact, but stresses arise that can tip or twist the tooth in the socket or pull it out of the socket.

A *fitting* refers to two structural components that can be fitted into one another and that have fitting surfaces with specific differences in dimensions; in other words, matched parts have the same nominal dimension with fixed tolerances. The first matched part, known as the *primary part* (inner matched part), can have a positive or a negative geometric shape. The second matched part, or *secondary part* (outer matched part), has a negative or positive geometric shape that matches the primary part (Fig 5-2). (Use of the term "female part," referring to a negative recessed fit into which the positive raised "male part" is inserted, is unclear in dental technology and leads to confusion.) In den-

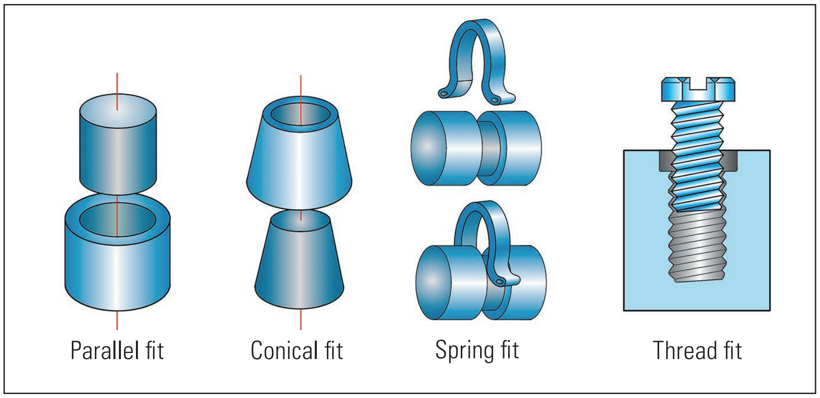


Fig 5-1 The usual precision fittings for dental anchoring components are fabricated by hand but are also available as prefabricated auxiliary parts.

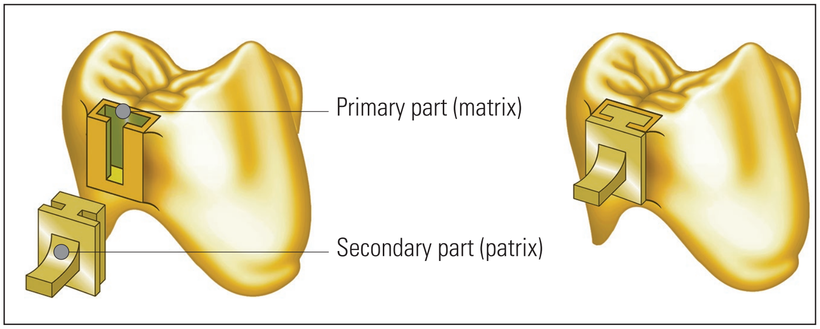


Fig 5-2 A parallel fitting that connects the residual dentition to a removable restoration has two structural parts that can be inserted into each other where the matching parts have the same nominal dimensions. The positive geometric structural parts are called *patrices*, and the negative matched parts are known as *matrices*. In dental technology, the primary matched part is located on the fixed tooth replacement (eg, a crown), and the secondary structural part is located on the removable prosthetic replacement.

tal technology, a fitting comprises a primary part fixed to the residual dentition and a secondary part located on the denture.

The denture is exposed to forces from all directions, which act on the abutment teeth via the anchoring components. An elastic anchoring element transfers forces to the periodontium of the abutment tooth in such a way that, in addition to the normal axial forces, tipping, twisting, and pulling forces act on the tooth and load it nonphysiologically. In periodontally borne and mucosa-borne dentures, elastic anchoring components produce statically indeterminate systems that cannot be calculated and are therefore always flawed.

By means of mobile anchoring elements, mainly uncontrolled dynamic stresses are transferred to the abutment tooth, which does not occur with a rigid connector; rocking movements on a yielding mucosal support can drag the abutment tooth to and fro in its socket until it loosens and is lost. The mucosal support will not withstand such dynamic stresses caused by a denture base.

The natural teeth are also exposed to forces from all directions; they compensate for these forces in a closed dental arch and convert them into physiologic stresses. Elastic anchoring elements with one or more movement possibilities load the abutment tooth and the edentulous parts of the dental arch in an uncontrolled way to the detriment of that tissue.

It is assumed that elastic or mobile connections between the residual dentition and the prosthesis reduce the loading for the abutment tooth. An elastic connection, however, only alters the loading direction. When a cantilever fixed partial denture is loaded perpendicular to the support by masticatory pressure and sinks into the mucosal support, a hinge or another elastic connection will convert the intrinsically axial load for the abutment tooth into additional tensile stress in the distal direction, thereby tipping the tooth. In addition, extremely uneven loading of the mucosal support occurs, which is very pronounced distally and only minimal mesially, in the pressure

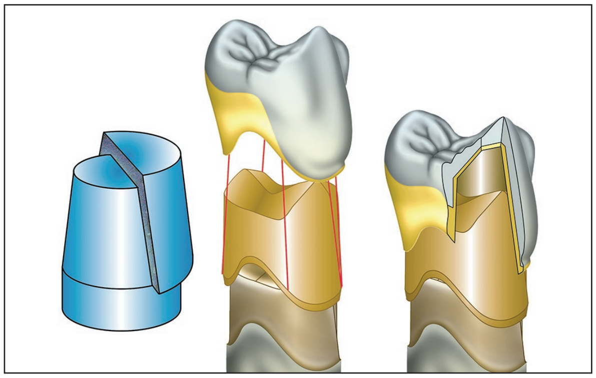


Fig 5-3 Another precision fitting in telescopic components is a conical fit, which can be used as a rigid anchoring element. Conical fittings are produced by hand as conical (tapered) crowns and industrially as conical attachments.

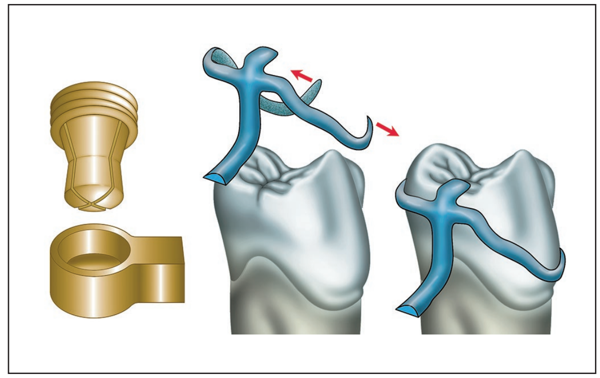


Fig 5-4 A resilient circumferential fitting is mainly used as a handmade cast clasp or as a prefabricated stud fitting. The elastic clasp arms are pushed over the widest circumference of the tooth, engage in the undercuts, and perform a retentive function.

shadow under the joint. In the process, the marginal periodontium of the abutment tooth close to the saddle can be crushed horizontally.

In a rigid connection (coupling), the vertical masticatory pressure can also lead to tipping of the abutment tooth, but most of the force is transferred axially. This protects the mucosal support in particular. If the abutment tooth is joined to several remaining teeth by splinting, the tipping is balanced by a rigid connection to the denture; conversely, if the connection is elastic, all the splinted teeth are pulled in a distal direction, not least to the detriment of the loaded mucosa.

A rigid coupling between denture and residual dentition can be achieved with telescopic components in the form of parallel and conical fittings (Fig 5-3). They should be preferred to elastic connections (Fig 5-4).

Parallel Fitting

Parallel fitting refers to two telescopic structural components in which the fitting surfaces run parallel throughout the entire insertion length—for example, a cylindric drill hole with a fixed diameter and specific depth into which a shaft of the same diameter is pushed. The shaft can easily be pushed in if the drill hole is slightly bigger, but it cannot be inserted, or can only be inserted with great force, if the shaft is bigger by a similar amount. The accuracy of a parallel fit can be ascertained directly from the difference between the diameter of the shaft and that of the drill hole (Figs 5-5 to 5-7).

The quality of a technical fit is measured by the difference between the internal diameter of the outer matched part and the external diameter of the inner matched part. Depending on the difference in diameters, the following parallel fits can be identified:

- *Press fit* exists if the shaft diameter (D_S) is greater than the drill-hole diameter (D_{DH}): $D_{DH} < D_S$
- *Transition fit* exists if the drill-hole diameter and shaft diameter are the same: $D_{DH} = D_S$
- *Clearance fit* exists if the drill-hole diameter is greater than the shaft diameter: $D_{DH} > D_S$

Clearance (or *play*) denotes a positive difference in size; that is, the drill hole is larger than the shaft. *Oversize* denotes a negative difference in size when the shaft is larger than the drill hole.

In mechanical engineering, parallel fittings are produced by a costly process with computer-controlled machine tools in which the dimensions are set and controlled via photoelectric measuring devices. The accuracy of these fits is in the region of ten-thousandths of millimeters. With dental technology techniques, surfaces polished to a

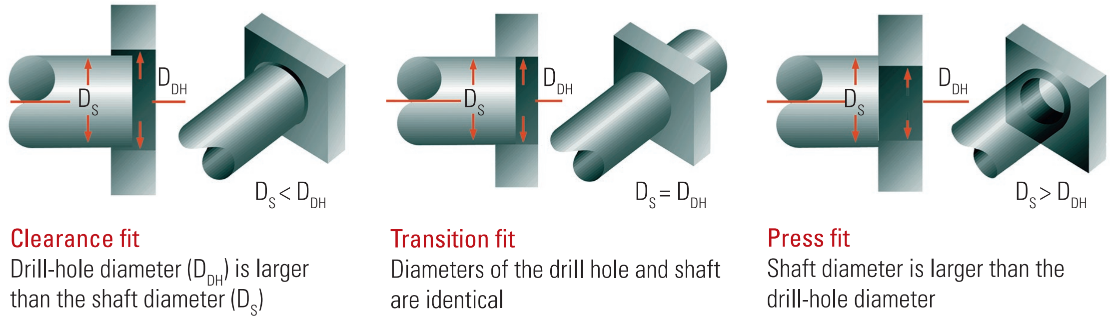


Fig 5-5 The accuracy of a parallel fitting is indicated by the match between the dimensions of the shaft and the drill hole; based on the dimensional conformance or difference between the diameters of the two matched parts, three types of fit are described.

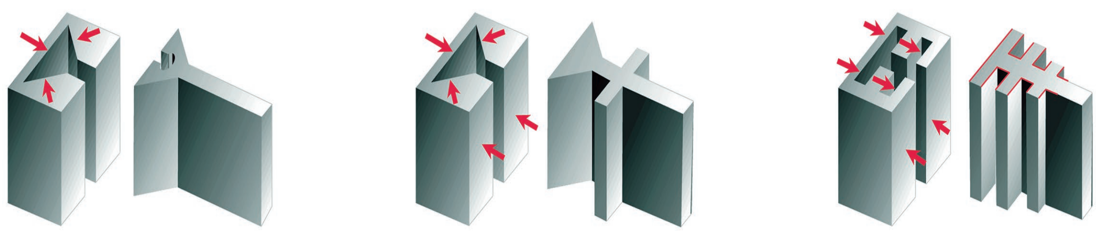


Fig 5-6 One measure of the quality of a parallel fit is the size of the fitting surfaces that touch each other in a specific design. In fittings for dental technology purposes, this absolute contact area can differ considerably in attachments of the same structural height and width. Furthermore, if the fitting surface is interrupted by additional activatable components, the absolute contact area will be further reduced, as shown here in a dovetail fitting.

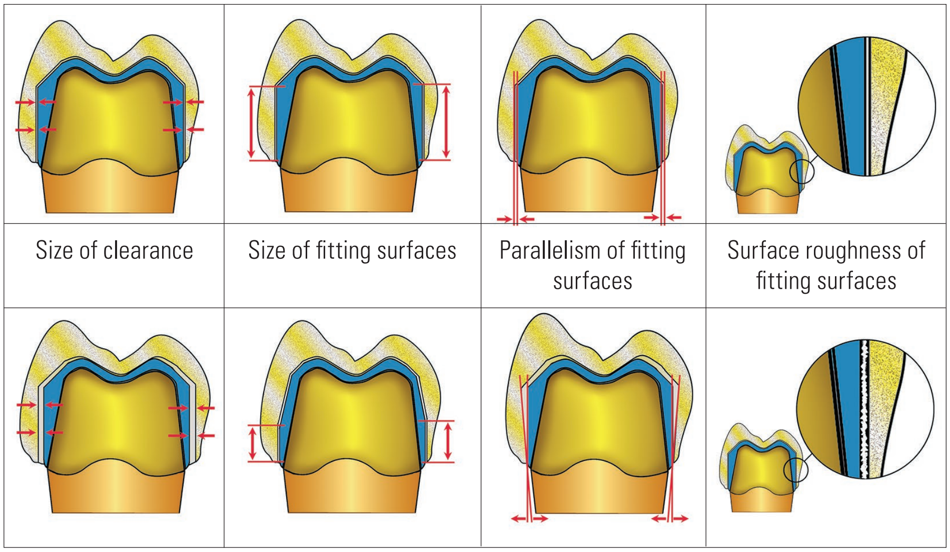
high glaze, for instance, have a surface roughness in the order of several thousandths of millimeters.

In mechanical engineering, parallel fittings are generally applied to inseparable connections. In dental technology, however, this fit is produced for separable connections with dimensional inaccuracies within the range of a tenth of a millimeter. The practicability of the different fit qualities in dental technology will be analyzed individually: Press fit is not used in dental technology because the matched parts can only be pushed on with considerable force. Once the matched parts are brought together, however, elastic deformation (the outer part is widened, the inner part compressed) will press the fitting surfaces so firmly against each other that they can only be disengaged with great difficulty. Even greater force is needed to separate the parts than to join them together. The matched parts are wedged together, the fitting surfaces can fuse together, and an inseparable connection can arise.

Transition fit (or snug fit) can only be used in certain cases. Joining and separating the matched parts is associated with considerable friction effects, depending on surface roughness. The parts fit together snugly as a good but incalculable adhesive effect occurs throughout the fitting surface. With moderate resistance to static and dynamic friction, a transition fit would be highly suitable for anchors in dental technology. However, the friction effects when joining and separating the parts quickly lead to wear of the fitting surfaces so that a clearance fit without appreciable adhesion results after prolonged use.

Clearance fit (or loose fit) is the preferred type of fit. Matched parts can easily be joined and separated with slight resistance to static and dynamic friction and without any signs of wear, even dur-

Fig 5-7 Quality of fit.



ing frequent use. Only slight, but calculable, adhesive effects occur, which are supported by additional anchors. The undeniable advantage lies in the fact that the matched parts have a defined path of insertion and end position. Except from the path of insertion, forces cannot lift off the restoration because a clearance fit also provides a rigid connection between the residual dentition and the denture.

The quality of fit can be determined from the size of the joining and separating forces, which in turn depend on the following:

- The size of the clearance
- The absolute size of the contact surfaces
- The absolute parallelism of the fitting surfaces
- The contact pressure of the fitting surfaces
- The surface roughness of the fitting surfaces (contact pressure and fitting surface roughness must be low to prevent abrasion)

Error Analysis of Parallel Fittings

The practical value of parallel fittings is measured by the extent to which they fulfill the defined functions of anchoring and supporting elements. While securing the horizontal and vertical position, defined adhesion and bracing of the residual dentition are ensured by fits that have little clearance (play) and absolute parallelism, that do not have any abrasion, and whose matched parts are not displaced. Clearance, parallelism, abrasion, and displacement of the matched parts depend on the technical process.

Size of clearance

In dental technology fabrication processes, the size of clearance depends on several factors. The primary part of the fitting is milled; the secondary part is carved out of wax over the primary part, cast, and finished, during which the following procedural and system errors can occur:

- Stresses during wax preparation
- Expansion inaccuracies of the investment material
- Granulation of the investment material for surface roughness
- Casting errors, such as blowholes, inclusions, and casting beads
- Casting temperature that is too high or too low
- Surface treatment errors, such as airborne-particle abrasion, glazing, corrective reduction, and polishing

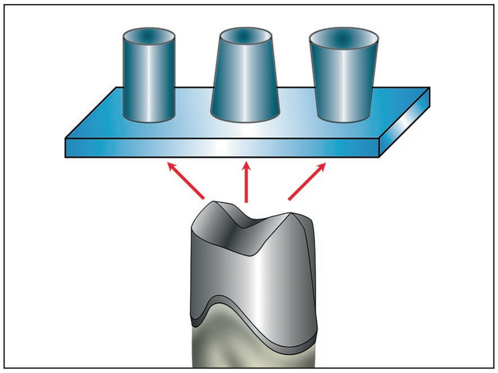


Fig 5-8 As a result of dental technology processing methods, all three types of fit—cylindric fit, conical fit, and inverted cone—can arise by chance when the aim is to produce a parallel fit.

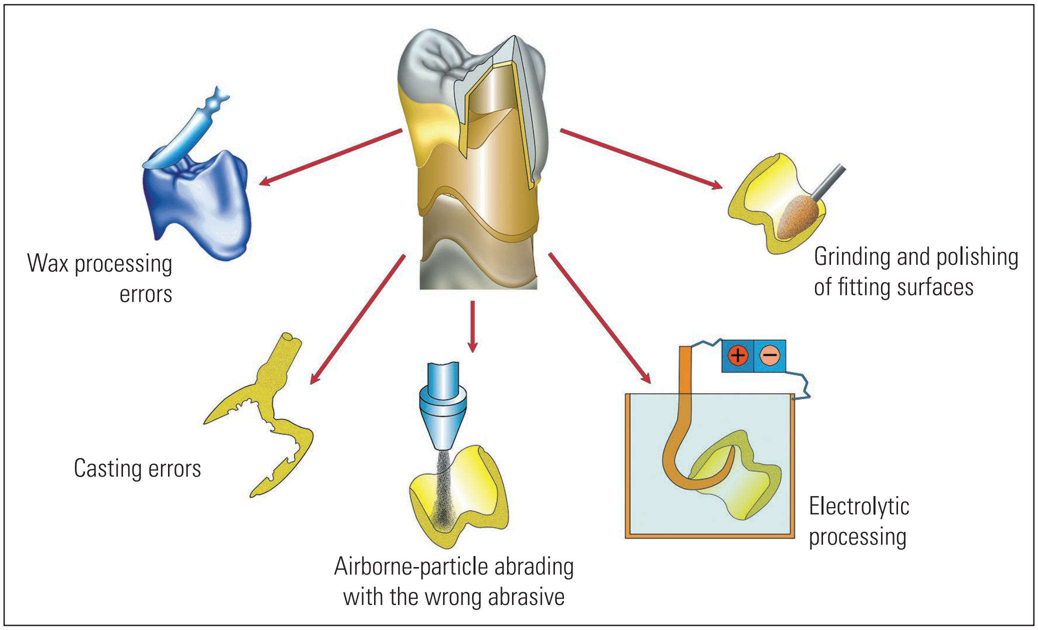


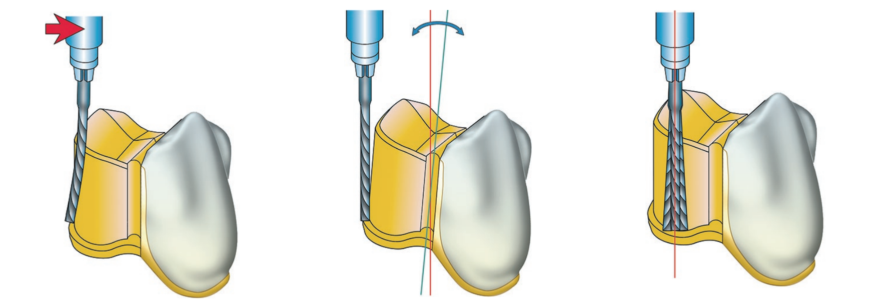
Fig 5-9 Error-free fabrication of the secondary part is not possible with dental technology processing methods. Quality of fit is influenced by procedural and system errors, which can add up to an unacceptable total error.

Typical procedural and system errors have such an effect during the fabrication of parallel fittings that all types of fit, such as clearance, transition, and press fit, occur by chance (Figs 5-8 and 5-9). This is mainly attributable not to the dental technician's shortcomings but to the special fabrication methods involved in dental technology, which are inadequate for such levels of accuracy.

Parallelism

A precise cylindric fit is difficult to achieve by dental technology fabrication methods because procedural and system errors occur, giving rise to different forms of fit by chance. A true cylindric fit is an inverted cone that is opposite to the direction of withdrawal or a true cone.

Fig 5-10 Precise parallelism can be reliably achieved with primary parts using dental technology processing methods. Procedural errors can occur, however, because the cutter is guided by hand.



When the parallel surface is being milled, the cutter is guided by hand. As a result, small differences in working pressure can cause a change in the milled surface, and grooves or chatter marks arise (Fig 5-10). If the part being worked is slightly raised or tilted from the base, partially undercut areas will be formed. If the bearings of the milling machine are worn out or if it is not possible to achieve accurate parallel guidance of the milling cutter, no parallel milled surface can be produced. This kind of system error due to the tool and milling machine can easily be overlooked.

Abrasion of parallel fittings

When the matched parts are joined and separated, dynamic friction takes place throughout the fitting surface from the moment the first movement starts until the end position is reached. This friction gives rise to abrasion, which is increased by the following:

- The surfaces fitting together more tightly; if there is very little clearance, the surfaces slide against each other under greater contact pressure
- The increased surface roughness of the fitting surfaces

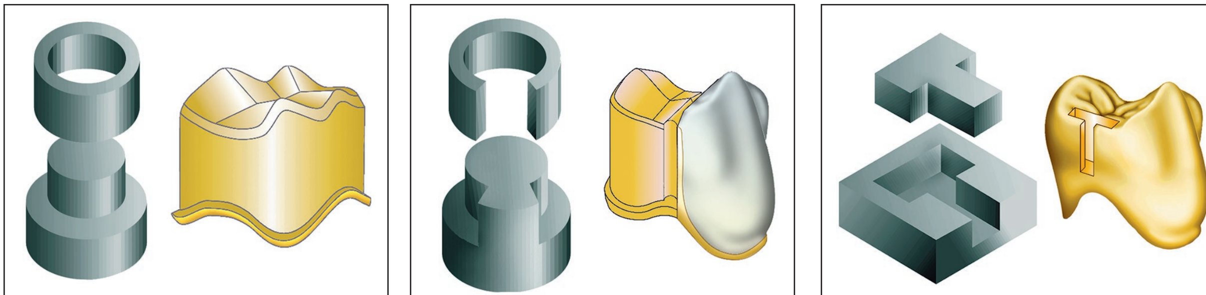
Even during normal use, a parallel fitting will change its shape due to abrasion. After a brief wearing time, a transition fit becomes a clearance fit, which calls into question the value of this fitting if no additional anchorage aids are provided.

Displacement of individual matched parts

From model die to tooth preparation in the patient's mouth, the matched parts can be displaced in relation to each other. In accurate parallel fittings, even a positional difference of 0.2 mm is problematic enough to jeopardize the success of the whole piece of work. Possible causes of displacement include the following:

- Inaccuracies in impression-taking; after the try-in, the primary parts are not placed in the correct position in the combined impression
- Individual primary parts are shifted on the milling model compared with the original model
- Secondary parts have warped during the processing steps performed
- Secondary parts shift in the mouth during cementation because of the space required for the cement

The primary part may also become tilted if both matched parts are cemented in place together in the prosthetic unit. On insertion, great pressure has to be exerted, which can tilt the tooth preparation. Insertion grooves on the prepared tooth may provide the simplest solution in this situation.



Cylindric form, used as a ring telescope or occlusally open telescope

Horseshoe form used as a half-ring with channels and pin millings

T-form, used as a T-attachment in a prefabricated version

Fig 5-11 Manually milled attachment fittings can be reduced to three basic forms. The cylindric form (as a ring telescope) and the horseshoe form (as a channel-shoulder-pin attachment) are the most commonly used in manual fabrication.

Manually Fabricated Attachment Fittings

The group of parallel fittings includes manually milled attachment fittings because of their mode of action and physical properties. These parallel fittings make up the primary part, which is milled in the replacement crown; the secondary part is fixed to the removable replacement. The three classic forms of manually fabricated attachments—ring or cylindric form, horseshoe form, and T-form (Fig 5-11)—were described by Steiger (Zürich) in 1924.

The ring or cylindric form is an occlusally open telescope that encircles the replacement crown as a closed ring. To increase the static friction, two channels can be milled approximally, into which the matching pins engage. These pins may comprise resilient wires and are activatable. To brace against axial masticatory forces, a shoulder around the neck prevents the cylindric fitting from slipping off. Transverse forces are absorbed by this cylindric attachment, just like a closed telescopic crown. An anchoring band clasp is a possible modification.

An anchoring band crown is the primary part of this attachment structure in the form of a full crown with circular parallel milling that has a 0.5-mm-wide cervical shoulder. The milled surface is interrupted on one approximal surface and has two parallel limiting channels. An anchoring band clasp is a telescopic clasp that is open approximally on one side and placed onto the anchoring band crown as the secondary part. It can be activated to increase the static and dynamic friction effects.

The horseshoe form encloses the replacement crown as a semicircular milling into which the accurately fitting secondary part engages. To increase adhesion, approximal channel and pin retentions are milled. A bar connection running occlusally and cervical shoulder millings help to secure the vertical position. The pin, channel, and shoulder millings enlarge the static friction surface areas and brace the structure. Possible designs are the channel-shoulder-pin attachment and the encircling catch with shear distribution arm.

The channel-shoulder-pin milling is applied to a veneered crown and runs over the approximal and lingual surfaces. The semicircular fitting surface ends in a cervical shoulder; it has pin inlets and parallel-milled channels that define the surface area as well as a channel running occlusally (Fig 5-12). The approximal and occlusal channels as well as the cervical shoulder offer the flexurally rigid frame for the semicircular secondary part; the occlusal surface can be formed by the secondary part. The pins, made of bend-resistant wires, are soldered into the cast outer crown; they are activatable spring pins that increase static friction. The vertical pins counteract withdrawal forces intraorally. A channel-shoulder milling is a semicircular milling reduced by the pin inlets.

The encircling catch is a semicircular parallel milling with a cervical shoulder on the lingual surface of an abutment crown to which a pre-

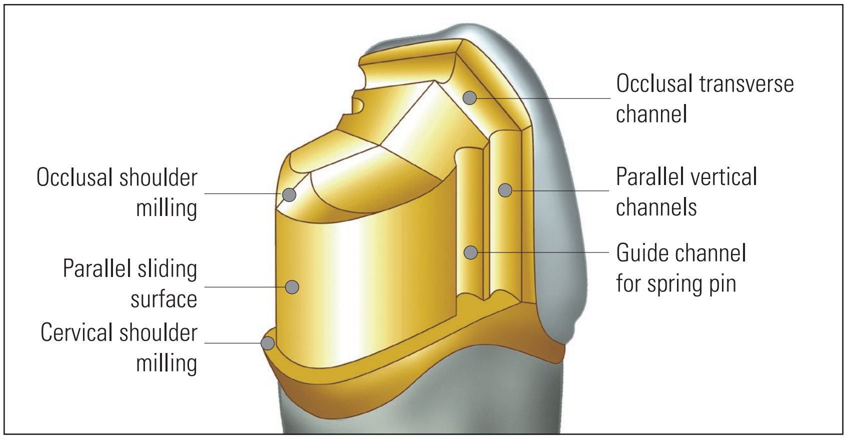


Fig 5-12 The occlusal surface can be formed by the subcrown in a channel-shoulder-pin attachment or be covered by the outer crown (as in the illustration). If there is no cervical shoulder milling, the occlusal surface should be formed by the outer crown, or a sturdy encircling occlusal shoulder should be milled.

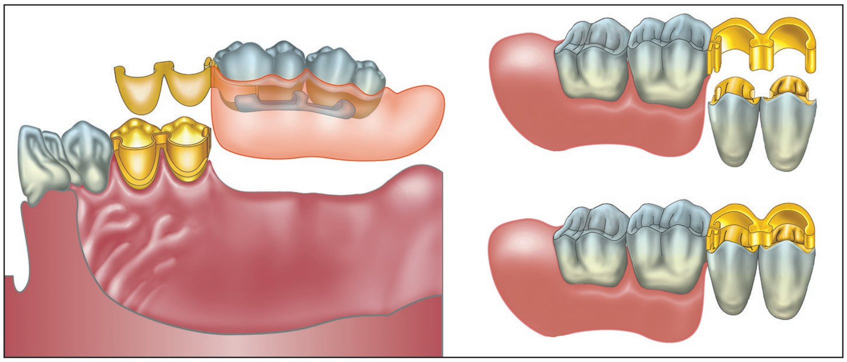


Fig 5-13 An encircling catch with shear distributor is used as a stabilizing element for prefabricated structural components and should rigidly secure the vertical and horizontal position for a removable restoration. An encircling catch and shear distribution arm run over the lingual surfaces of the abutment teeth; for positional stability, approximal stabilizing channels are milled parallel to the prefabricated attachment.

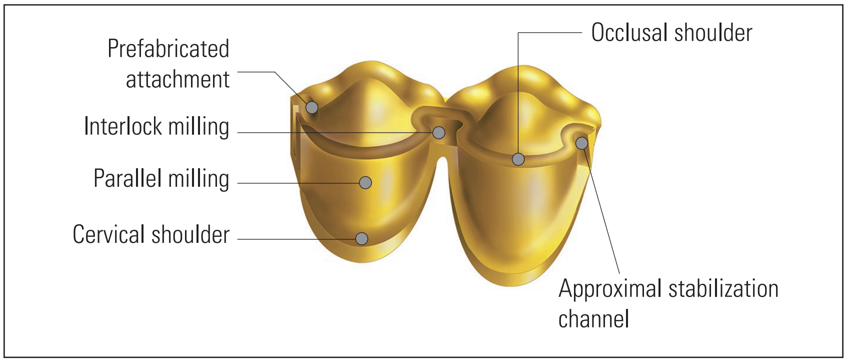


Fig 5-14 The encircling catch for the shear distribution arm is milled parallel to the prefabricated attachment and has approximal stabilization or end channels. If the encircling catch passes over two abutment teeth, the stabilization channel can be prepared as an interlock milling. The cervical shoulder offers vertical positional safeguarding, and the occlusal shoulder marks the upper end of the milled surface.

fabricated attachment is fitted approximally. The milled surface runs from the attachment over the lingual surface to the opposing approximal surface, which has a cylindric end groove that limits the surface area. The milled surface and cylindric milling run parallel to the attachment's path of insertion. The cylindric milling can be conical and widened occlusally; this makes handling easier.

The shear distribution arm (balancing component) is an open semicircular telescope with an approximal stabilizer. The shear distribution arm engages in the encircling catch, aids secure positioning during insertion, secures the horizontal and vertical position, and supports the rigid coupling of the prefabricated attachment (Figs 5-13 and 5-14). Encircling catches with shear distributors can also be combined with a resilient anchoring component (stud anchor).

The T-form or T-attachment is sunk approximally into the replacement crown as a hollow form. The T-shaped secondary part is seated on the removable replacement. The shape of a T-attachment requires considerable loss of tooth substance approximally, which may be available because of a very pronounced cavity. The T-form is milled by hand but also used in industrially fabricated attachments. In principle, manually fabricated attachment fittings have the same indications as telescopic crowns. The advantage of semicircular channel-shoulder-pin attachments is that they require a smaller space than telescopic crowns because the vestibular portion of the anchoring crown does not have to be double walled.

Encircling Catch with Shear Distributor

The encircling catch is milled parallel into a full crown, while the matching shear distributor on a removable replacement is integrated as a supporting element. An additional anchoring element has to take on the anchoring function.

Encircling catches with shear distributors are the most popular structural forms as stabilizing elements for delicate prefabricated attachments. They are also combined with stud anchors, such as CEKA and ZL anchors (ZL Microdent); in this combination, the encircling catches rigidly secure the vertical and horizontal position, while the stud anchors take on the retentive function. The shear distribution arm can also be combined with a clasp as a splinting element. The basic form of a double-arm clasp with onlay has an active vestibular retentive arm and a lingual shear distributor as the guide arm.

Following is the fabrication process for an encircling catch with shear distributor: The tooth is prepared to receive a veneered crown, and the preparation margin is shaped with a pronounced shoulder. The dental tissue usually has to be removed more than normal (approximately 1.2 mm). An insertion channel is required to avoid shifts in the model-to-intraoral situation.

The veneered crown framework can be prepared to receive an acrylic resin or ceramic veneer. The primary crown can be veneered with ceramic, which is not possible with a telescopic crown because the ceramic might flake off in response to dynamic stresses from the outer telescope.

The milled surface of the encircling catch is let into the framework and is characterized by cervical shoulder milling. The milling of the encircling catch has a threefold function:

1. It provides static support.
2. The shoulder depth ensures the material thickness of the shear distributor.
3. It aids stability to prevent bending open.

A 0.5-mm-wide metal bar is left between the veneer and the milled surface to reinforce the veneer material. The encircling catch must have a minimum height of 2.5 mm, which means the shape of the anterior teeth may appear bulky. The milled surface ends approximally in the parallel (or conical) end channel, which becomes effective in a lingual direction against transverse withdrawal forces.

To brace against the half-ring being bent open and food compaction, the transitions from the milled surface to the occlusal parts of the crown are chamfered or end in occlusal shoulder milling. The encircling catch is waxed up/milled directly into the replacement crown, invested, and cast. During milling of the fitting surfaces, it is important to ensure the following:

- Milled surfaces are completely parallel.
- The milled surface and prefabricated attachment lie parallel.
- Both portions are parallel in their path of insertion.
- A milling model with milling base is prepared.

The shear distributor is waxed up together with the denture framework. It fully covers the milled fitting surfaces and shoulder millings and completes the anatomical shape of the tooth. Its material thickness is at least 0.5 mm, and the transitions overlap slightly so that they can be refined.

Manually prefabricated structures place high demands on craftsmanship and have wide fit tol-

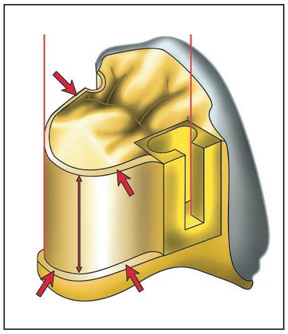


Fig 5-15 In the case of manually milled encircling catches, which are associated with prefabricated attachments, end channels, and occlusal and cervical shoulders, the following errors occur (see Figs 5-16 to 5-18).

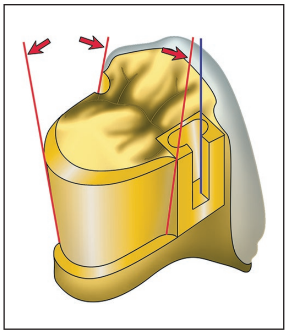


Fig 5-16 The fitting surfaces do not run parallel. If the fitting surfaces and channels are negatively conical and undercut, the encircling catch and shear distributor cannot be joined together.

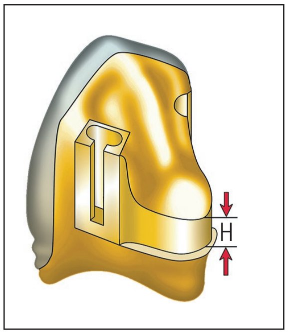


Fig 5-17 The height (H) of the parallel fitting surface is smaller than 2.5 mm, and the absolute contact surface of the fitting is too small; this height is inadequate to ensure positional stability.

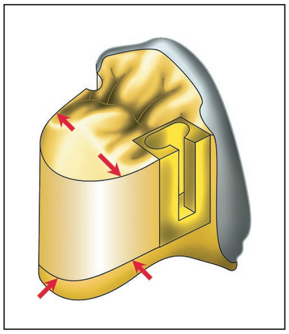


Fig 5-18 If there are no occlusal and cervical shoulders, the shear distributor ends in sharp edges and the vertical position is not secured; food can be trapped between the fitting surfaces.

erances (Fig 5-15). If manually fabricated parallel fittings are combined with prefabricated parallel attachments, the differing fit tolerances have an unbalanced effect: The smaller fit tolerance of the prefabricated components produces a firmer seating; the prefabricated components have to absorb the bulk of the stresses and are overloaded.

Error analysis of the encircling catch

- Poor parallelism: If the fitting surfaces follow a positive conical course, there is no dynamic friction; static friction depends on the slope of the milled surfaces. If the fitting surfaces are negatively conical and undercut, the matched parts cannot be joined (Fig 5-16).
- Fitting surface is lower than 2.5 mm and the absolute contact surface of the fitting is too small: This height does not provide stable anchorage against tilting, twisting, or transfer of masticatory forces; the area of static friction is also too small (Fig 5-17).
- No cervical shoulder and channels are too long: Without a cervical shoulder milling, the vertical position is jeopardized.
- No occlusal shoulder but a sharp edge at the margin of the milled surface: As a result, food is easily compacted between the fitting surfaces (Fig 5-18).

Telescopic Crowns

Telescopic crowns are double crowns in which the inner crown is cemented onto the tooth preparation and the outer crown is coupled with a removable tooth replacement. The fitting surfaces of the telescopic components can be worked as parallel or conical fits. A telescopic crown, based on the principle of a parallel fit, comprises two structural parts where the inner telescope (primary part) has at least two plane-parallel surfaces facing each other and is completely enclosed by the outer telescope (secondary part), which has the anatomical tooth shape (Fig 5-19).

The inner telescope is fabricated by the milling process and has plane-parallel outer surfaces. The parallel surfaces lying opposite each other approximally are usually sufficient for retention, while the vestibular and lingual surfaces can follow a conical course. The parallel surfaces must be slightly rough for static friction effects. The surfaces polished during dental laboratory working achieve just the right level of roughness. The inner telescope is cemented onto the tooth preparation, which has an insertion channel for a defined path of insertion.

When telescopic crowns are combined in a unit, all of the telescopic surfaces must be parallel with the path of insertion. The slightest deviations will cause stresses. The inner telescope is flat occlus-

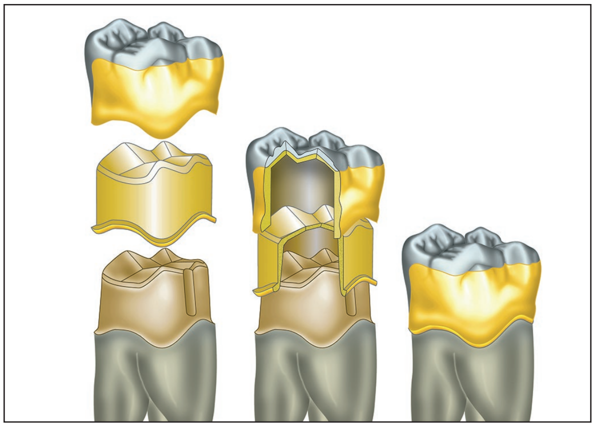


Fig 5-19 Telescopic crowns are one form of parallel fit. These double crowns have an inner crown as the inner matched part and an outer crown as the outer matched part. Telescopic crowns are constructed so that at least two opposing external surfaces of the inner crown run parallel. The outer crown has an anatomical shape, and its inner wall is adapted to the inner crown. The cervical crown margin is formed by the inner crown, and the outer crown ends about 2 mm above the cervical margin. A cervical shoulder can be prepared on the inner crown, or the outer crown has a tapered margin that is technically difficult to produce and is usually unstable.

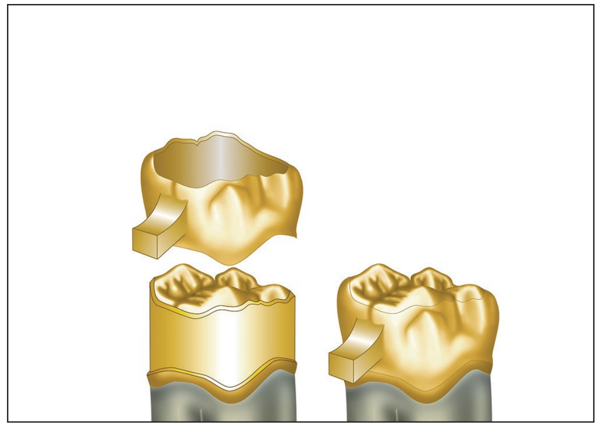


Fig 5-20 The occlusally open ring telescope is a special form of telescopic crown. The telescopic part is a ring that is supported by a cervical shoulder in the inner telescope or by an occlusal shoulder. The advantage of an occlusal shoulder on a ring telescope is that no food collects between the matched parts because the gap between them is horizontally directed.

ally and has chamfered transitions to the milled surfaces for ease of positioning during insertion.

The outer telescope is removable and has an anatomical shape as a full-cast crown, veneered crown, or occlusally open ring telescope and as a telescopic band clasp (anchor band clasp), which is supported on a circular shoulder on the inner telescope (Fig 5-20). The outer telescope contacts the parallel surfaces of the inner telescope evenly throughout the retentive surface from initial placement to the stop. The telescopic parts adhere by means of static and dynamic friction effects; in addition, resilient elements or locking devices may be used.

Indications for telescopic crowns

Telescopic crowns are used for removable dentures and removable partial prostheses. The parallel guided fit offers a fixed path of insertion and a precisely rigid connection between the denture and the residual dentition in a defined end position. Telescopic units on several abutments provide excellent bracing of the residual dentition by means of secondary splinting. The hygiene conditions are particularly favorable with telescopic crowns.

A double-walled crown demands more space and requires greater loss of tooth substance during preparation than normal replacement crowns (Fig 5-21). Fabrication of a telescopic crown involves considerably more work and hence is more prone to error. Additional retentions incorporated into the double crown require further space and involve a more time-consuming technique that is also prone to error.

Additional retentive elements for telescopic crowns are mainly prefabricated components in the form of activatable resilient and passive lockable components. They are elements for primary and subsequent assembly that compensate for inadequate adhesion and provide positional stabilization of the matched parts.

Activatable resilient elements are prefabricated systems that are typically integrated into the outer matched part. The resilient element of the outer crown snaps into a groove on the inner crown and holds the matched parts by a gripping

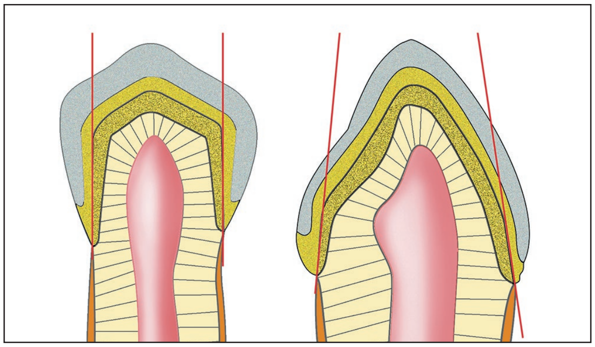


Fig 5-21 A double-walled telescopic crown requires more space than a normal-walled crown, which is why the tooth has to undergo more extensive corrective reduction. Relatively clumsy forms of outer telescope often result, however, because the parallel walls of the inner telescope do not support the anatomical tooth shape. If only the approximal surfaces are placed parallel, relatively delicate shaping of the vestibular surface is possible.

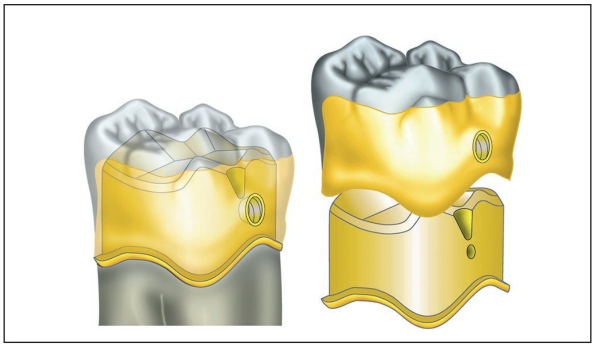


Fig 5-22 An active anchorage aid in the form of a spring bolt is housed in the outer telescope, which engages in a groove in the inner crown in the resting position. A notch occlusally on the inner telescope allows the spring bolt to be securely joined.

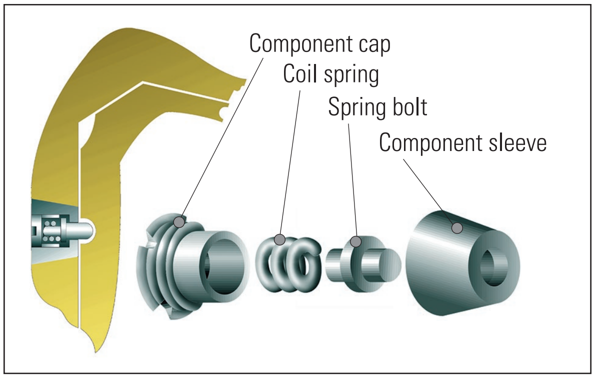


Fig 5-23 The parts of the additional spring bolt anchor, here the Ipsoclip, are delicately constructed so that they can be housed in the outer wall of the secondary part. The spring bolt and coil spring are replaceable.

effect (Fig 5-22). Numerous intracoronal retentive components are available from various manufacturers; their spring elements are activatable and replaceable (eg, Pressomatic [Romagnoli], Ipsoclip [Guglielmetti; Fig 5-23], snap attachment, leaf springs). Activatable components can be overstretched so that the periodontium is overloaded when the telescope is withdrawn. Excessively large clearance fittings cannot be stabilized with these retentive components.

Components subsequently mounted for worn matched parts are mainly rubberlike nubs that are stuck into the outer crown. An angled depression is milled into the outer telescope, and the rubber nub is set in place so that a slight elevation is formed on the fitting surface and rubs on the inner telescope.

Therefore, the requirements of telescopes are the following:

- Easy to join and separate the matched parts
- Defined end position as a rigid connection
- Retention in resting position by static friction
- Abrasion-resistant fit
- Delicate periodontally hygienic shape

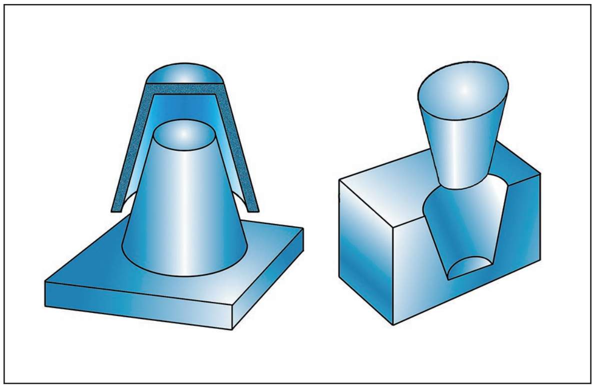


Fig 5-24 A cone means a truncated cone that has side walls sloping toward each other. A conical crown is a double crown in which the inner crown displays the positive shape of a cone. The fitting surfaces of the double crown run parallel. A conical fitting is a separable join.

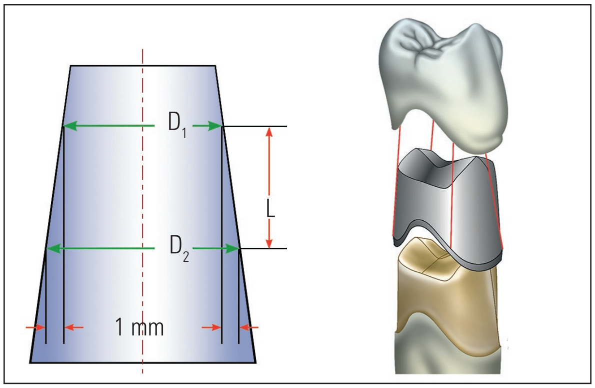


Fig 5-25 The cone is a truncated cone that changes diameter by 1 mm over a specific height; this is the degree of taper of the cone.

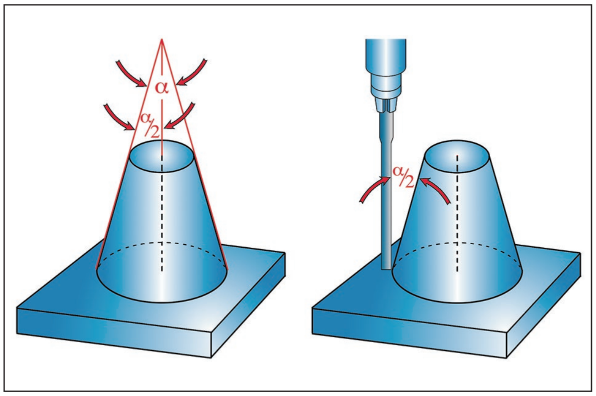


Fig 5-26 The slope of the side walls of a cone can be determined by the angle (α) to which a cone can be extended. The angle of taper is half the cone angle (α/2). The taper angle indicates the sloping of the side walls to the perpendicular. The taper angle can be measured with a parallelometer. The angle between the parallelometer rod and the cone wall gives the angle of taper.

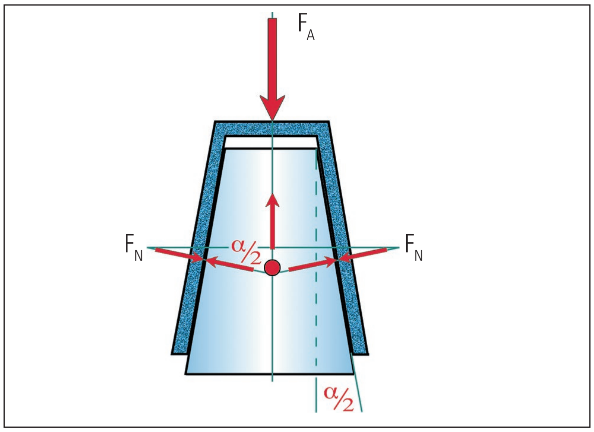


Fig 5-27 The fitting surfaces of the conical crown come in contact in the end position, and static friction arises. If the outer cone is exposed to contact pressure F_A, a flank force that is vertical on the fitting surfaces occurs at the surfaces and is referred to as normal force F_N. The magnitude of static friction forces depends on the taper angle.

Conical Fittings

Conical crowns (after K. H. Körber) are manually fabricated fittings in the form of telescopic double crowns. The primary part has the positive shape of a cone and is referred to as the *inner cone* or *inner crown*; the secondary part is known as the *outer cone* or *outer crown* and has an anatomical tooth shape.

The cone is truncated and fits into an analogous hollow cone, where the external surfaces of the truncated cone are parallel to the internal surfaces of the hollow cone (Fig 5-24). In engineering, a cone is defined by the height of the truncated cone, over which the diameter changes by 1 mm (Fig 5-25). The occlusal diameter of the primary part of a conical crown is smaller than the diameter in the cervical area.

The surfaces of a cone can be extended as far as the original cone. The angle of the cone lies in the apex of the cone. Halving this angle by the central axis of the cone gives the angle of taper.

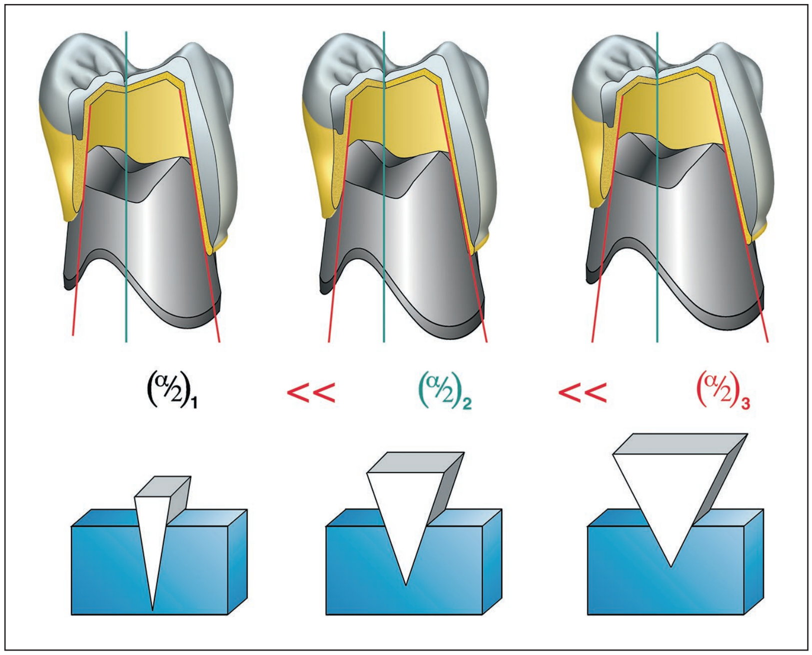


Fig 5-28 Comparison with a wedge shows that the size of the taper angle has a direct influence on the adhesive force of the cone: The smaller the taper angle, the steeper the wedge, the larger the flanks, or the larger the normal forces on the sides of the cone. If the taper or wedge angle is larger, the flank forces decrease and may reach the point where the wedge or the cone comes off. This happens because the slope forces become greater than the static friction forces.

The angle of taper can be measured between a parallelometer pin and the surface of the cone (Fig 5-26). Therefore, the taper angle is defined as the machining angle between the outer surface of the cone and the parallelometer axis. In dental technology, this taper angle is used to describe the conical shape because the adhesive force of the conical fit can be specified with this angle.

The central axis of a cone lies parallel to the path of insertion. The taper angle can be measured on the basis of this path of insertion. In some cases, the central axes of individual cones of a combination of abutments differ from the path of insertion; one cone surface runs parallel to the path of insertion, and the other cone surfaces are at a positive angle to the path of insertion. This occurs if abutment teeth are excessively tilted toward each other.

The adhesive force of a cone does not arise until the inner and outer crown touch in the resting position. In a parallel fit, dynamic friction occurs from initial contact between the fitting surfaces until the matched parts are fully pushed inside each other. If a cone is placed in a matching hollow cone, adhesion ensues when the plane surfaces of the two parts come into contact in the end position.

Dynamic friction and abrasion do not occur in a conical fitting because the fitting surfaces only touch when the end position of the structure is reached; these surfaces do not slide against each other in contact. If a telescopic conical fitting is joined together, the cone surfaces do not rest loosely but press against each other; thus, more pressure is applied to the outer part. The inner cone is pushed into the outer crown like a wedge, whereby the outer crown is subject to slight elastic deformation. The contact surfaces press firmly together and static friction arises (Fig 5-27).

The physical principle of the adhesive force, which depends on the contact force due to insertion and masticatory pressure as well as on the taper angle, can be explained by a wedge (Fig 5-28): If differently pointed wedges are driven into a block of wood with the same force, a pointed wedge will penetrate deeply and remain firmly in position, a blunt wedge will have difficulty penetrating the wood and can easily be removed, and an even blunter wedge will not penetrate but will repeatedly pop out.

The relationship between adhesive force and taper angle can be determined by calculations and experimental tests and can be graphically represented: The degrees are plotted on the horizontal

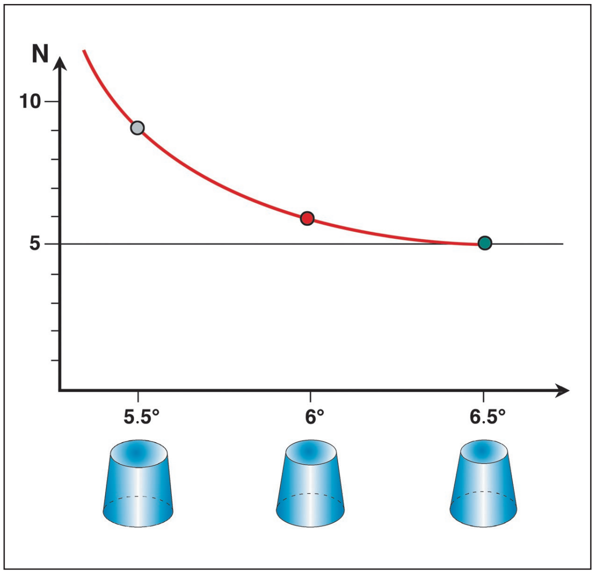


Fig 5-29 The adhesive force of a cone depends on the angle of taper. According to Körber, the mean values for adhesive force can be defined for three angles of taper of function-related cones: A 5.5-degree angle of taper produces a retentive anchor with approximately 10 N of adhesive force; a 6-degree angle of taper produces a normal anchor with approximately 6 N of adhesive force; and a 6.5-degree angle of taper produces a supporting anchor with approximately 5 N of adhesive force.

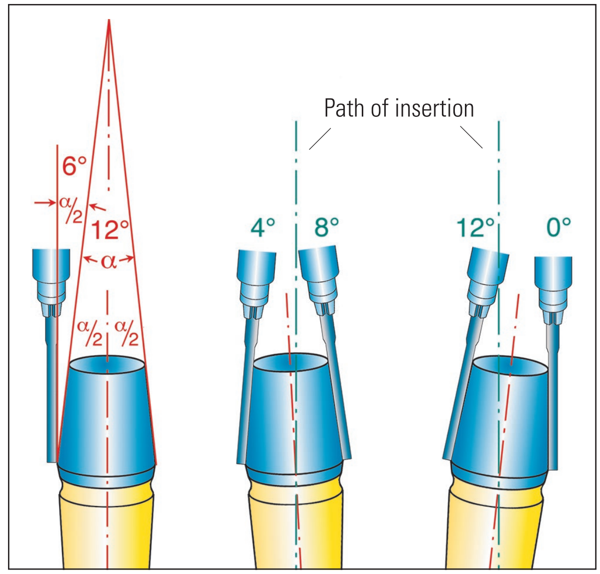


Fig 5-30 The most favorable taper angle for dental technology constructions is 6 degrees, which is equivalent to a cone angle of 12 degrees. If, in the case of tilted teeth within a group of tapered crowns, the cone axis does not coincide with the tooth axis, this difference can still be tolerated within a range of up to 12 degrees. The chosen path of insertion is the axis, which is used as the reference for the taper angle. If an angle of 8 degrees is chosen on one side and an angle of 4 degrees is selected on the opposite side, this gives a cone angle of 12 degrees.

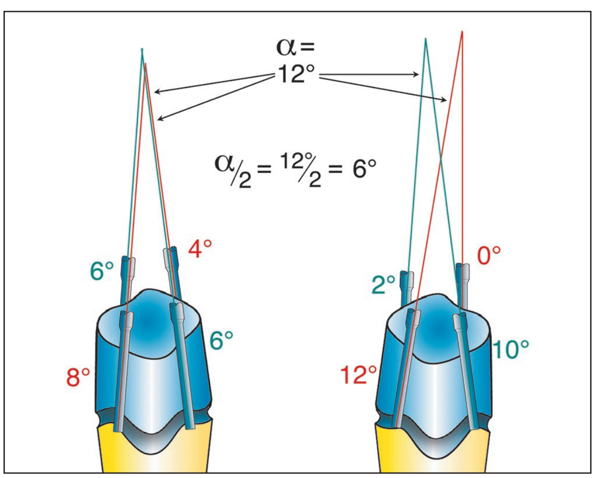


Fig 5-31 To give the inner crown an evenly thin wall thickness, the taper angle of the different sides of a crown can vary. The only decisive factor is that the total of the opposing angles results in the desired cone angle. If a cone angle of 12 degrees is chosen, the total of the opposing taper angles must result in exactly this number of degrees. For a normal adhesive cone, 12 degrees is appropriate. If the cone adheres very strongly, a cone angle of less than 12 degrees must be selected.

line (abscissa or x-axis) and the corresponding adhesion values on the vertical line (ordinate or y-axis). A small taper angle produces high adhesive force, whereas a large taper angle has little or no adhesive force (Fig 5-29).

In relation to adhesive force and taper angle, Körber identifies three types of cone (Figs 5-30 and 5-31):

- Adhesive cone (adhesive anchor) with a taper angle of 5.5 degrees (cone angle of 11 degrees)
- Normal cone (normal anchor) with a taper angle of 6 degrees (cone angle of 12 degrees)
- Support cone (support anchor) with a taper angle of 6.5 degrees (cone angle of 13 degrees)

Groups of conical crowns can be fabricated in which crowns with different taper angles between 5.5 and 6.5 degrees produce different adhesive forces:

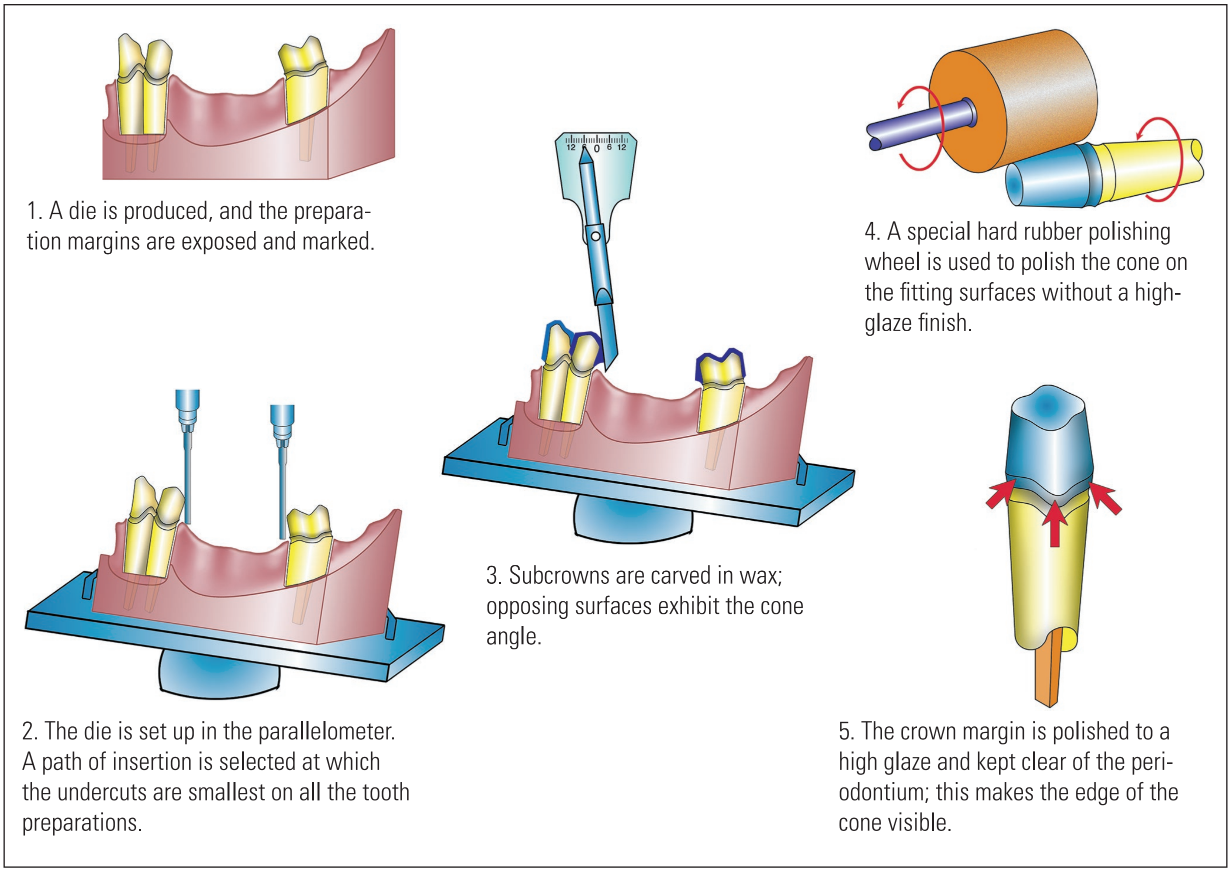


Fig 5-32 Schematic illustration of the fabrication of a tapered crown construction.

- Taper angles less than 5.5 degrees produce excessive adhesive forces (several times the contact pressure)
- Taper angles greater than 6.5 degrees no longer have defined adhesive force

The advantage of conical crowns lies in the fact that, as with other conventional fittings, adhesive force is fixed beforehand and can thus be exploited for therapeutic purposes.

Practical Value of Conical Fittings

Figure 5-32 illustrates the fabrication of a tapered crown construction. In the case of conical fittings, the adhesive force can be variably fixed, depending on taper angle and hence the retention of a partial prosthesis. They come apart without any dynamic friction effects and thus show virtually no wear and tear.

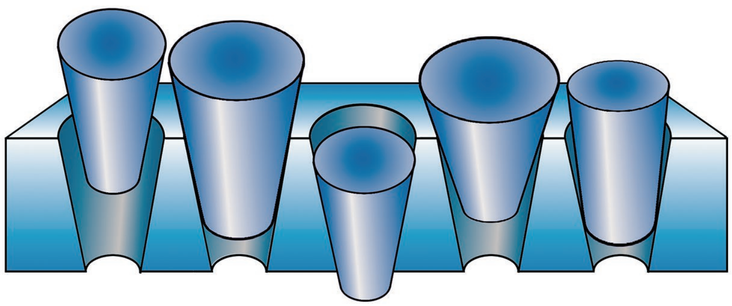


Fig 5-33 Conical fittings can be assembled even when there are fabrication inaccuracies. *(1)* A cone-shaped drill hole is created, and the cone fits accurately. *(2)* The cone is too big, but the fitting surfaces have static friction contact and perform their function. *(3)* The cone is too small and slips more deeply into the drill hole; it fulfills the necessary retentive function. *(4)* The angle of the cone is larger than that of the drill hole; the cone becomes wedged in the drill hole and holds. *(5)* The angle of the drill hole is larger than that of the cone; the cone becomes wedged in the drill hole and holds. In the case of tapered crowns, these kinds of errors are tolerated within a group of crowns.

Processing errors can be tolerated (compensated for) by conical crowns to a certain extent (Fig 5-33). For example, casting inaccuracies due to incorrect casting construction are fully tolerated by the cone because the fit does not alter with different tolerances of crowns. An oversized outer crown can be positioned more deeply, and an undersized outer crown cannot quite be pushed into place. There is no difference in adhesive force.

Groups of conical crowns can be used because of ease of insertion and contact closure of the dental arches; the conical crown finds its end position by itself. When conical crowns are fabricated with good accuracy of fit, a complete marginal seal is also attained, which prevents odor buildup under the crown.

Cone tolerance refers to the characteristic of conical fits to compensate for positional variation between the model and intraoral situation in single conical crowns forming part of a group of conical crowns. If the conical crowns for a group of abutments are made separately based on one path of insertion, positional discrepancies occur between the model situation and the intraoral situation; the individual crowns can be rigidly joined together based on a new impression of the real intraoral situation without impairing the fit of the crown unit. This can only be done, however, if the positional discrepancies are within the range of the taper angle. Conical crowns can always be slimmed in the occlusal area, thereby approaching the natural tooth shape.

Restoring partially edentulous dental arches with abutment teeth converging toward the path of insertion is easier with a conical unit than with parallel fittings (Fig 5-34). The inclined tooth preparations are fitted with conical subcrowns that are all related to one path of insertion (Fig 5-35). In the edentulous area narrowed by convergence, small taper angles can be used that are offset by the complementary angle on the opposite side of the crown.

Disadvantages of conical crowns

If the outer crown is oversized due to casting faults, this error can be compensated for by trimming the inner crown by the necessary amount so that the outer crown can be positioned more deeply. A cone treated in this way will fit and adhere, but the occlusal relationship with the antagonist will be disrupted by the amount to which it is placed more deeply. Where occlusal surfaces are accurately reconstructed, this is an error that cannot be tolerated.

If the outer crown is undersized, hence too small, the result is a vertical increase of occlusion, which the patient cannot be expected to tolerate. A possible remedy might be targeted polishing of the inner crown to remove material. This is difficult, however, because the material is not removed evenly. The inside of the outer crown could also be treated (possibly by airborne-particle abrasion). In both cases, the coefficient of friction is

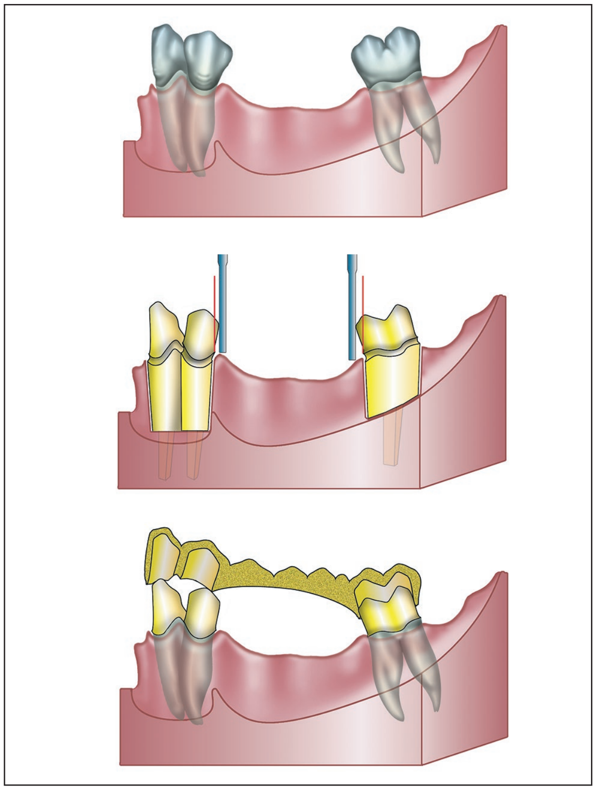


Fig 5-34 Restoring a partially edentulous dental arch with converging tooth positions is particularly difficult. A normal fixed partial denture cannot be inserted if the tooth preparations have undercuts. Such a fixed partial denture ought to be a two-part construction joined together with a screw connection once it is in the mouth.

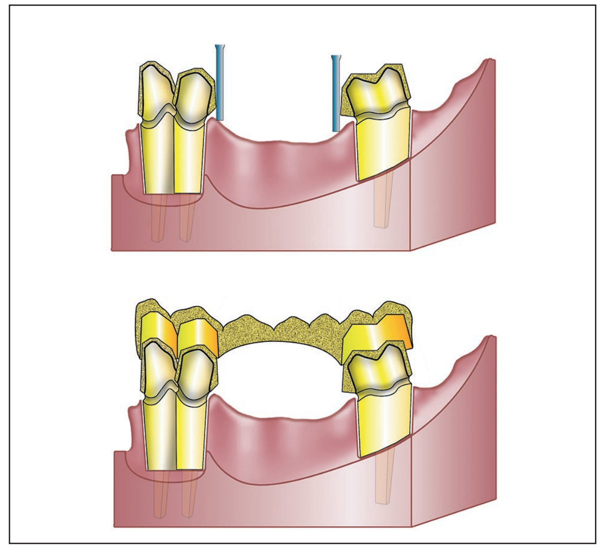


Fig 5-35 A partial denture with tapered crowns may be the solution even when teeth are extremely tilted. The undercut tooth preparations are fitted with conical subcrowns that are all referenced to one path of insertion. The tapered crown partial denture can be inserted without difficulty. A removable partial denture also offers the advantage of more favorable periodontal hygiene.

altered by the surface roughness; the taper angle at the machined surfaces usually varies as well. The adhesive force of the cone, which could be precisely determined by means of the taper angle, is now altered in an uncontrolled way.

Discrepancies in the accuracy of fit lead to occlusal interferences if the outer crown has a complete occlusal relief. If the outer crown is subsequently veneered occlusally, this source of error can be corrected. Discrepancies in the taper angle between the matched parts lead to pronounced interferences because the matched parts only have linear contact and are wedged into each other. The adhesive forces can no longer be calculated when this wedging happens. Discrepancies in the position of individual cones from the model situation to the intraoral situation are tolerated if the discrepancies remain within the range of the taper angle, but occlusal interferences may be expected here too if the outer crown contains an occlusal relief adapted to the antagonist.

The major disadvantage of a conical fit is that the adhesive force depends not only on the taper angle but also on the joining forces of the matched parts. As a result of masticatory force, a conical crown can become wedged onto the subcrown in such a way that the permitted limit for adhesive force of 10 N is greatly exceeded.

Industrially Fabricated Attachment Fittings

Industrially fabricated attachment fittings are also referred to as structural components, prosthetic auxiliary parts, prefabricated components, or precision attachments. Prosthetic auxiliary parts are structural components in the form of two-part telescopic (parallel) fittings in very small dimensions that comprise the primary part on a fixed crown and the secondary part on a removable restoration (Fig 5-36). Soldering plates or retentive components are mounted on the two matched parts, and these can be used to create an inseparable connection to the fixed crown on the one hand and to the removable replacement on the other hand.

These prefabricated components do not differ from the previously described parallel fittings in their function and physical characteristics. They have fitting surfaces with high accuracy and minimal clearance. The reason for this accuracy lies in the method of manufacture. The prosthetic auxiliary parts are produced with high-grade, computerized, special machine tools in small batches.

The matched parts are fabricated using computer-controlled, metal-cutting shaping techniques (such as turning, milling, and drilling) or in suitable cold-forming processes (such as drawing or punching). These two cold-forming processes, as well as the metal-cutting techniques, are ideal for producing precise matched parts, so the term *precision attachment* justifiably applies. Complicated molded parts are produced in high-standard precision casting processes.

Physical material properties, such as strength, hardness, abrasion resistance, and surface smoothness, are achieved as a result of the specific materials. In addition to having these physical characteristics, the materials have to be biocompatible (ie, tolerated by the tissues). Because they are also soldered or cast onto porcelain-fused-to-metal structures, they need to be especially high fusing and heat resistant. These materials must also not be altered by special dental technology processing methods, such as acidifying, glazing, or other electrolytic methods. Generally speaking, the matched parts consist of proven precious metal alloys such as gold-platinum, platinum-iridium, and silver-palladium. Resilient components of these attachment fittings (springs, spring pins, leaf springs, screws, and pins) are fabricated from special high-grade steels.

The tolerances of the matched parts are a hundredth of a millimeter and are in keeping with the surface quality of the fitting surfaces. Smaller tolerances (ie, less clearance) would cause excessive static friction effects so that the matched parts could only be separated applying considerable force and would wear unduly.

The absolute contact area is not the measurable size of the fitting surfaces but the actual contact area of the metallic matched parts. The absolute contact area is smaller than the measurable size of the fitting surfaces because the metal surfaces can only have partial contact because of surface roughness. If there is minimal clearance, the fitting surfaces are brought closer together; that is, the absolute contact area becomes larger, as does the static friction.

The high accuracy of fit and low tolerances ensure the defined static and dynamic friction resistance. If the absolute size of the contact area or the minimal height of the fitting surfaces is insufficient for retentive force, additional resilient or locking retentive components are mounted. The size of the contact area decreases if retentive parts lie within the fitting surfaces. To support horizontal and vertical positional stability, the delicate components are usually prepared in conjunction with a circular notch and a shear distribution arm.

An extensive range of prefabricated attachment fittings is available. Manufacturers produce catalogs of prosthodontic auxiliary parts that describe the individual fittings in terms of their application and function. Classification criteria for prefabricated attachments can be derived from the different geometric profile shapes of the matched parts. The two types of attachments are box-shaped and cylindric attachments. Box-shaped profiles can be shaped like T, double-T, or H attachments. In the case of cylindric profiles, one matched part can be constructed as a roller and the other as a ring-shaped sleeve. The most common profile shape for parallel attachments is a double roller or rounded T shape, in which the profile blades can be spread apart to activate the attachment (Figs 5-37 and 5-38).

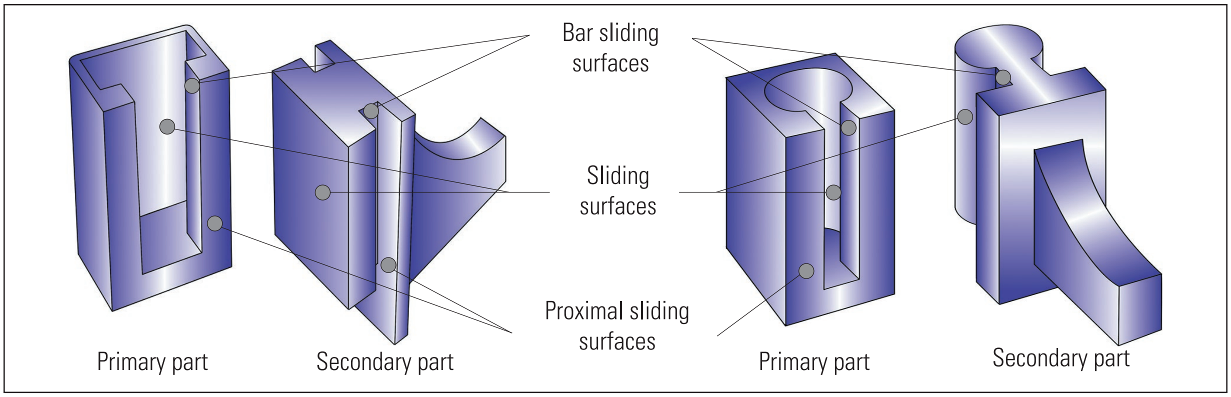


Fig 5-36 Industrially fabricated attachment fittings have two telescopic components with defined fit tolerances. The primary matched part is integrated into the crown, and the secondary matched part is fixed to the removable restoration. The geometric profile of an attachment can be box shaped or cylindric and determines the size of the sliding surfaces, which are supplemented by the bar and proximal sliding surfaces.

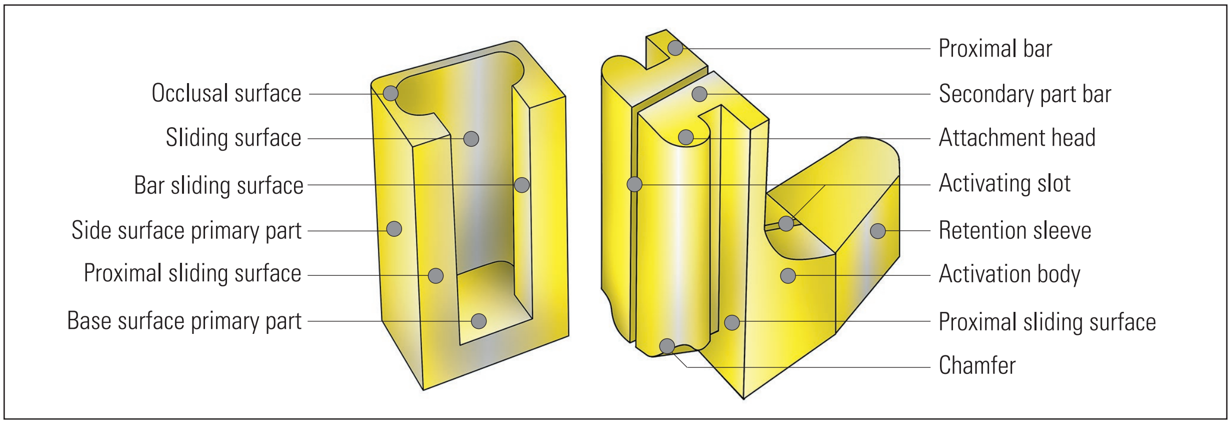


Fig 5-37 A T-attachment or double roller attachment can be derived from the box-shaped or cylindric profile shapes, representing the modern design of an activatable and replaceable attachment, for example, the multi-CON from DeguDent or the DuoLock attachment from ZL Microdent.

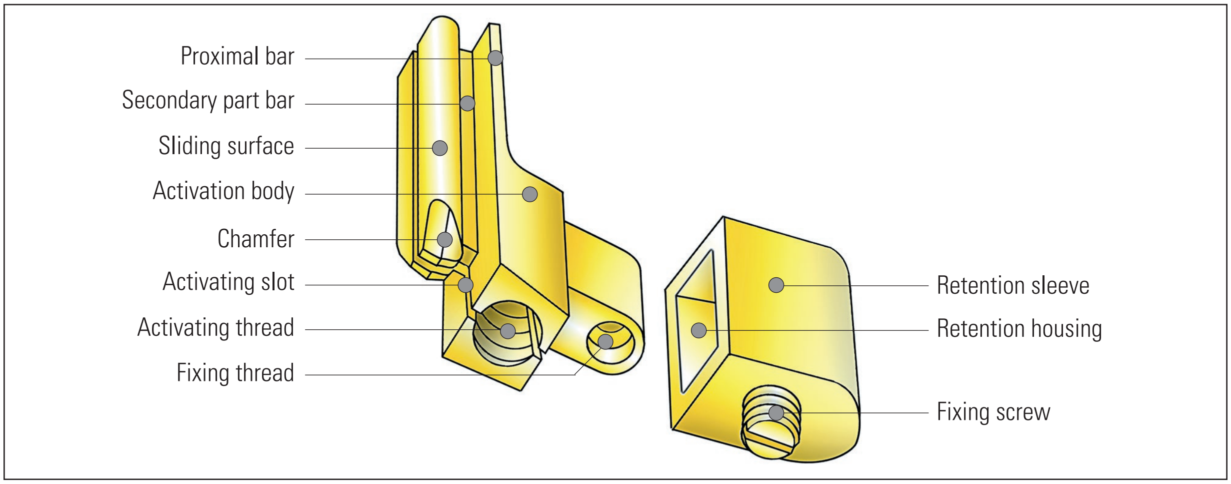


Fig 5-38 Secondary part with retention sleeve, activating slot, and activating thread; chamfering of the attachment head makes it easy to join the attachment parts together.

Practical Value of Prefabricated Attachments

Figure 5-39 outlines the practical value of different attachment designs. Prefabricated attachment fittings can be used for any type of removable tooth replacement. They make it possible to restore dentition in difficult cases because the space required for a prefabricated attachment is generally less than that required for manually fabricated fittings. Prefabricated attachments can be easily and reliably worked. Prefabricated finished parts can be mounted within crowns (intracoronally), outside crowns (extracoronally), and between crowns (intercoronally) as well as onto root crowns and in very small edentulous gaps. They can be used as separable or partly separable connectors.

Full-cast crowns and closed veneered crown frameworks are most suitable for receiving prefabricated attachment fittings. The retentive surfaces of the veneers must be clearly separated from the anchoring surfaces of the attachment fittings.

The primary part can be fixed to the crown framework by a variety of methods. It can be soldered or joined in the casting process; less commonly, the primary part is bonded in place. The primary fitting surfaces can also be integrated into the crown framework in the erosion process or by a spacer technique. Secondary parts can be fixed in the denture saddle with acrylic resin, soldered, or bonded to the model casting base. For this purpose, the soldering or bonding surface is prepared on the metal base.

The quality of prefabricated finished parts is measured by the extent to which they perform the required functions of anchoring and supporting elements. Differentiation is therefore based on the nature and extent to which function is fulfilled, giving rise to the following distinctions:

- Intracoronal and extracoronal attachments, which affect periodontal hygiene
- Activatable and passive attachments, which affect the defined retentive force
- Rigid and articulated/elastic attachments, which affect horizontal positional stability
- Open and closed attachments, which affect vertical positional stability

Periodontal hygiene

Intracoronal (also paracoronal) positioning exists if the primary part is sunk into the approximal outer wall of an anchoring crown. For this to happen, either the tooth preparation must be substantially reduced and the crown wall made thicker, or the primary part must be constructed to be very flat. The interface to the marginal periodontium is not covered, and the fitting surfaces and the bottom of the fitting surfaces lie within the crown contour. This is the correct design in terms of periodontal hygiene, as in a normal coronal restoration.

Extracoronal positioning arises if the primary part is placed outside the approximal crown wall and the marginal periodontium is permanently covered. This is unfavorable in terms of periodontal hygiene. Encapsulation, suction, and compressive effects on the gingiva, due to slight denture movements while functioning, will occur at the interface. The mucosa will proliferate in this area, which can result in inflammation.

The different positioning of an attachment fitting does not influence transfer of forces, provided the fitting results in a true rigid connection. If the replacement crown is rigidly connected to the denture body via the attachment, it is irrelevant whether the join is fitted inside the crown, on the side of the crown, or farther away in the denture body. The positioning may be important in attachment fittings with several degrees of freedom, which, besides the path of insertion, permit movement in other directions. In this case, accurate analysis is required to identify how this additional degree of freedom may affect the periodontium of the abutment tooth and the loaded mucosa.

Defined retentive force

Prefabricated attachment fittings have defined adhesive forces because of small fitting tolerances, or they are activatable by means of finely adjusted spring components. In passive (nonactivatable) attachments, the initially adequate static friction effects are lost because of abrasion; then the fittings only ensure horizontal and vertical positional stability. The activatable secondary parts are either divided into blades that can be spread apart, or they have additional spring elements that engage in notches on the primary part. Activatable spring components or secondary parts are usually replaceable.

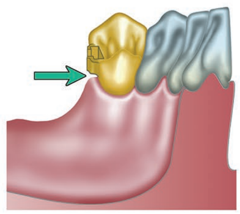
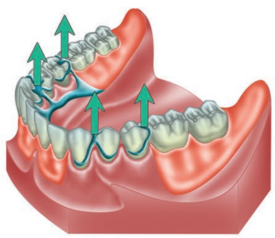
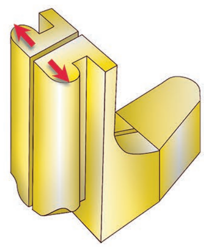
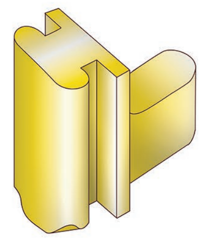
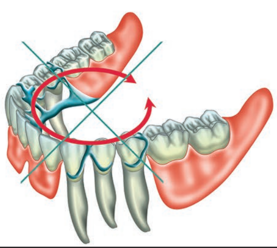
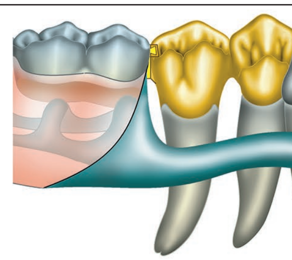
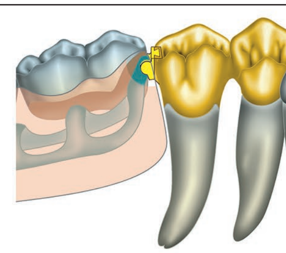
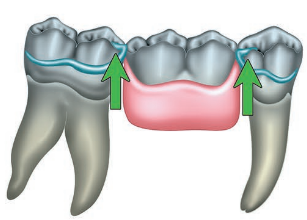
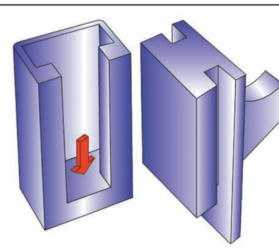
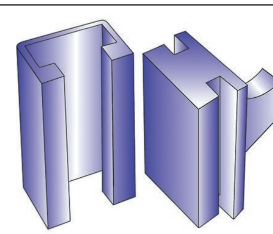
	Practical attachment	Impractical attachment
Periodontal hygiene Protects the interface 	 Intracoronal positioning of the primary part is favorable in terms of periodontal hygiene	 Extracoronal positioning is unfavorable in terms of periodontal hygiene (gingival irritation may occur)
Defined retentive force Performs a retentive function 	 Activatable attachment parts offer permanently defined retentive forces	 Nonactivatable primary parts offer temporarily defined retentive forces via fit tolerances
Horizontal positional stability Provides physiologic coupling 	 Rigid coupling between the denture and the residual dentition secures the horizontal position	 Articulated coupling between the denture and the residual dentition does not secure the horizontal position
Vertical positional stability Provides periodontal support 	 Closed attachments provide vertical positional stability and periodontal transfer of forces	 Open attachments do not offer vertical positional stability or periodontal transfer of forces

Fig 5-39 Differentiation of attachment designs based on their functional and practical value.

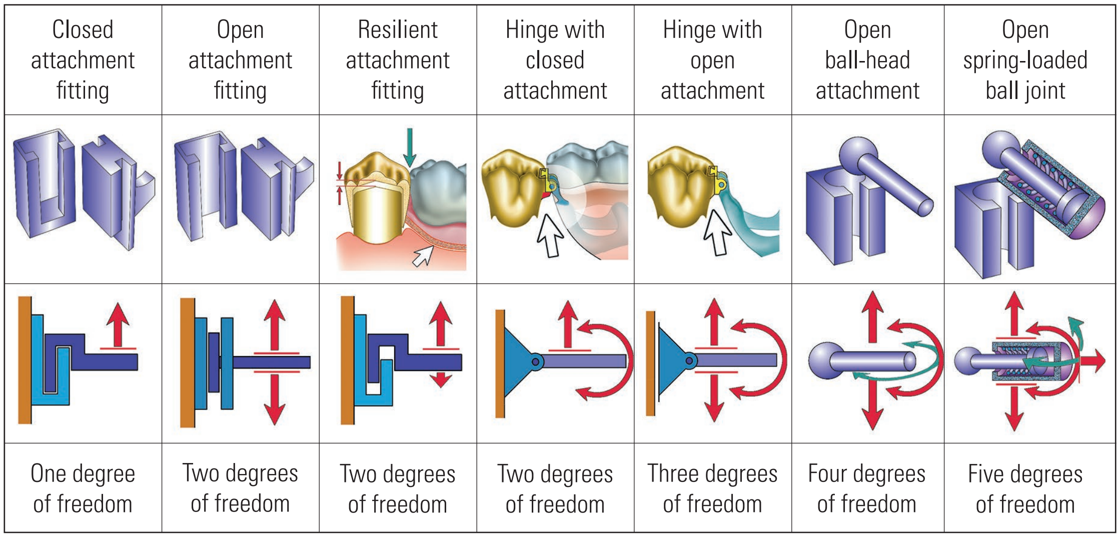


Fig 5-40 Classification of attachments according to degrees of freedom.

Positional Stability with Prefabricated Attachments

Anchoring and supporting elements are intended to secure the horizontal and vertical position. Horizontal positional stability means preventing shifting, twisting, and tipping of the denture in the horizontal plane. Vertical positional stability means that vertical masticatory forces are largely transferred axially onto the periodontium of the abutments.

The rigid coupling between the denture and the residual dentition with a rigid attachment provides horizontal and vertical positional stability. The connection quality of attachments is defined by the amount and direction of movements possible, which can be expressed as degrees of freedom. Degrees of freedom indicate the free movements that are possible independently of each other (Fig 5-40). Connecting components can have the following degrees of freedom:

- Rotation about three axes, equivalent to three degrees of freedom
- Translation in three spatial planes, equivalent to another three degrees of freedom

Structural components with several degrees of freedom provide no rigid coupling. Prefabricated connecting components can be distinguished according to the number of degrees of freedom:

- A closed attachment fitting with a depth stop permits movements of the denture part perpendicular to the alveolar ridge only via the periodontium of the abutment tooth (one degree of freedom) (Fig 5-41).
- An open attachment fitting without a depth stop allows movements of the denture part parallel to the alveolar ridge (two degrees of freedom) (Fig 5-42).
- A resilient attachment enables movements of the saddle parallel to the alveolar ridge to a limited extent as far as the shifted depth stop (two degrees of freedom) (Fig 5-43).
- A hinge joint with a closed attachment allows rotary movements of the saddle about a fixed pivot point (two degrees of freedom) (Fig 5-44).
- A hinge joint with an open attachment allows parallel displacements and rotary movements of the saddle (three degrees of freedom) (Fig 5-45).
- An open ball-head attachment permits tipping and twisting as well as vertical movements of the saddle (four degrees of freedom).

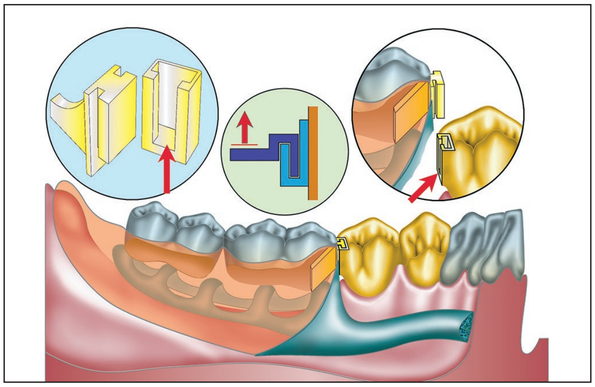


Fig 5-41 When evaluating attachment fittings, determining possible movements of the connected denture saddle within and outside the path of insertion is important. A closed attachment fitting permits no movement of the denture saddle, except what is required for insertion and removal. This attachment fitting is absolutely rigid because vertical masticatory forces are transmitted fully via the depth stop.

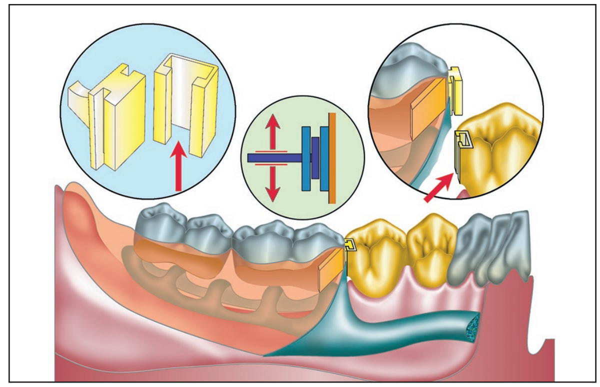


Fig 5-42 An open attachment fitting without a depth stop permits movement of the denture part parallel to the alveolar ridge. This attachment fitting is not rigid and cannot transfer any axial masticatory forces. The horizontal position is secured against transverse thrusts.

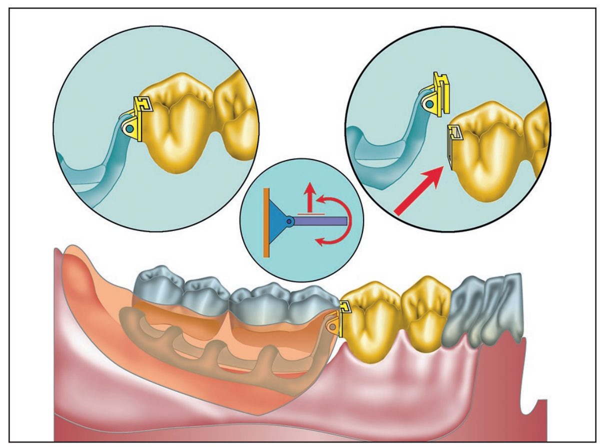


Fig 5-44 A closed attachment fitting with a joint has several possible movements besides the path of insertion. These attachments have two degrees of freedom: the limited movement in the path of insertion and the rotary movement of the hinge.

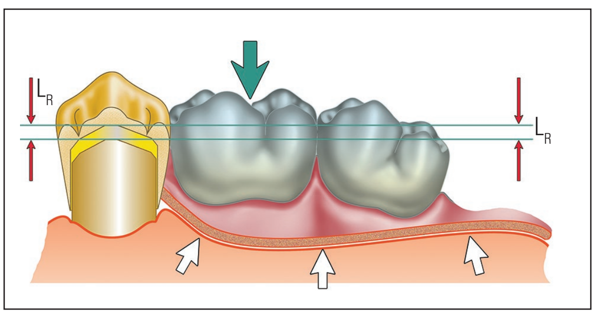


Fig 5-43 The resilient attachment is a compromise between closed and open attachment fittings. The depth stop is placed so that the denture saddle can be moved toward the mucosa in the path of insertion. As a result, the mucosa absorbs part of the masticatory force before the periodontium is loaded. Resilience leeway (L_R) must be determined individually for a denture structure.

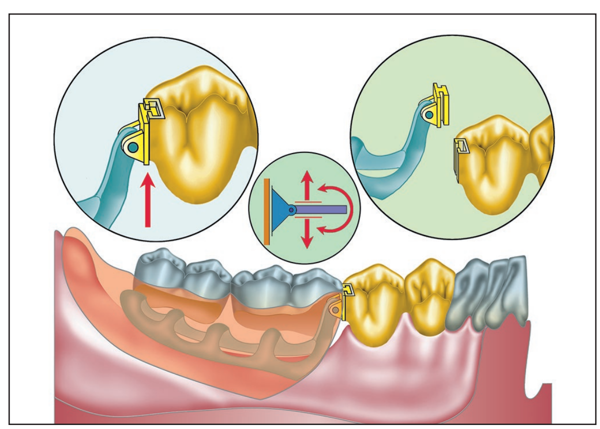


Fig 5-45 If a hinge is combined with an open attachment in which vertical movement is not limited, the denture saddle can settle into the mucosa parallel to the path of insertion and perform rotating movements. Horizontal positional stability is merely confined to bracing against tipping off sideways; apart from that, the mucosa has to absorb all the masticatory pressures. This kind of structure is outmoded and should be rejected.

- A spring-loaded ball attachment permits movements in all directions relative to the mucosa (five degrees of freedom).

Closed attachments have only one degree of freedom in the vertical plane: These are box-shaped parallel attachments with a depth stop, in which the secondary part can only be pushed in as far as this depth stop, usually the floor of the primary part. A rigid connection between the denture and the residual dentition is achieved because tipping, displacement, and twisting movements are prevented and periodontal support takes place. A closed attachment produces a periodontally borne restoration. A closed attachment can be placed intracoronally and extracoronally. If the attachment is closed at the bottom, the cleaning possibilities are limited, so the vertical position of the secondary part may be disrupted because of a buildup of tartar.

A free-end saddle is anchored with rigid connectors and not with an attachment that has several degrees of freedom. Severe tipping stresses on the abutment teeth are absorbed by the splinting of several abutments.

Attachments with several degrees of freedom permit movements of the denture in one, two, or all three spatial directions. They are resilient components, loose guides, and true hinge joints with return mechanisms, which restore the denture to the original position when the strain is relieved. The support on fixed abutment teeth and yielding mucosa produces mechanically indeterminate systems with all the disadvantages of mixed-support dentures:

- No true distribution of load occurs between the periodontium and the mucosal support.
- Distal parts of the jaw and marginal periodontal tissue in the interface are destroyed.
- Abutment teeth and jaw segments are non-physiologically loaded by idle movements; the patient plays with the mobile denture.
- Mobile connectors wear out badly after a short period of wearing.
- The denture becomes deeply embedded.
- Occlusal contacts are lost.
- Transverse stresses loosen the abutment tooth.

Mobile connecting components provide very unsatisfactory positional stability and should therefore be rejected.

Open Attachments

In an open attachment, the fitting surfaces are fabricated in the path of insertion without a depth stop; they secure the vertical position. The secondary part can be pushed into the primary part to any chosen depth. In principle, the secondary part can be pushed fully through the primary part. An open attachment permits movements of the denture saddle parallel to the path of insertion, and it can settle into the mucosa.

A bounded saddle, anchored in this way, is guided axially and supported on the mucosa when loaded by masticatory pressure; this produces a mucosa-supported prosthetic restoration. The indication for open attachments is very limited. Only cantilever fixed partial dentures with an extensive base (snowshoe principle) can be anchored better with an open attachment than by the use of normal clasps with an occlusal rest remote from the saddle. This is because open attachments secure the horizontal position and guide the free-end saddle parallel, which produces even mucosal loading. Open attachments have to be positioned extracoronally and must cover or touch the mucosa in the interface region; they are easy to clean.

Open attachments prevent tipping and twisting of the denture via vertical guidance and secure the horizontal position, but there are still several disadvantages of their use:

- Axial masticatory pressures are not transferred to the periodontium.
- There is no support on the residual dentition.
- Involved jaw segments are overloaded and atrophy.
- Denture components become embedded.
- Occlusal contacts are lost.
- The marginal periodontium in the interface is destroyed by mechanical effects.
- Antagonists elongate and become displaced.

Industrially fabricated open-attachment fittings are mainly supplied in rod lengths (rollers with

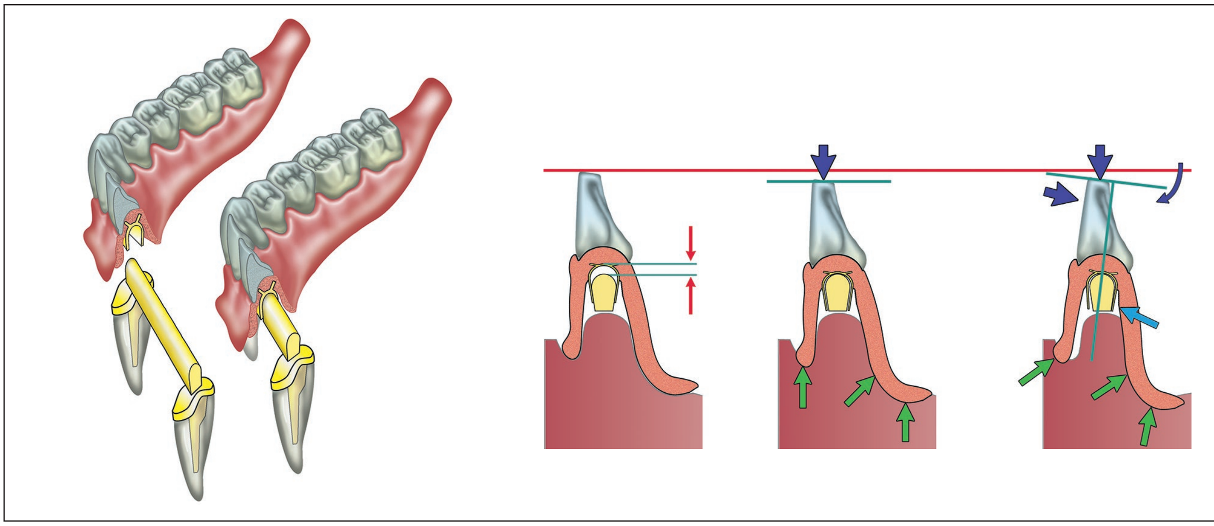


Fig 5-46 An overdenture prosthesis with a Dolder bar has a resilience leeway, which means the mucosa has to absorb loading from masticatory pressure. The Dolder bar anchorage permits rotating movements around the bar axis, which means the denture tilts toward the mucosa. The Dolder bar (jointed bar) has three degrees of freedom: a limited movement within the path of insertion as the resilience leeway, a rotary movement around the bar axis on bilateral loading of the denture, and tilting toward the axis of rotation on unilateral loading.

sleeves), from which the desired length is cut off and integrated into the anchoring crown. Starting from the denture base, a rigid cover is guided onto the primary part, which then covers the attachment as an occlusal rest and performs the function of securing the vertical position. This gives rise to a closed attachment with an occlusal stop on the secondary part.

Resilient attachments have a displaced depth stop that allows the denture saddle to rest on the mucosa in the resting position. In response to masticatory pressure, the mucosa is loaded first; when the resilience of the mucosa is exhausted, the secondary part settles onto the displaced depth stop, and axial forces are transferred to the periodontium of the abutment tooth. There is resilience leeway (interocclusal clearance of approximately 0.2 to 0.5 mm) between the internal and external fitting, but it closes in response to masticatory pressure as mucosal resilience is exhausted; only then is the periodontium loaded. The depth stop can be adapted to the individual resilience response of the mucosa. The result is a denture with mixed (mucosal/periodontal) support.

In severely reduced residual dentitions, resilient attachments are indicated if the remaining dentition is inadequate for complete periodontal support, whether due to periodontal insufficiency or statically unfavorable distribution of the remaining teeth. These concepts are put into practice in complete dentures that cover the existing remaining teeth with resilient telescopes or bar-connected root crowns with resilient attachments (overdenture). The prosthesis in extended form is guided vertically by the remaining teeth, horizontal tipping and twisting are prevented, and masticatory forces are absorbed by the periodontium in a weakened form.

Overdenture prostheses can be supported in the mandible on the root crowns of the canines, which are connected by a Dolder resilient bar attachment where the bar clip has the required resilience leeway (Fig 5-46).

Clinically, resilience leeway cannot be measured accurately, which means either overloading of the mucosa or overloading of the periodontium occurs if the leeway is too small. Settling and loss of resilience leeway occur after lengthy wearing times, which ultimately calls into question the whole concept.

Atrophy of the periodontium is possible if the abutment teeth are only loaded by masticatory pressure above mucosal resilience but otherwise remain inactive.

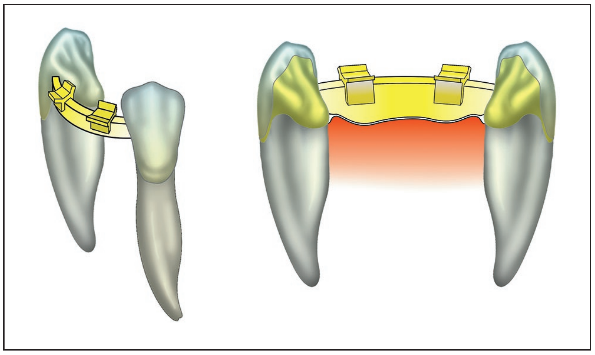


Fig 5-47 Internal parts of bars can be fitted in a straight line or following the curvature of the alveolar ridge.

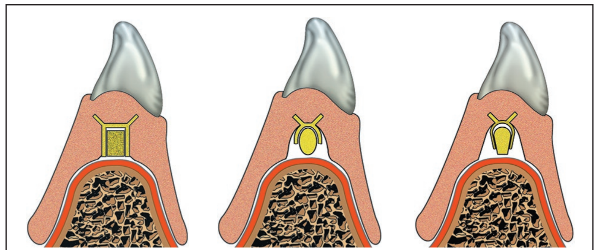


Fig 5-48 The profiles of bars can be divided into round and parallel-sided shapes.

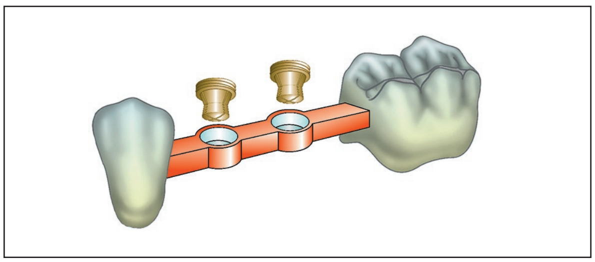


Fig 5-49 Prefabricated bar systems are fitted with anchor eyelets for stud anchors. They provide static positional stability but are unfavorable in terms of periodontal hygiene.

Bars

Bars are manually milled or prefabricated metal connectors between crowns, root crowns, and implant posts. They serve to anchor and support partial dentures in a severely reduced residual dentition. Bars can run in a straight or curved line between the anchoring abutments (Fig 5-47). They can be round, egg shaped, or parallel sided in profile (Fig 5-48); they can be fitted with additional retentive components (eg, stud anchors [Fig 5-49]), or they can carry activatable bar sleeves.

Bars or internal parts of bars are referred to as bar-type attachments with a parallel-sided angular cross-section. Both manually milled and industrially produced components have an occlusally rounded rectangular profile. For reasons of periodontal hygiene, they lie approximately 2 mm away from the mucosa (Dolder bar attachment) or are shaped as contact bars.

Internal parts of bars are fitted with parallel-sided bar sleeves as supporting and anchoring bars; as secondary parts, these provide the defined retentive force by means of static and dynamic friction effects. The Gilmore clip system is a prefabricated bar sleeve that can be placed directly in an acrylic resin base. Rod-type bars are prefabricated square bars with double-conical drill holes into which activatable stud attachments engage.

Bar connectors can be used to create primary, permanent splinting situations. As a result, the residual teeth are rigidly connected to each other and formed into a mechanically solid, functional resistance block that secures the horizontal and vertical position of the denture. Even distribution of stresses becomes possible with full splinting, in which all the teeth are encompassed in the splinted group; where partial splinting is performed, only individual teeth are connected with bars.

Round bars or bars with a drop-shaped (oval) profile have activatable bar sleeves that, once inserted, engage over the widest circumference of the bar profile and ensure defined retention by means of spring forces. The bar sleeves permit movement of the denture around the bar axis and are known as *bar joints* or *resilient bars*.

A Dolder bar joint is a prefabricated, resilient, articulated bar with an oval profile in which the apex is placed nearest to the alveolar ridge. The resilient bar sleeve is adapted to the bar and has

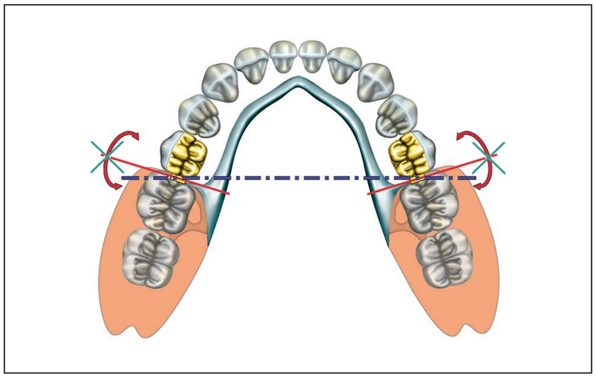


Fig 5-50 Bilateral free-end saddles fixed to the residual dentition with joints must not be joined together with a denture framework. This is because, in addition to parallelization within the path of insertion, this would require uprighting to a common axis of rotation, which is not technically possible even in symmetric residual dentition situations.

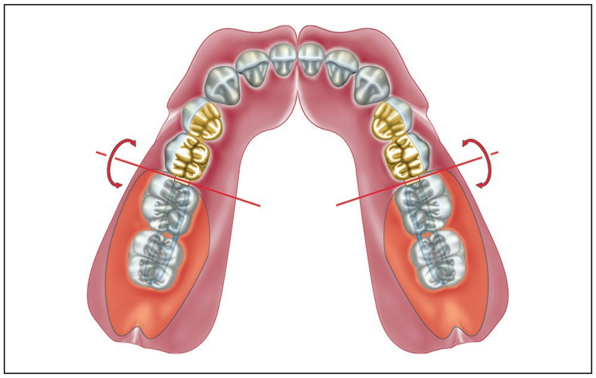


Fig 5-51 Bilaterally shortened dental arches should be fitted with separate monoreducers if anchorage with joints is being attempted; the jointed attachments have to be lockable.

to be widened over the bar curvature when being joined and separated. Resilience leeway is created between the sleeve and the bar. This bar attachment is placed in a straight line between two remaining teeth where it has three degrees of freedom:

- Rotation around the bar axis on symmetric loading
- Rotation around an eccentric axis; on one-sided loading, the bar sleeve sinks toward the loaded side
- Vertical translation on central loading over the bar, then the bar sleeve sinks onto the bar

Any movement of the denture leads to elastic deformation of the bar sleeve, and the denture is returned to its resting position on relief of loading.

Resilient bar articulated attachments (eg, Dolder bar) are used in a residual dentition of two teeth between which a straight bar can be laid onto the middle of the alveolar ridge. Canines are the preferred abutment teeth in the mandible. Performing corrective reduction of the abutment teeth down to the roots will shorten the extra-alveolar lever arm of the abutments and thereby reduce their tipping stress.

Resilient bar dentures have high retention and secure seating; masticatory pressure is transferred from the whole denture base onto the mucosa. After the resilience leeway is exhausted, the bar still has a supporting function. To secure the horizontal position, primary bar splinting offers an adequate resistance block.

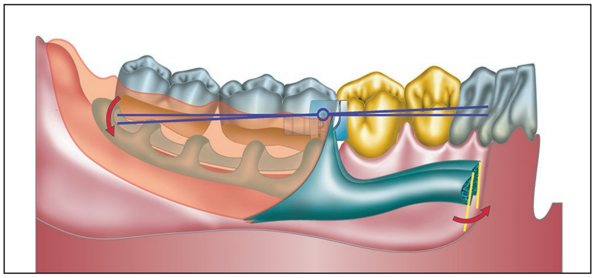


Fig 5-52 Free-end saddles with jointed anchorage settle distally into the mucosa. If the free-end saddle sinks distally, a sublingual bar is lifted mesially and presses against the alveolar ridge.

Hinge joints, which have limited freedom of movement, can roughly replace the function of a resilient bar joint. These anchoring and supporting elements can be used in symmetric residual dentitions for bilateral free-end saddle support (Figs 5-50 to 5-52). Limitation of movement is defined by a depth stop; spring bolts press the hinges back into their starting position on relief of loading.

Limitation of movement becomes necessary to avoid overloading the mucosa and prevent framework components from becoming embedded. In the case of hinge joints without limitation of movement, extremely uneven mucosal stresses arise; these components are unserviceable.

Passive and Active Retention Accessories

Telescopic anchoring and supporting elements gain their defined retentive forces from adhesive and dynamic friction resistance (parallel and conical fittings) or from spring forces of activatable secondary parts (spreadable attachment blades or resilient bar sleeves). To protect the periodontal tissue and compensate for discrepancies in a parallel fit, additional intracoronal retention accessories can be used. These can be divided into *(1)* passive interlocking parts (locks or latches), such as turn-type locks, swivel-type locks, and sliding or push-type locks; and *(2)* active retentions, such as stud anchors and spring bolts.

Locks and latches are passive retentions that are worked together with telescopic components (double crowns or bars). They can be cams, sliders, or bolts that swivel, slide, or turn. They fit into the removable prosthesis and can be moved by the patient into a matching slot (keyway) or drill hole on a fixed primary part in order to anchor the denture firmly.

A turn-type lock is a twistable cam with an eccentric slot (keyway) accommodated in the secondary part (outer telescope). In the resting position, this cam wedges in a slot or drill hole on the primary part (inner telescope), and the prosthesis is locked (Figs 5-53 and 5-54). If the cam is twisted, the telescopic crowns unlock, and the structure can be lifted off without stressing (extruding) the abutment tooth, as occurs with active retentive elements.

A swivel-type lock is a horizontally fitted swiveling slider that is located in the removable part of the denture and can be swiveled into a matching slot on the primary part of a telescopic anchoring component (Fig 5-55). A slide-type lock has a bolt in the removable secondary part, which is locked in a locking catch on the primary part (Fig 5-56). The bolt is guided horizontally and pressed into a locking position by means of a spring. When the matched parts are joined, the eccentric cam of the bolt slides over an inclined surface into the locking catch. To unlock the device, the bolt can be depressed within its guide so that the eccentric cam slides out of the catch.

A lock attachment is a spring-bolt lock that is integrated into a parallel attachment. This prefabricated anchoring and supporting element comprises a flat primary part with a T-profile with a cylindric locking slot recessed into a fitting surface. A spring bolt engages in the slot and can be moved by a second, horizontally guided spring bolt. When the matched parts are joined, the first spring bolt slides into the locking slot. To release, the first spring bolt can be lifted out of the slot by the second, depressible spring bolt, and the parallel attachment is separated (Fig 5-57).

The advantage of locking mechanisms is that the dentures are absolutely firmly seated in their locked state and, after unlocking, can be removed without putting any stress on the abutment tooth. All forms of passive lockable retainers are available as prefabricated components or as prefabricated sets with special tools, but they can also be made manually using dental technology techniques. The technical effort involved is considerable, as is the space required by such components in telescopic anchoring and supporting elements. Locks are not easy to handle and should not be recommended for less dexterous patients.

Active retention accessories are resilient components that can be accommodated in the outer crowns of telescopes or in bar components. In the case of resilient retention accessories, joining and separating forces have to be overcome, which can put stress on the periodontium.

A spring-bolt anchor is preferably housed in the outer wall of a telescopic crown and has a spring-loaded bolt that engages in a slot on the primary part. A ball anchor consists of a metal ball in the outer telescope, which by means of a spring engages in a concave fitting on the internal anchor. A stud anchor is made up of a cross-cut, spherical, secondary part that engages in a double-conical drill hole. Stud anchors can be housed in bar stubs or rod-type bars and are only used in combination with telescopic supporting elements.

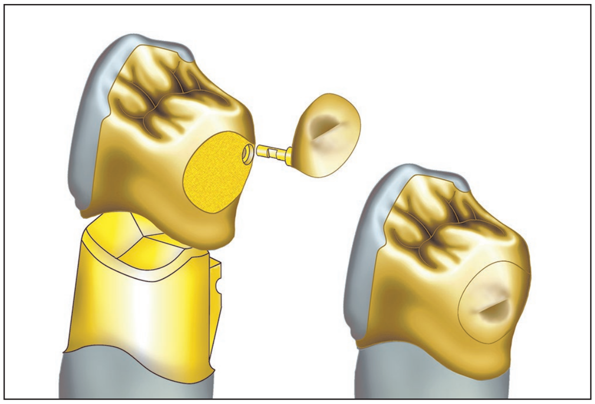


Fig 5-53 Passive, lockable retainers include turn-type locks. A turnable cam (latch pin) is housed in the outer telescope. In the resting position, the latch pin engages in a slot on the inner telescope. To unlock, the pin is turned, and the structure can be lifted off.

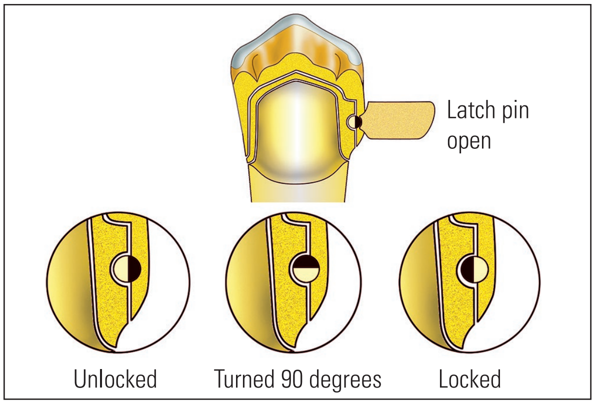


Fig 5-54 Interlocking between the primary and secondary crown by a turn-type lock is achieved by turning the latch pin 180 degrees.

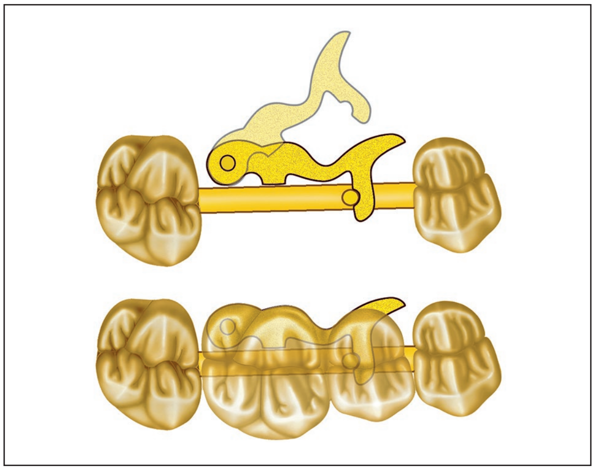


Fig 5-55 A swivel-type lock belongs to the group of passive, lockable retentive elements. The lock is housed in the outer telescope and can be swiveled around a pin or into a slot on the inner telescope. To unlock, the swivel arm can be twisted outward.

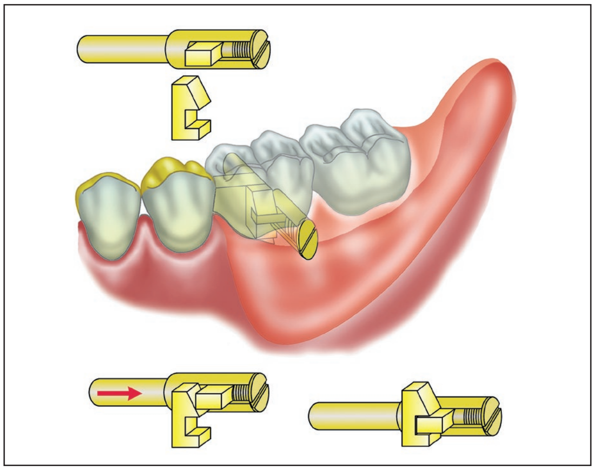


Fig 5-56 With a slide-type lock, the bolt of the lock is pushed into the resting position by means of a spring. The lock slides over an inclined surface into the locking catch. To unlock, the bolt is manually depressed from the outside.

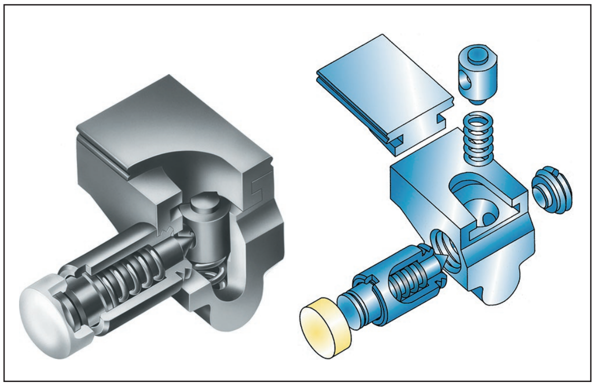


Fig 5-57 The Robolock lock attachment from ZL Microdent is a rigid retentive element used for locking unilateral cantilever dentures and removable partial dentures. The screw-fastened guide sleeve of the lock can be inserted from both sides so that it can be used on the left and right. The denture is loosened from its anchorage by gentle pressure applied to the pin screwed into the side.

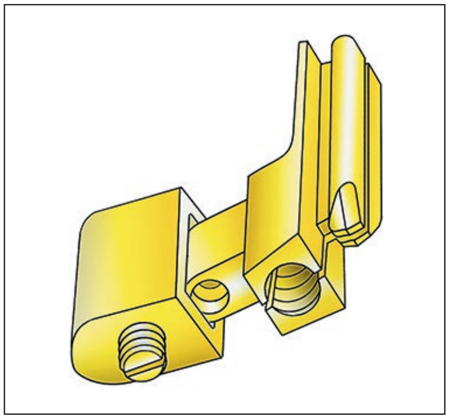


Fig 5-58 The design of the T-attachment in the multi-CON system is a double cylinder that can be spread over the activation body.

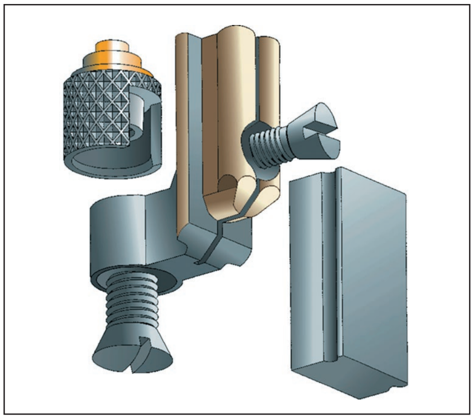


Fig 5-59 The design of the DuoLock attachment is the same as that of the multi-CON attachment. Both have replaceable secondary parts.

Prefabricated Attachments

T-attachments are simple, box-shaped attachments in which the matched parts have a rounded T-profile. The primary part often has a central activation slot that goes through to the bar, so that the sliding surfaces can be pushed apart and the attachments are activatable. Depending on size, they are suitable for placement within or outside the crowns. These rigid anchoring and supporting elements gain their retention from resistance to static friction.

The multi-CON system (DeguDent) provides rigid anchoring and supporting elements where the flat primary part can be positioned intracoronally and the secondary part is available in three different versions for different indications (Fig 5-58). The secondary part is made up of the T-shaped sliding profile, the activation body, and a retention bar that is engaged in a retention sleeve (Fig 5-59). The activation body runs either horizontally (multi-CON 90) for use with flat alveolar ridges, or it is shifted in a basal direction for atrophied alveolar ridges (multi-CON 1). The third version (multi-CON TR) is a flat secondary part that cannot be activated or exchanged; it is used as a passive stress-breaker attachment for prospective planning of restorations.

In the case of the activatable secondary part, the activation screw engages in the activation body from the base and is able to push the sliding surfaces apart in parallel, which means the joining and separating forces can be precisely measured.

The primary part is supplied as a high-fusing prefabricated component for soldering or casting on as a spacer matrix or as an erosion electrode. The closed retention box has a basal, conical drill hole and can be soldered or bonded to the framework.

In dovetail attachments, the sliding profile is triangular. These attachments can also be activated via an activation slot in the secondary part. They are rigid and relatively sturdy attachments for anchoring free-end saddles. Generally speaking, dovetail attachments are used for interdental saddles and removable partial dentures and mounted intracoronally.

The dovetail attachment according to Crismani can be integrated intracoronally (Fig 5-60). Both parts of the attachment are made from a high-fusing gold-platinum alloy for direct casting on with other gold-platinum alloys or for soldering in place. The secondary part is slotted throughout its length and is spread to activate it. The height of the attachment can be shortened to the required proportions; preparation must be done from the top down with the attachment parts put together.

Roller attachments are connectors with limited rigidity for intracoronal and extracoronal placement. The cylindric component engages in an activatable sleeve open on one side.

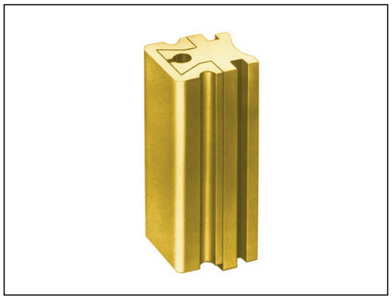


Fig 5-60 The closed, activatable dovetail attachment is used with a circular notch and shear distributor.

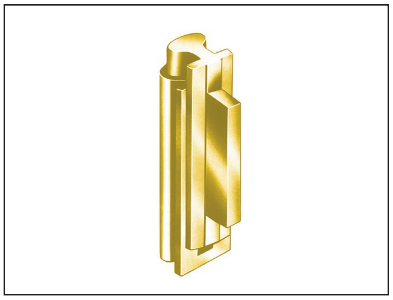


Fig 5-61 The precision attachment from Degussa is a small, closed, and activatable roller attachment.

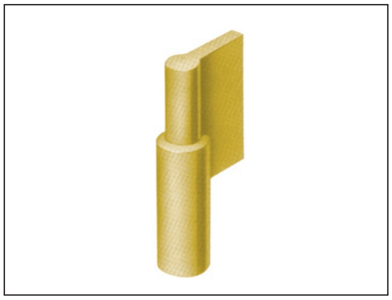


Fig 5-62 The special attachment is a simple, open roller attachment that can be activated to a limited extent.

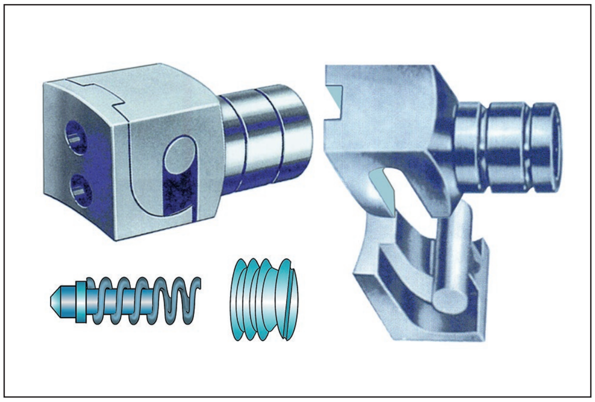


Fig 5-63 The FM hinge joint is used for unilateral free-end saddles with two or three teeth (monoreducer); bilateral free-end saddles must not be joined transversally. Rotary movement is limited by a stop. On loading of the free-end saddle, a hinge movement presses the spring bolt back into its guide; when loading ends, the spring bolt returns the free-end saddle to its initial position.

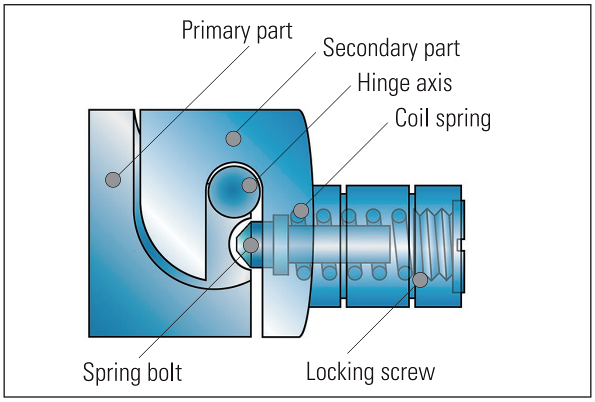


Fig 5-64 Components of the FM hinge: Both parts of the joint are directed horizontally by a parallel guide. When the parts of the joint are joined, the spring bolt engages in a slot on the primary part, and both parts lock. Coil springs and spring bolts are replaceable.

The precision attachment from Degussa is a small, rigid, activatable roller attachment for removable partial dentures and fixed partial dentures (Fig 5-61). The secondary part has a spring blade in the gingival third, which means a cam can engage in the slot on the primary part.

Degussa's special attachment is a roller attachment that has limited rigidity (Fig 5-62). It comprises a slotted sleeve and a roller with a bar extension, which are supplied in gold-platinum and in high-fusing gold-platinum alloy. This special attachment is supplied in two thicknesses and is available in rod lengths of 50 mm for efficient working.

The special attachment is suitable as an interlock attachment because the sleeve is placed approximally between two abutment teeth with the roller acting as the secondary part. The roller can also be integrated with a connecting bar extracoronally to the anchoring crowns as the primary part, while the sleeve is occlusally closed and fixed in the removable restoration. Roller attachments are supplied in prefabricated profiles and separated into suitable lengths. They are used as stress-breaker attachments because of their small dimensions.

Articulated attachments are available in various designs; the most common is the Dolder bar joint. Other designs include the FM hinge joint (Figs 5-63 and 5-64) and the Ancorvis hinge stress breaker (both from Degussa). These articulated attachments are not suitable for simultaneous bilateral use but for unilateral use only.

Root Crown Anchors

Root crown anchors are prefabricated anchoring components that are placed onto root pin crowns. They are used to anchor hybrid prostheses.

Root crown anchors for hybrid dentures are prefabricated systems comprising sleeve and cylinder, annular spring and spring sleeve, or press-stud as well as bar systems. These anchoring systems are designed for placement on root crowns. If a rigid connection is intended, several anchors are placed in one jaw because rotary movements occur around the vertical axis. Root crown anchors are supplied as partly rigid or resilient anchors (Figs 5-65 and 5-66). Retention is achieved by static friction and resilient restraints (Figs 5-67 and 5-68). The anchorage according to Rothermann (Degussa), the Dalbo anchor (Degussa), the retention cylinder by Gerber, and the Dolder bar are examples.

The Rothermann anchorage system is a form of root crown anchorage that can be used as a rigid and a resilient connector. The primary part consists of a flat cylinder with a circular channel into which the secondary part engages in the form of an open spring clip. The secondary part has saddle retentions for integration into the plastic base. The flat design means it can be used in situations with very limited space.

Dalbo anchors are press-stud–like anchoring elements in which the primary part is a small cylinder stub or a ball-head, and these are fitted onto root crowns. The secondary part is an activatable sleeve with four slots, which is polymerized into the denture base. They are resilient root crown anchors for partial and hybrid prostheses. The Dalbo cylinder is rigid in the horizontal plane and permits vertical and rotary movements. The blades of the secondary part engage over the spherical or cylindric primary part and can be pressed inward to be activated. During assembly, a polyvinyl chloride ring is pushed over the secondary part; it is polymerized into the acrylic resin base and remains in the finished denture. In addition, during assembly the supplied tin disc is incorporated as a spacer between the two parts of the attachment to create the resilience leeway. The Dalbo anchor with a ball-head (Degussa ball-anchor system) has only limited rigidity, even when it is used in combination with several single anchors.

The Gerber retention cylinder is a root crown anchor for removable partial dentures or fixed partial dentures as well as overdentures. The primary part, the retention core, is a replaceable cylinder pin with a ring groove; an annular spring that is open on one side and integrated into the secondary part engages in this groove. The retention core is screwed onto a solder base for the root crown. The secondary part is a sleeve housing with retentive surfaces for anchoring in the denture acrylic resin. The annular spring located in the housing of the secondary part snaps into the ring groove on the retention core when the parts of the anchor are joined together. The replaceable annular spring is held in the sleeve housing with a threaded ring.

The root crown to receive anchors is fixed in a prepared root canal of the abutment tooth with a root (endodontic) pin. Preparation of the root is based on the described principles for pin anchorage in devitalized teeth, with circular enclosure of the root and auxiliary cavity. The root crown satisfies periodontal hygiene requirements and must not cause mechanical irritation to the marginal periodontium. It covers the root preparation as far as the gingival crevice and allows the denture base to engage bodily if rigid anchorage is the aim. For this purpose, the crown surface is made smooth and sharp-edged and has a circular chamfer; the crown walls are slightly tapered.

Table 5-1 outlines the various functions, hygiene considerations, reparability, and indications for different telescopic components.

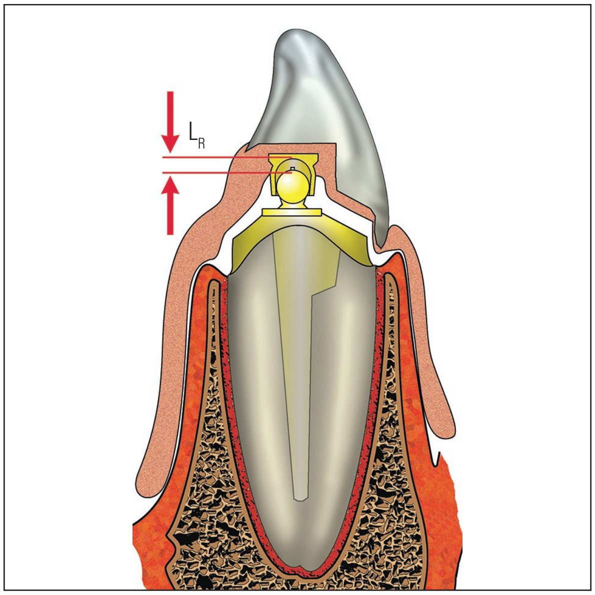


Fig 5-65 Quasi-complete dentures can be anchored onto root preparations fitted with root crowns; the root preparations are fully covered by the denture. These structures are known as *hybrid prostheses* or *overdentures*. Anchorage can be achieved with ball anchors and resilient sleeves. The anchorage components have resilience leeway (L_R) that relieves the root preparations.

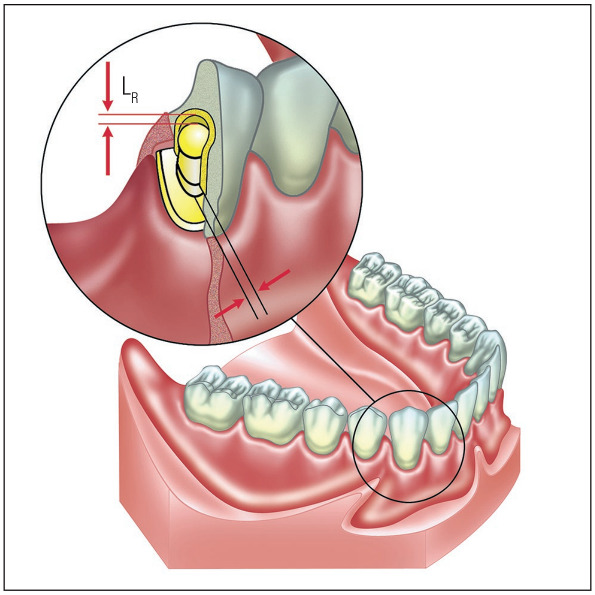


Fig 5-66 If two canine root preparations are used for support, the horizontal position is secured; vertical position is secured via two supports: the mucosal support and the periodontal tissues of the canines. This structure can be successful for decades if encapsulation of the marginal periodontium is offset by rigorous oral hygiene.

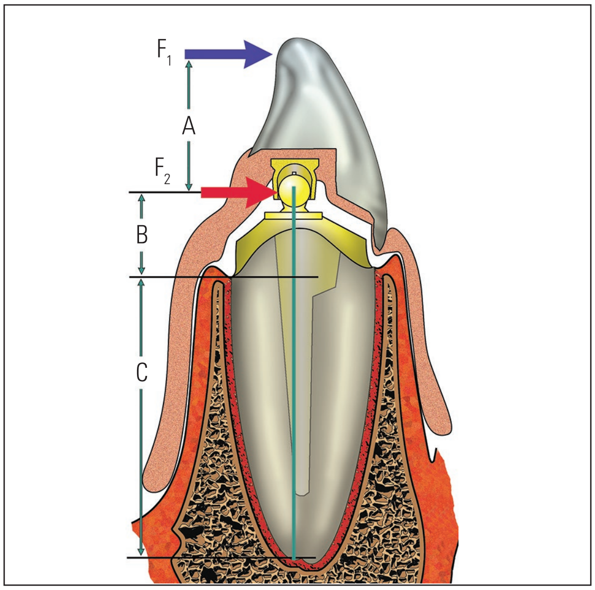


Fig 5-67 Support on root crowns with ball anchors or bars has static advantages: The force exerted (F_1) acts on the denture with a lever arm (A) on the denture rest area and the movable connection at the root crown. At the root crown, the force (F_2) acts with the force arm (B) at the fulcrum, which is far shorter than the load arm (C) in the root area.

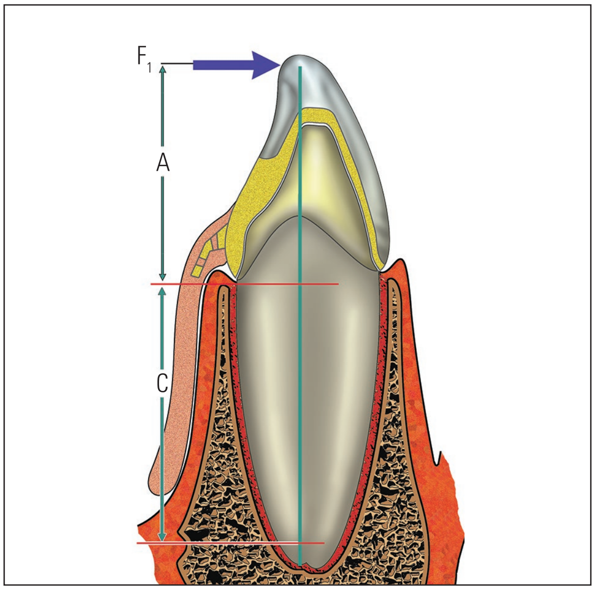
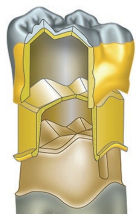
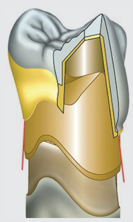
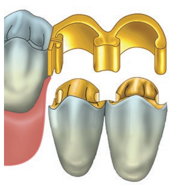
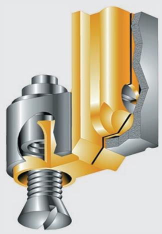
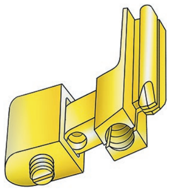


Fig 5-68 Lever relationships that consist of a force arm (A) on a telescopic crown and a work arm (C) in the root area are far less favorable with a telescopic crown.

Table 5-1 Telescopic components

Component	Supporting function of the securing horizontal	Anchoring function of the defined retentive force
Telescopic crown: • Parallel-guided double crown • Fixed inner crown • Removable outer telescope • Tooth-colored veneer 	Rigid connecting element: • Absolutely secures the horizontal and vertical position • Secures supporting function • In a group, they provide very good splinting of abutments	Matched parts anchor by means of static and dynamic friction: • Retention is not calculable • Retention is dependent on: – Fitting tolerances – Surface quality – Size of contact surfaces
Conical crown: • Double crown with conical fitting surfaces • Fixed inner crown • Removable outer crown • Tooth-colored veneer 	Rigid anchoring and supporting element: • Firmly secures the horizontal and vertical position • Secures supporting function • In a group, they provide very good splinting of abutments	Matched parts are retained by means of static friction in the final position: • Retention is defined and can be determined in advance due to: – Variable taper angle – Joining force
Circular notch with shear distributor: • Parallel guidance on lingual wall of crown • Approximal finishing groove • Cervical shoulder 	Stabilizing element with cervical shoulder: • Secures the vertical position very well • Secures the horizontal position only in interaction with combined attachment • With a stud anchor, rigid coupling is not possible	No inherent retentive forces: • Only in conjunction with anchoring elements such as: – Stud anchors – Activatable attachments
DuoLock attachment: • Rigid parallel attachment • Secondary part a double cylinder • Flat primary part 	Rigid connecting elements: • For rigid coupling • Closed attachment • For periodontal support • Extended proximal bars protect against rotation and tipping • Lingual circular notch is necessary	Defined retentive forces due to the following: • Spring blades can be activated to a defined extent • Slotted bar is spread with conical activation screw
Multi-CON system: • Rigid T-attachment • Flat primary part • Secondary part in three versions 	Rigid connecting elements: • Closed attachment • For periodontal support • With lingual circular notch, provides absolutely rigid coupling and securing of horizontal position	Defined joining and separating forces: • This occurs because of spring blades that can be activated to a defined extent • Basal activation screw pushes sliding surfaces apart in parallel

Periodontal hygiene and cleanability	Handling and reparability	Indications and affordability
Double-walled crowns: • Have large space requirement • Because of anatomical tooth shape, they have surface bulges conducive to periodontal hygiene • Plaque accumulation possible in fitting gaps and additional retainers	Best handling for patients: • Can be readily inserted • Adequate accuracy of fit • Subsequent incorporation of friction plugs if retention is poor • Minimal reparability • Retentive elements can be replaced	Broad range of uses: • Used for fixed and removable partial dentures • Teeth are substantially prepared • Cannot be used in teeth with a large pulp cavity • Medium life span • Sufficiently economical
Conical crowns: • Have medium space requirement • Are very good for periodontal hygiene because of anatomical surface bulges • Result in no plaque accumulation in fitting gaps	Good handling for patients: • Easy to use • Good accuracy of fit • High joining forces lead to wedging with very high separating forces • Minimal reparability • Cannot be replaced	Universal use: • Used for fixed and removable partial dentures • When used in a group, the residual dentition is splinted • Cannot be used in teeth with a large pulp cavity • Medium life span • Economical
Shear distribution arms: • Sunk into the crown wall • Have surface bulges conducive to periodontal hygiene • Plaque accumulation is possible in fitting gaps • In case of press-stud anchorage, mucosal irritation could occur in the tooth-denture interface	Good handling for patients: • Offers good guidance for prefabricated attachment • Not reparable • Cannot be replaced	Universal use: • Used for fixed partial dentures • Used for teeth undergoing substantial corrective reduction • Cannot be used in teeth with a large pulp cavity • Medium life span (approximately 6 years) • Sufficiently economical
Primary parts are flat: • Flat surface allows for intracoronal integration • Primary part covers marginal periodontium slightly • Secondary part has gingival contact • No encapsulation spaces • Good cleanability • Satisfactory in terms of periodontal hygiene	Handling is problematic: • If circular notch is present, handling is good • Very good accuracy of fit • Activatable for permanent retentive forces • Worn parts are replaceable • Very good reparability	Universal use: • Used for partial cantilever and interdental dentures • Can be integrated with all full crowns • Used in anterior area • Bonded, soldered, and cast on • Long life span • Very economical • Technical fabrication is straightforward
Primary part is flat: • Flat surface allows for intracoronal integration • Activation body in the secondary part runs horizontally or is displaced basally • Has gingival contact • No encapsulation spaces • Safe in terms of periodontal hygiene	Handling is good: • But only with circular notch • Very good accuracy of fit • Activatable for permanent retentive forces • Worn parts are replaceable • Very good reparability	Universal use: • Used for dentures and prospective planning as stress-breaker attachment • Used for flat, atrophied alveolar ridges • Bonded, soldered, and cast on • Spacer technique, erosion technique • Very long life span • Economical

Processing Prefabricated Attachments

Following are the steps for processing a prefabricated attachment fitting (Fig 5-69):

1. Crown frameworks are waxed up and, if necessary, given a circular notch for a shear distributor.
2. In a parallelometer, the primary part is integrated into the crown frameworks with a paralleling mandrel.
3. Integration can be done by:
   - Soldering the component into a recess in the crown framework
   - Casting on; joining together directly with alloys that can be cast on
   - Bonding into a recess in the crown framework
   - Using a spacer technique with a shaped spacer
   - Spark erosion with a forming electrode
4. The primary part is captured with modeling wax over the entire length at a minimum layer thickness of 0.3 mm.
5. One of the following is done to the wax crown framework:
   - It is invested with the waxed-in component for the casting-on process.
   - The component is removed from the wax template so it can later be soldered or bonded in place.
   - It is invested with the spacer.
6. After casting, the crown framework is finished; if the component is to be soldered or bonded, the recess/spacer sleeve is cleaned (airborne-particle abraded). The edges of the recess are beveled slightly. For soldering, a notch is milled into the lingual side wall.
7. Components are shortened to the occlusion level. It is important to check beforehand whether the remaining attachment surface is still adequate. The secondary part is also shortened to the occlusion level.
8. A duplicating aid is then inserted, on which the retention sleeve for the secondary part sits.
9. The retention sleeve (or the secondary part) can also be cast on, soldered on, bonded, or directly fixed in the denture acrylic resin.
10. The denture framework with the shear distribution arm is modeled on an investment cast in the model casting technique, encompassing the retention sleeve.
11. After casting, airborne-particle abrasion, and finishing, the retention sleeve is fixed using the chosen method and the secondary part is screwed in place.

Prefabricated attachments consist of the primary part, which is known as the *matrix* irrespective of its geometric shape, and the secondary part, which by analogy is called the *patrix*. Primary parts are supplied in different alloys for casting on, soldering on, or bonding; they are available as spacer matrices or as erosion electrodes. The parts supplied include modeling parts made of plastic as primary part spacers for the soldering and bonding techniques, as well as cast-on spacer sleeves for the soldering technique. Secondary parts have multiple components and comprise the patrix, the retention sleeve, and the activation and retention screws. For model casting fabrication, duplicating aids and modeling patrices with retention sleeves are available.

The special tool kit contains a torque screwdriver with blade insert, the patrix holder, a screwdriver for activation, retention screws, and a carbon splint as a fixing aid for soldering model fabrication.

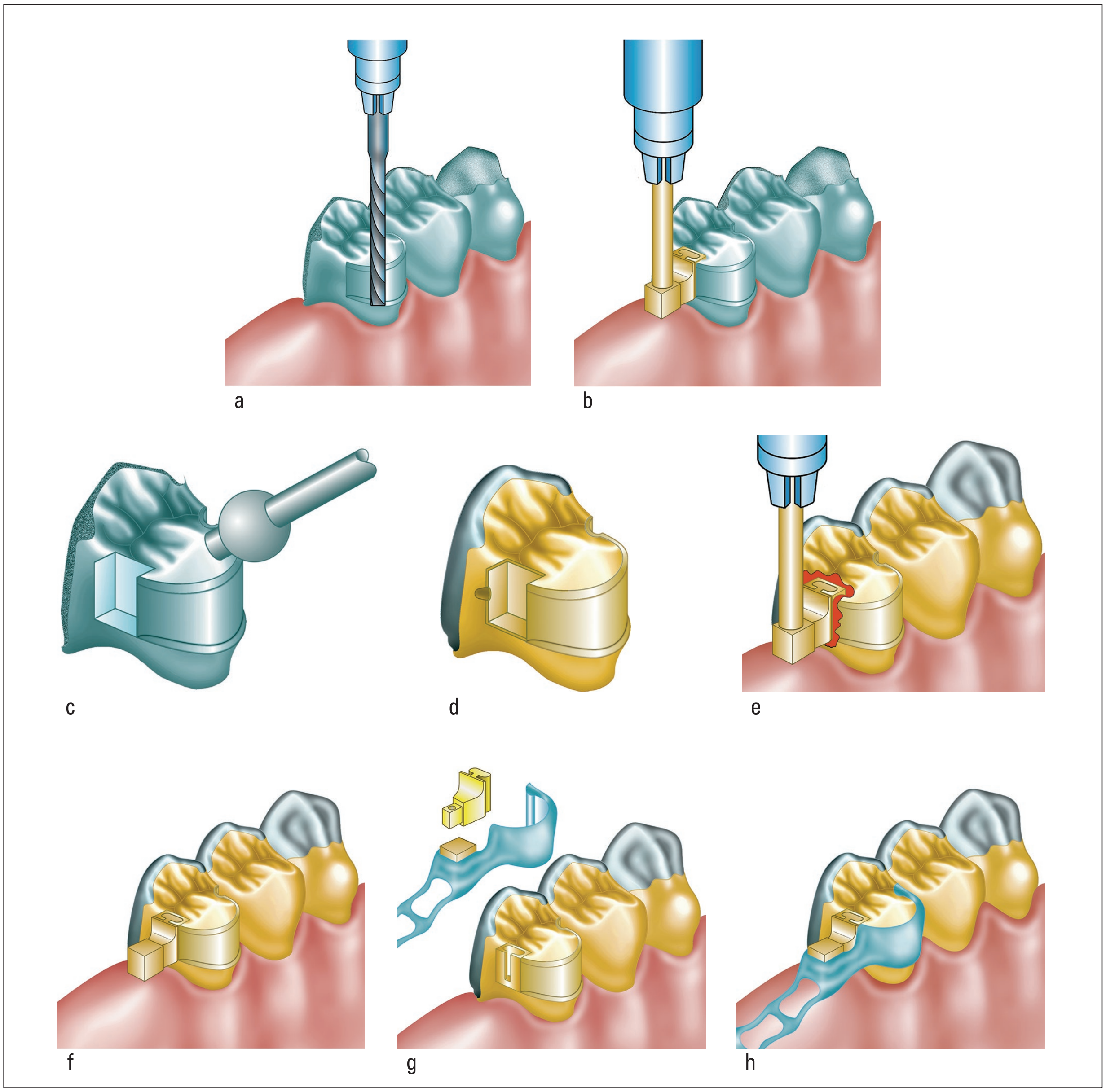


Fig 5-69 Basic procedure for processing a prefabricated attachment fitting. *(a)* The crown framework is waxed up in casting wax and, if necessary, given a circular notch. *(b)* The attachment part is positioned parallel to the circular notch with the parallelometer. Methods for doing this include recess for soldering, casting-on technique, spacer technique, or spark erosion. *(c)* So that the primary part can later be soldered in place, a recess is created or a cast-on spacer is modeled in. *(d)* The recess for soldering is prepared: The edges are beveled, and a small notch to receive the solder is milled. *(e)* The attachment is inserted with the parallelometer, fixed with sticky wax, and soldered onto a soldering model. *(f)* The attachment is shortened occlusally, and the secondary part with the retention sleeve is inserted and prepared for model casting. The denture framework embraces the retention sleeve and forms the shear distributor. *(g)* The retention sleeves of the secondary parts are usually bonded in place; cast-on retention sleeves can be invested at the same time in the casting-on technique. *(h)* The secondary part is screwed in and, together with the shear distributor, must be capable of being joined and separated smoothly.

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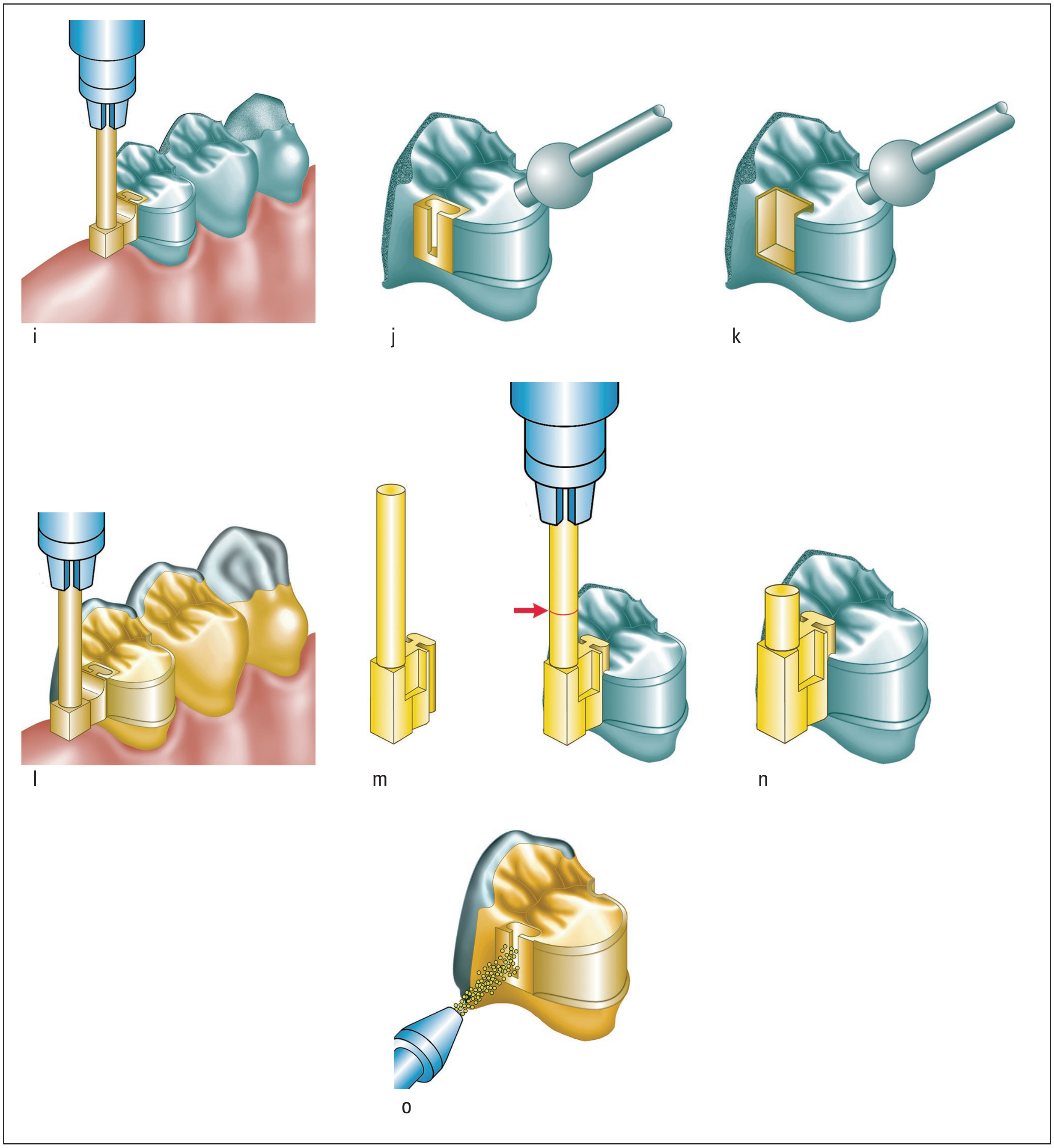


Fig 5-69 *(cont) (i)* Cast-on attachment parts are fitted into place in the parallelometer and modeled into the crown framework. *(j)* Cast-on attachment parts made of high-fusing alloys are invested at the same time. *(k)* For bonding the primary part in place, a cast-on spacer is waxed in; the spacer protrudes above the wax-up for fixation in the investment material. *(l)* The attachment part is fitted into place after casting and bonded into the finished crown framework with the aid of the parallelometer. *(m)* The spacer is made of ceramic; with the shaft part, it is clamped into the parallelometer and modeled into the crown framework. *(n)* The shaft part of the spacer is unclamped, trimmed with a diamond separating disk, and invested with the crown framework. *(o)* After casting, the spacer is airborne-particle abraded with glass or plastic beads at 2 bars; the secondary part is fitted into place.

Integrating Prefabricated Components

Soldering, the most common method of joining components, is multipurpose and easy to use. Soldering involves joining metallic materials in their solid state by means of an added molten material. At working temperature, the solder flows into a narrow solder gap and completely fills it. The melting temperature of the solder is slightly below the solidus temperature of the basic material, and diffusion causes the solder to mix with the alloy in the border area (diffusion zone) of the solder gap. The following requirements must be met for the diffusion zone to form:

- The working temperature of the solder is matched to the alloy.
- The composition of alloy and solder are matched.
- The oxide layer is prevented by flux.
- The surfaces being soldered should be roughened.
- Narrow parallel solder gaps should be shaped to use capillary action.

For soldering, the component is positioned in the parallelometer with a paralleling mandrel and fixed into the recess created on the crown framework. In the soldering model, the component is fixed with a carbon splint. The solder gap and milled notch for placing the solder must be readily accessible.

Casting on is a method of joining components in which a solid material is wetted with a liquid alloy during casting. Unlike soldering, the second component being attached is liquid when melted onto the first component. The molten mass must increase the temperature of the cast-on part so much that a diffusion zone is formed in the solid cast-on material and a metallic join is created. The recommendations for casting on include the following:

- Only use special cast-on alloys.
- The melting range of the cast-on alloy must be higher than that of the molten alloy.
- The cast-on part should be preheated to working temperature.
- The cast-on alloys do not form an oxide layer during preheating.

If the solidus point of the cast-on alloy and casting temperature are too close, hot molten material may penetrate the thin walls of the cast-on parts. As a result of expansion differences between the investment material and cast-on part during preheating and casting, gaps may arise between the investment and the cast-on part, and the liquid alloy may run into the cast-on part. If the coefficients of expansion differ between the casting alloys and cast-on part, the cast-on components may deform as they cool, and casting stresses may cause the component to separate or shift its position.

The spacer technique is a combination of soldering and casting on, which can compensate for processing difficulties during casting on. For intracoronally placed components, a spacer sleeve made from castable alloy is used. The spacer is dimensioned so that, after casting on, slight changes to the position of the primary part can be made before it is soldered in place; casting stresses affecting the spacer that are caused by casting on can thus be compensated for.

The bonding technique for joining components in crown and denture frameworks replaces soldering or casting on. The surfaces of the components to be bonded are airborne-particle abraded with alumina and coated with adhesive. The synthetic dual-component adhesives (powder/liquid or paste/paste) are organic compounds that set when cold as a result of chemical reactions, or setting is triggered and accelerated by exposure to light. The specially developed adhesives are biocompatible and dimensionally stable up to 120°C so that hot-curing denture acrylic resins can be used.

The spacer technique is a method for fabricating a primary fitting part of an attachment with the aid of a molded part (spacer). The spacer retains space in the shape of the secondary part; it is made of alumina and has an extremely smooth surface and a high melting point (2,045°C). The spacer is integrated into the wax template of the anchoring crown and invested with the crown wax-up. The casting metal is cast directly onto the spacer, which is then airborne-particle abraded to create the appropriate fitting surface in the anchoring crown.

The procedure starts with waxing up of the crown frameworks, in which a circular notch is created. Once the blades (lamellae) of the spacer have been coated with a thin layer of modeling wax, the spacer shaft can be clamped in the paralleling mandrel in order to place the lamellar part intracoronally in the crown framework in the path of insertion. The circular notch is taken up to the spacer. The spacer shaft is then unclamped and separated at its marking with a diamond separating disc so that part of the spacer protrudes out of the wax template to provide retention in the investment material.

Investing and casting are performed as usual. Expansion of the investment material has no influence on the size of fitting surfaces after casting. After casting, the spacer can be blasted out of the cast part with glass or plastic beads at a maximum of 2 bars.

Spark erosion is a processing method in which the material is removed by means of electric arcs or periodic spark discharges between the tool (negative electrode) and the workpiece (positive electrode), whereby both parts are separated by a nonconductive working medium known as the *dielectric*. The electrode has the negative shape of the primary fitting part. As a result of the discharge processes, the material particles are removed by melting and vaporizing and flushed away by the dielectric. In dental technology, specially shaped graphite and copper electrodes are used to erode very accurate shapes of fitting surfaces for attachments, bars, grooves, and locks.

Fabricating a Three-Unit Partial Denture and Inner Telescope

Figure 5-70 diagrams important considerations regarding fabrication of the partial denture and inner telescope, and Figs 5-71 to 5-73 diagram the error analysis considerations. The steps for fabrication of the three-unit partial denture are as follows:

1. Fabricating the milling base (Fig 5-74)
2. Waxing up the telescope (Fig 5-75)
3. Waxing up the partial denture (Fig 5-76)
4. Casting and fitting on the cast objects (Fig 5-77)
5. Ceramic veneering (Fig 5-78)
6. Finishing the milled work and polishing (Fig 5-79)

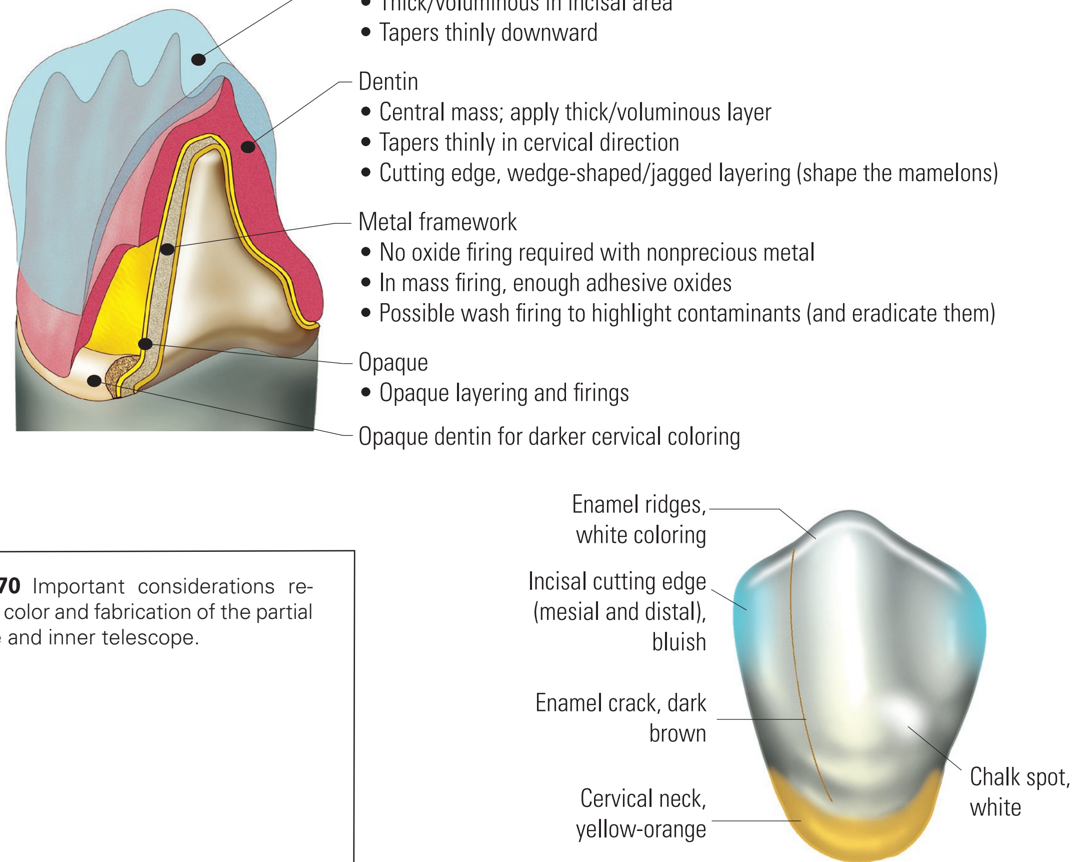


Fig 5-70 Important considerations regarding color and fabrication of the partial denture and inner telescope.

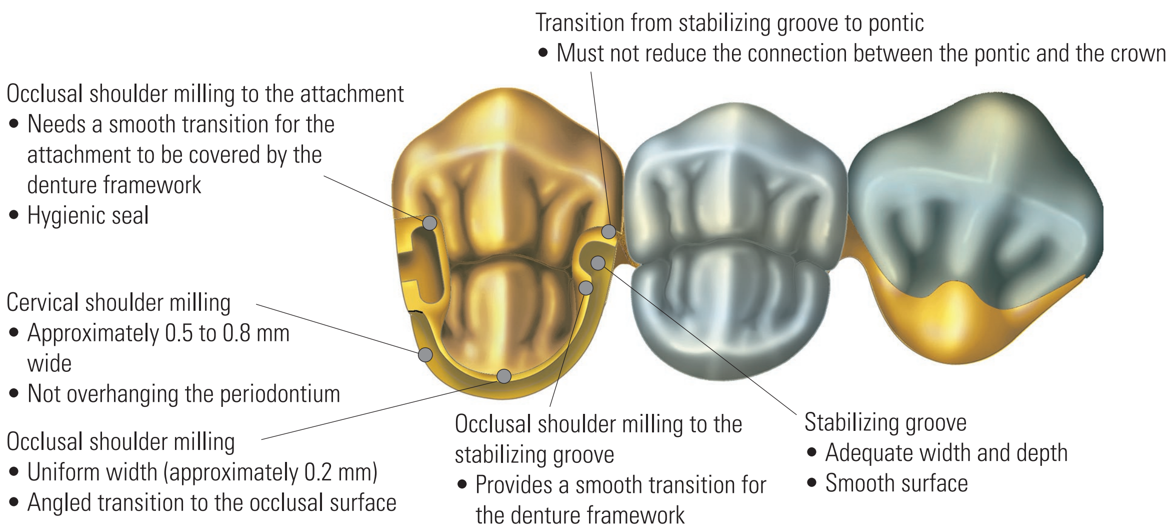


Fig 5-71 Error analysis facts found in this occlusal view of a circular notch.

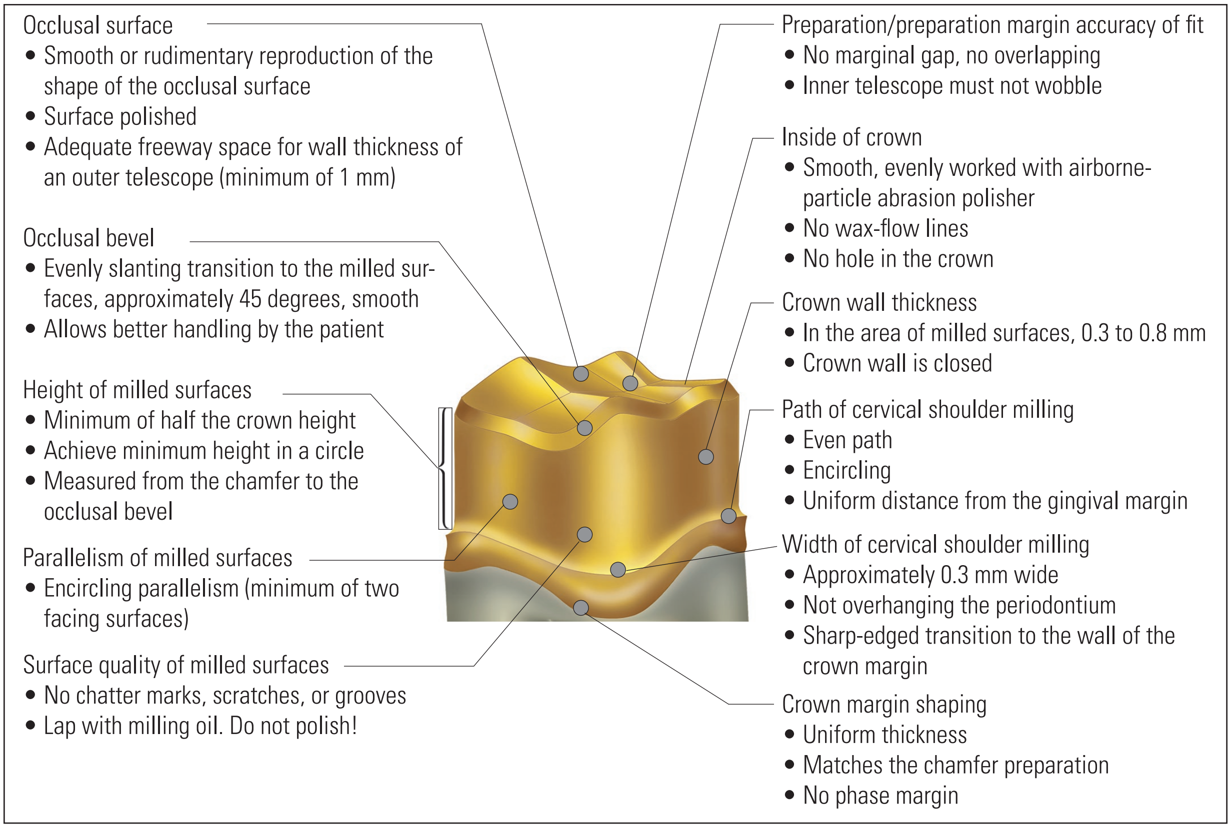


Fig 5-72 Error analysis facts found for an inner telescope.

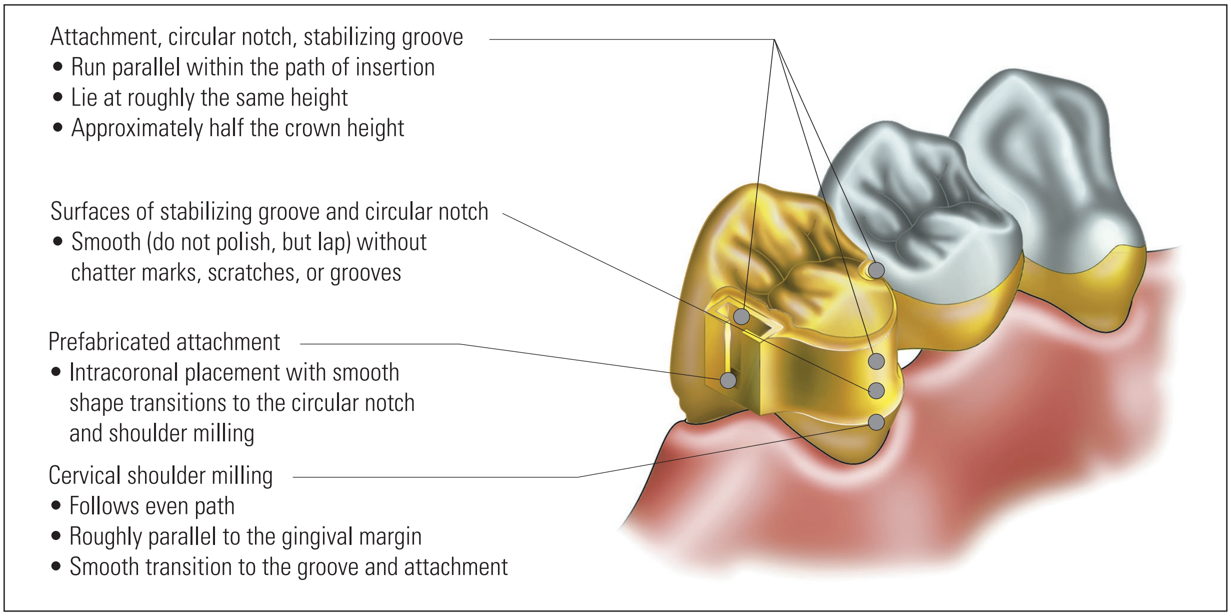
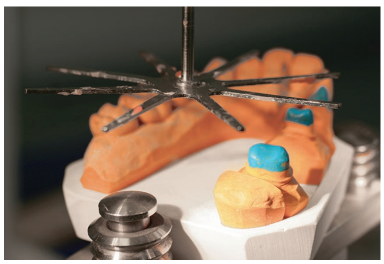


Fig 5-73 Error analysis facts found for a circular notch.

a

Sawn, sectioned model

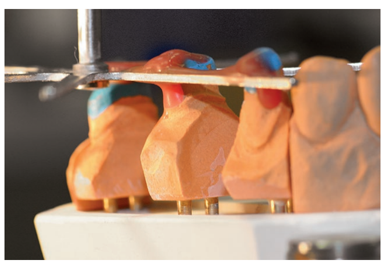
- Set up on the milling machine in the model holder.
- Determine the path of insertion with a surveying rod.
- Allow for the position of attachment, stabilizing groove, and telescope; pay attention to wall thicknesses.
- Ensure slight mesial tipping.
- The attachment lies cervically on the die.
- The stabilizing groove is set back cervically from the die.
- The telescope has uniform wall thickness.



b

Transfer spider

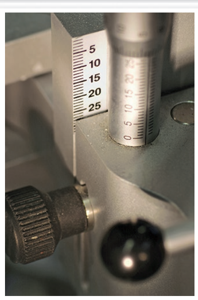
- Insert and establish a depth stop on the milling machine.
- Bring the transfer spider in contact with all the dies.
- Stably fix the dies onto the transfer spider with sticky wax.
- Magnetically establish the swivel arm and model holder.



c

Die segments

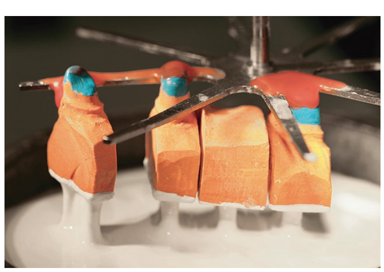
- First detach swivel arm, then the depth stop.
- Carefully extract die segments from the model base.
- Spray dies with plaster isolating agent and leave to dry.
- Handle everything with great care because of the risk of fracture.



d

Depth stop

- Locate the depth stop on the milling machine for the milling base.
- Use a glass plate to provide an absolutely flat surface.
- For better hold during remilling, work with magnetic adhesive disc or magnetic auxiliary molds.
- Fabricate the base to be as flat and broad as possible to ensure stability.

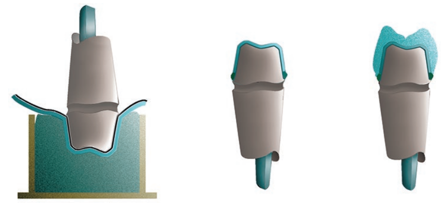


e

Milling base

- Place the correct amount of base plaster on a glass plate or mold.
- Fix the swivel arm of the milling machine.
- Lower the isolated dies into the plaster to the depth stop and leave to set.
- Do not embed dies too deeply in the base plaster.
- Ensure adequate fixation and stability.

Fig 5-74 Fabricating the milling base. *(a)* Set up the sawn, sectioned model. *(b)* Insert the transfer spider. *(c)* Lift out the die segments. *(d)* Locate the depth stop. *(e)* Shape the milling base.

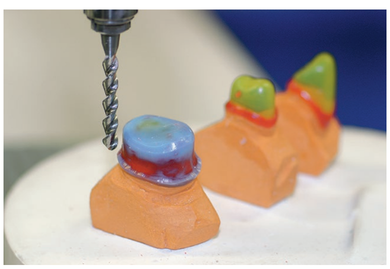


a

Underlining foils
- Heat up the underlining and spacer foil.
- Press the die into the foil/modeling material.
- After cooling, extract the die.
- Cut off foil 1 mm above the preparation margin.
- Take out spacer foils and mark out the crown margin.
- Immerse the coping.
- Pay attention to wax temperature.
- Withdraw steadily from the wax bath.

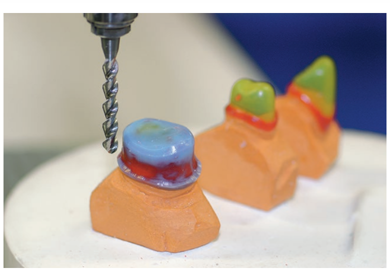
b

Red cervical wax
- Thinly place a warning layer over the wax or acrylic resin coping (to indicate minimum thickness when milling in wax).
- Generously apply milling wax to create the shape of the eventual milled surfaces.
- Apply cervical wax at the crown margin.
- Apply a thin layer of wax to the occlusal surface.
- Pay attention to freeway space.
- Create the rudimentary shape of occlusal surfaces.



c

Milling surfaces
- Take up a suitable wax cutter (3-mm diameter).
- Do not create chatter marks or grooves in wax.
- Pay attention to wall thickness:
  - → A red warning layer is visible in the cervical wax.
  - → Check with a wax gauge (maximum of 0.6 mm).
- Cervical shoulder milling follows a gingival course.
- There is a sharp-edged transition to the crown margin.
- The crown margin is uniformly thin to protect the marginal periodontium.



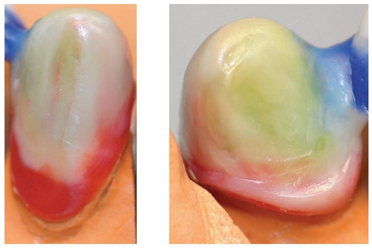
d

Parallel milling
- Uniformly adjust the height of the milling surfaces (half the crown height).
- Remill wax until smooth (with a spiral wax cutter or sharp blade and at a low speed).
- Mill the cervical shoulder to 0.3 mm wide.
- The occlusal bevel should be approximately 45 degrees and 1.5 mm wide.

e

Occlusal surface
- Shape until smooth; possibly create an occlusal contour of the die.
- Check for adequate freeway space (at least 1.5 mm from the antagonist).
- Check surfaces externally and internally.
- Flood with matt glaze to render smooth and clean.
- Attach a 3-mm sprue to the occlusal surface in the direction of the flow of molten material without any volume change in the sprue.

Fig 5-75 Waxing up the telescope. *(a)* Draw the underlining foils. *(b)* Place warning layer. *(c)* Premill the milling surfaces. *(d)* Mill around the milling surfaces in parallel. *(e)* Create an occlusal surface.


a

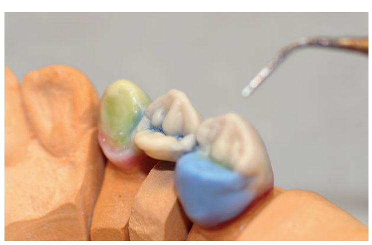
Reinforcing the coping
- Flood on modeling wax (uniformly about 0.5 mm thick).
- Utilize the transparency of the wax.
- Cervically create the metal margin (channel-shaped for metal-ceramic).
- Distally build up the join to the adjacent tooth (which is not veneered cervically with ceramic).
- Smooth veneer surface and wax edges.


b

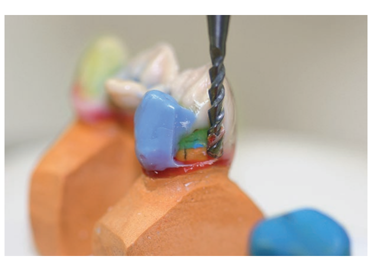
Pontic wax-up
- Place wax wire in the shape of the tooth.
- Create stable connection points.
- Ensure rinsability in the interdental space.
- The pontic is in a reduced premolar shape (for uniform ceramic layer thickness).
- Pay attention to length gingivally and buccally.
- Shape veneer surfaces until convex and smooth.
- Create a channel-shaped rim at the metal-ceramic junction.


c

Cusp tip wax-up
- Wax-up starts with defining the cusp tips.
- Next, wax up cusp ridges mesially and distally.
- Establish size and position of the occlusal surface in relation to tooth shape.
- Place antagonist contacts on the marginal ridge.


d

Occlusal wax-up
- Shape cusp slopes and medial ridges.
- Pay attention to dimension buccally and cervically.
- Build up marginal ridges convexly.
- Fill fissures on the vestibular surface.
- Draw in the tooth neck in the approximal cervical area.
- Shape the lingual and buccal cusp crests to form the antagonist contact.
- Create triangular ridges with supplemental grooves without contact; pay attention to anatomical tooth shape.


e

Space for attachment
- Mark distance from the attachment to the gingiva in the cervical area.
- Create space for positioning the attachment in the cervical area.
- For acrylic resin copings, carve a window beforehand.
- The die must shine through the wax pattern.

Fig 5-76 Waxing up the partial denture. *(a)* Reinforce the coping. *(b)* Wax up the pontic. *(c)* Wax up the cusp tips and ridges. *(d)* Wax up the vestibular and occlusal surfaces. *(e)* Create space for the attachment.

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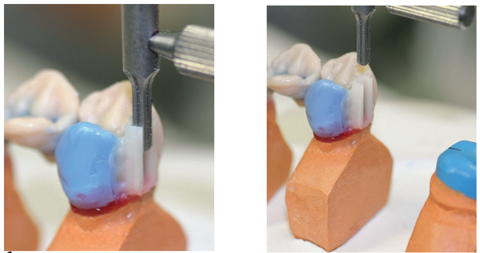
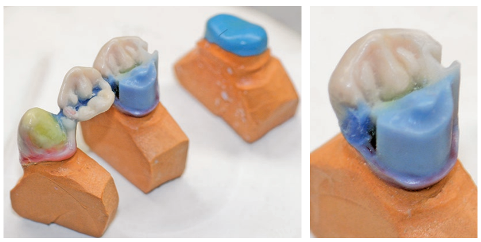

f

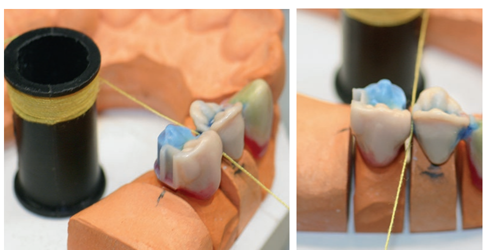
Placement

- Integrate the attachment into the wax pattern intercoronally on the attachment holder.
- Align the attachment with the middle of the alveolar ridge.
- Ensure that there is no mucosal contact (stay clear of the periodontium).
- Fix with very hot wax.
- Fill up the inside of the crown.
- Do not flood the fitting surfaces.
- Twist open attachment holder and start up the milling machine.
- Trim the attachment in metal.


g

Circular notch

- Mill a U-shaped circular notch in wax.
- Create a cervical shoulder milling 0.3 mm wide (as a hygienic seal and channel-shaped around the attachment, circular notch, and stabilizing groove).
- The occlusal shoulder should be 1.5 mm wide (if static support) to absorb axial forces.
- Excavate the stabilizing groove with a thin cutter opposite the attachment.


h

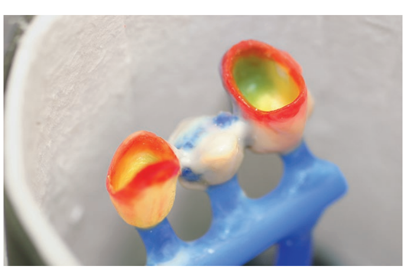
Separation

- Separate the partial denture with sewing thread (and remove wax clamps).
- Guide the sewing thread carefully like a bandsaw.
- Shape the pontic to be smooth and convex at the base, without mucosal contact.
- Check cervical-interdental rinsability.
- Join separated partial denture segments on the model base (with wax or adhesive).


i

Sprues

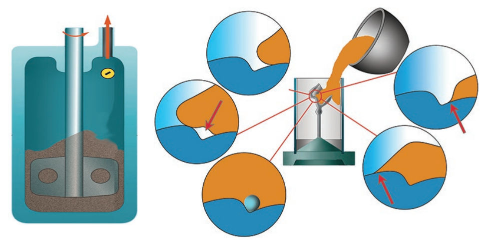
- Attach the sprues to the partial denture pontics at the thickest part.
- Ensure a crossbeam 4 to 5 mm thick in the partial denture.
- Attach the sprues to the partial denture: diameter 2.0 to 2.5 mm (3.0 mm for thick pontics).
- The distance from the beam should be approximately 3 mm.
- The distance from the sprues to the crossbeam should be approximately 3.5 mm.
- Shape all transitions to be smooth and clean (otherwise investment material may chip during casting).


j

Placement in casting flask

- Lift the partial denture very carefully off the model (risk of warping).
- Place the partial denture outside the heat center toward the outer wall.
- The crossbeam should lie in the center.
- The crown edges should show outward.
- The safety distance from the casting flask liner is 3 to 4 mm.
- The safety distance from the top is approximately 4 to 5 mm.

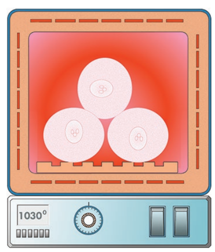
Fig 5-76 *(cont) (f)* Place the attachment. *(g)* Mill the circular notch. *(h)* Separate the partial denture. *(i)* Sprue and merge the partial denture together. *(j)* Place the partial denture in the casting flask.



a

Investing

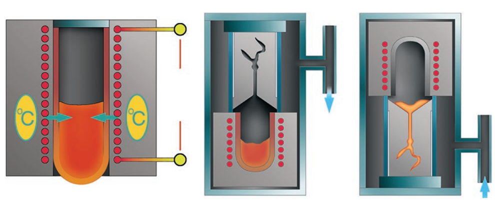
- Mix the investment material according to the manufacturer's instructions.
- Brush the attachment, stabilizing groove, occlusal surfaces, and inside of the crown.
- Quickly pour in the remaining material without bubbles.
- If possible, perform pressure investment (usually 20 minutes).



b

Casting flasks

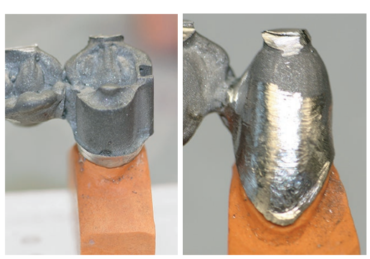
- Follow the instructions of the investment material manufacturer.
- Use the in-speed technique or conventionally bring the casting flasks to their precise preheating temperature.
- Roughen/dry-trim the flask lid for better water circulation when speeding the casting flasks.
- Strictly adhere to holding times and preheating temperature according to instructions from the alloy and investment manufacturers.



c

Casting

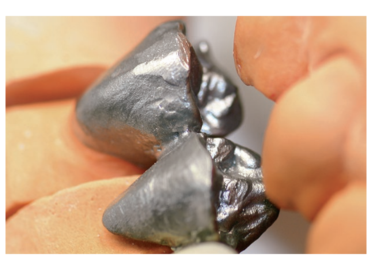
- Set up the casting unit, making sure it is technically okay and clean.
- After preheating the casting flasks, preheat the alloy in the casting unit, quickly load flasks into the casting unit, and continue melting the alloy.
- Cast nonprecious metal for 3 seconds after the shadow falling on the molten metal has broken up.
- Remove casting flasks and cool to room temperature.
- Deflask without knocking on the casting buttons.



d

Fitting

- First remove the oxide residues completely.
- Fit each crown individually onto the die.
- Watch for casting beads and excessively waxed-up crown margins, removing any.
- Create a precise fit with slight friction on the plaster dies.
- Then fully set up the partial denture.
- Check that there is no rocking and possibly separate, solder, or laser the partial denture.



e

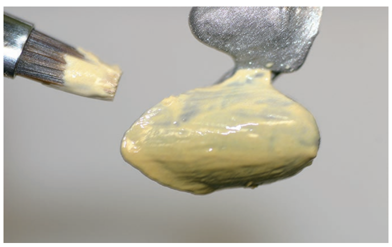
Corrective reduction

- Prepare the sprues and machine out the shape.
- Trim the attachment:
  - → Adjust the occlusion in the articulator.
  - → Check all contacts with articulating paper.
  - → Ensure that the attachment has space occlusally for the tertiary structure.
  - → Ensure a minimum 1-mm space from antagonists.

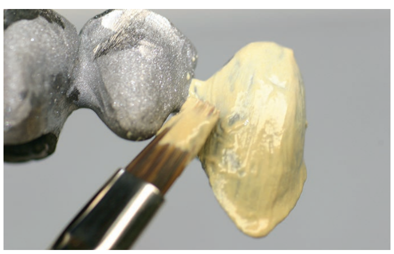
Fig 5-77 Casting and fitting on the cast objects. *(a)* Invest the cast objects. *(b)* Set up the casting flasks. *(c)* Cast the cast objects. *(d)* Fit on the framework. *(e)* Perform corrective reduction of the occlusion.


a

Framework
- Prepare the metal surface for ceramic.
- Make it thin at the margins (0.3 mm) with a smooth surface and open porosities.
- Do not "rivet" in case of blunt grinding tools.
- Do not introduce any foreign bodies.
- Use sharp cutters/suitable stones.
- Roughen/clean the surface with airborne-particle abrasion.
- Be careful with abrasion pressures at crown margins (do not use circulation unit).


b

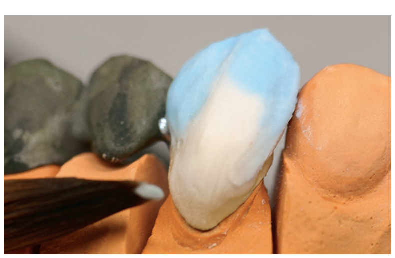
Oxide firing
- Carry out oxide firing.
- For nonprecious metal alloys, perform as cleaning firing to get rid of contaminants (base alloy constituents form sufficient adhesive oxides during firings).
- If metal surface appears unremarkable and homogenous, airborne-particle abrade oxides again.
- Perform corrective reduction of noticeable features and airborne-particle abrade.


c

Opaquer
- Apply the opaquer thinly but in uniform thickness in two firings.
- Possibly carry out a third opaque firing or use a bonder in advance.
- Follow the firing instructions of the ceramic manufacturer.


d

Dentin material
- Layer the dentin material in the shape of the tooth:
  - → Evenly without air bubbles, and not too wet.
  - → Work with small amounts of material.
- Insert more intensely colored opaque dentin cervically.
- Incisally cover thin areas with warmer tones (special porcelain).
- Create a transition to cutting edge/mamelons for soft, meshed transition.
- Possibly repeat the firing to solidify the material.


e

Cutting edge
- Complete the tooth shape incisally with incisal porcelain.
- Layer the shape approximately one-fourth larger to compensate for shrinkage during firing.
- Raise the incisal pin by 1 mm on the articulator.

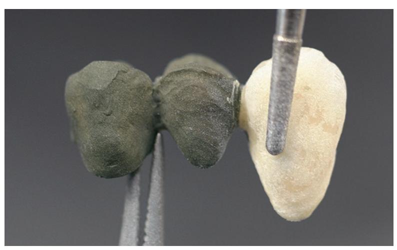
Fig 5-78 Ceramic veneering. *(a)* Prepare the framework of a veneer crown. *(b)* Carry out oxide firing. *(c)* Apply/fire the opaquer. *(d)* Apply/fire the dentin material. *(e)* Layer/fire the cutting edge.


f

Corrective reduction
- Prepare contact points and check them.
- Machine out shape characteristics and overprepare.
- Establish the height and width of the tooth.
- Ensure that the tip of the canine is displaced mesially.
- Position the vestibular medial ridge in a fanglike fashion.
- Create marginal ridges that are convex mesially.
- Ensure that the distal marginal ridge has a pronounced embrasure.


g

Tooth shape
- Are the length and width of the tooth correct?
- Does the vestibular surface have a convex shape?
- Are the angle and mass characteristics present?
- Have the margin and medial ridges been created properly?
- Does the size fit with the other teeth?
- Are topographic details (eg, dental tubercle) present?


h

Occlusal reduction
- Overprepare the tooth surface with sharp diamonds and roughen slightly.
- Create developmental grooves on the vestibular surface.
- Do not introduce any roughness interdentally because of the risk of plaque accumulation.

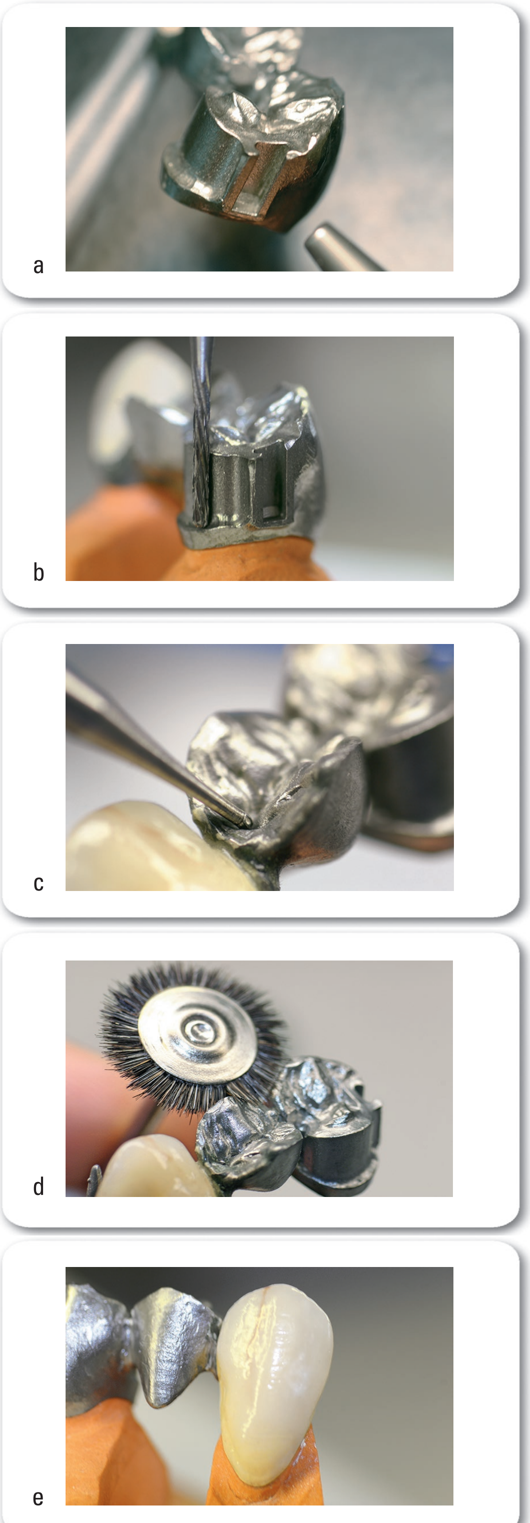

i

Glaze/staining
- Check the tooth color by applying staining fluid.
- Apply glaze if there are very pronounced rough areas, and fill up depressions with glaze.
- Carry out only very discreet staining of the tooth.
- Do a breakdown of the shades used.


j

Glaze firing
- Surface structure glazes on firing.
- Use the manufacturer's information.
- Tooth surface must display a closed, glassy structure.
- Shape and surface characteristics must remain noticeable.

Fig 5-78 *(cont) (f)* Perform corrective reduction of the veneer into the appropriate shape. *(g)* Check the tooth shape. *(h)* Prepare the surface. *(i)* Apply glaze/staining. *(j)* Fire the glaze with ceramic stains.



Cleaning

- Carefully airborne-particle abrade the framework using a pen-type abrasion tool.
- Under no circumstances abrade the ceramic; cover it with wax or a finger.
- Reduce abrasion pressure to 2 bars.
- Abrade the inside of the crown until clean (and watch for oxide and ceramic residues).
- Clean the attachment/occlusal surfaces with polishing beads (which makes finishing and polishing easier).

Reworking

- Remill the milled surfaces with a milling tool.
- Use a suitable, correct-size tungsten carbide cutter combined with milling oil.
- Work at the specified revolutions per minute so that no chatter marks or scratches are created.

Finishing

- Perform corrective reduction of occlusal details with a blunt spherical bur.
- Smooth any flaws in the wax processing.
- Occlusal relief may have some rough areas.
- The structure and shape of the occlusal surface is discernible.
- It must be possible to identify the kind of tooth.

Buffing/polishing

- Smooth metal surfaces with stones and rubber polishers.
- First use abrasive rubber polishers, then use fine rubber polishers for a very smooth surface.
- Perform polishing and high-glaze finishing, possibly using a handpiece with suitable polishing pastes (eg, nonprecious metal with diamond polishing paste).

Final clean/check

- Steam-clean the partial denture.
- Handle the ceramic veneer very carefully (risk of cracks above 145°C).
- All polishing debris and oxide residues must be removed.
- All of the surfaces must be smooth and have no rough areas (especially interdentally).

Fig 5-79 Finishing the milled work and polishing. *(a)* Clean the framework. *(b)* Rework milled surfaces and interlock. *(c)* Finish the occlusal surfaces. *(d)* Buff and polish the surfaces. *(e)* Clean and perform a final check.

6

Resilient Anchoring and Supporting Elements

Clasps as Anchoring and Supporting Elements

The simplest, cheapest, and most commonly used anchoring and supporting element for fixing a removable partial denture to the residual dentition is a clasp. There are two types of clasps: wrought-wire clasps and cast clasps.

Clasps are flexible rings that are open on one side and that embrace the bulbous tooth and gain retention in the undercut area of the tooth. This implies the actual principle of a clasp: The parts of the clasp engaged in the undercut area have to be bent apart when the clasp is being inserted and withdrawn and must therefore be flexibly malleable.

The anchoring function takes place because the lower clasp arms positioned below the most bulbous part of the anatomically shaped tooth bend apart, are flexibly malleable, and develop spring forces on insertion and withdrawal of the clasp. The path of the clasp arms and the position of the clasp tip are designed so that the arms can be flexibly bent open on insertion and withdrawal, without any permanent deformation and while applying only defined clasp forces.

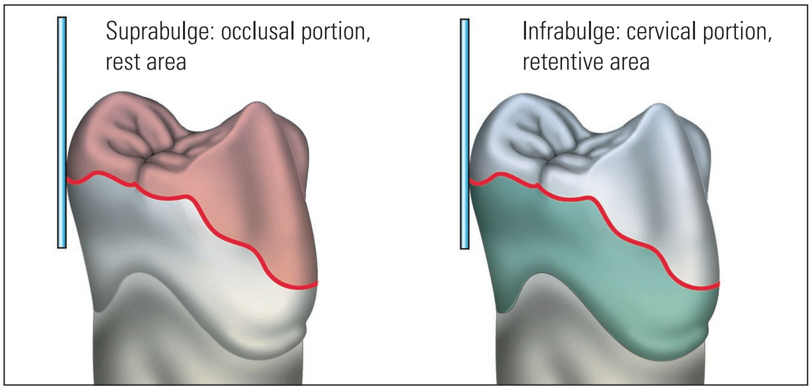


Fig 6-1 The widest circumference of the tooth can be defined with a parallel-guided graphite point. Depending on the incline of the tooth, the following emerge: *(1)* the anatomical equator relative to the tooth axis and *(2)* the prosthetic equator relative to the path of insertion of a denture. This equator divides the tooth into the suprabulge and infrabulge areas. A clasp is placed so that the resilient lower arm lies in the infrabulge position and all the other parts of the clasp are in the suprabulge position.

Spring deflection is the amount by which a clasp has to be bent open when it is being withdrawn from or placed on the tooth. The spring deflection of a clasp on a tooth is equivalent to the horizontal undercut width of the curved tooth surface in the infrabulge area, relative to the prosthetic equator. The *prosthetic equator* or *clasp survey line* is the widest circumference of the tooth relative to the denture's path of insertion. This prosthetic equator divides the crown of the tooth into two areas, where the occlusal area denotes the *suprabulge* and the cervical area the *infrabulge* (Fig 6-1). The cervical area, relative to the prosthetic equator, is undercut and suitable for retention of clasps.

The basic clasp design can be demonstrated using the example of a double-arm clasp with rest. The double-arm clasp engages in the undercuts with the two clasp arms on the vestibular and lingual aspect. Both clasp arms have to be bent apart on insertion and withdrawal and thereby offer retentive forces.

Following are the functioning segments of a double-arm clasp (Figs 6-2 to 6-5):

- The clasp body or encircling part is the central segment from which all the other clasp components originate.
- The clasp rest is a tongue-shaped occlusal rest on the clasped tooth that is always arranged horizontally and secures the vertical position (periodontal support).
- The clasp shoulder is part of the encircling part and forms the transition between the clasp body and upper arm.
- The upper arm (or proximal arm) surrounds the tooth from the occlusal in the suprabulge area and widens the enclosure of the tooth.
- The enclosure parts are rigid and secure the horizontal position (shear distribution).
- The lower arm (or distal arm) is the resilient retaining arm that engages in the retention area and takes on the actual retentive function.
- The clasp tip forms the outer end of the tapering clasp arm. The clasp tip lies deepest in the infrabulge area and is bent open throughout the spring deflection.
- The clasp appendix (clasp anchor, retention) or minor connector extends from the clasp body to the denture framework as a partial enclosure (see Fig 6-5). The minor connector is rigidly connected to the denture framework.

The lingual clasp arm can be constructed as a so-called guide arm (reciprocal/bracing arm) whose entire length runs along or above the equator. It is intended to counterbalance the retaining arm and prevent the tooth from tipping lingually if the retaining arm is pulled above the equator. The tooth surface of the guide arm must be prepared parallel to the path of insertion so that the (rigid) guide arm can lie against the tooth throughout the entire movement of the retaining arm out of the undercut area to above the equator.

It is possible to design a clasp with a functional separation into guide and retaining arms, but the vestibular clasp arm has to be placed far into the infrabulge area for esthetic reasons. Otherwise, this design should be rejected, because the teeth

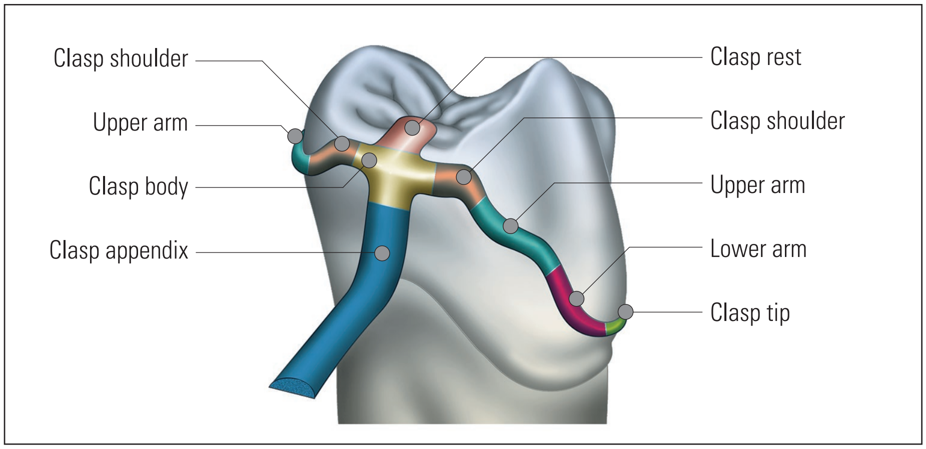


Fig 6-2 A clasp can be divided into several functional segments, which are marked here in different colors.

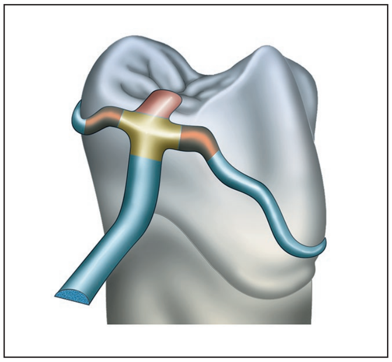


Fig 6-3 The clasp body with clasp shoulder is referred to as the *enclosure* and acts to brace against horizontal shear forces. The clasp rest is an occlusal rest that transfers masticatory forces to the clasped tooth as it secures the vertical position.

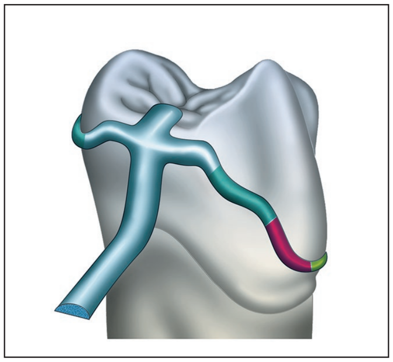


Fig 6-4 The clasp arm divides into an upper (proximal) and lower (distal) arm as well as the clasp tip. The resilient lower arm is placed in the infrabulge area and takes on the retentive function. The clasp arms taper down toward the clasp tip.

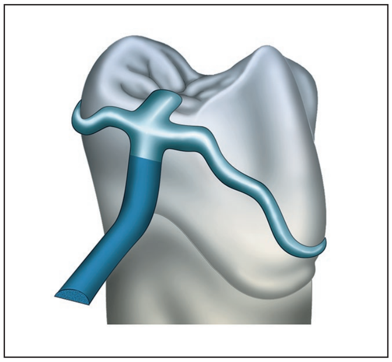


Fig 6-5 The minor connector to the denture framework starts from the clasp body; it is also known as the *clasp appendix* or *retention*. It connects the clasp structure to the denture framework or the denture saddle.

have to be prepared and the best retention areas usually lie on the lingual aspect.

Wrought-Wire Clasps

Wrought-wire clasps are pieces of wire that are bent out of spring-hard, orally compatible steel wire or a wire made of precious metal alloy. The diameter of the wire is generally 0.8 mm for steel and 1.0 mm for precious metal. Semifinished parts (eg, clasp crosses) are also used.

The range of uses for wrought-wire clasps is limited because they do not fulfill the requirements of anchoring and supporting elements. In particular, they lend themselves to interim dentures because hardly any damage can occur due to the shorter wearing time. A wrought-wire clasp has the advantage of low cost.

Wrought-wire clasps cannot be bent so precisely that they lie entirely pressure free in the resting position and evenly around the tooth. They do not ensure adequate positional stability against horizontal thrusts because of the excessive elasticity of the wrought wire, which, despite strain hardening, flexes too much in response to bending.

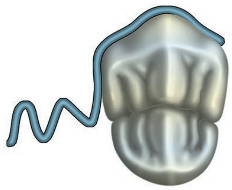
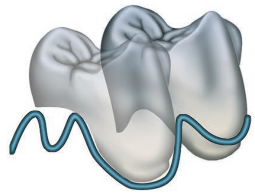
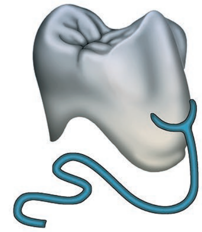
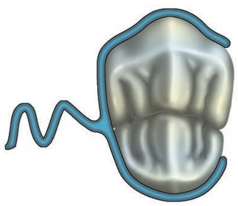
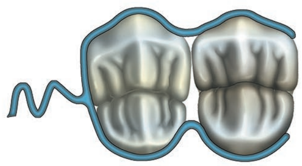
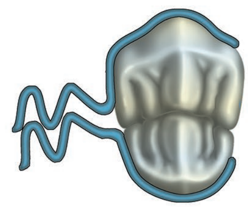
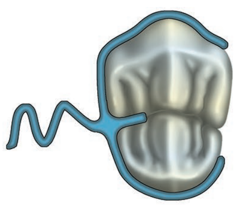
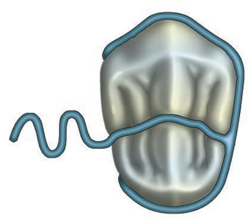
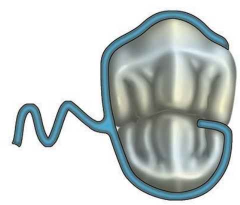
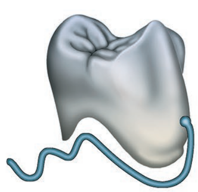
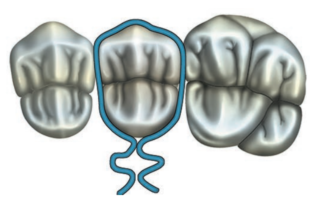
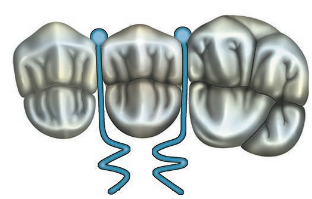
Single-arm wire clasps	 A C-clasp is a single-arm wire clasp in which the counterbearing is the denture flange; used as an interim solution.	 A double-crescent (butterfly) clasp is guided around a denture tooth into the saddle.	 A J-clasp is a single-arm clasp with a long retaining arm.
Double-arm wire clasps	 A double-arm clasp is bent out of a T-clasp cross and engages in the undercuts on both sides.	 A double-arm clasp embraces two teeth from the buccal/labial and lingual aspect.	 A double-arm clasp can also be shaped out of two single-arm clasps.
Double-arm clasps with rest	 A double-arm clasp with occlusal rest is also called a *three-arm clasp* and is bent out of a clasp cross.	 The appendix of a T-clasp cross can be laid over the occlusal surface (Elbrecht clasp).	 In a G-clasp, the lingual clasp arm is guided occlusally to a rest that is distant from the saddle.
Wire clasp modifications	 A single-arm clasp made of a prepared ball-head prefabricated part is guided into the infrabulge position from the buccal/labial direction.	 A Jackson clasp is a closed circumferential clasp that is guided approximally over sections of the closed dentition.	 A ball-head clasp or drop clasp is made from a prefabricated part and engages in the interdental niche.

Fig 6-6 Common forms of wrought-wire clasps.

There is no bodily enclosure of a tooth with a wrought-wire clasp; that is, the clasp does not protect the clasped tooth from twisting. A wrought-wire clasp can be bent out of shape by stress caused by denture movements. Correction by activation (rebending) ultimately means that, in the resting position, the clasp transfers uncontrollable forces to the clasped tooth and tips or twists it.

Many wrought-wire clasp designs do not include an occlusal rest, and if they do, it is not stable enough and warps. The denture will be displaced under masticatory pressure, and the wire clasp may sink into the marginal periodontium. A sunken clasp loses retentive function because the tooth tapers in a cervical direction and the clasp arm no longer touches the tooth. When it is then activated, the clasp bends open again on insertion over the wide tooth circumference.

Greatly reduced residual dentitions in which the static relationships do not permit rigid support offer a specific indication for this type of clasp. In such cases, the wrought-wire clasp only takes on a retentive function and no periodontal support is possible.

Wrought-wire clasp constructions are important in orthodontics, where, owing to their high elasticity, they are used as active spring components for regulating malpositions of teeth.

Following are possible wrought-wire clasp designs for use as retentive elements for interim dentures (Fig 6-6):

- Single-arm clasps (C-clasps) only touch the tooth on the vestibular (labial/buccal) surface, which is why the denture base must be guided to the tooth as the reciprocal. The base is made hollow to avoid stresses on tissues. The C-clasp lies with the clasp shoulder on the prosthetic equator and runs from there into the retention area; it can be guided over two teeth to form a double crescent shape.
- A J-clasp (Bonyhard clasp) is a single-arm clasp made from a prefabricated part. It lies close to the cervical margin and is placed with the long retaining arm inserted into the denture body.
- A clasp with an angled arm in a double crescent shape is placed in the retention area of the clasped tooth; then, with one bend around the artificial tooth on the denture, it is fitted into the denture material. As a result, the retaining arm and spring deflection are enlarged, which is why the clasp can be very deeply positioned.
- Double-arm clasps are bent out of semifinished parts (clasp crosses) with and without occlusal rests. Double-arm clasps embrace the tooth, approaching from the approximal aspect as well as the vestibular and lingual aspect; the clasp arms are usually guided into the retention area of the teeth just behind the clasp shoulder. A double-arm clasp can also be placed in the form of two double crescent shapes around two premolars simultaneously.
- A G-clasp is a double-arm clasp where the extended lingual clasp arm with the clasp tip is bent in an occlusal direction to form a rest. The lingual arm does not run in the retention area of the clasped tooth.
- Loop-type clasps are pieces of wire that are scalloped around the tooth as the vestibular part of the clasp engages in the retention area. Examples of this type of clasp include the Jackson clasp and the O-clasp.
- Ball-head clasps are made from prefabricated parts. They are guided in the interdental embrasure over the teeth and placed in the interdental niche of two teeth; in orthodontics, these are known as *drop clasps*.

Cast Clasps

Cast clasps are generally waxed up as a unit with the denture framework using the model casting technique and then cast from chromium-nickel alloy. The high modulus of elasticity of this alloy gives cast clasps relatively high rigidity. The spring deflections of such clasps must be precisely fixed in order to achieve a defined withdrawal force, and these deflections must be adhered to. Even slight variations (± 0.1 mm) can cause the clasp force to be too strong or not strong enough.

Fixed rules govern the design, that is, the shape and path of the clasp arms (Figs 6-7 and 6-8). Shortening, lengthening, strengthening, or weakening the clasp arm has a direct influence on clasp force. It is also necessary to use specially preformed (wax) profiles and only modify these while closely monitoring the clasp forces that arise.

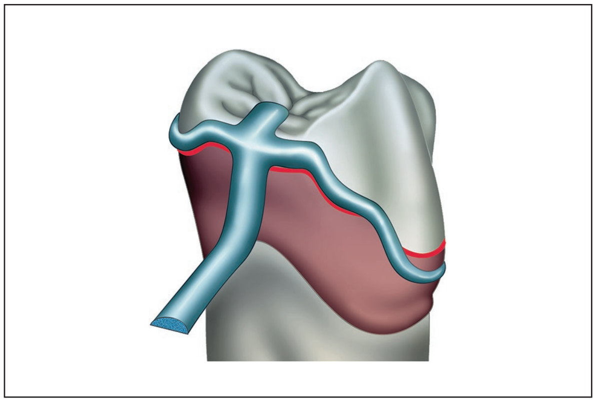


Fig 6-7 Fixed rules govern the position and path of cast clasps. The rigid clasp parts (clasp body, shoulder, and upper arm) lie in the rest area (suprabulge position), and resilient lower clasp arms are guided into the undercut retentive area (infrabulge position) so that the clasp tips lie at the deepest point and have to be bent open as wide as possible on insertion and withdrawal of the clasp.

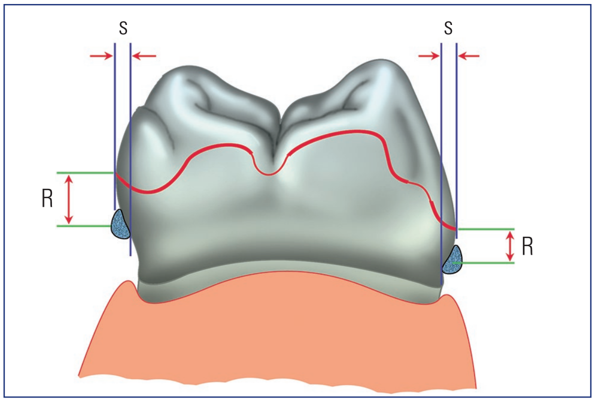


Fig 6-8 The position of the clasp tip relative to the prosthetic equator can be determined in the vertical and horizontal direction: The vertical distance of the clasp tip from the prosthetic equator is called the *retention depth* (R); this is how far the clasp has to be raised out of the resting position. In the process, it opens by the spring deflection (s), which is the horizontal distance; this distance is measured to determine the retentive force of a clasp.

When used properly and fabricated correctly, a cast clasp is a reliable, technically simple structure and the most affordable retentive and supporting element. A cast-clasp design is preferable to any wrought-wire clasp. A cast clasp consists of the aforementioned functional parts.

Advantages of cast clasps

Cast clasps have high accuracy of fit, apart from variations caused by processing errors. This accuracy of fit means only a conditionally rigid connection between the residual dentition and the denture, but it prevents twisting of the clasped tooth because of its great stiffness and bodily enclosure of the tooth. The residual dentition can be adequately braced with groups of cast clasps and a stable cast denture framework (Fig 6-9).

Roughly axial loading of the clasped tooth can be achieved because of the occlusal rest, which is part of every cast clasp. The low elasticity of the clasp material allows clasp structures to have a slim design.

Disadvantages of cast clasps

Mechanical wear of the enamel occurs during insertion and removal of the denture and in response to relative movements of the denture while functioning (Fig 6-10). Deposits, and consequently caries, can develop under the clasps; this risk is increased if the occlusal rest or a lingual guide plane is prepared. A clasped tooth should therefore be protected against mechanical destruction with a coronal restoration, especially because occlusal rest surfaces and adequate retention areas relative to the path of insertion can be created in the process. If, however, an abutment tooth has a coronal restoration, a different anchoring element should be used, such as a prefabricated attachment instead of a clasp.

Cast clasps do not provide a rigid connection between the residual dentition and the denture. In response to stresses, denture movement always affects the anchoring tooth. Denture movements put an eccentric load on the clasped tooth because, in the case of a clasp, forces are always transmitted in a punctiform fashion via the different clasp parts: Vertical forces are transferred eccentrically to the approximal marginal ridge by the occlusal rests. Transverse stresses are transmitted by alternating parts of the enclosure or by the resilient lower arms of the clasp. The clasp and the clasped tooth do not form a mechanical unit but only a loose, unstable join.

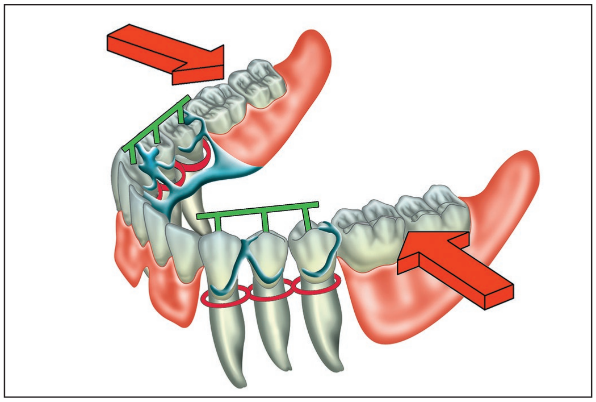


Fig 6-9 The advantages of cast clasps over wrought-wire clasps lie in their higher accuracy of fit, their higher rigidity, and their bodily enclosure of the tooth. As a result, the residual dentition is splinted and stabilized. All the forces acting on the denture are transferred to the remaining teeth via the group of clasps. All of the teeth enclosed in the group of clasps are able to support each other in this grouping.

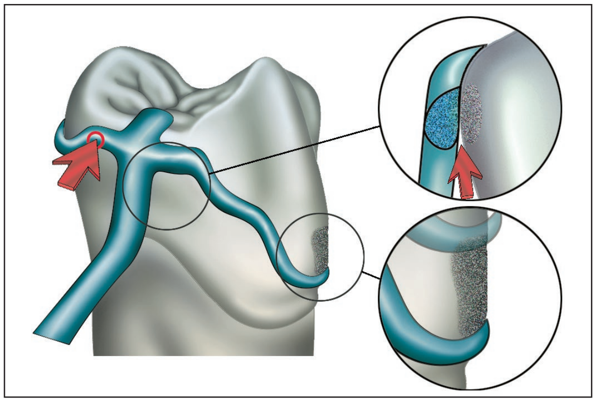


Fig 6-10 The enclosure of the clasped tooth also brings disadvantages: *(1)* Deposits and caries lesions can form under the relatively wide clasp arms. *(2)* Mechanical wear of the enamel results every time the clasp is inserted and withdrawn. *(3)* Horizontal thrusts are only transferred to the clasped tooth in a punctiform or linear fashion, and the tooth is tipped.

Activation of cast clasps is not possible because it leads to mechanical weakening of the cast material. Strain hardening of the metal arises and the clasp becomes harder; however, the permanent bending strength decreases rapidly, microcracks appear, and the clasp breaks. If cast clasps are activated, the retentive force increases for the time being, but the actual functioning of the clasp is lost. The clasp arms no longer fit without pressure but are now in a prestressed state, even in the resting position, and they transfer forces to the tooth. The occlusal rest normally holds the tooth while the activated clasp arms lift and thereby tip the tooth in the opposing region. The tooth loosens and is lost.

In addition, clasps are always cosmetically unfavorable.

Requirements for Cast Clasps

Cast-clasp components must meet the requirements that apply to anchoring and supporting elements (Fig 6-11):

- They must secure the horizontal position by means of rigid enclosing parts.
- They must brace the residual dentition by physically engaging the abutment tooth.
- They must ensure periodontal hygiene due to precise fit.
- They must provide pressure-free close fitting in the resting position to avoid orthodontic forces.
- They must secure the vertical position by means of occlusal rests.
- They must ensure the retentive function by means of defined spring forces.

In terms of securing horizontal position, the clasp body, clasp shoulders, clasp upper arms, the projection to the minor connector, and the occlusal rest form the rigid enclosing parts. They lie above the surveyed prosthetic equator in the suprabulge area. They brace the denture against horizontal thrusts and stabilize it. Horizontal forces from a specific direction are not transferred by the whole enclosure, only by certain, mainly punctiform parts, and this results in eccentric tooth loading. The horizontal positional stability of the clasp also applies to the clasped tooth, which is secured against twisting, tipping, and displacement.

Bracing the residual dentition by means of splinting is possible because the aforementioned parts are relatively rigid and embrace the tooth bodily (ie, extensively and with accuracy of fit). These anchoring parts achieve the effect of splint-

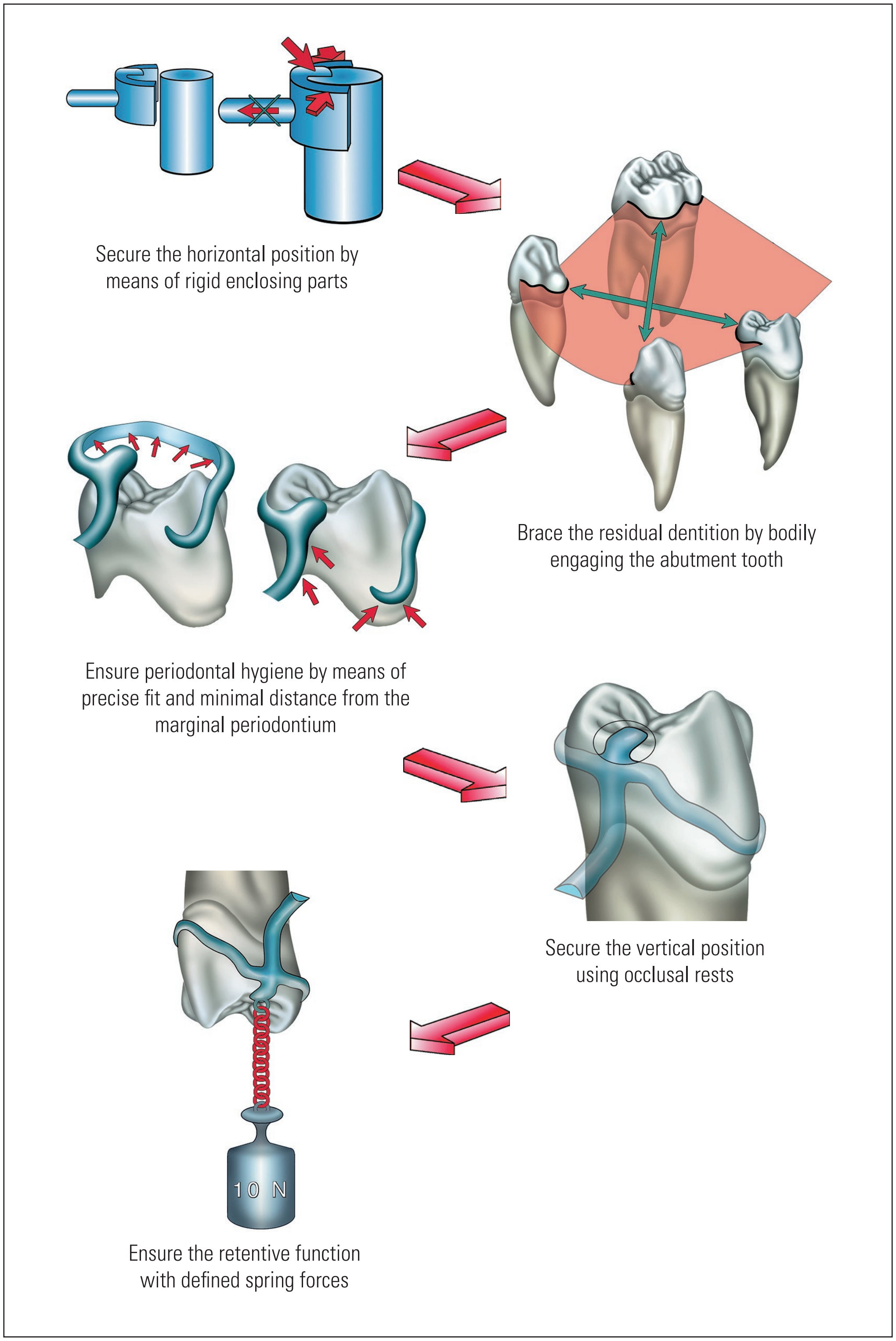


Fig 6-11 Requirements for cast clasps.

ing the residual dentition because the denture framework acts as a large, relatively rigid connector between the individual clasps. In addition, the rigid clasp parts on the lingual tooth surfaces can be guided over one quadrant or the whole dental arch as continuous enclosures or splinting elements.

Achieving periodontal hygiene is problematic with clasp structures. Fabricating clasp components by the model casting process ensures very good accuracy of fit. The enclosure provided by the clasping parts lies flat on the tooth surface and thereby provides a place for deposits and caries to accumulate, and this is accentuated if the insides of the clasps are rough and unpolished.

Problem areas with clasps, apart from the extensive embracing parts, are the minor connectors and their junctions with the clasp body. The minor connectors should always be guided clear of the periodontium, especially if they have to be directed to the clasp interdentally within closed parts of the dental arch (eg, Bonwill clasp). In the case of closed-saddle shaping of the minor connector, acrylic coverage is avoided on the mucosal side, and the metal is polished to a smooth finish.

Pressure-free close fitting in the resting position means the clasp arms must lie entirely tension free; that is, they absolutely must not be activated. It is only on insertion, on withdrawal, and during functioning that clasps develop their precisely defined retentive forces and transfer them to the clasped tooth.

Any prestressing of the clasp arms by activation (rebending) can exert forces on the tooth in the resting position, which produce tipping or twisting on the tooth. The periodontal tissues are first loaded in the final position of the denture, then additionally as they are functioning. Even if the precise direction and the extent of these force effects cannot be determined, the clasp in the resting position acts as a form of regulation, and when functioning, overloading of the periodontium ensues.

The requirement for a tension-free resting position of the clasp indicates that uncontrolled forces must not be transferred to the tooth. Every cast clasp leads to calculable and controllable inappropriate stresses on the clasped tooth; these must not be increased, however, by rebending the clasp arms, because this means the structure will definitely fail.

Activation of cast clasps should basically be rejected for the reasons outlined earlier (ie, strain hardening, microcracks, prestressing). Bending cast clasps open to better fit the model cast denture onto the model is wrong! The need to rebend is always a sign of planning and surveying errors; in most cases, these are attributable to the dental technician. Securing the vertical position by means of occlusal rests and the retentive function by means of defined spring forces is discussed in the sections that follow.

Securing the Vertical Position with Cast Clasps

The partial denture is supported on the residual teeth, which is why every clasp is provided with an occlusal rest. The functions of the occlusal rest are the following:

- To absorb masticatory loads that strike the replacement teeth and distribute them to the periodontium of the clasped teeth by means of axial pressure.
- To divert food particles away from the interface between the denture and the residual dentition, thus taking on a similar function to the approximal contact points.
- To stabilize the position of the clasp relative to the tooth.
- To prevent the denture from tipping sideways onto the mucosa.
- To prevent the clasp arms from slipping down in a cervical direction. Failure to do this would damage the marginal periodontium, the retentive function would no longer be fulfilled because the clasped tooth tapers cervically, and in this case the clasp arms would stand out. In the process, the nonresilient enclosure by the upper clasp arms would be displaced, and the actual splinting effect would be lost. The denture might become embedded, thereby overloading the mucosal areas and causing the marginal periodontium to be squeezed and destroyed in the area bordering the gap.

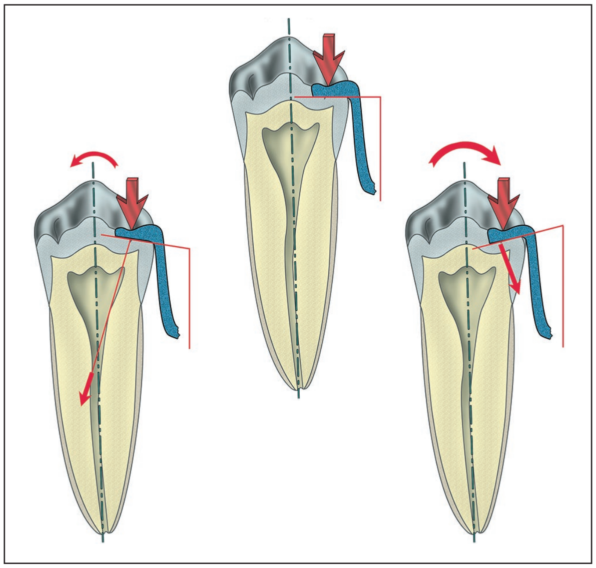


Fig 6-12 The bottom of the rest should always be placed horizontally so that axial loading on the teeth is roughly achieved. If the bottom of the rest slopes away, it acts like an inclined plane; the rest will slip off, and the tooth will be tipped. If the bottom of the rest slopes down to the middle of the tooth, the tooth will tip toward the rest, which will have no effect in the case of a bounded saddle but will lead to tooth loosening in a free-end saddle because the tooth is pulled in a distal direction.

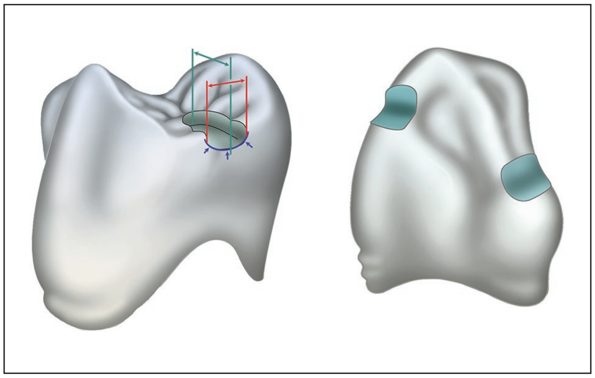


Fig 6-13 For an occlusal rest, the surface must be prepared so that no malocclusions can arise. The recess should be spoon shaped rather than box shaped in order to avoid a notch effect and thus fracture of the rest as well as to ensure that slight movement of the rest is still possible.

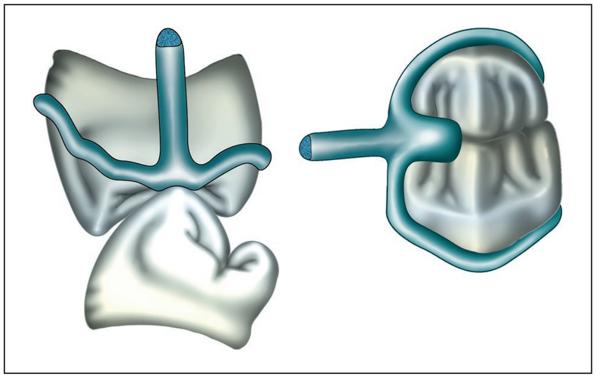


Fig 6-14 The rest must not interfere with the opposing occlusion and is therefore recessed in the tooth. To ensure resistance to fracture, the rest should be 2.5 to 3.0 mm long and wide and 1.5 mm thick. The tooth should be protected with a filling in the rest area or a coronal restoration.

The shape and position of the occlusal rest have a decisive influence on the functioning of this important part of the clasp. Positioning of the rest in the dental arch is guided by static considerations. The teeth with the largest root surface area and hence the greatest periodontal loading capacity should ideally be chosen: first molars, then premolars, then canines and incisors.

The bottom of the rest lies perpendicular to the tooth axis because it is essential to ensure that largely axial forces are transferred. If the bottom of the rest inclines outward, the rest will act like an inclined plane so that the tooth is tipped and the clasp slips away from the tooth and downward (Fig 6-12). The disadvantages of a clasp that has slipped off have been mentioned; in this case, the tooth will suffer additional damage to its periodontal tissue as a result of tipping.

The rest area is prepared into the tooth as a cavity so that no malocclusions will occur (Fig 6-13). A spoon-shaped, not a box-shaped, recess should be created. This shape avoids notch effects and allows rotational movements of the occlusal rest, which can occur as the denture is functioning. The

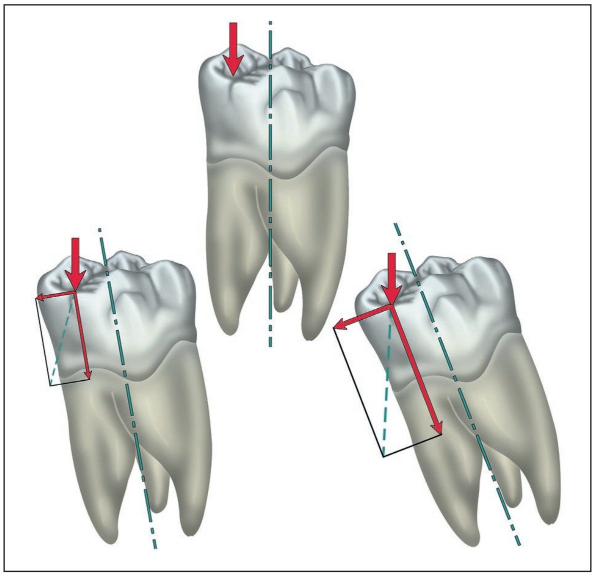


Fig 6-15 Every clasp loads a tooth eccentrically; that is, the tooth is tipped by a clasp rest. An upright tooth with a healthy periodontium can tolerate such stresses. In the case of an inclined tooth, a rest will further increase the tipping if the rest is placed on the side of the tilt. The more inclined a tooth is, the more it will be tipped by the rest. The rest therefore should be positioned on the opposite side.

dimensions of the recess allow a break-proof rest to be created: The width and length of a rest is approximately 2.5 to 3.0 mm, and the thickness must not be less than 1.5 mm (Fig 6-14). The transition from the bottom of the rest to the clasp body should be rounded off so that no notch effect occurs at this point and the rest does not fracture. The tooth should be protected, at least in the rest area, by a precise (gold) filling that is reasonably substantial if coronal restoration is not being considered. The occlusal rests are prepared in the same way as crowns.

An occlusal rest produces unfavorable static relationships on a tooth. Because it will always lie on the approximal marginal ridge, any rest will eccentrically load the abutment tooth and tip it slightly (Fig 6-15). An upright tooth with a healthy periodontium will bear such loading to a limited extent without being damaged. Tipped teeth—and tipping is usually the case—should not be loaded by the rest but instead should be provided with support on the opposite side to their tilt. Beveling the bottom of the occlusal rest at the middle of the tooth increases the tipping because of the effect of the inclined plane.

Double rests are suitable for achieving axial loading; if a free-end saddle sinks, however, one of the rests becomes the fulcrum and the other rest lifts off. For the same reason, letting the occlusal rest extend over the entire occlusal surface is not a solution.

Claw-like rests on canines and incisors embrace the incisal edges over to the labial aspect. For this purpose, a cavity for the rest must always be prepared in order to produce a horizontal surface for the vertical forces.

The drawback of occlusal rests is indicated by the very name: the rest merely lies on and is not rigidly connected to the clasped tooth; it offers a statically indeterminate system with all of its disadvantages. A cast clasp with occlusal rest is nevertheless a far better solution than a single-arm wrought-wire clasp.

Defined Retentive Force with Cast Clasps

The main function of a cast clasp is to hold the denture on the residual dentition. The retentive force of a clasp is mainly based on the elasticity of the clasp arms: On withdrawal from the tooth, the lower clasp arms have to be widened over the prosthetic equator. The clasp force on withdrawal is in the region of 5 to 10 N. If every clasp on a denture achieves this clasp force, a denture cannot be lifted off, even by sticky foods, by its own weight, or by tongue pressure.

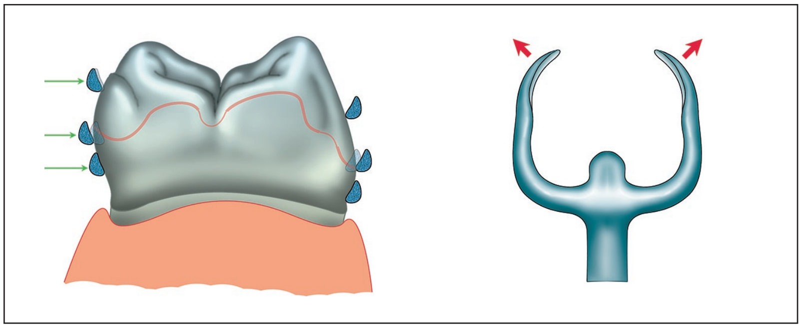


Fig 6-16 Ideally both clasp arms bend open evenly on insertion and withdrawal of the clasp, provided that they have the same retention depth and simultaneously reach the prosthetic equator; then they are widened by the maximum spring deflection and produce maximum spring force. The tooth is loaded axially and not transversally.

First requirement

The same retentive forces should be assigned to all of the clasps in a group in order to achieve a uniformly firm seating of the denture. The retentive force of a clasp depends on the extent to which the resilient clasp arms are bent open. This means a clasp arm must be pulled off the tooth so that it is bent open by precisely the defined spring deflection (Fig 6-16). The spring deflection must be accurately defined and measured relative to the dimensions of the clasp arms.

Second requirement

A clasp must not tip or twist a clasped tooth on withdrawal. Therefore, both clasp arms (lingual and labial/buccal) extend into the retention area and develop the same spring forces on withdrawal. If the undercut widths differ, this can be offset by changing the length of the clasp arms or changing the profile thickness.

Third requirement

Both clasp arms have the same retention depth below the prosthetic equator. The retention depth is the amount by which the clasp arms have to be raised until they lie on the prosthetic equator. It is no use if both clasp arms are able to develop the same spring force but one clasp arm lies on the prosthetic equator after the clasp has briefly been lifted, while the other arm still lies below the equator; the first clasp arm will exert its full spring force, and the second may only exert half its spring force (Fig 6-17). As a result, the clasped tooth is tipped in the direction of the lower-lying clasp arm. If the clasp is lifted higher, the first arm loses contact with the tooth; now it lies in the suprabulge position, and the second clasp arm acts alone. The clasped tooth tips in the direction of the higher-lying arm. The clasped tooth is subject to tensile loading and is vigorously shaken in the process.

Alternative requirement

The cast clasp is constructed with a vestibular retaining arm and a lingual guide arm; that is, the vestibular clasp arm lies with its last third in the retention area, while the lingual clasp arm runs above or on the prosthetic equator and becomes the reciprocal of the retaining arm. These clasp paths are universally proposed. If the clasp is pulled off, the lingual reciprocal clasp immediately loses contact with the tooth because it is located in the suprabulge area (Fig 6-18). The further the clasp is lifted off, the more the vestibular resilient arm will load the clasped tooth transversally (ie, tip it lingually). On insertion or withdrawal, the clasped tooth is tipped with the spring force, leading to damage to the periodontium.

To avoid tipping of teeth, the guide arm must be guided parallel to the path of insertion, which is ensured by corrective reduction in the tooth surface (Fig 6-19). The advantage of the structural subdivision into retaining arm and guide arm is that even sections of dental arches in which there are no lingual undercuts on the teeth can be treated; this can happen with maxillary teeth that have a labial/buccal inclination, especially anterior teeth. The vestibular clasp arm can be placed more deeply and thus is more esthetically acceptable. Insertion and withdrawal is easier in a group

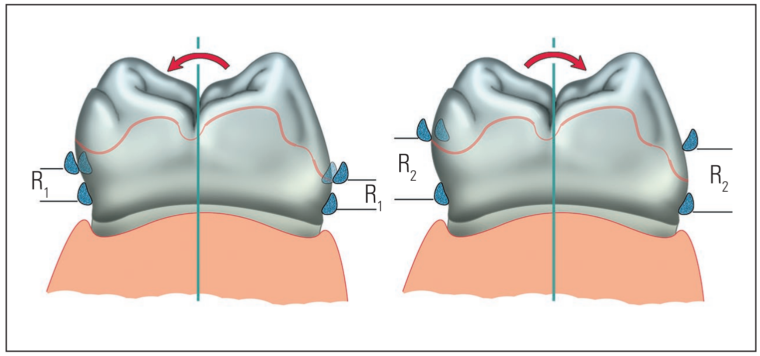


Fig 6-17 Both clasp arms belong in the retention area and should have the same retention depth, which means they both have to be lifted by the same amount in order to travel through their full spring deflection. If a clasp arm moves lower below the equator to achieve the same spring deflection as the other clasp arm, the tooth will be subject to tipping. In fact, if one clasp arm has reached its full spring force because it lies on the equator, the other arm might have only developed half its spring force. The tooth will be vigorously shaken on withdrawal of the clasp, or the clasp will jump off the tooth before that clasp arm has developed its full spring force.

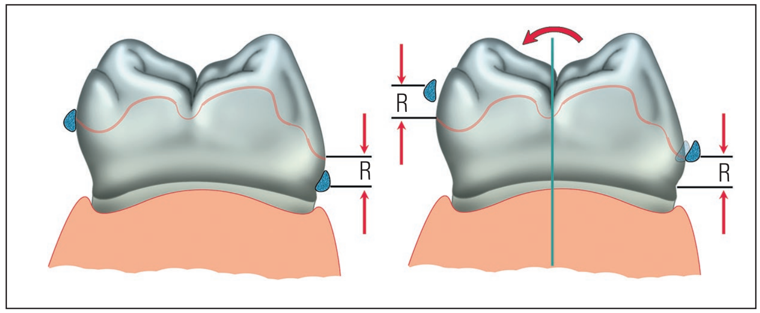


Fig 6-18 If one clasp arm lies properly in the retention area but the other arm is left on the prosthetic equator as a guide arm, the guide arm will immediately lose its tooth contact on lifting of the denture and will be ineffective as a reciprocal. The clasped tooth tips toward the guide arm. Such clasp structures use the retention area on one side and allow the clasp arm to be positioned more deeply. In the case of anterior teeth, the vestibular clasp arm is placed as low as possible in a cervical direction.

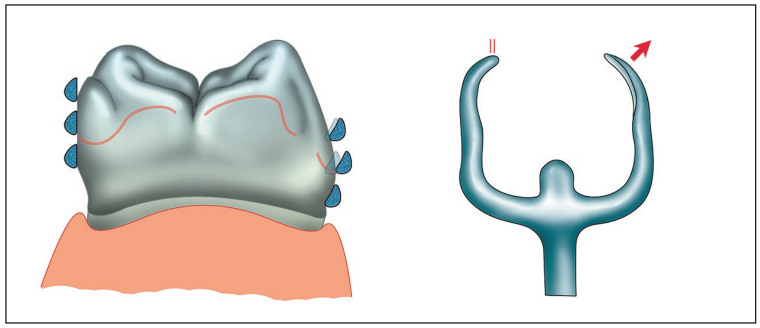


Fig 6-19 If the lingual clasp arm is designed as a guide arm, it must be guided in parallel over the entire retention depth of the retaining arm and maintain contact with the tooth. To do this, the bulge of the lingual surface must be flattened (ie, prepared parallel to the path of insertion). In addition, the guide arm is reinforced so that it remains rigid.

of clasps in which only the vestibular retaining arms are active. It is assumed that horizontal positional stability is more effective if a rigid guide arm runs over the entire lingual surface of the teeth.

The disadvantage is that a guide plane has to be prepared in the tooth, which impairs caries prevention. The active retaining arm acting with full spring force produces distinct signs of wear on the tooth surface. Undercuts lying lingually enough can always be found on posterior teeth, especially if the clasp tips are guided to the approximal interdental area. Therefore, there is limited justification for constructing a guide arm for anterior teeth only.

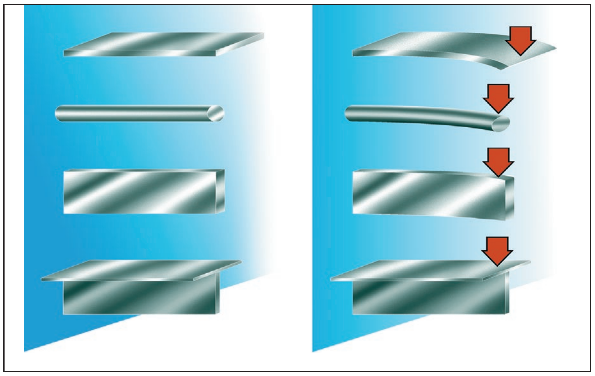


Fig 6-20 A firmly anchored bar can bend when it is loaded with a force at one end. The deflection is dependent on the force acting on the bar, the shape of the bar, and the material the bar is made from. The illustration assumes a defined force, which acts on bars made from the same material but with different profiles. A board will deflect more than a round bar with the same cross-sectional surface area. A board placed on its edge, however, will deflect more than a beam with a T-profile.

Determinants of Spring Force

The underlying principle of clasps as resilient anchoring elements is a technical spring-clip fitting: A resilient ring open on one side can be bent apart and springs back into its original position when the force of bending open subsides. If such a ring is pushed over a conical shaft, it widens with the gradient of the cone. More and more force is needed to push the ring further because the restoring force—the force that tries to restore the ring to its original shape—also becomes greater.

The necessary retentive forces of a clasp should lie in the region of 5 to 10 N so that the tensile loading on withdrawal of the clasp cannot damage the periodontal tissue. Therefore, an appropriate spring deflection is set for every clasp, particularly to ensure that the same withdrawal forces are achieved for each clasp within a group. The necessary spring deflections have to be measured for this purpose.

The *spring deflection* is the amount by which such a ring is bent apart. The force with which the ring is bent apart or will spring back is referred to as *spring force*. The relationship between spring force and spring deflection is linear:

Spring force = Spring deflection × Spring constant

or

$$F = s \times c$$

The spring constant is a guide value that combines several values relating to a clasp (indicating the property of elasticity). The elastic behavior of a body is described by Hooke's law, which states that a solid body (eg, a bar) can be deformed by external influences up to a certain degree and will spring back into its original state when these external forces are no longer effective. Permanent deformation occurs when the body is deformed beyond a certain limit. The limit of loading capacity above which permanent deformation remains is known as the *elastic limit*.

The deformation of a body depends on its material; a wooden bar is easier to bend than a bar made of steel. To describe the elastic behavior of a material, there is a measure known as the modulus of elasticity (Young's modulus [E]). This is a material specification; similar to the value for the hardness of a substance, it is a specific value for that material.

A firmly anchored bar that is subject to a force at its free end will bend in the direction of the exerted force (Fig 6-20). The greater the force, the greater the bending (deflection). If the force is too great, the bar will bend out of shape or even break. The deflection of the bar for a fixed load will vary in size as a result of the following changes in its shape:

- The longer the bar is, the more it will deflect in response to the same load.
- The thicker the bar is, the smaller the deflection in response to the same load; a short, thick bar can absorb considerable force.
- A round bar will not deflect as much as a flat board with the same surface area of the cross section.
- If the board is placed on its edge, it will not bend as much as the round bar with the same cross-sectional surface area.
- A bar with a T-profile and the same cross-sectional surface area deflects the least.
- A bar tapered down to the tip will bend most at its tip; its stiffness is greatest at the thick end.

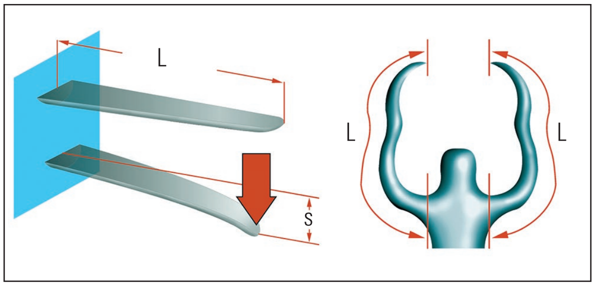


Fig 6-21 The profile for a clasp arm is semi-ellipsoid and tapers down to the clasp tip. The variables used for calculating the spring force of such a profile bar are the length of the retaining arm (clasp arm length, L), profile width, profile height, taper factor, and modulus of elasticity as a material constant. These make up the spring constant. Once the spring deflection (s) is measured, the spring force can be determined from the equation $F = s \times c$. The clasp force should lie in the region of 5 to 10 N, which means a range of 2.5 to 5 N for the arm of a double-arm clasp. For this retentive force, with reference to clasp arm length and profile thickness, a spring deflection is determined, and then the path of the clasp arm around the tooth is defined.

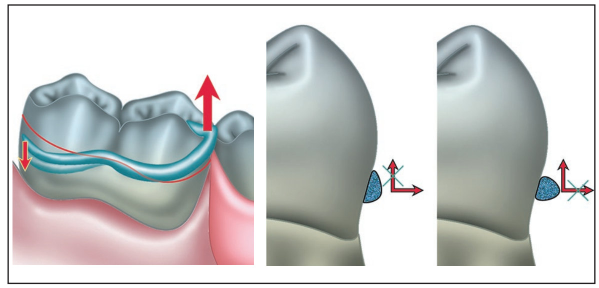


Fig 6-22 A flat clasp-arm profile will easily bend open on withdrawal from the clasped tooth without bending vertically; a high clasp-arm profile develops considerable clasp forces but will deflect in the vertical direction.

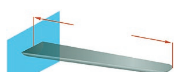
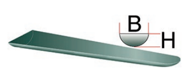
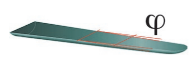
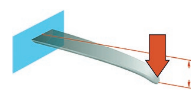
Variables affecting clasp force	 Length of clasp arm	 Thickness of clasp profile	 Taper of clasp arm	 Size of spring deflection	 Modulus of elasticity.
Effect on spring force	The longer the clasp arm, the smaller the clasp force.	The thicker the clasp profile, the greater the clasp force.	The more pronounced the taper, the more elastic the clasp arm.	The larger the spring deflection, the greater the clasp force.	The higher the modulus of elasticity, the greater the clasp force.

Fig 6-23 Determinants of clasp force.

A semi-ellipsoid profile that tapers to its tip is used for cast clasps (Fig 6-21). The clasp arms are placed so far into the infrabulge area of the teeth that the arms bend open by a certain spring deflection. The spring deflection is precisely measured and must not exceed a specific value to ensure that the clasp does not deform permanently. The relationships outlined previously also apply to the clasp arm:

- The longer a clasp arm is, the less spring force arises in the clasp when the same spring deflection is chosen as for a short clasp arm.
- A shorter clasp arm has greater spring forces for the same spring deflection.
- The smaller the modulus of elasticity, the smaller the spring force.
- Tapering of the profile makes the clasp tip more elastic.

When constructing a clasp, a certain retentive force is required at which the exact spring deflection is determined with reference to clasp arm length, profile thickness (Fig 6-22), and material properties (modulus of elasticity). Figure 6-23 outlines the determinants of clasp force.

Determining Retentive Force

The retentive forces of a clasp are generally determined experimentally because the conditions for calculating the forces are complex and include variables that change at every point of the clasp arm's movement on the tooth surface. A distinction must be made between spring force and retentive force: *spring force* is the force with which the clasp arm is bent open, while *retentive force* arises as a reaction force on the tooth surface.

All of the variables included in the spring constant as a guide value—such as bar length, cross-section geometry, and modulus of elasticity—are used to determine spring force. For a semi-ellipsoid bar (the shape of a clasp arm) that tapers down to the bar tip (clasp tip), the following formula has been developed; spring force *(F)* is equivalent to spring deflection *(s)* times spring constant *(c)*:

$$F = s \times c$$

The formula for the spring constant is as follows:

$$C = 3 \times E \times J_0 / L^3$$

where E is the modulus of elasticity, J_0 is the axial moment of inertia, and L is the clasp arm length or bar length.

The axial moment of inertia indicates the specific inherent stability of a semi-ellipsoid profile:

$$J_0 = \pi \times B \times H^3/12$$

where B is the profile width and H is the profile height.

The ratio of final thickness to initial thickness is given to describe the taper; a variable φ is derived from this. The complete formula for calculating spring force is therefore:

$$F = \frac{1}{4 \cdot \varphi} \times \frac{3 \cdot B \cdot H^3 \cdot \pi}{12} \times \frac{E}{L^3} \times s$$

If real values for a clasp arm are inserted into this formula, the spring force is obtained. A clasp arm with the following dimensions is used as an example: clasp arm length = 12 mm, profile width = 1 mm, profile height = 0.8 mm, spring deflection = 0.5 mm, taper factor (ratio 8:10) = 1.054, modulus of elasticity (for steel) = 2.2×10^5 N/mm^2. A spring force of 6.1 N is calculated from these values.

The spring force acts in the plane of the spring clip. On withdrawal, the clasp is pulled over the tooth perpendicular to this direction of spring force in the path of insertion. In the process, the clasp arms bend apart on the inclined surfaces of the tooth. The force relationships at the tooth surface can be represented by the physical model of an inclined plane.

The physical model breaks down the forces on the body lying on the inclined plane into weight force, slope force, and normal force (Figs 6-24 and 6-25). In this case, weight force can be equated to spring force. The slope of the inclined plane is expressed as the angle α and coincides with the angle of inclination of the tooth surface (relative to the path of insertion), the undercut angle. *Normal force* is the vertical force on the inclined plane (tooth surface) and is determined by the expression: spring force $\times$ cos α. *Slope force* is the force that pulls the body downward. When applied to clasps, it is the force that tries to pull the clasp arm back into its resting position; it is calculated on the inclined plane from the expression: spring force $\times$ sin α (see Fig 6-24). *Withdrawal force* runs in the path of insertion and is related to the slope force in the angle α. The withdrawal force can be calculated from the expression: slope force $\times$ cos α. Thus, withdrawal force equals spring force $\times$ tan α (Fig 6-26).

One variable of withdrawal force is the undercut angle, which is 10 degrees on average (Figs 6-27 and 6-28). In the clasp resting position, the undercut angle is very large (up to 30 degrees) and the spring force is zero. If the clasp arm lies on the prosthetic equator, the spring force is at its maximum and the undercut angle is 0 degrees with tan $\alpha = 0$; the withdrawal force would also be zero in this position.

Spring force also produces friction on the tooth surface, which runs parallel to the slope force and becomes effective on withdrawal. It is calculated as the normal force multiplied by the friction coefficient μ and is added to the withdrawal force. This results in the retentive force of the clasp as the sum of the withdrawal and friction forces (Fig 6-29):

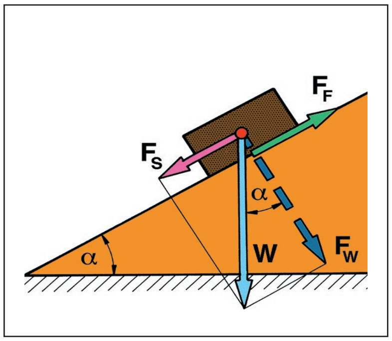


Fig 6-24 A body with weight W lying on the inclined plane is pressed vertically onto the inclined plane with a normal force (F_W = W cos α). The slope force (F_S = W sin α) pulls the body downward onto the inclined plane depending on the existing friction force ($F_F = F_W\mu$).

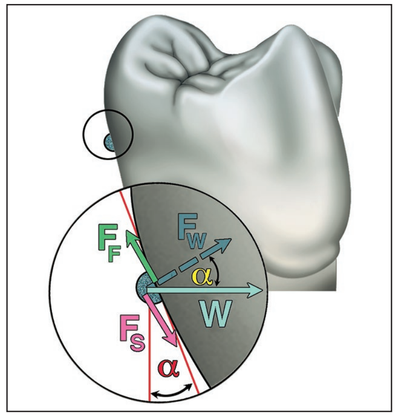
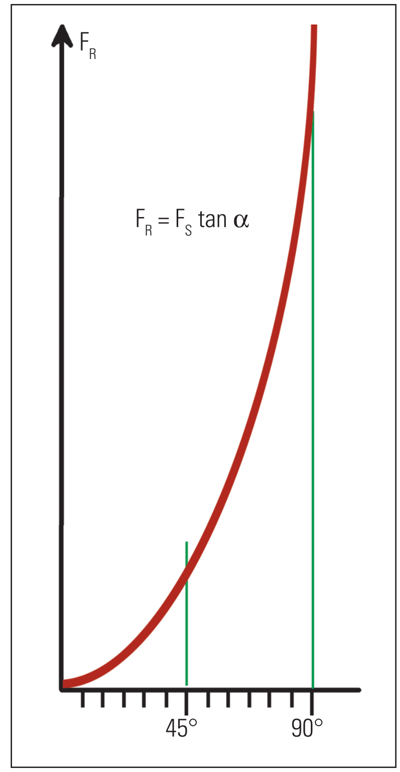


Fig 6-25 The relationships of the inclined plane, when applied to the tooth surface, give this picture: Weight force W is equivalent to the spring force.

Fig 6-26 *(right)* The retentive force due to bending open along the tooth surface as a function of the angle of inclination of an inclined plane.



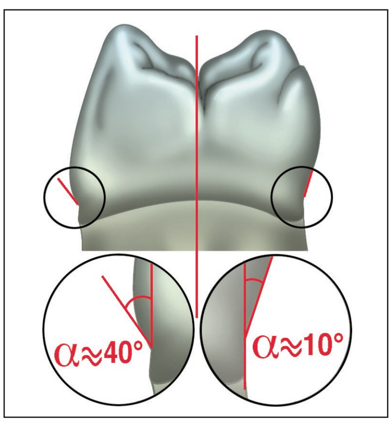


Fig 6-27 The inclines of the tooth surfaces to the path of insertion differ in size on the vestibular and lingual aspects. The undercut angle decreases toward the equator. On the vestibular side, the undercut angle is very large at the resting point of the clasp, so that clasp force is initially very high despite low spring force. On the lingual side, the undercut angle and clasp force are smaller.

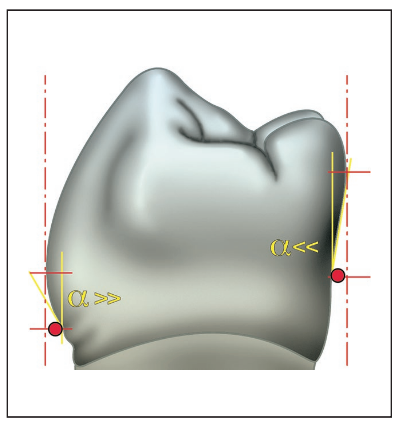


Fig 6-28 Where the undercut angle is smaller, the retention depth is very large (lingually) and the retentive force slowly increases. Conversely, a large undercut inclination means the retention depth remains small (vestibular aspect); the retentive force starts immediately and can become larger than on the lingual side. This correlation can be used as an argument for using a design with a stable guide arm if the undercut angle can be determined individually relative to the path of insertion.

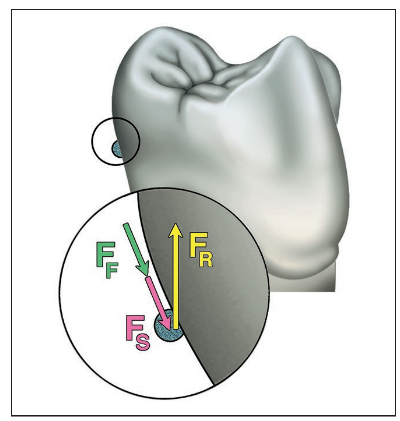


Fig 6-29 Retentive force is calculated from the slope and friction forces: Retentive force = (Spring force × tan α) + (Spring force × cos α) × μ.

Retentive force = (Spring force × tan α) + (Spring force × cos α) × μ

$$\text{Retentive force} = (\text{Spring force} \times \tan\alpha) + (\text{Spring force} \times \cos\alpha) \times \mu$$

The friction coefficient as a first approximation is taken to be tan α, which gives the following formula for calculating the retentive force of a clasp:

$$\text{Retentive force} = \text{Spring force} \times \tan\alpha \times (1 + \cos\alpha)$$

This gives a retentive force of 5.4 N if an undercut angle of 25 degrees is assumed and the previously calculated spring force of 6.1 N is applied. This value is very close to the value ascertained experimentally by a surveying system.

Surveying Casts

As detailed previously, the variables determining the retentive force of a clasp are spring deflection (undercut width), undercut angle, elastic material behavior (modulus of elasticity), spring length (clasp arm length), and thickness and shape of the spring profile (clasp profile). One or more of these variables are determined by means of measuring equipment and used for clasp fabrication.

When surveying casts, an attempt is made to establish the prosthetic equator for all of the teeth that will hold clasps and, relative to that equator, to determine the spring deflection for each clasp arm as a variable of retentive force. The prosthetic equator is the clasp survey line with reference to a common path of insertion. The *path of insertion* is the direction in which a denture is inserted and lifted out. With reference to the path of insertion, the cast is centered in a parallelometer. The position of the prosthetic equators and hence the undercuts on the clasped teeth can be altered by tipping the cast. The aim is to find the most favorable position of the clasp survey line for all of the teeth, thereby ensuring large enough retention areas and a sufficient safety distance (approximately 1 mm) from the marginal periodontium.

There are three cast positions (Fig 6-30):

- *Neutral position:* The cast is located in the horizontal plane relative to the occlusal plane; the undercuts are balanced.
- *Mesial tipping:* The cast is mesially lowered relative to the occlusal plane. The mesial undercuts become larger; on the anterior teeth, the clasp survey line is displaced in the incisal direction. The denture has to be moved backward into the mouth to be removed.
- *Distal tipping:* The cast is distally inclined relative to the occlusal plane. The distal undercuts become larger; on the anterior teeth, the clasp survey line is displaced cervically in the oral vestibule. The denture has to be lifted forward out of the mouth.

A parallelometer (surveyor) is needed to establish the tipping of the cast, the clasp survey line, and spring deflection. A favorable inclination of the cast is first determined with this device, and the teeth are checked with a gauge to ensure that adequate undercuts are available and the minimum distance from the marginal periodontium can be maintained. The clasp survey line is then marked, and the spring deflection is established with a suitable analyzing rod or gauge.

The undercut width or spring deflection is the horizontal distance to the clasp survey line. Therefore, the gauge for checking undercut width must be a parallel rod that enables a horizontal distance to be measured at its lower end. The undercut gauges in the Ney system (Dentsply) are available for measuring this distance (Fig 6-31).

Ney undercut gauges are parallel rods that widen into a bead shape at the end (Fig 6-32). The edge of the bead protrudes beyond the parallel rod by a certain amount. The width of the bead edge corresponds to the necessary spring deflection. The parallel rod can then be guided around the tooth being surveyed so that the edge of the bead and the rod touch the tooth at the same time—the rod at the prosthetic equator and the bead in the retention area. If different spring deflections are planned, the dentist can choose from three different bead sizes with different edge thicknesses: 0.25, 0.5, or 0.75 mm in the Ney system. The Ney surveying system uses only spring deflection in this rough three-way division for a clasp material based on chromium-nickel: *(1)* short clasp arm = small gauge, *(2)* medium clasp arm = medium gauge, and *(3)* long clasp arm = large gauge. For this purpose, a standardized clasp arm profile tapering toward its tip and made from wax or flexible plastic patterns is supplied, and this is moved in line with the marking on the cast.

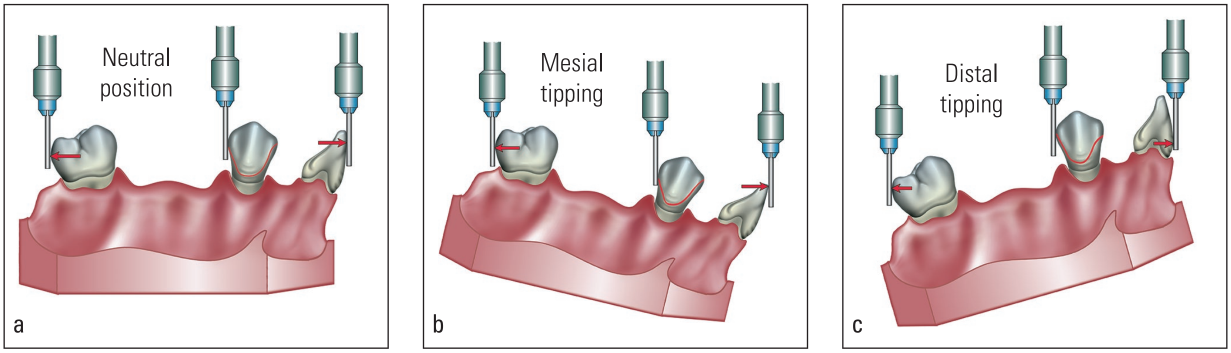


Fig 6-30 As a result of tooth tipping, the position of the prosthetic equator and hence the size and position of the undercuts will change. Three cast positions in relation to the parallelometer axis are distinguished: *(a)* Neutral position, in which the cast and hence the occlusal plane are located in the horizontal plane. *(b)* Mesial tipping, in which the occlusal plane tilts in a mesial direction. *(c)* Distal tipping, in which the occlusal plane, represented by the cast, drops distally.

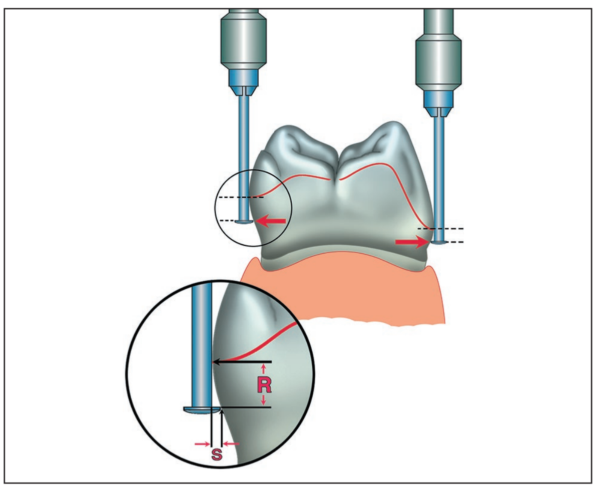


Fig 6-31 The gauges in the Ney system can be used to determine the spring deflection (s) or the retention depth (R). The shank of the gauge lies against the tooth at the widest circumference and is pushed up until the edge of the bead also touches the tooth in the undercut. The contact point of the edge of the bead indicates the position of the clasp tip.

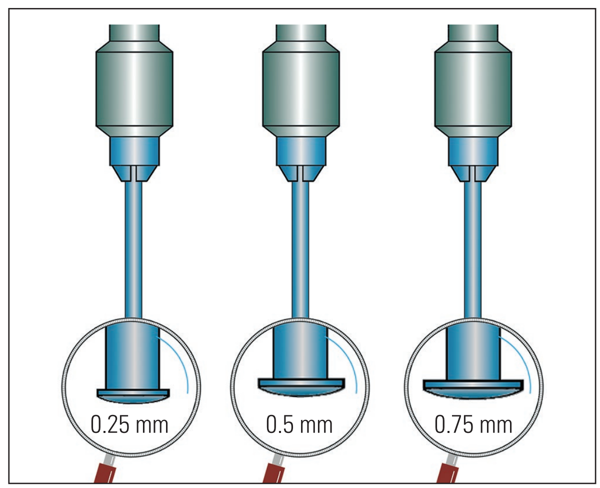


Fig 6-32 The Ney undercut gauges are parallel rods in which the ends have been widened to form a bead; the size is measured from the shank to the edge of the bead. Three edge widths make up the basic set (0.25 mm, 0.5 mm, and 0.75 mm). The small bead is for short clasp arms, the medium bead for medium clasp arms, and the large bead for long clasp arms.

The maximum spring deflection denotes the position of the clasp tip, from where the arm rises continuously out of the undercut as far as the clasp survey line. It is important to ensure that no part of the clasp arm is placed in an undercut depth larger than that of the tip, because otherwise, on withdrawal of the clasp, the arm will be widened above this point up to the equator, producing considerably greater spring force. Keep the following in mind as simple rules:

- The first third of the clasp arm, starting with the clasp shoulder, should lie above the equator.
- One third should lie on the prosthetic equator.
- The last third should lie in the retention area.

Figures 6-33 to 6-36 describe the components of a parallelometer.

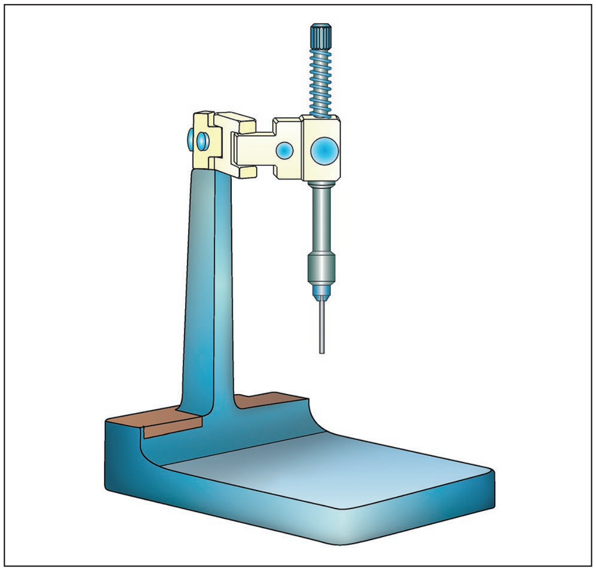


Fig 6-33 The surveyor (parallelometer) consists of a horizontal base (platform) with a vertical column to which a rigid or movable horizontal arm is fixed. On the surveying platform, a surveying table can be moved horizontally. The parallelometer rod is fixed onto the horizontal arm with a clamping device to receive carbon markers, analyzing rods, or undercut gauges.

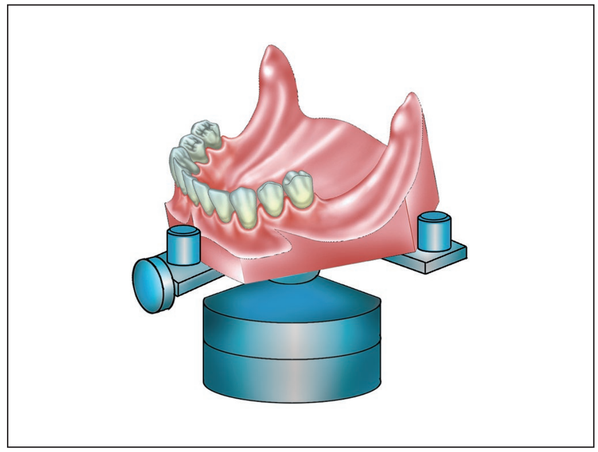


Fig 6-34 The surveying table has a clamping device for the cast and can be tipped in all directions via a ball joint.

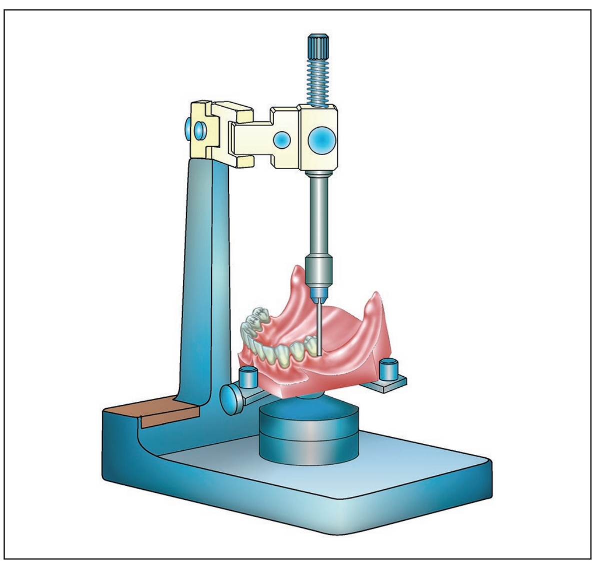


Fig 6-35 The prosthetic equator can be established with the parallelometer. The perpendicular parallelometer rod can be moved at will in the horizontal plane. The vertical parallelometer rod indicates the insertion path of the denture. The cast being surveyed is tipped relative to the insertion path. The cast holder can be moved as desired in relation to the insertion path so that the cast can be placed in the appropriate inclination to the insertion path. The cast holder can be moved on the bottom part of the parallelometer entirely without interference.

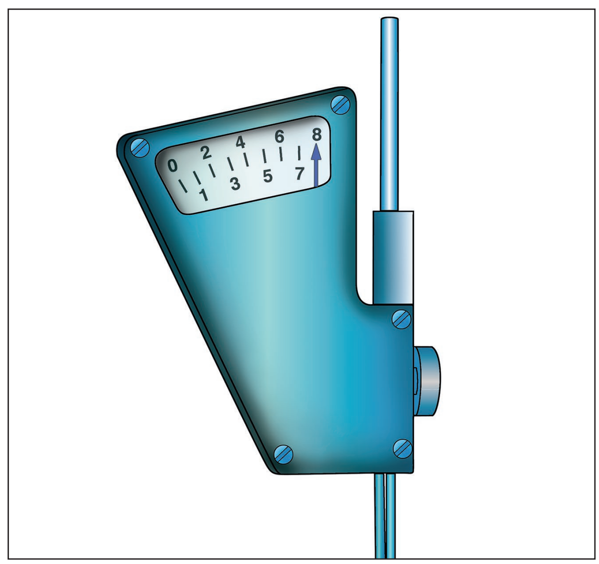


Fig 6-36 A microanalyzer is a surveying instrument for determining the spring deflection in the infrabulge area of a clasped tooth when surveying for cast clasps. The device can be clamped into the parallelometer rod and moved in parallel. The surveying head has a removable probe that can be extended up to 0.8 mm and can be continuously pressed in. The amount the probe is extended can be read off the instrument scale.

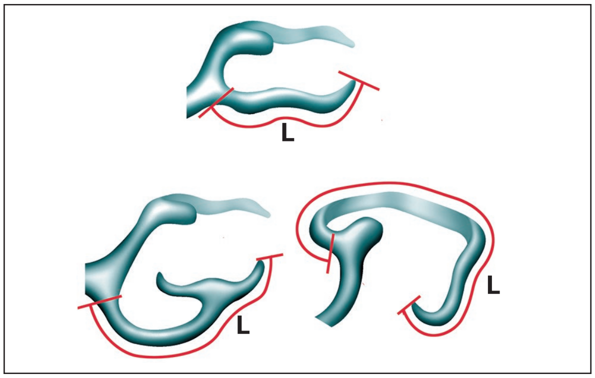


Fig 6-37 Clasp arm length, which is determined by the shape of the clasp, is measured first. The length of the free retaining arm is measured from clasp tip to clasp body or to the rigid clamping device.

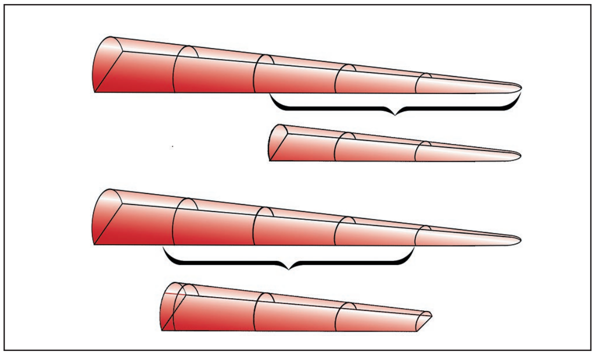


Fig 6-38 The correct part can be cut out of a uniform clasp profile with semi-ellipsoid cross section and constant taper toward the tip. If a clasp arm of a specific length is required, the profile can be adapted to the clasped tooth starting from the tip, without changing the profile; the excess is cut off. If, based on data from the tables, the profile is trimmed from the tip by 5 mm, for instance, and the clasp profile is then adapted, the result is a markedly thicker clasp arm.

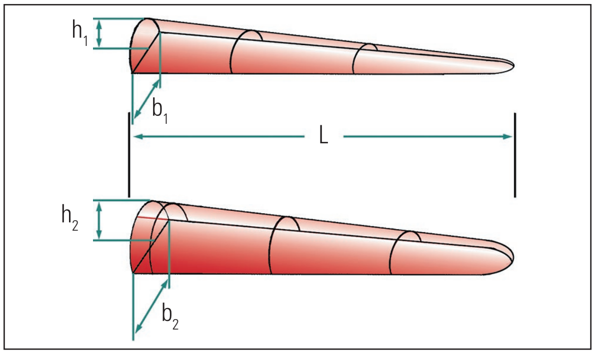


Fig 6-39 A comparison of the two parts shows that they have the same clasp arm length, profile shape, and taper but different profile thicknesses. If the same spring deflection is created in both clasp arms, the thicker profile will be more rigid and produce more spring force. However, because the same spring force is meant to be generated with both clasp arms, the thin profile will require a larger spring deflection.

Measuring Spring Deflection

Spring deflection is not measured with the Ney system, but three variables to measure the bending open of a spring are offered for short, medium, and long clasp arms. The requirement for defined retentive force cannot be satisfied with this surveying system—even as a rough approximation—because only one variable of retentive force is used in the aforementioned three-way grading. Modern surveying systems, such as the Rapid Flex system (DeguDent), interrelate four variables: modulus of elasticity, clasp arm length, profile thicknesses, and spring deflection. The clasp arm length or the free retaining arm length is measured for each clasp from the clasp tip to the clasp shoulder in millimeter graduations (Fig 6-37). The undercut widths (ie, the spring deflection with reference to the anticipated retentive force) can be read off suitable tables. In the process, clasp arm thickness (profile thickness) is also included as a variable. This is because a longer spring deflection pertains more to a long, thin clasp than to a short, thick clasp.

The semi-ellipsoid wax profile has a constant height-to-width ratio and tapers toward the tip (Fig 6-38). The appropriate clasp arm lengths can be cut from 30-mm-long wax profiles. If an 18-mm-long clasp is required, a thick clasp arm can be cut out if the profile is shortened starting from the apex; a thin clasp arm is produced if the thick end of the profile is cut off. This demonstrates the principle of variability of profile thickness (Fig 6-39). This variability, however, is not unlimited with the Rapid Flex system because the wax profile can only be changed by trimming the

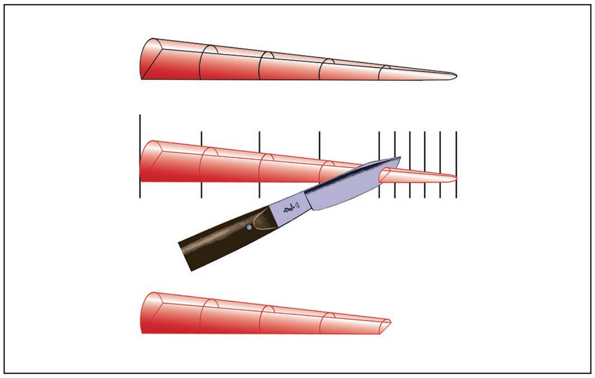


Fig 6-40 The spring deflection related to clasp arm length can be found from a table. By reference to that, the clasp profile is trimmed from the tip. The Rapid Flex system allows a maximum of 5 mm of trimming in millimeter steps.

tip in millimeter steps (Fig 6-40). The maximum shortening allowed is only 5 mm. This range of variation is enough to allow for any clasp arm length between 5 and 30 mm with the necessary spring forces between 0 and 10 N. The permitted tolerance of spring force is +0.01 N, which is less than the variation caused by process and system errors in casting and finishing.

The tables (data template) indicate the exact spring deflection for each clasp arm in the different thicknesses and lengths and thereby identify the expected spring force. For an 18-mm-long clasp arm, six clasp arm thicknesses can be matched in the tables with spring deflections between 0.1 and 1.0 mm for achievable spring forces between 1.0 and 11 N. Thus, differentiation and accuracy in terms of retentive force can be achieved with the Rapid Flex system that are not possible using the Ney surveyor.

Practical procedure

The path of the clasp arm is temporarily marked with reference to the surveyed clasp survey line (prosthetic equator) so that the location of the clasp tip is defined. A surveying wheel (micromini) is used to measure the clasp arm length accurately from the clasp tip to the rigid clamping device (clasp body).

If a clasp is being constructed in which both arms engage in the retention area—which happens in most cases—the retentive force of the two arms must be equivalent to the total force of the clasp; for example, if the assumed retentive force is 10 N, the value of 5 N per clasp arm is sought in the table, and the spring deflection as well as the profile thickness are selected accordingly.

The data template is a set of tables for two moduli of elasticity (chromium-nickel and gold-platinum alloys). These indicate the spring forces that may be expected, arranged according to clasp arm lengths, profile thicknesses (or in 1-mm trimming steps), and spring deflections (undercut widths).

The value from the table indicating maximum spring deflection is transferred to the cast with an electromechanical measuring device known as the Scribtometer. The Scribtometer allows for continuous measurement of distance in the horizontal plane. A movable measuring needle is fitted into the parallel guide shaft of this instrument, and the horizontal excursion of this needle can be read off a scale. The shaft touches the tooth at the clasp survey line, and the measuring needle touches in the retention area; the undercut width is therefore readable. Once the Scribtometer shows the selected undercut width, the measuring needle marks the point where the clasp tip should lie by applying an electrical impulse to the lacquer-coated tooth surface (Fig 6-41).

The path of the clasp arm is precisely plotted; the clasp profile is trimmed (or not), starting from the tip and based on the information from the data template, and then moved. The rest of the clasp profile is trimmed at the clasp shoulder and removed (Fig 6-42).

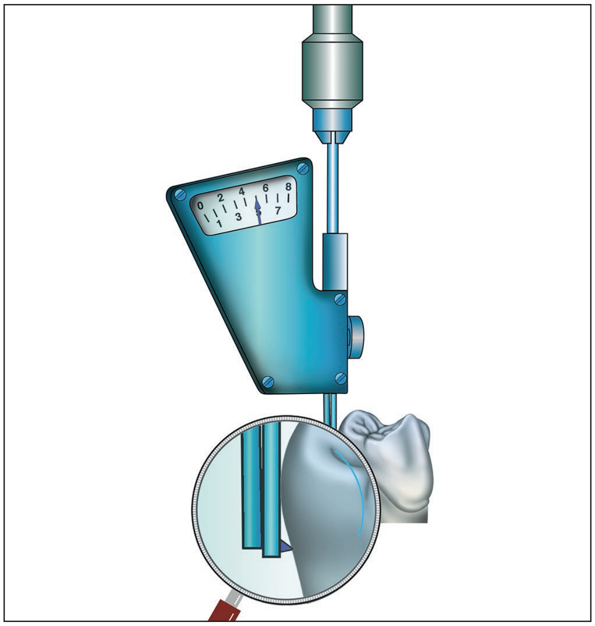


Fig 6-41 The surveying head is positioned in the undercut area of the tooth, where the clasp tip is expected to lie, and at the same time is guided with the parallel shaft against the prosthetic equator. The surveying head is guided vertically along the tooth until the horizontal undercut value (spring deflection) found in the data tables is displayed on an instrument scale. This point is color-marked in contact paint on the tooth surface via an electrical impulse.

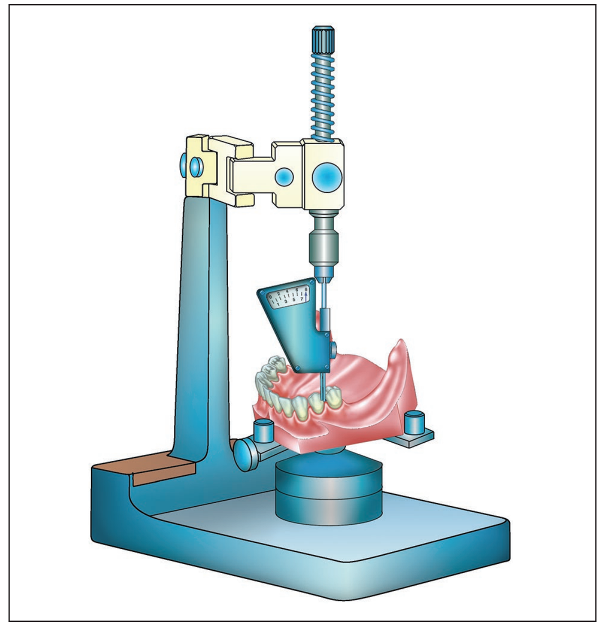


Fig 6-42 The first surveying step involves locating the provisional clasp path and checking whether there are sufficient undercuts without the clasp lying too close to the marginal periodontium. The clasp arm lengths are then measured, and the individual spring deflections are established for all the clasp arms. This means consulting the data tables to find out how much the clasp profile needs to be shortened. An intermediate step involves checking whether the chosen spring deflections are available on the actual clasped tooth; if necessary, a different shortening factor and different spring deflection will have to be selected. This process seems laborious, but therein lies its advantage: Several variables (spring deflection, profile thickness, and clasp arm length) for determining the precise clasp force and clasp length are combined. This means a level of accuracy is achieved that no other method can provide.

Cast-Clasp Designs

All forms of cast clasps must meet the requirements previously outlined:

- Secure the horizontal and vertical position
- Enclose the body of the clasped tooth
- Present a fit that aids periodontal hygiene
- Meet the defined retentive force

Only the double-arm clasp with occlusal rest meets all of these requirements. Any modification of the double-arm clasp and any other form of clasp will fall short of the basic form to some extent when it comes to fulfilling these functions. However, 90% of all prosthetic cases can be treated with double-arm clasps.

The classic Ney clasp system with its five clasp types offers calculable retentive forces identical for all clasps if surveying is done properly. The differences lie in their functional quality, depending on which of the aforementioned requirements have priority or are to be ignored.

The double-arm clasp with occlusal rest is the standard design of cast clasp. It is also called an *E-clasp*, *Ney No. 1*, or *Akers clasp* (Fig 6-43). It is the simplest and most practicable form of clasp because it ensures adequate positional stability

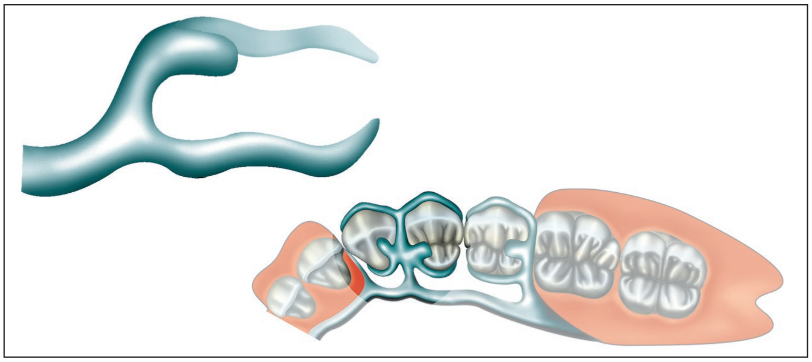


Fig 6-43 The simplest double-arm clasp with occlusal rest is the Ney No. 1, also known as an E-clasp, which is the most practicable and most commonly used clasp. The E-clasp engages in the retention areas on both sides and can also be used on teeth that have minimal undercuts.

and offers rigid occlusal support. The design is also conducive to periodontal hygiene. Double-arm clasps fulfill all the tasks required of them. They are universally indicated; they can be used in small, bilateral undercut widths as well as for bounded or free-end dentures and in alternating partially edentulous dental arches.

Modifications of the double-arm clasp

Following are a number of modifications of the double-arm clasp. Note that none of the modifications offers any advantages over double-arm clasps.

1. Bonwill clasp

A Bonwill clasp is a common modification in the form of two double-arm clasps that are connected to the denture framework at the clasp shoulder via a shared minor connector (Figs 6-44 and 6-45). The Bonwill clasp is used within closed segments of the dental arch. For this purpose, the interdental embrasure between the teeth and the two rest surfaces has to be prepared. The joint clasp shoulder then runs lingually to buccally/labially.

From the standpoint of statics, the Bonwill clasp is an excellent solution. The minor connector is unfavorable in terms of periodontal hygiene, however, because it covers the interdental papilla. The shared clasp shoulder can be esthetically disadvantageous with premolars; if the necessary preparation is not protected with fillings, there is a strong susceptibility to caries.

2. Split or Bonyhard clasp

A split or Bonyhard clasp is a double-arm clasp with two rests that is fixed to the framework by two minor connectors; each connector bears an occlusal rest and one clasp arm, one lingual and the other buccal/labial (Figs 6-46 and 6-47).

The periodontal support is absolutely secured; horizontal thrusts can be absorbed well enough. The minor connectors are questionable in terms of periodontal hygiene, while the abutment tooth is always subject to rotation during placement and removal of the clasp.

3. Back-action clasp

A back-action clasp is a single-arm clasp in which the lingual clasp arm runs from the minor connector over the lingual tooth surface and around the tooth in a vestibular direction and engages in the retention area on one side; the occlusal rest sits rigidly on the minor connector (Fig 6-48). The clasp arm can start directly from the denture saddle or be directed to the clasped tooth by its own minor connector remote from the saddle. This clasp modification offers sufficient periodontal support but not complete horizontal positional stability. Only unilateral retention areas are exploited, and the undercut widths have to be large enough with these elastic clasps. If a clasp arm is guided through an interdental embrasure over the row of teeth, the clasp bed must be prepared. This modification is therefore unfavorable in terms of esthetics, caries prevention (interdental clasp bed), and periodontal hygiene (minor connector).

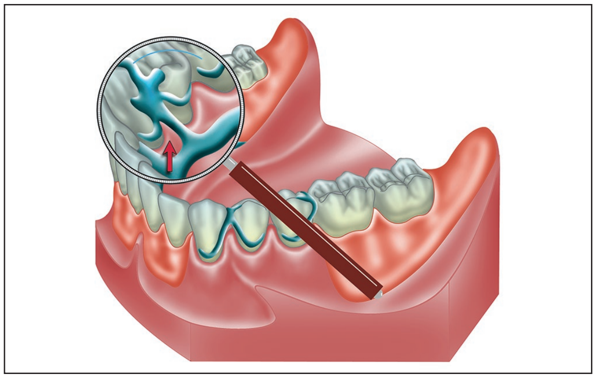


Fig 6-44 A Bonwill clasp has two double-arm clasps that are joined together at the clasp shoulders. They have a shared minor connector to the denture framework that covers the interdental papilla, which is hygienically disadvantageous. The Bonwill clasp is used on teeth that stand close together. Interdental embrasures have to be prepared for these clasps.

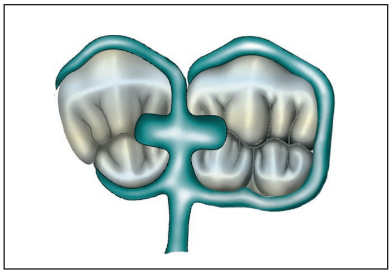


Fig 6-45 The combination of a double-arm clasp with a back-action clasp is a possible modification of the Bonwill clasp.

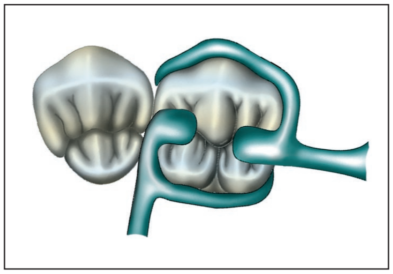


Fig 6-46 The split double-arm clasp with two rests and two minor connectors to the framework offers no advantages.

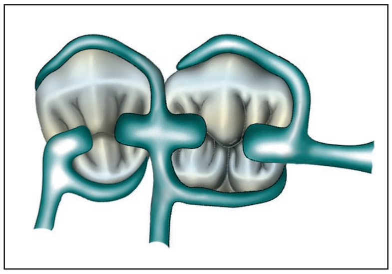


Fig 6-47 Bonyhard clasps (clasps with stems) are split clasps with four rests and three minor connectors to the denture framework.

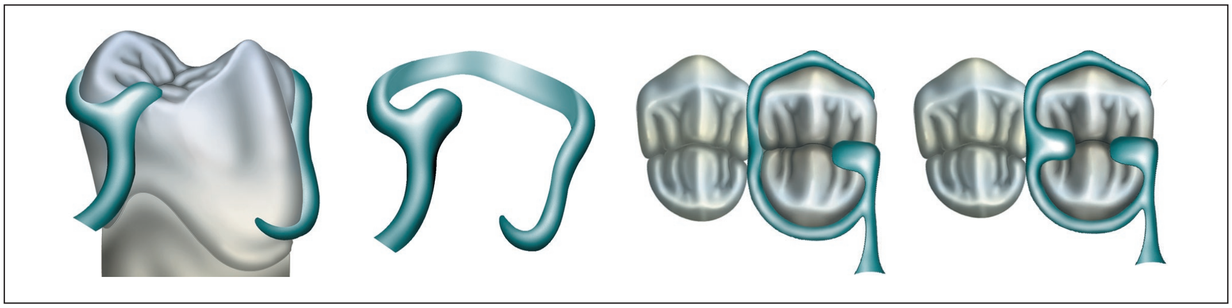


Fig 6-48 The back-action clasp is a single-arm clasp in which one rest starts from the minor connector. The long clasp arm is very elastic and can be directed into the undercut area. One modification involves placing a second rest on the clasp arm that is remote from the saddle; this clasp is known as a *circumferential* or *ring clasp*.

4. Circumferential clasp

A circumferential clasp has the same design as the back-action clasp and has a second rest on half of the clasp arm distance. The modification uses unilateral retention areas and offers good bodily enclosure; yet it is also esthetically and functionally unfavorable. Back-action and circumferential clasps are indicated if precise positional bracing can be omitted or if positional bracing is guaranteed by other clasps in a group of clasps.

Figures 6-49 to 6-57 show various cast-clasp designs and their effects.

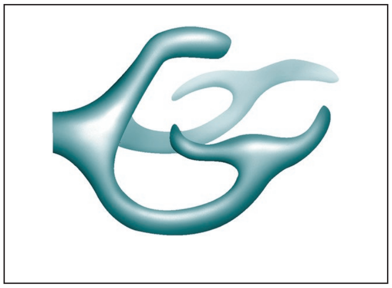


Fig 6-49 The Ney No. 2 clasp is a split double clasp with a rigid rest on the clasp body. The clasp arms are borne by arch-shaped denture saddles made of guided spring stems. Retention areas close to the saddle with large undercut widths can be used. This clasp does not offer horizontal stability and is questionable in terms of periodontal hygiene. In free-end dentures, the lower clasp arms directed toward the saddle press the free-end saddle onto the dental arch.

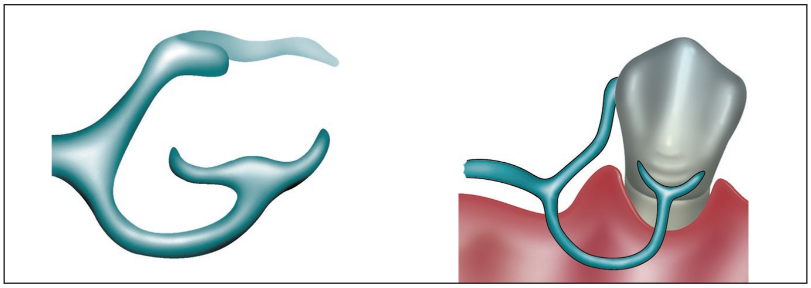


Fig 6-50 The Ney No. 3 is a combination of the Ney No. 1 and Ney No. 2 clasps. The occlusal rest is rigidly connected to the clasp body. The clasp does not secure horizontal position and does not offer bodily enclosure; the vestibular clasp arm can be placed far down in a cervical position and is disadvantageous for periodontal hygiene. It is used for teeth with large undercut depths that are tipped in the vestibular direction.

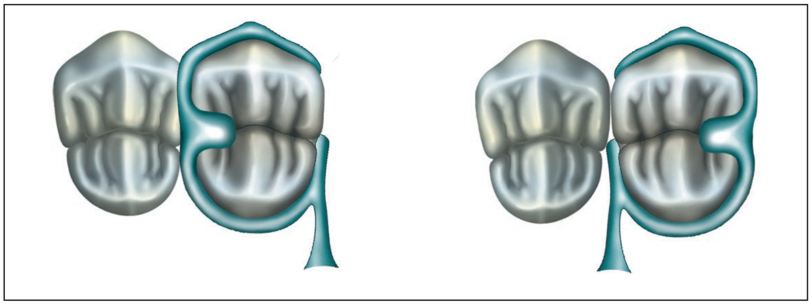


Fig 6-51 The Ney No. 4 clasp is a ring-shaped single-arm clasp that bears an occlusal rest on half of the clasp ring. It is an elastic clasp without adequate horizontal and vertical positional stability. This clasp is used on teeth with unilateral retention surfaces. In the case of free-end dentures, this clasp, open distally, can press the free-end saddle onto the dental arch.

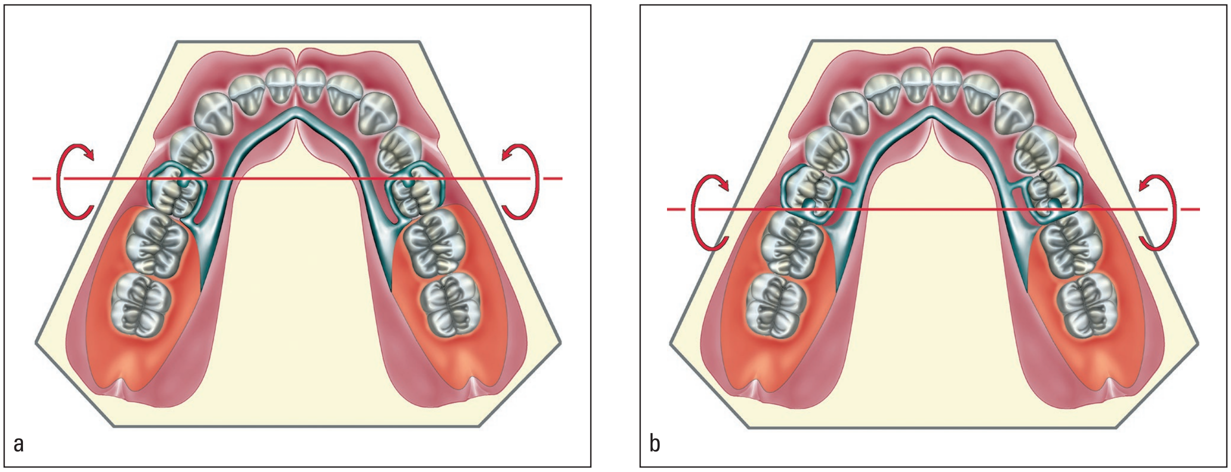


Fig 6-52 The use of a Ney No. 4 clasp as a corresponding system for free-end dentures produces a pivot about which the denture moves. *(a)* Rest close to the saddle. *(b)* Rest remote from the saddle; this design can function as a secondary or indirect retainer.

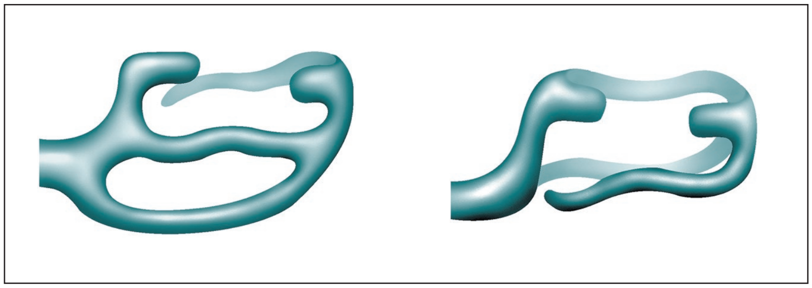


Fig 6-53 The Ney No. 5 clasp is a double-arm clasp in which the lingual part is fixed to the denture framework and supported by a minor connector on half of the arm. This framework clasp has two rests. The elastic vestibular clasp arm extends into the retention area on one side. This clasp offers precise positional stability as a splinting element for terminal molars. It is unfavorable in terms of periodontal hygiene.

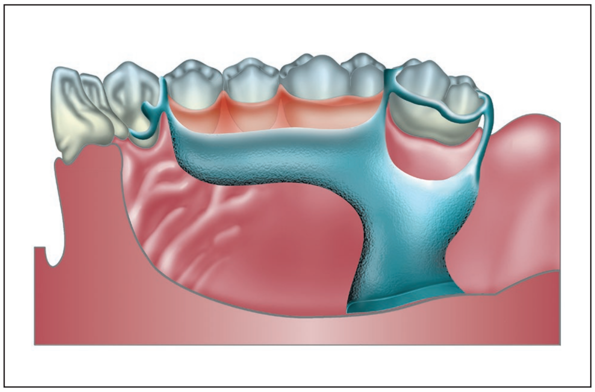


Fig 6-54 The rigid parts of the Ney No. 5 clasp are the two occlusal rests and the lingual clasp arm, which is joined to the clasp appendix by a rigid clasp tail. It is used as a rigid splinting element. If this clasp is used with a bounded denture, the double rest ensures exact axial loading of the clasped tooth.

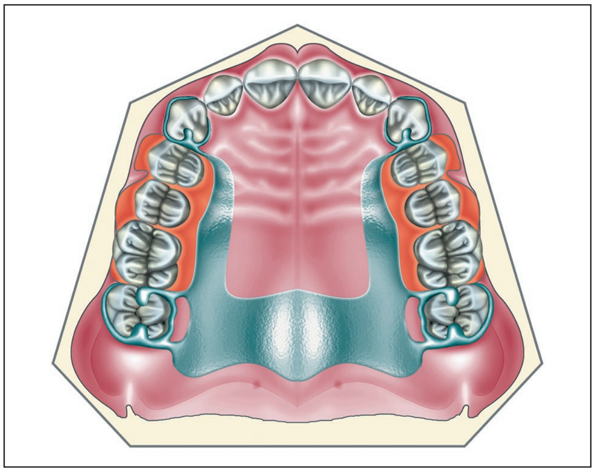


Fig 6-55 The good splinting effect of the Ney No. 5 clasp can be exploited by fitting this clasp symmetrically onto both halves of the jaw, making sure that the braced inner clasp arm does not lie in the retention area. It is still necessary to check that the good splinting effect is not undermined by unilateral loading of the tooth on clasp withdrawal.

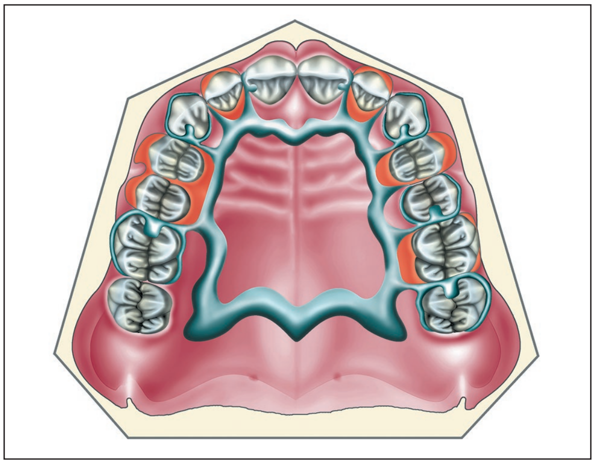


Fig 6-56 For alternating bounded dentures, full clasping with double-arm clasps is adequate for periodontal hygiene purposes.

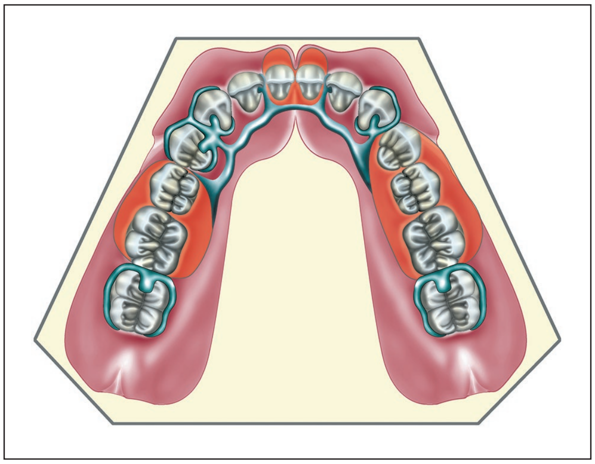


Fig 6-57 Full clasping of the residual dentition, in which a Bonwill clasp has been placed, is not satisfactory in terms of periodontal hygiene.

Cast Clasps on Coronal Restorations

If a tooth has a restoration to protect it as a clasped tooth, the retention areas are prepared during the wax-up procedure. It is generally enough to give the replacement tooth the appropriate bulging anatomical shape because the clasp systems are adapted to the anatomically shaped teeth (Figs 6-58 and 6-59). If a single crown is integrated into a group of clasps, the direction of inclination and retention surfaces of a common path of insertion can be adapted to those of the other clasped teeth.

When the clasped teeth of a clasp unit have coronal restorations, the path of insertion for the teeth is fixed, even at the wax-up stage. Slight distal tipping is always the least advantageous inclination as a path of insertion for the patient and for the anterior clasp position. Once the cross section of the restoration has been roughly waxed up, the undercut areas are ascertained with a parallelometer, and the vertical surface curvature is suitably thickened or reduced. In this situation, it is appropriate for every clasp structure, and especially for loading of the tooth, to wax up the undercuts, which guarantees a uniform retention depth below the prosthetic equator for all the teeth affected by a clasp.

The natural tooth shape has the following distinctive feature: At its widest circumference (prosthetic equator), there are different degrees of curvature of the buccal and oral surfaces depending on the inclination of the tooth. Thus, in a mandibular premolar, in keeping with the crown inclination, the oral undercut runs very steeply, while the buccal undercut is poorly developed despite the pronounced curvature. Where the maxillary teeth have a vestibular inclination, the vestibular undercuts are often steeper.

If a clasp is placed in which both clasp arms have to be bent open by the same spring deflection, different buccal and lingual retention depths arise. This influences clasp forces and the transverse loading of the tooth. It is assumed that the vestibular retention depth is smaller than the lingual. During withdrawal, the vestibular clasp arm is bent open by its spring deflection, while the lingual arm is only partly bent open. In the process, the following phenomena occur: The tooth is jolted to and fro on withdrawal of the clasp, and the transverse thrusts that arise are uncontrolled and harmful. On coronal restorations, the vestibular and lingual retention depth for the clasp arms can be shaped to the same size during wax-up by correcting the vertical curvatures.

If a lingual guide arm is constructed to the vestibular retention depth, a parallel guide is waxed up in the form of a circular notch (Fig 6-60). The circular notch is created by reference to the path of insertion and should be milled according to the same principles as when combined with prefabricated components. The lingual clasp arm is sunk into the replacement crown material and secures the vertical and horizontal position.

In this context, it becomes clear that it is questionable to design cast clasps with guide arms and retaining arms for teeth that do not have restorations. All the guide arms of a group of clasps must run parallel to each other and to the path of insertion. Milling the lingual surfaces in the mouth in the same way in parallel is very time-consuming and is not justified by the outcome. If an acrylic resin veneer crown is fitted with a clasp construction, the functional clasp arm may abrade the veneer, and the retentive force of the clasp may be lost. Therefore, the veneer should be shaped so that the lower clasp arm in the resting position does not lie on the acrylic resin but on a metal guide (Fig 6-61). In the mandible, such a design is usually possible without loss of esthetics. Because a removable partial denture has to be protected periodontally against masticatory forces, at least one occlusal rest is necessary on each cast clasp. This rest is already prepared on the replacement crown.

The shape of the occlusal rest also determines the shape of the floor of the rest in the replacement crown. Thus, the floor of the rest is modeled perpendicular to the tooth axis in a spoon-shaped recess; the rest is modeled so broadly (approximately 2.5 to 3 mm) and deeply (1.5 mm) that the eventual rest is fracture resistant and does not interfere with occlusion. If a guide arm is constructed, the floor of the rest can be shaped with its walls parallel to the parallel milling. Where a circular notch is shaped with a cervical shoulder, an occlusal rest can be dispensed with.

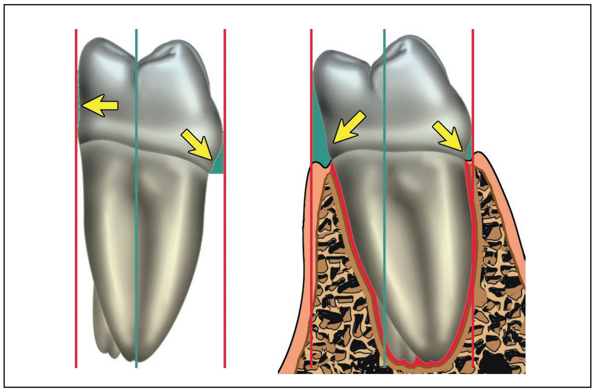


Fig 6-58 The surface bulbosities of natural mandibular teeth produce more pronounced undercuts on the buccal side; as a result of the lingual inclination of the posterior teeth, undercuts for clasps are found in the lingual area. Where coronal restoration is done, reproducing the natural surface bulbosity is enough to obtain adequate undercuts for clasps.

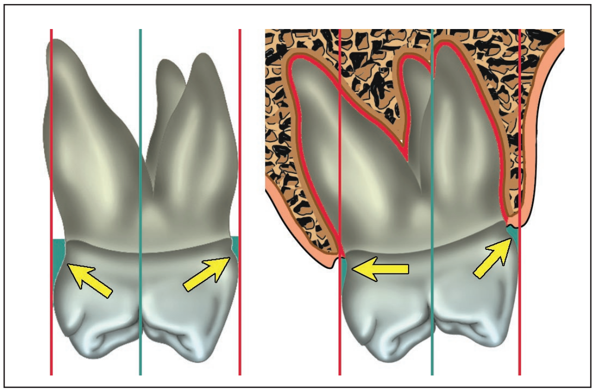


Fig 6-59 In the case of maxillary posterior teeth, the undercuts relative to the tooth axis mainly lie lingually, which is put into perspective by the vestibular inclination within the position in the dental arch. For cast clasps, these undercuts are generally adequate, which requires reproduction of the surface bulbosity when making coronal restorations.

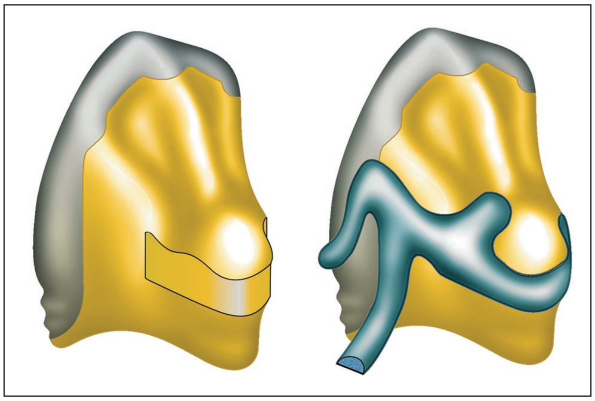


Fig 6-60 If the lingual clasp arm is to be shaped as the guide arm, it must be directed parallel to the path of insertion throughout the length of the retention depth of the active clasp arm. A guide plane is milled into the crown so that the clasp arm acts as a shear distributor. This method lends itself to anterior teeth because the lingual undercuts are very poor. Fitting a canine with a veneer crown and then placing a cast clasp is extremely questionable from an esthetic viewpoint.

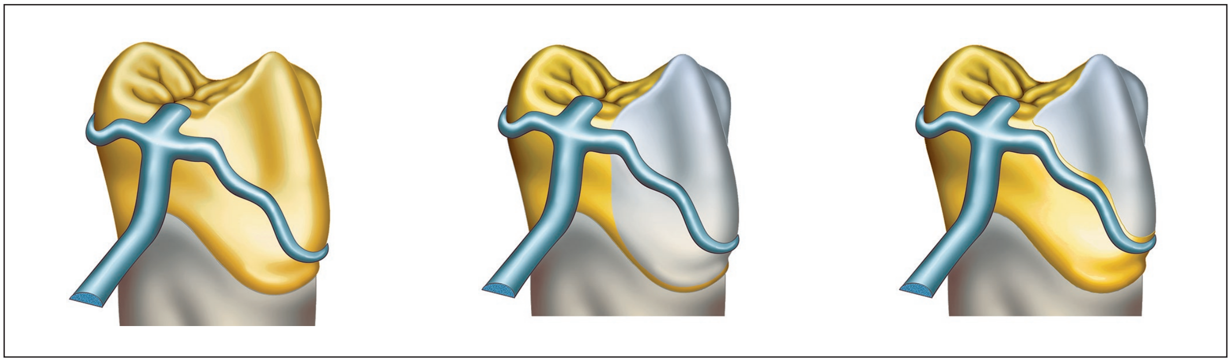


Fig 6-61 If a clasped tooth will undergo coronal restoration, a full-metal crown is best suited for bearing the mechanical stress. If two different metals are combined in the mouth, galvanic processes may arise, which argues against such an indication. In the case of a full crown with an acrylic resin veneer, the acrylic resin is subject to mechanical stress, which is why a metallic sliding surface must be created for the clasp arm. This reduces the esthetic advantage of the veneer crown, apart from the fact that clasps are always esthetically disadvantageous.

7

Statics of Partial Dentures

Basic Terms in Mechanics

This section outlines the basic terms in statics and dynamics that are used in dental technology. *Statics* is the study of the equilibrium of forces acting on a rigid body. In statics, rigid bodies are structures that deform so little when loaded by forces that the points of application of force undergo minimal displacement. *Equilibrium* refers to the state when a rigid body is at rest or in uniform motion.

There are seven variables fundamental to physics and engineering: length, time, mass, temperature, current intensity, amount of substance, and light intensity. Other variables are derived from these, including velocity, work, and density. Quantities are either scalar or vector. Scalar quantities are represented by a numeric value and a unit—for example, time (t), temperature (T), mass (m), and electric charge (Q). Vector (or vectorial) quantities are represented by a numeric value, a unit, and a direction—for example, velocity (v = m/s), electric field strength, and force. The character of a vector quantity is determined by the directional dependence of its action.

Forces are bound, aligned vectors that can be displaced along their line of action. They can be depicted as arrows in a diagram. The official unit of force is the Newton ($1 N = 1 kg \times 1 m/s^2$), and force is characterized by the following:

- Magnitude, number, and unit (eg, 30 N)
- Direction, represented by the vector arrow, in which the tip points the direction and the length represents the measure of force
- Position of the line of action on which the force can be moved

In equilibrium, any force (action force or input force) causes a counterforce (reaction force or output force) that is equal and in the opposite direction (Newton's third law). If, for example, a body rests on a solid support, its weight presses on that support; the

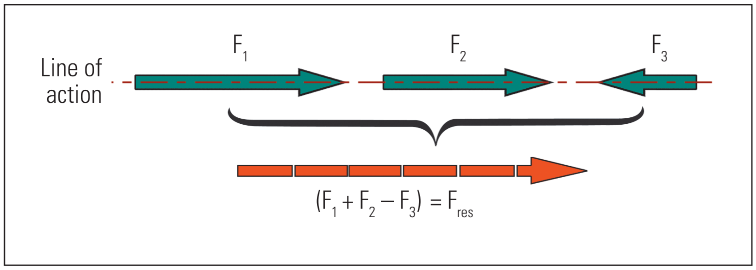


Fig 7-1 Forces that have a common line of action can be combined by simple addition or subtraction. The resultant force lies on this same line of action.

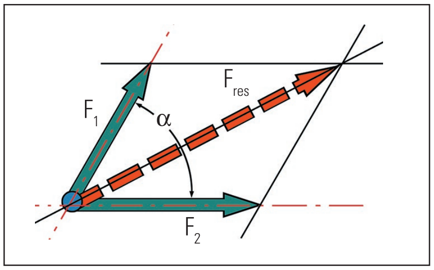


Fig 7-2 If two forces are not parallel but have a common point of application, the resultant force is determined by means of a parallelogram of forces. A parallelogram is formed, the diagonal is plotted, and the resultant is determined based on magnitude and direction.

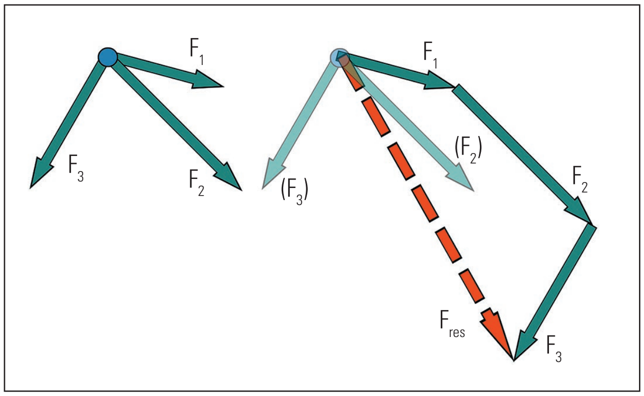


Fig 7-3 The resultant of several nonparallel forces is determined by means of a polygon of forces. The force vectors are moved parallel to each other and strung together so that the resultant can be plotted from the origin of the first vector to the tip of the last vector.

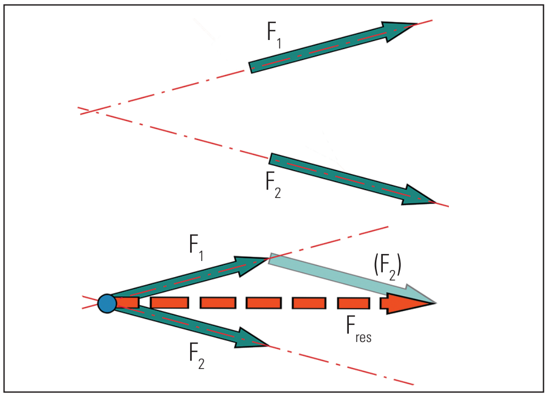


Fig 7-4 Force vectors that are not acting at one point can be extended on their lines of action until they intersect. The resultant can then be determined from a polygon of forces.

action force (G) is absorbed by the support by an equivalently sized reaction force (F), or else the body is not in the resting state (action force = reaction force).

Forces that act on a body are combined by geometric addition to form a resultant force. This is done with a parallelogram of forces for two forces or with a polygon of forces for several forces.

Single forces (components) on a common line of action can be added together or subtracted; the sum or difference is the resultant (Fig 7-1). Single forces on different lines of action are combined to form a polygon of forces, and the resultant is determined from the diagram.

In a parallelogram of forces, two forces with different directions but the same point of force application are combined in the diagram to produce a resultant. This resultant is obtained by drawing a straight line from the origin to the intersection of the parallel forces (Fig 7-2). If there are more than two forces, a polygon of forces is constructed, and the resultant is drawn from the origin of the first vector to the tip of the last vector (Fig 7-3).

Where there are different points of force application, the forces are moved along their lines of action to a common point of intersection to form a polygon of forces (Fig 7-4). Now the line of action and magnitude of the resultant are known but not its point of force application.

Forces can also be resolved into two components with the parallelogram of forces, provided the direction or magnitude of the components is known. If the direction is known, the lines of action are placed through the point of force application, and the parallelogram of forces is constructed. If the magnitude of the components is known,

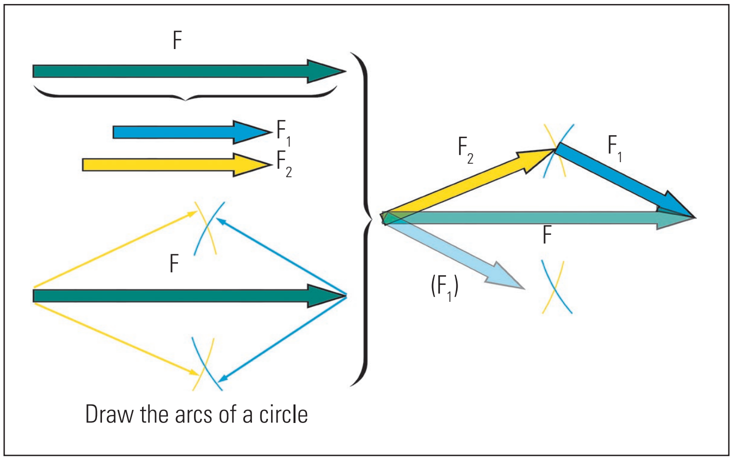


Fig 7-5 A given force can be resolved if the magnitudes of the single forces are known. To do this, a polygon of forces is constructed by drawing arcs of circles at the origin and at the tip of the force being resolved, along with the radius of the components. The intersection of the arcs establishes the apices of the components. If the angle between the given force and the unknown forces is known, the forces are drawn in the corresponding angle without the magnitude; they are moved parallel to the polygon of forces until they enclose the given force as a diagonal.

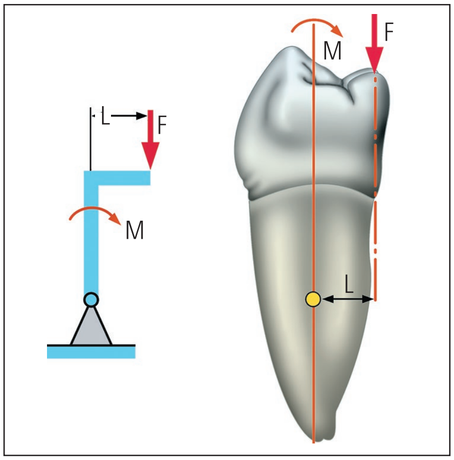
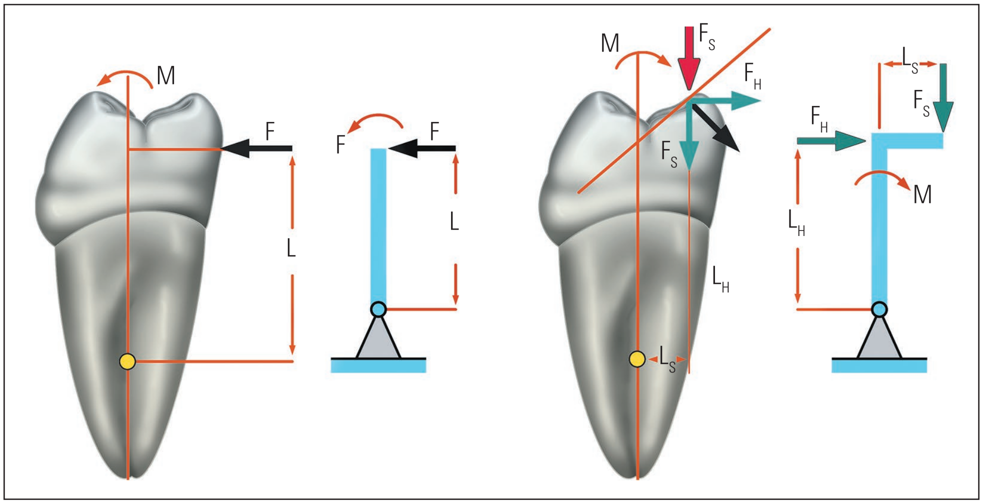


Fig 7-6 Torque is an axial vector. Such vectors can be classified as free vectors, which are not bound to any lines of action but can be moved in parallel. Counterclockwise moments are identified with a negative sign, and clockwise moments are identified with a positive sign. If a force acting on a tooth is not in the direction of the tooth axis or runs at a distance from the axis, a torque acts on the tooth. The torques countering the acting forces have to be applied by the periodontium.

Fig 7-7 The periodontium is the least protected against eccentric forces (not acting axially). In multiple-rooted teeth, eccentric forces can be absorbed to a certain degree. In the case of tilted teeth, forces encountered have disastrous effects when they produce torques that tip the tooth.



one arc of a circle is drawn at the origin of the force being resolved and another arc at the tip; the magnitude of the force forms the radius of the arc. The point of intersection of the arcs provides the corners of the parallelogram (Fig 7-5).

A *force couple* comprises two equal and parallel but oppositely directed forces. A force couple exerts a static moment; if rotation takes place, it is known as the *turning moment (torque)*. Torque is produced by a force that acts on a rigid body when the line of action runs at some distance from the fulcrum (Figs 7-6 and 7-7). Torque is the product of force and the perpendicular distance of its line of action from the fulcrum:

Moment (M) = Force (F) × Distance of action (X)

Newton's Laws of Motion

The forces acting on a rigid body can produce either a progressive motion (translation) or a circular motion (rotation). Newton's first law of motion states that a rigid body is in equilibrium if the resultant of all the forces and the sum of all the torques equal zero. Without any additional external force being exerted, the body continues in a state of rest or in uniform motion in a straight line. This property of a body can also be referred to as *inertia*. From this, it may naturally be deduced that any change in the state of a motion or rest is based on the action of forces. Furthermore, the degree of force can actually be determined by measuring the strength of the change in the state of motion.

According to Newton's second law of motion, the acting force and the acceleration achieved behave in proportion to each other based on the following equation:

$$\text{Force } (F) = \text{Mass } (m) \times \text{Acceleration } (a)$$

Here a new term is introduced: *mass*. Based on what was outlined earlier, mass is bound to have something to do with inertia. The mass of a body depends on the speed at which it moves. Thus, if a body moves very quickly, inertia will be very great, or a great deal of force needs to be applied to brake the motion of the body or make it move even faster.

The unit of *force* is defined on the basis of this equation: $F = m \times a$. According to this, 1 N is the force required to accelerate a mass of 1 kg by 1 m per second squared:

$$1\ N = 1\ kg \times 1\ m/s^2$$

Newton's third law of motion states that forces always occur in pairs in the nature of an action and reaction force. If a body exerts a force on another body, it is reacted to with an equal and opposite force. This is also known as *Newton's law of reaction*. These interactive forces include:

- Gravitational forces or forces of attraction between two bodies
- Attraction and repulsion forces between electrically charged bodies or magnets
- Intermolecular forces
- Forces between the nucleons in the nucleus of an atom

Volume is the spatial extent of the mass. Bodies that have the same volume but are made of different materials therefore have a different mass.

Density defines the ratio of the mass of a body to its volume:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \text{or} \quad \rho = \frac{m}{v}$$

where ρ stands for density, *m* stands for mass, and *v* stands for volume.

The term *density* is initially hard to grasp because, based on the experience of our senses, wood seems just as dense as metal: Both are solid and both are opaque; wood is simply lighter than metal. This property should be referred to as *density*, namely, how much mass of a substance is accommodated in a specific spatial volume. The dimension of density is g/cm^3 (kg/dm^3 or kg/m^3). The atoms are most densely packed together in metal because this is the only way the metallic bond can function; thus, metal is very dense and heavy, certainly heavier than wood. In the casting technique, the amount of metal required can be calculated from the mass of the wax pattern, the density of the wax, and the density of the metal.

The density of solid and liquid bodies depends on temperature; that is, density decreases with rising temperature. In gaseous bodies, density is also dependent on pressure, which is why the term *condensing* is used when gaseous bodies are compressed.

Principles of Mechanical Systems

When partial and complete dentures are being constructed, the aim is always to achieve a compromise that combines the esthetic concerns with secure seating of the denture under functional conditions. Secure seating is determined not only by the possibilities of anchorage to the residual dentition or mucosa but also by the forms of functional loading and the static relationships of dentures on the dental arches. For this purpose, it is necessary to work on the basic terms in stat-

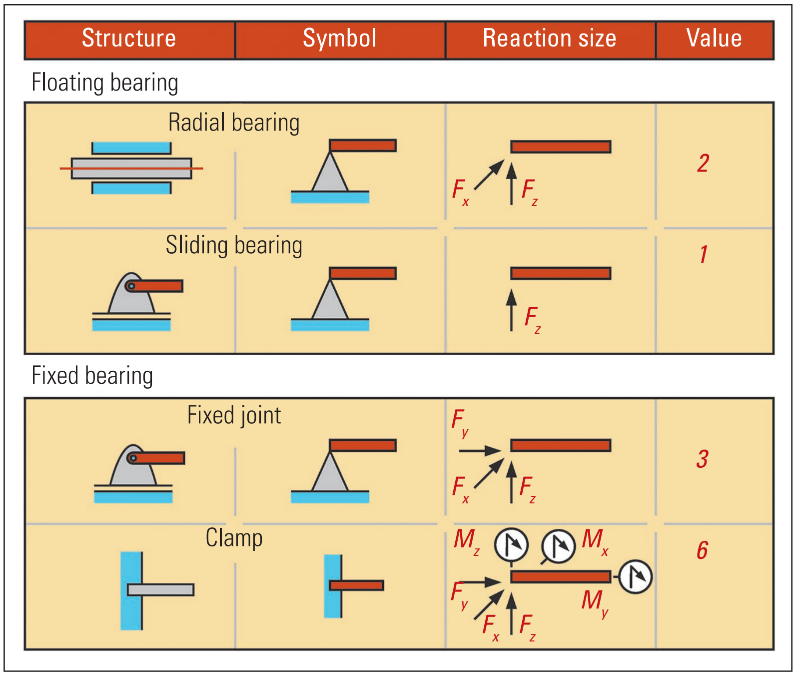


Fig 7-8 This chart shows different types of bearings, the structure and symbols for the bearings, and the corresponding reaction sizes and bearing values. Note that only a fixed clamp is able to absorb all the acting forces and moments.

ics that can be applied to a rigid body that rests on a base and is supported by what are known as *bearings*. These bearings are meant to absorb all the forces acting on the rigid body. Depending on the type of bearing, different support reactions occur; bearings can be classified as ranging from single-value to six-value bearings (Fig 7-8).

A single-value bearing can only absorb compressive forces from one direction in space; this is known as a *floating* or *movable bearing*. A floating bearing does not offer stability because a body whose bearing can only absorb compressive forces threatens to tip when external forces are applied. A fixed bearing absorbs forces but no moments from three directions in space; this is a three-value bearing. A fixed clamp is a six-value bearing that can absorb all forces and moments.

Support reactions are determined by means of the equilibrium conditions that apply to the static system. There are two types of static systems: statically determinate and statically indeterminate systems. The notion of statically determinate or indeterminate systems becomes clear when one looks at a three-legged and a four-legged table. A three-legged table will always stand stably; a four-legged table will wobble unless one of the table legs is variable in length and adjusted to allow for the base on which it stands. If a four-legged table does not wobble, even without a variable fourth leg, this is because the table is adapting to the support by distorting slightly. Similarly, a statically indeterminate system wobbles and will only reach a state of equilibrium if it deforms. In a statically indeterminate system, the equilibrium conditions are insufficient to calculate support reactions; here the deformation conditions provide the equations that are lacking.

In a statically determinate system, the support reactions can be ascertained from its equilibrium conditions alone. Adding the term *equilibrium* further broadens our insight into static systems. There are three static states in relation to the equilibrium position (Fig 7-9):

1. Stable equilibrium exists when a body seeks to return to its initial position if displaced by external forces.
2. Unstable equilibrium exists when a body tries to leave its original position.
3. Neutral equilibrium exists when any displacement brings the body into a new equilibrium position.

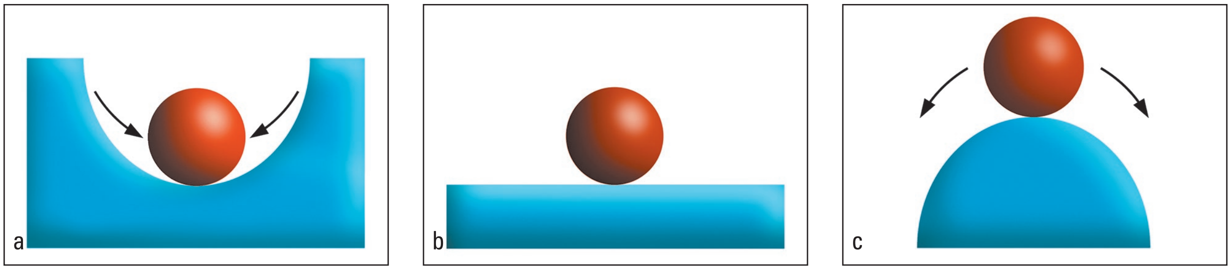


Fig 7-9 The three static states: *(a)* In the stable equilibrium position, the body returns to its initial position when it is displaced by external forces. *(b)* In the neutral equilibrium position, any displacement of the body produces a new equilibrium position. *(c)* In the unstable equilibrium position, the body tries to leave its original position.

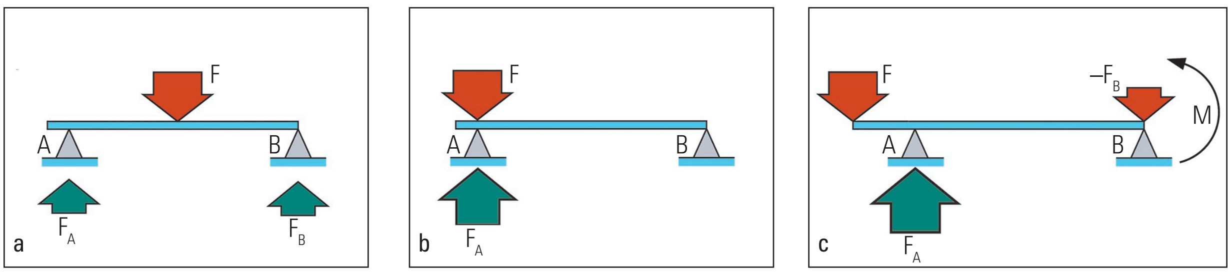


Fig 7-10 The static states, when transferred to a real case, demonstrate the special features of a static system: *(a)* A bar is placed on two bearings and loaded in the middle; both bearings must absorb equal forces, namely ½F. *(b)* If the bar is not loaded in the middle but over bearing A, bearing A has to absorb the entire force. While a stable state existed in the first case, a neutral state now exists because bearing B remains fully unloaded; this support reaction cannot be calculated at all. *(c)* If the same bar is now loaded outside the bearings, an unstable state exists whereby bearing B is unable to compensate for the torque that arises. If bearing B is a floating bearing, the bar will be levered off.

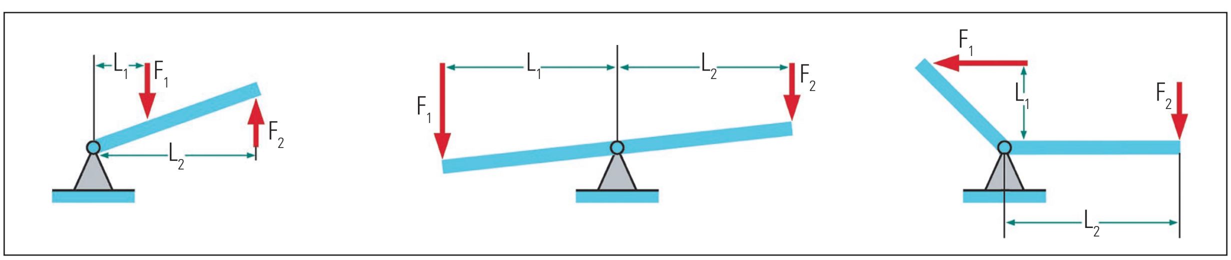


Fig 7-11 A lever is a rigid body that can turn around an axis. In a class 2 lever, the fulcrum lies at one end and forces can act on the lever at different distances from the fulcrum. In a class 1 lever, the fulcrum lies between the forces applied. For both types, the law of levers applies: *Force* × *Force arm* = *Load* × *Load arm* ($F_1 \times L_1 = F_2 \times L_2$). In this condition, the lever is in equilibrium (ie, it does not move). Torques of equal size are acting on the lever in opposite directions, so the lever stays in the resting state.

The static states become clear from the following system: A bar rests on two bearings without being fixed and protrudes beyond the bearing points on one side. A load can be applied at three different points on the bar (Fig 7-10):

1. The load lies between the two bearing points so that all the compressive forces are placed on the bearings, and the bar rests in stable equilibrium.

2. The load is located outside the bearing points so that the compressive force can no longer be absorbed by the bearing and the bar will tip; the bar is in unstable equilibrium.
3. The load lies on one bearing point so that all the compressive forces rest on that one bearing, and the bar is in neutral equilibrium.

Unstable equilibrium can be converted into a stable state if the bar is fixed in a bearing. That bearing now absorbs the forces that arise from the torque of load and load arm up to the first bearing. Two terms now emerge that are taken from the description of the first law of levers. This law expresses special equilibrium conditions pertaining to a lever.

A lever is a rigid body that can be turned around an axis (Fig 7-11). In a class 2 lever, the fulcrum lies at one end, and in a class 1 lever, the fulcrum lies in the middle. When equilibrium exists, the following law of levers applies:

$$\textit{Force} \times \textit{Force arm} = \textit{Load} \times \textit{Load arm}$$

Forces Acting on the Residual Dentition

Centric occlusion is defined as the hinge position (maximal intercuspation) in which the teeth are loaded axially (ie, centrically to their periodontium). Eccentric loads during dynamic occlusion are compensated for in a closed dental arch by the approximal contacts, tissue coupling, and anatomical double interlocking. In a partially edentulous dentition, this functional interaction is disrupted; the essential approximal support is interrupted. Horizontally acting forces lead to tipping and twisting of the remaining teeth.

On a solitary tooth, a horizontal action of force occurs on the sloping surfaces of the cusps. If a vertical force acts on a sloping surface, this load is split into vertically and horizontally acting components. The horizontally acting force component will tip the tooth. The more sloping the surface, the larger the horizontal force component becomes in relation to the vertical component. Where tooth surfaces slope by about 45 degrees, the vertical and horizontal actions of force are equal. With more pronounced tipping, the horizontal as well as the vertical action becomes smaller in relation to the perpendicular force being exerted. The geometric and mathematic illustrations in Figs 7-12 to 7-14 show the relationship between the force loading the tooth and the horizontally and vertically acting forces.

The mathematic depiction of the actions of force demonstrates the basic relationships. However, this view needs to be qualified. In normal punctiform occlusal contact in a healthy dentition, the slopes of the cusps will ensure that all of the teeth are loaded centrically to their periodontal tissues.

In a partially edentulous dentition with solitary teeth, the horizontal force action cannot be absorbed; the tooth is tipped and becomes displaced. As a result, the loading conditions become pathologic. A tooth that is already tilted will be extremely stressed in its tipping by a vertically acting force because the vertical force component no longer loads the tooth exactly axially. The pressure on the tilt becomes even greater.

Forces acting at a distance from the central axis of the tooth act like lever forces, where the distance from the central axis equates to the lever arm. The vertical force component can work with a lever arm that roughly corresponds to two-thirds of the tooth length. If a tooth is already displaced, horizontal and vertical force components with different lever arms will act in the direction of tipping.

When constructing partial dentures, it is important to ensure that the remaining teeth are not exposed to any eccentric action of force by the retainers. Tipping of an abutment tooth by occlusal rests must be prevented. In particular, a tooth that is already tipped should not be engaged in its sloping position.

Sagittal forces should run so that an abutment tooth can brace itself via existing approximal contacts. Therefore, in a shortened dental arch, sagittal thrusts can be compensated for mesially if the dental arch is closed mesially.

Transverse forces in a vestibular direction can be prevented by contouring the artificial occlusal field of the denture so that no effect arises from transverse thrusts. Therefore, the artificial teeth on the partial denture must be placed as far lingually

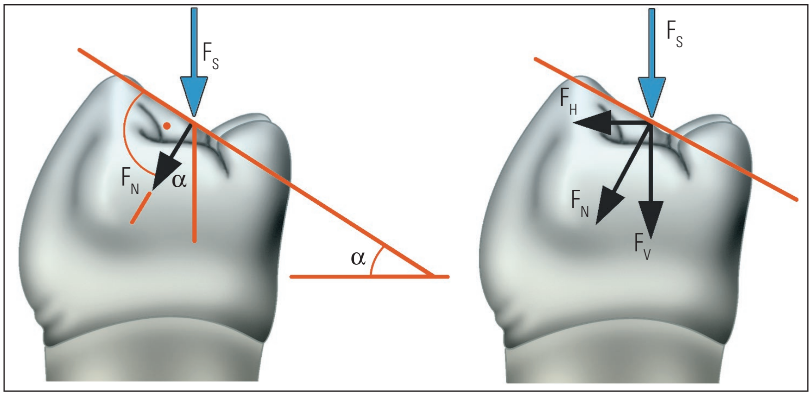


Fig 7-12 When calculating the force components, the size of normal force is first established, which is perpendicular to the sloping surface: $F_N = F_S \times \cos\alpha$, where F_N is the normal force, F_S is the force impacting on the tooth, and α is the angle of inclination of the tooth surface. Normal force is now broken down into horizontally and vertically acting forces. The angle of inclination of the tooth surface occurs again between the vertical force component and normal force, so that it can be used for calculation.

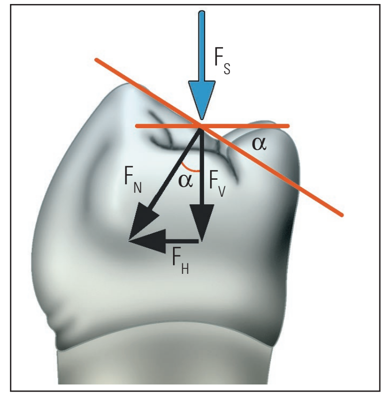


Fig 7-13 The horizontal force is then defined as follows: $F_H = F_S \times \sin\alpha = F_S \times \cos\alpha \times \sin\alpha$. The vertical component F_V is then calculated: $F_V = F_N \times \cos\alpha = F_S \times \cos^2\alpha$. If the tooth surface slopes by 45 degrees, the vertical component is as large as the horizontal component.

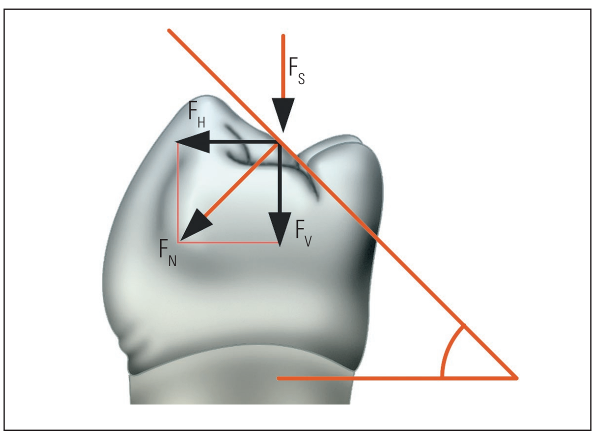


Fig 7-14 If the ratio of vertical to horizontal force component is to be calculated, the result is

$$\frac{F_H}{F_V} = \frac{F_N \cdot \sin\alpha}{F_N \cdot \cos\alpha} = \tan\alpha, \text{ where } F_H = F_V \times \tan\alpha \ (\tan 45° = 1).$$

The more the angle of the slope of the tooth surface increases beyond 45 degrees, the larger the horizontal force component on the tooth becomes in relation to the vertical force. Having said that, the horizontal force action becomes smaller in relation to the vertical masticatory force striking the tooth surface (F_S); that is, the horizontal force component is largest when the cusp inclination is 45 degrees. Mathematic deduction of the function yields a maximum at α = 45 degrees; it thus becomes clear that the tipping force for a tooth will not exceed half of the vertically striking force if the tooth stands perpendicular.

as possible so that the masticatory forces run roughly through the middle of the alveolar ridge of the edentulous segments of the dental arch.

Vertical masticatory forces should be absorbed by occlusal rests in a supported denture. The splinting parts of the retainers must absorb the horizontally acting forces. The support points created by the occlusal rests are assumed to be rigid.

The rigid anchorage of free-end saddles to the residual dentition is the method of choice for achieving statically determinate systems and controllable loading on abutment teeth. Statically indeterminate systems are outside the area of statics analysis. If a free-end saddle has mixed support, the mechanical system is no longer at rest and can no longer be calculated by statics methods. For this purpose, kinetics analysis criteria should be used, and because this is the sphere of anatomy and biology, the approaches of biokinetics should be adopted. *Kinetics* is the study of movements and deformations in response to forces and stresses (Fig 7-15).

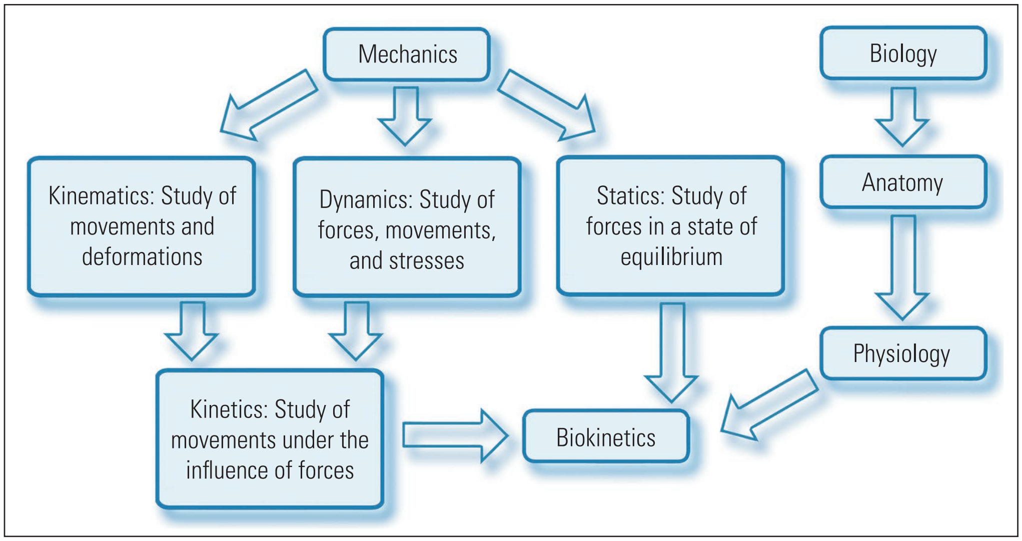


Fig 7-15 Analysis of denture construction encompasses the following: *(1)* statics of the rigid denture body, where the retentive forces of the anchoring elements and the support reactions are examined; *(2)* science of the strength of materials, whereby the dimensions of denture frameworks for removable and fixed dentures are determined to compensate for deformation caused by masticatory forces or thermal stresses; and *(3)* kinetics (biokinetics) to determine movements and support reactions of dentures with mixed support.

Spring Force and Friction

According to Newton's first and second laws of motion, forces cause changes in the movement of a rigid body. In the case of a nonrigid body, however, forces can also produce changes of shape; for instance, compressive forces can press together and tensile force can pull apart. There is actually no absolutely rigid body; every material has a certain elasticity.

Metals display the property of returning to their original state after deformation. Although metals are not as elastic as rubber, within certain limits they can be bent or pulled by the application of force and then afterward spring back to their original state. Only when metals are exposed to excessive force can they deform permanently.

In the elastic range of a material (whether rubber or metal), deformation is proportional to the application of force so that a proportionality factor is introduced, which, in the case of springs, is known as the *spring constant*. This yields the following formula:

Spring force = Spring constant × Spring deflection or $F = c \times s$

Spring force is the cause of a change in the shape of a body, here specifically a spring. The spring constant is the key value that is dependent on the material and on the shape of the spring body. The *spring deflection* is the magnitude of the change of shape, here specifically the change in length of a spring or the bending of a clasp arm. In dental technology, spring clip fittings are used mainly in the form of clasps as retainers.

The proportionality of spring force and spring deflection can be represented in a diagram illustrating Hooke's law, according to which deformation is linear within the elastic range (Fig 7-16). Diagrams depicting the behavior of elastic bodies are known as *spring characteristics*; the area under the spring characteristic curve is the *spring work*. The steeper the spring characteristic curve, or the straight line according to Hooke's law, the harder a spring is; this means the spring constant is very large.

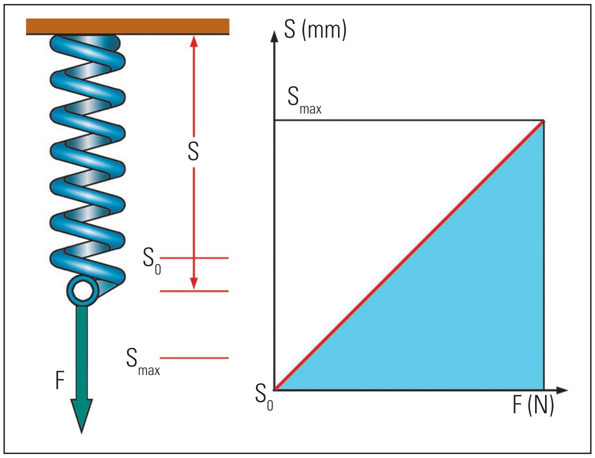


Fig 7-16 A spring is described by several terms. Spring force (F) is the force with which a spring is compressed, pulled, or bent. Spring deflection (S) is the amount by which the spring force compresses, lengthens, or bends a spring. The variable S_0 characterizes the original spring length before application of force; S_{max} denotes the maximum spring deflection. In the diagram, the spring characteristic curve, which indicates spring deflection over spring force, is an ascending straight line. The area under the spring characteristic curve represents the amount of spring work.

		Sliding friction	
Material pairing	Static friction	Dry	Lubricated
Steel/steel	0.15	0.1	0.01
Steel/cast steel	0.19	0.18	0.01
Cast iron/cast iron	0.25	0.2	0.1

Fig 7-17 Static and sliding friction coefficients μ and μ_0.

Friction is an energy-consuming form of resistance that impedes the relative motion of two bodies being moved against each other with their surfaces in contact. Friction force always acts in parallel to the contact surface; it is consistently smaller than the normal force with which the bodies press against each other, and it opposes movement. Following is the formula for calculating friction force:

Friction force = Friction coefficient × *Normal force* or $F = \mu \times F_n$

The friction coefficient μ is a reference value that depends on several factors: *(1)* the material from which the friction bodies are composed; *(2)* the surface properties of the bodies; and *(3)* the nature of the movement in which the bodies slide past each other. The following distinctions are made.

Static friction occurs when a body at rest on a supporting surface is being set in motion by external forces. In this arrangement, static friction is as great as the acting force when the body starts to move. In this case, the friction is entirely independent of the size of the contact area. Static friction only arises due to vertically acting normal force and the friction coefficient. The coefficient of static friction is denoted as μ_0.

The coefficient of static friction can be experimentally determined by inclining a plane until the body lying on it is set in motion. Equilibrium between static friction force and slope force then prevails. The geometric relationship can be expressed as follows:

$\mu_0 = \tan \alpha_0$ (α_0 = *Angle of static friction*)

Sliding (or dynamic) friction occurs when a body in motion rubs on its supporting surface; when a body slides down an inclined plane at constant speed, this is known as *sliding friction*. The coefficient of sliding friction is calculated as:

$\mu = \tan \alpha$ (α= *Angle of sliding friction*)

Figure 7-17 lists the values of static and sliding friction coefficients for various material pairs. Rolling friction occurs when a body rolls on the supporting surface. Rolling friction is much smaller than sliding friction. It is dependent on the material and radius of the rolling wheel.

Mixed Support

This section applies the terms previously discussed to concrete prosthodontic situations. This includes considering the static relationships in the case of a removable denture that is replacing a free-end segment of the dental arch. The statics of the support of a cantilever prosthesis are also examined.

Edentulous segments of a dental arch are less suitable than the residual teeth for absorbing masticatory forces because of the resilience of the mucosa. If the mucosa is also compressed by denture movements, the alveolar ridge or the denture-bearing area will quickly shrink. If a removable denture is attached to the remaining teeth, masticatory forces should be absorbed via that support, and movements or embedding of the denture should be prevented.

Mucosa-borne dentures can be interpreted as rigid bodies that rest on floating bearings or springs; all compressive, tensile, shearing, and tipping forces will tilt, twist, displace, or tip the rigid body. This is a statically indeterminate system. Mucosa-borne complete dentures have indeterminate static support; the acting forces have to be directed so that the denture remains in the mouth. Attempts are made to achieve this by special tooth positioning and specific contouring of the denture base. The system of a semirigid cantilever denture or a free-end prosthesis with hinged anchorage is also statically indeterminate. The semirigid and hinged coupling between the residual dentition and the prosthesis produces mixed support of the restoration, as described earlier. It arises in dentures that have clasps with rests, regular joints, or resilient connectors.

True load distribution between the supports (periodontium and mucosa) is not achieved. Extremely uneven loading on the mucosal support may even occur, causing a triangular impression in the mucosa. If the rigid body is tipped around the periodontal support with the semirigid or hinged coupling because no moments can be absorbed, the rigid body and the support are twisted and displaced in the horizontal plane in a totally uncontrolled way. This type of loading is extremely damaging to a periodontal support (tooth) because the tooth is not protected against transverse thrusts.

Support on the mucosa can only be assumed to act as a spring bearing to a limited extent. In fact, mucosal resilience is not merely a matter of tissue compressibility (as in the case of an air-filled container) but involves squeezing tissue fluid as well as compressing and displacing the tissue. Therefore, the resilient behavior of the mucosa is dependent on the body's constitution; the tissue's fluid content; and the underlying layers, comprising connective tissue, glandular, or fat accumulations. The compressibility of the mucosa is also influenced by the shape of the support: Parts that are subject to punctiform loading will sink more deeply (up to 3 mm) than edges with linear loading (up to 2 mm), while extensive saddle areas undergo relatively little sinking (up to 0.5 mm). Therefore, viscoelastic bedding of the denture should be assumed (Fig 7-18).

Sinking of a mucosa-borne denture is greatest at the point of load application as the denture base is shifted and twisted. In the case of mixed support on the residual dentition and mucosa, displacements of the statically indeterminate system always occur (Fig 7-19). Even extensive denture saddles fail to bring about uniform mucosal loading but always exhibit triangular embedding facing away from the rest area (see Figs 7-23 and 7-24). Any observed and measured sinking of a saddle will provide information about the maximum amount to which the mucosa is squeezed. Resorption of the mucosa results in alternating, intermittent, and uneven loading and sinking of the saddle. In the process, this will jiggle the abutment tooth to and fro so that it is soon lost as well.

Based on observations of static relationships, the most practical support is a rigid coupling of free-end saddles to the residual dentition. A fixed bearing is statically determinate and able to transfer all masticatory forces to the abutment teeth. Vertical and horizontal forces and moments do not load the mucosa but are absorbed by the periodontium. The more residual teeth that are connected by the rigid anchorage—in other words, the more extensive the fixed bearing is—the more secure the support.

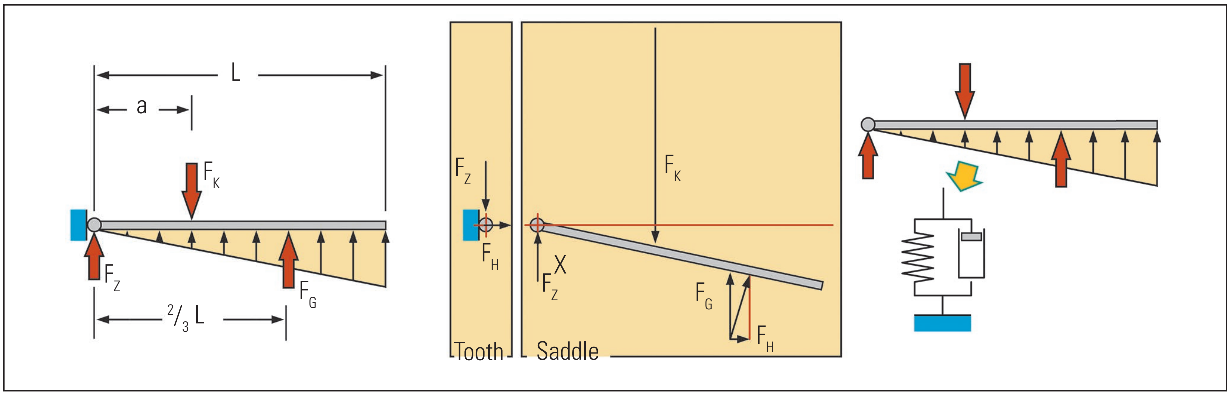


Fig 7-18 When calculating movements and support reactions of a supported free-end saddle in a mixed-support situation, viscoelastic bedding of the denture on the mucosa may be assumed. A free-end saddle is loaded with masticatory force (F_K), which is absorbed by bearing force (F_Z) and mucosal loading (F_G) on the active length of the free-end saddle. To solve the mechanical problem, the saddle is cut free in order to isolate the effective forces. It becomes clear that the bearing force of the mucosa is always perpendicular to the saddle; as a result, a distally directed force (F_H) almost parallel to the saddle becomes effective and will tip the abutment tooth distally. In the bearing forces of the tooth, this tipping force is called F_{HZ}. The right-hand diagram shows a model of the viscoelastic behavior of the mucosa, which is not equivalent to that of a rubber base but is determined by tissue elasticity and fluid displacement.

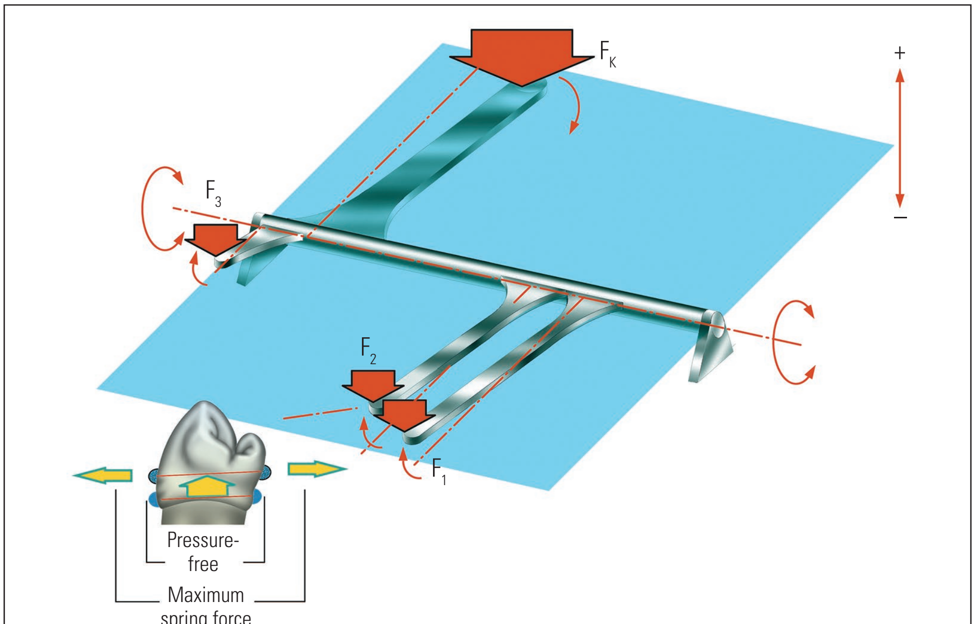


Fig 7-19 A clasp denture for restoring a free-end saddle is always a statically indeterminate system because it has mixed support. When loaded by masticatory forces, the free-end saddle will sink, and the denture will tip around the rests on the terminal abutments. Resistance leverage can only become active once the denture has been tipped by a certain amount, at least equivalent to the retention depth of the clasp arms. Only when the clasps are tilted during denture movement will resistance leverage immediately take effect. This situation is illustrated in a three-dimensional model: Only when the long load arm is affected by masticatory force (F_K) can the resistance levers F_1, F_2, and F_3 become active because they require a certain stroke to achieve maximum spring force.

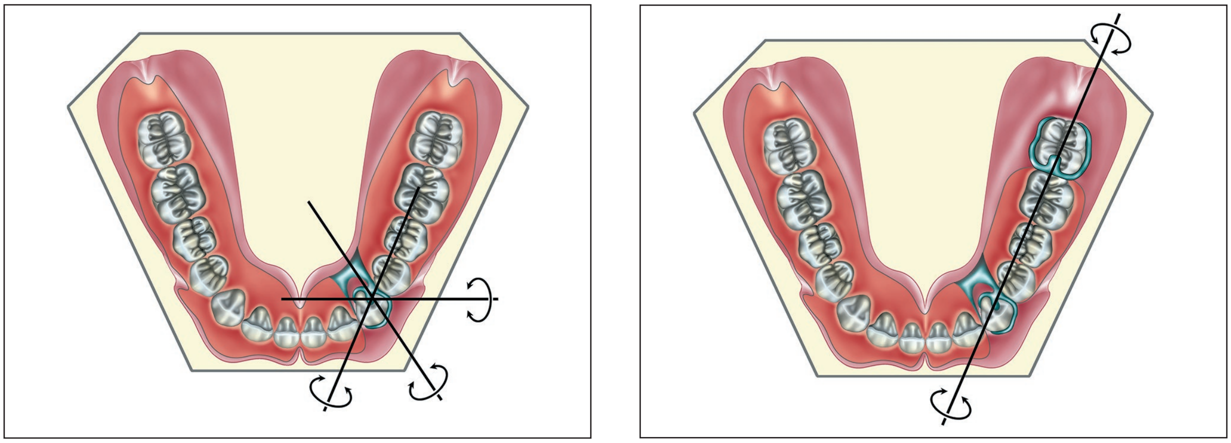


Fig 7-20 Supporting a partial denture periodontally is a basic principle of denture constructions. Because the mucosa is more yielding than the periodontium, a denture supported by occlusal rests and simultaneously mucosa borne can be tipped around the occlusal rests. If all of the available rests of a denture are joined together, the results are support lines around which the denture can be rotated. Depending on the available residual dentition, different arrangements of support lines can be constructed. If a denture is supported on only one remaining tooth, this is by far the least satisfactory form because the denture can be rotated around all the spatial axes. A support line between two rests always represents an axis of rotation.

Periodontal Support of Free-End Saddles

Anchorage with cast clasps produces statically indeterminate systems because these anchoring and supporting elements create semirigid or articulated couplings between the denture and the residual dentition. Anchorage of interdental saddles running straight between the abutments bordering the gap is relatively unproblematic if the abutments bordering the gap are supported. Special considerations come into play when constructing free-end dentures and large, arch-shaped bounded or interdental dentures.

The occlusal rests of clasps act in cantilever dentures as pivot points about which the free-end saddles can rotate. To ascertain how the denture is turned around the rests under loading from masticatory pressure, the statics can be analyzed by constructing support lines. The support lines connect the rest points on the abutment teeth tangentially to the dental arch. In relation to situations with partially edentulous arches, the support lines follow different paths so that different periodontal support areas are formed (Figs 7-20 to 7-22):

- Polygonal support areas for alternating edentulous spaces
- Square (trapezoidal) support areas
- Triangular support areas
- Linear supports
- Punctiform supports

The positional stability of a denture is secured if the denture saddles are located inside the periodontal support area. When a support line intersects the denture, this creates an axis of rotation around which the dentures will tip, resulting in settling of the denture saddles (see Fig 7-21).

The *law of clasp lines* describes a situation where the support lines are tangential to the denture. The support line indicates the axis around which the denture tips, or the active lever arm of a free-end saddle is measured from the support line.

A free-end saddle that lies outside the periodontal support area acts like a lever arm. Such denture saddles may tip the whole prosthesis around the support line on masticatory loading. The longer the denture saddle and hence the lever arm, the more pronounced the tipping. To shorten the lever arm, the support line must be placed as far as possible on the eccentric denture saddle. Support lines run through the occlusal rests of the clasps. With regard to the position of the occlusal

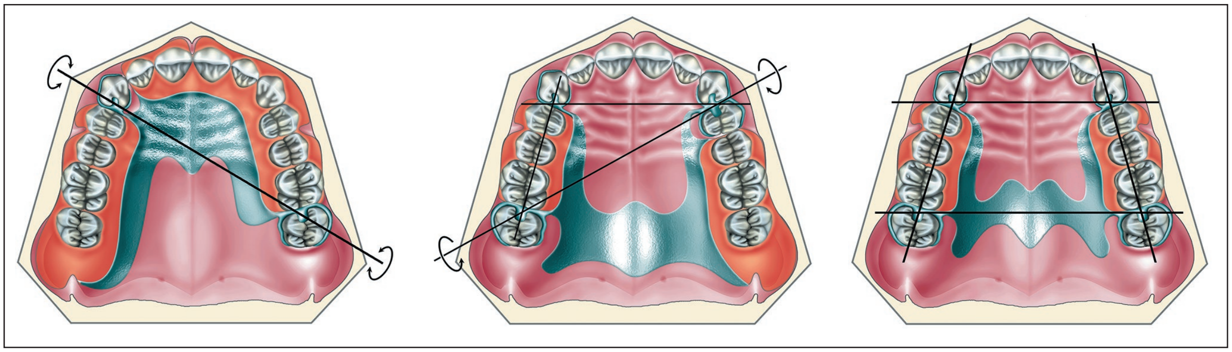


Fig 7-21 An axis of rotation also arises when the support line divides the denture body. The support lines should always be tangential to the dental arch and thereby encompass an area. Even a triangular support area can provide stable support for a denture. In the case of a triangular area, however, if a denture saddle lies outside the support area, one support line of the construction will depict the axis of rotation, namely the line that divides the denture body. Only a square area, where the denture saddles lie within that area, is stably supported.

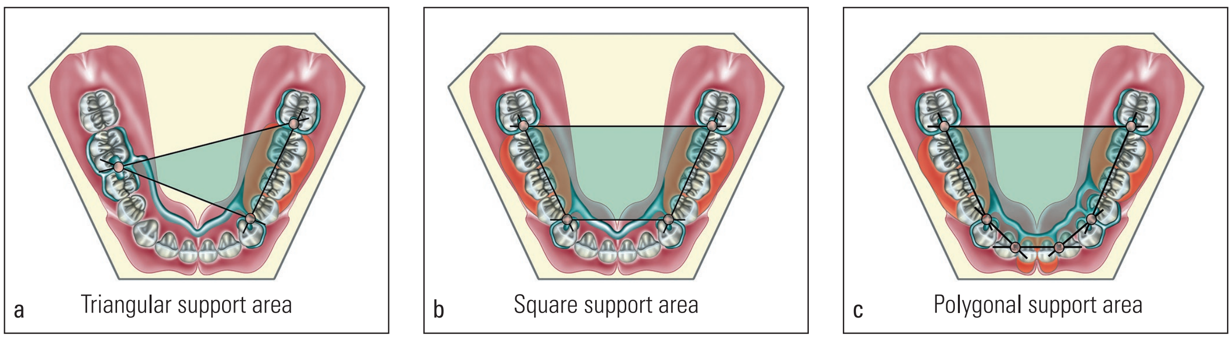


Fig 7-22 Punctiform or linear support will arise, depending on the arrangement of the support lines. A support area is formed when spanned by three or more support lines: *(a)* a triangular support area by three support lines, *(b)* a square support area by four support lines, and *(c)* a polygonal support area by at least five support lines.

rest, there are three forms of support: *(1)* support close to the saddle, *(2)* support remote from the saddle, and *(3)* support on the residual dentition remote from the saddle.

Support close to the saddle is provided on the saddle-facing approximal marginal ridge of the abutment bordering the gap. The result is severe rotation around the rest with triangular sinking of the denture base and the following effects (Fig 7-23):

- The saddle presses onto the marginal periodontium bordering the gap if the border area has not been relieved.
- The abutment tooth is pulled distally, depending on the amount of rotation; the more the saddle is tipped toward the horizontal, the greater the horizontally acting force components that pull the saddle from the rest point.
- The distribution of load is balanced between the abutment and the mucosal base. The two support areas distribute the load from masticatory pressure, assuming that the point of force application is in the middle of the denture saddle.

Support remote from the saddle is support on the marginal ridge of the abutment tooth bordering the gap, on the side that faces away from the saddle. This also results in a rotational movement with sinking of the denture saddle and the following effects (Fig 7-24):

- The marginal periodontium bordering the edentulous gap is loaded.
- The saddle sinks uniformly; mucosal areas close to abutments also absorb masticatory forces.
- The abutment tooth is pulled distally, depending on the sinking (Fig 7-25).

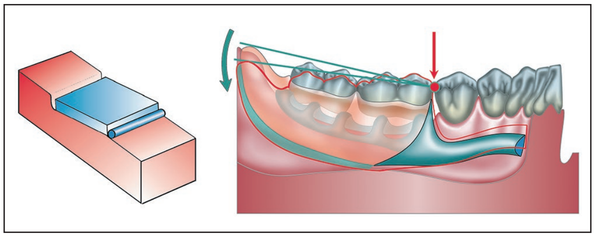


Fig 7-23 If a free-end saddle is supported on the abutment bordering the edentulous gap, there is pronounced rotational movement around this rest with substantial triangular sinking of the base and pressure on the marginal periodontium. The greater the mucosal loading, the shorter the free-end saddle.

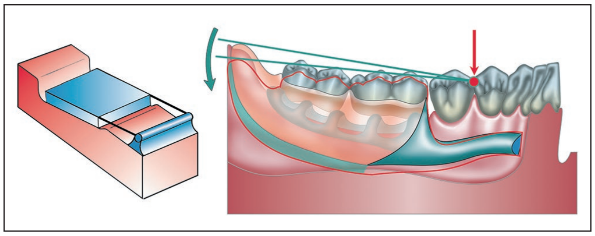


Fig 7-24 A rest remote from the saddle is created on the side that is turned away or on the marginal ridge on the same abutment tooth. As a result, the lever arm is lengthened mesially; this leads to roughly parallel sinking of the base and reduced loading of the interface. However, distribution of the load shifts to the detriment of mucosal loading.

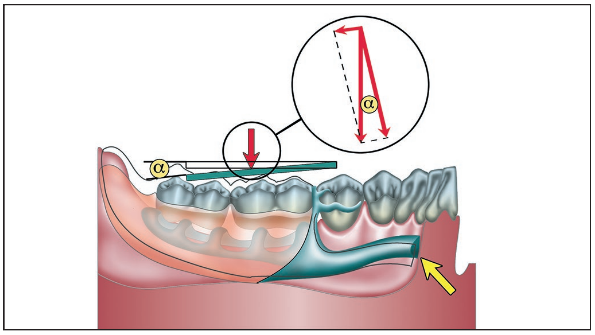


Fig 7-25 Depending on the amount of sinking, the masticatory load becomes a distal pull on the saddle and will therefore act on the abutment tooth. A vertical force on an inclined plane produces a slope force dependent on the angle of inclination α; this slope force produces the pull on the abutment tooth directed distally. Depending on the degree to which the saddle sinks, the sublingual bar will move toward the alveolar ridge and settle.

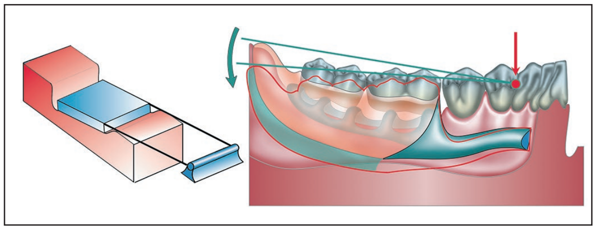


Fig 7-26 Almost-parallel sinking of the base occurs where support on the residual dentition is remote from the saddle. The longer and more extensive the base, the more uniform the sinking of the base. The function of the periodontal support is lost, and the mucosa is overloaded.

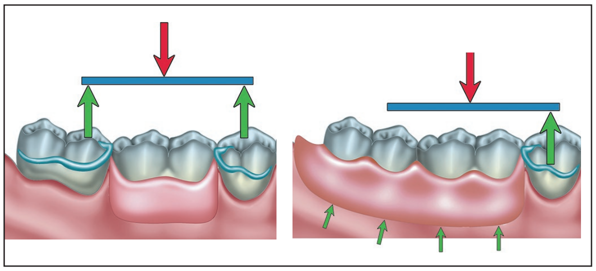


Fig 7-27 If a bounded saddle is loaded centrally, the abutments bordering the gap absorb this load in equal parts. Moving further away from the distal abutment, its load is applied to the mucosal support and the saddle may sink, as described earlier. The mesial abutment continues to absorb its force component.

- Because the lever arm of the eccentric saddle is longer, the mucosa has to absorb more load; the periodontal support is relieved of loading.

Support on the residual dentition remote from the saddle involves an abutment tooth remote from the saddle. The rotational movements around such a rest lead to almost-parallel movement of the denture saddle relative to the mucosa with the following effects (Fig 7-26):

- The sinking is more uniform the longer and larger the saddle is.
- The periodontium bordering the edentulous gap is not loaded (Fig 7-27).
- The abutment tooth is not pulled to the saddle.
- The periodontal support decreases rapidly; the masticatory load is absorbed almost entirely by the mucosal support.

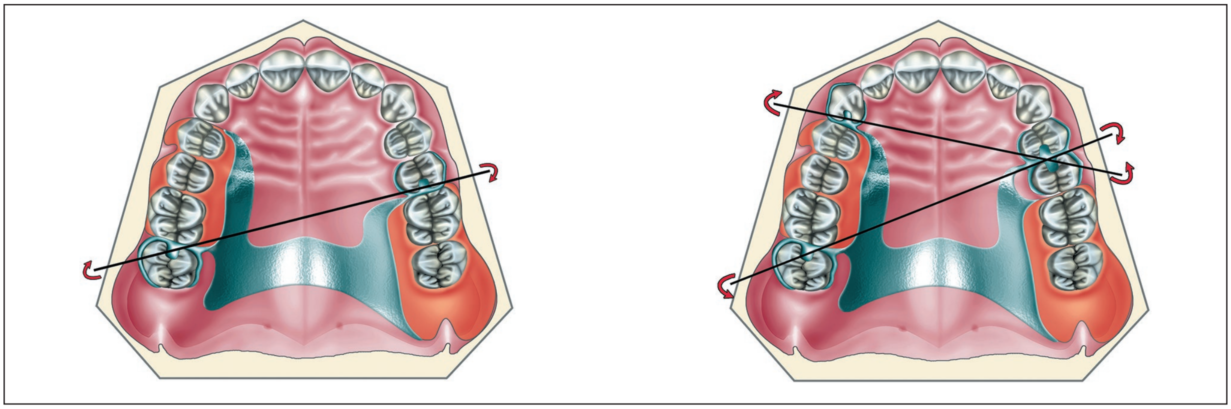


Fig 7-28 In response to horizontal thrusts, the clasped teeth are loaded by the enclosing parts of the clasps. Denture design must take this fact into account by supporting the denture saddles with clasps so that the denture is not twisted on the underlying mucosa in response to horizontal thrusts. The clasp line is obtained by connecting opposing open clasps on different halves of the jaw. A clasp line must traverse the denture body. It must be possible to draw at least two clasp lines for denture construction. Only then is the denture definitely secured against twisting in response to horizontal thrusts. An important point is that the clasp line connects two opposing open clasps.

Action and Resistance Levers

A clasp denture does not offer rigid anchorage, and the statically indeterminate system of mixed support will always result with free-end dentures, in which the mucosa is subject to nonphysiologic stress from masticatory pressure. A decrease in mucosal loading can be achieved if a free-end saddle covers the mucosa extensively, as the load is transferred to a large area based on the snowshoe principle and hence the degree of sinking is reduced. A free-end saddle should be shaped as an extension saddle that embraces the maxillary tuberosity in the maxilla and the retromolar pad in the mandible. In addition, the last third of the denture saddle is not loaded by masticatory pressure. The terminal molars are placed out of occlusal contact, thereby shortening the lever arm to the support line. The lever arm to the support line can be further shortened if a rest is placed close to the saddle, giving rise to uniform load distribution between the periodontal support and the mucosa.

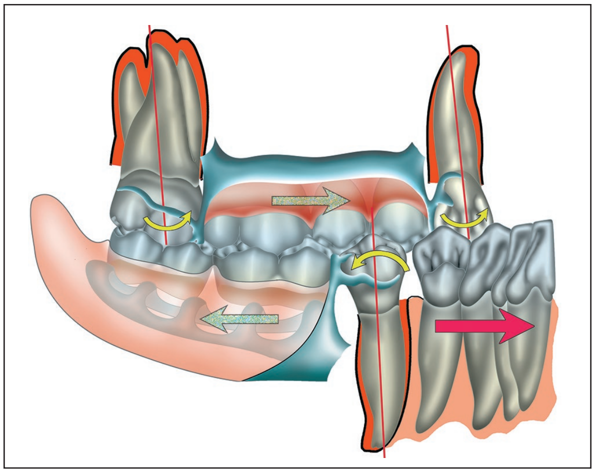
In the case of large, arch-shaped bounded saddles, the following considerations are important: If a denture is to be supported on two terminal molars, masticatory pressure will be absorbed almost entirely by the underlying mucosal support. This kind of denture must be designed like a complete prosthesis. The terminal molars merely secure the horizontal position and serve as retention. Occlusal support is necessary to prevent the denture from embedding at the molars and to prevent the development of occlusal interferences and sinking of the clasps.

Sinking of the free-end saddle can most successfully be prevented by opposing the load arm (free-end saddle) and the load (masticatory force) with a force on one force arm. For this purpose, another clasp is placed in the dental arch ahead of the abutment tooth bordering the edentulous gap; this clasp is withdrawn when the saddle sinks. This gives rise to a system of levers comprising an action lever (free-end saddle) and a resistance lever to the additional clasp.

The maximum retentive force of a clasp is 10 N, which would be too low to resist sinking. However, because the clasp is not pulled in the path of insertion but in a circular movement from the tooth, it tilts and offers adequate resistance. The result is quasi-rigid anchorage of the free-end saddle.

The resistance lever arm should be at least as long as or longer than the action lever. Clasping of the resistance lever arm subjects the abutment

Fig 7-29 Mandibular movement and denture movement interact as follows: When the mandible is moved forward, the dentures can be shifted relative to the dental arch being restored. A mandibular prosthesis is held by the antagonists and therefore moves distally relative to the underlying support, which means the clasped tooth tips distally. A maxillary denture is moved forward by its antagonists on protrusive movement of the mandible, and the clasped teeth are tipped mesially. Generally speaking, on protrusion of the mandible, a maxillary denture will be pushed mesially and a mandibular denture distally.



tooth to traction, which has to be compensated for by the splinting effects of the whole group of clasps. Therefore, as many residual teeth as possible are enclosed in the groups of clasps: one anchoring and supporting element for each tooth being replaced.

The construction involving action and resistance levers also counteracts the tipping of denture saddles by pull-off forces (eg, sticky food or the appliance's weight). In the case of normal clasping, the saddle acts like a beam suspended from one side, which can tip downward. This movement is prevented by the resistance lever, which acts to prevent tipping.

Horizontal positional stability is determined not only by the position of the support points but also by the position of the splinting parts. If all of the rigid clasp parts lie mesially in the maxilla (all the clasps being open distally), the denture can be displaced mesially on the mucosal support. If all of the clasps are open mesially in the maxilla, the denture moves on the underlying support when the mandible is retracted. The same applies to a mandibular denture.

If clasps open in the opposite direction are mounted on each half of the jaw, the denture is secured against horizontal shifts and twisting. For statics analysis, connecting lines can be drawn between such clasps (Fig 7-28). These lines are referred to as *clasp lines* or *traction lines*. According to the law of clasp lines, these lines should divide the denture. The clasp or traction line shows whether a denture can be twisted by horizontal shearing and tractive forces. If such twisting is possible, the clasps are altered so that the splinting parts will counteract this twisting.

Based on the analysis of static relationships, the following design principles apply to free-end saddles:

- They ensure support close to the saddle.
- They make use of a resistance lever to construct tilting elements.
- They shape the extension saddle.
- The terminal molar is positioned outside occlusal contact.

Figures 7-29 to 7-39 illustrate various lever effects with dentures.

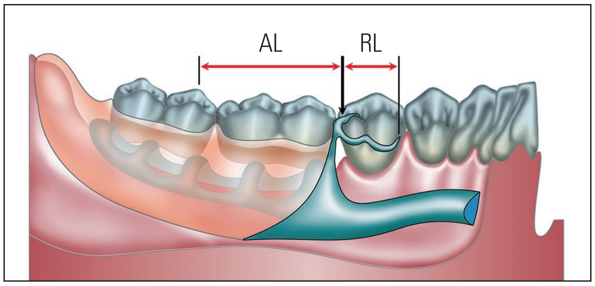


Fig 7-30 Resistance lever arms (RL) can be used to reduce mucosal loading with free-end saddles. The free-end saddle as the action lever (AL) rotates around the occlusal rest on loading by masticatory pressure; in the process, the clasp arm of a normal double-arm clasp counteracts this twisting movement.

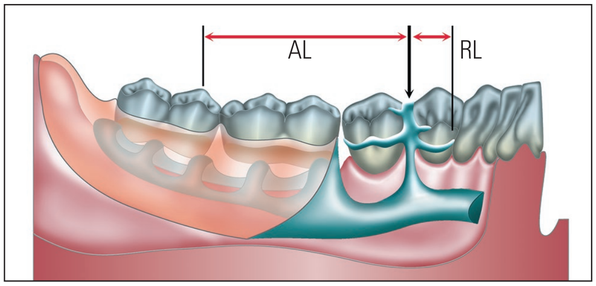


Fig 7-31 If a Bonwill clasp with a rest remote from the saddle is used, the action lever arm (AL) becomes longer while the resistance lever arm (RL) remains the same length. The clasp part opened distally acts to prevent tipping against withdrawal forces acting on the free-end saddle. The mucosal loading is not reduced in this case but actually increases; the abutment teeth absorb less load.

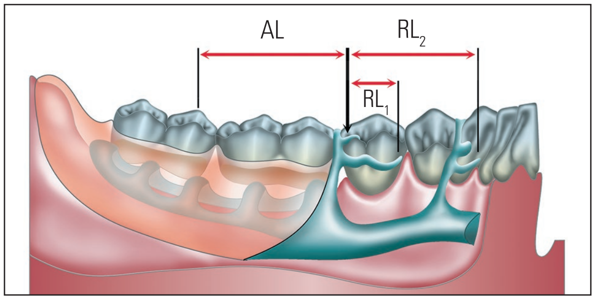


Fig 7-32 Effective reduction of mucosal loading is achieved by means of several resistance lever arms (RL_1 and RL_2). In addition to the normal double-arm clasp, another double-arm clasp is mounted mesially on the residual dentition. With the distance from the pivot, this clasp acts as a resistance lever and to prevent tipping.

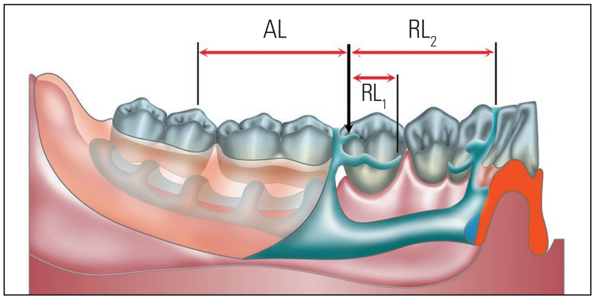


Fig 7-33 If a free-end denture and an anterior interdental saddle are supported on the abutments bordering the gap, the resistance lever lifts the clasp off the abutment tooth on loading. Because the clasp is not lifted off in the path of insertion, it tilts, and a semirigid coupling ensues between the denture and the residual dentition.

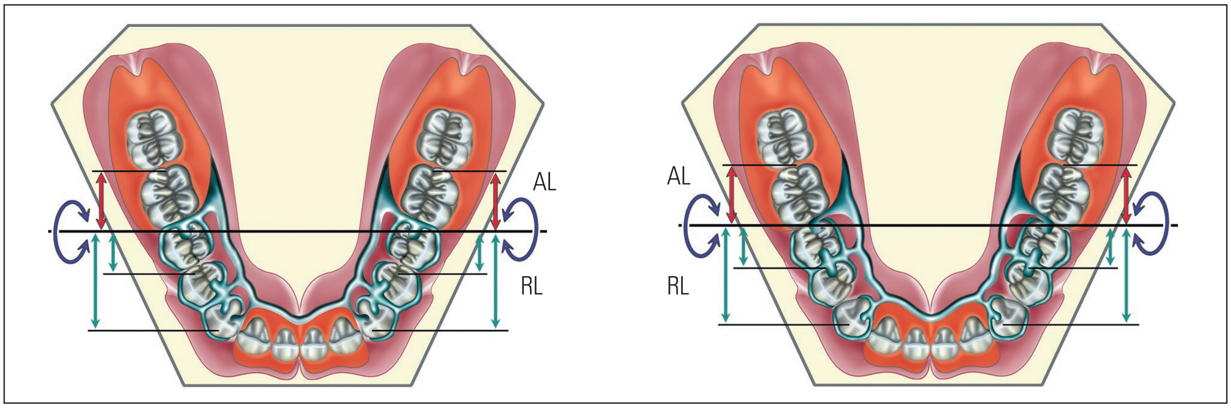


Fig 7-34 A free-end denture is constrained on the terminal abutments with occlusal rests. All of the clasps mounted mesially from the free-end saddle act as resistance lever arms; they reduce mucosal loading and prevent tipping. Both solutions bear two resistance lever arms, but in the second case the clasps on the canine tilt more effectively, leading to better bracing of the residual dentition and better vertical positional stability. However, the second solution may still have to be rejected because this clasp position is esthetically less satisfactory in patients with a short lower lip; in addition, the minor connectors to the Bonwill clasps lie more distally, where self-cleaning is not as effective as mesially.

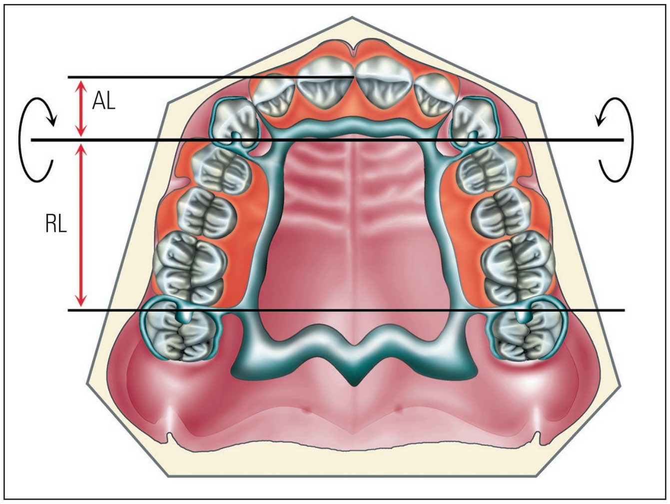


Fig 7-35 In the case of an anterior interdental saddle, which follows an arched course, support similar to that achieved with a free-end saddle should be constructed. With four Bonwill clasps, this denture is oversized, but the problem becomes clear: The action lever arm is far shorter than the resistance lever arm. As a result, the pull on the resistance abutment tooth is very low. An attempt should be made to achieve these conditions when constructing resistance levers.

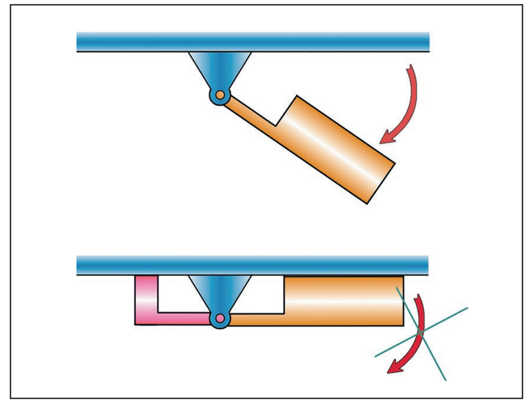


Fig 7-36 The principle of a tipping preventer is clearly illustrated by a bar suspended on one side. The bar will tip downward as a result of its own weight. If counterbearing is applied by lengthening the bar beyond the suspension mounting, the beam supports itself and does not tip. This principle of a tipping preventer becomes effective because of the application of resistance levers.

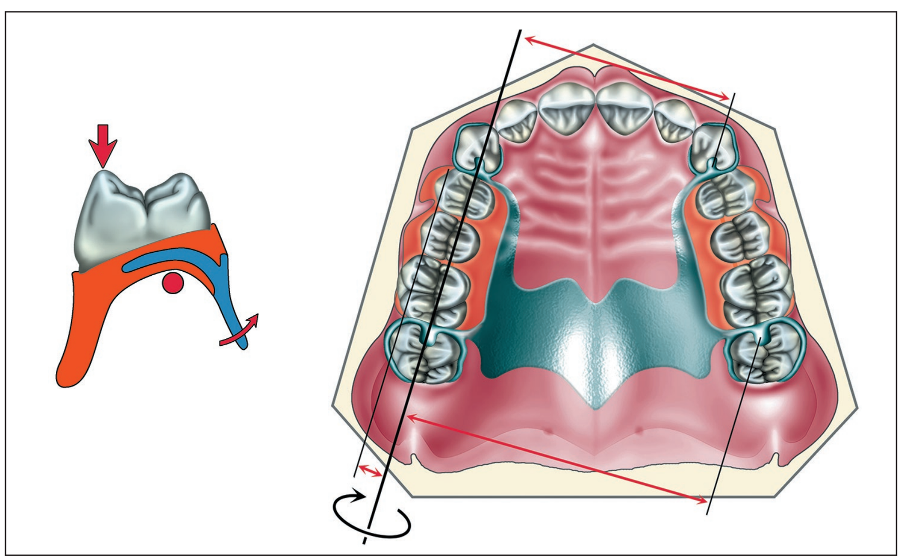


Fig 7-37 If the teeth on a denture are set up slightly outside the alveolar ridge on the vestibular side, lever effects may occur, and the denture may be tipped off. The distance from the point of force application to the center of the alveolar ridge is regarded as the action lever arm. Clasping the denture on the opposite side of the jaw counteracts the tipping as a resistance lever arm.

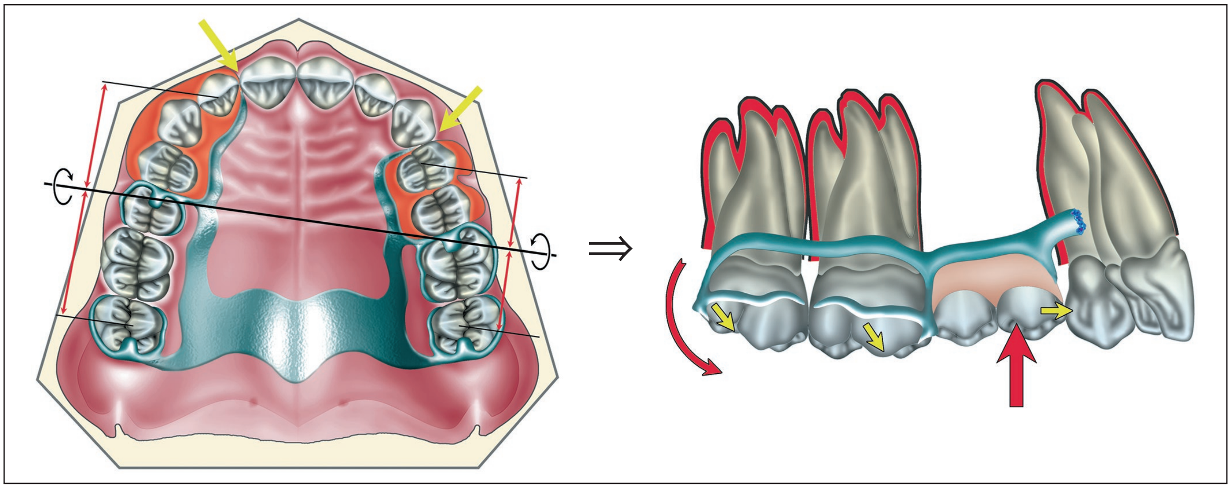


Fig 7-38 If clasp structures are dispensed within the visible anterior area, free-end saddles may result. These structures clearly reveal the disadvantage of free-end dentures: The free-end saddle embeds mesially to the detriment of the tooth-prosthesis interface and forces the adjacent tooth out of the dental arch. This tooth will be the first one to be lost.

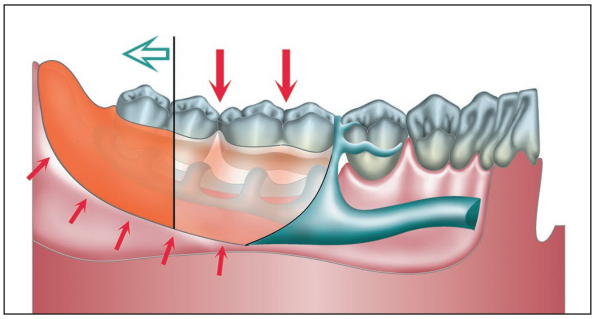


Fig 7-39 To prevent overloading of the mucosa in the case of free-end saddles, the last third of the free-end saddle can be relieved (ie, the terminal molar should be placed outside occlusal contact if necessary). The free-end saddle may only be shaped in extended form (ie, as generously as possible to distribute masticatory force according to the snowshoe principle).

Design-Planning Criteria

The planning and design of tooth replacements is the dentist's responsibility. The dental technician carries out the prosthodontic work based on the dentist's instructions and relevant working documents. However, the dental technician shares a great deal of responsibility for fabricating a prosthesis, and this includes not only the technical production but also the planning and design.

Defining the criteria for design planning of partial dentures simply involves applying and summarizing the facts previously outlined. These criteria are primarily intended to enable dental technicians to understand dentists' design planning and instructions properly and implement them productively in order to fabricate a functional restoration. Only then will dental technicians be capable of presenting technically sound design proposals to complement the treatment provision offered by the dentist.

A pragmatic approach to handling design planning involves deducing objectively established criteria for error analysis as a systematic element of treatment optimization. Error analysis leads to reflection about one's own actions, assessment of one's own work outcomes, and optimization of one's technical material-processing methods and organizational structures. Error analysis means anticipating and eliminating possible mistakes in planning and carrying out prosthodontic work. The purpose of error analysis is hence to identify the correct procedure and to optimize processes and products; it also helps technicians develop planning expertise and technical skills. Error analysis is a dynamic process that should lead to maturity in technical and manual expertise; it is documentary evidence of a dental technician's current level of professionalism and represents a never-ending process.

Defining the targets for a working process, a product, or use of a material is the first step toward formal implementation of error analysis. An extensive collection of facts can be derived from this, in order to draw up a list of criteria for quality control. The analysis criteria should be practical, clearly understandable, and appropriate; they provide a basis for assessment and pointers for optimizing the object of the analysis.

The criteria of design planning or error analysis outlined here relate solely to the technical realization of dental restorations. However, because the restoration is intended to merge into a functional unit with the residual dentition, any design planning must incorporate the physiologic environment. Medical indications will not be discussed in this context.

For a denture that is expected to be durable, reliable, and practical, the following areas must be analyzed from the technical point of view:

- Static relationships
- Physiologic conditions
- Cost-effectiveness

Analysis of static relationships

Analysis criteria are derived from observations of the statics of the partial denture and the functional principles governing anchoring elements. Based on a statics diagram in which tipping lines, action levers, and resistance levers are plotted, horizontal and vertical positional stability is checked:

- An effort should be made to achieve complete periodontal support in which denture movements are stopped, mucosal overloading is prevented, and there is uniform distribution of forces to as many residual teeth as possible.
- Anchoring elements should have defined retentive forces so that abutment teeth are not overloaded on denture removal and a secure and firm seating of the denture is guaranteed in the mouth during functioning and in the resting phase.
- For clasp dentures, there should be one clasp with support close to the saddle for each tooth being replaced.
- The denture design must actively support the residual dentition through splinting.

Analysis of physiologic conditions

This area of analysis concerns the structural details of the anchoring and supporting elements, the denture frameworks, and the saddles, from which the practical value of the denture is directly determined:

- Observe the principles of periodontal hygiene:
  - Shape details should facilitate the self-cleaning function and normal oral hygiene measures.
  - Plaque accumulation or mechanical wear of the tooth surface by prosthodontic components should be avoided.
  - The fixed prosthodontic components should not cover the mucosa.
  - Intracoronal integration of retaining components should be established to relieve the interface.
- Design denture frameworks to be stable, slim, and clear of the periodontium and tongue.
- Make handling and cleaning easy for the patient.
- Allow for the possibility of periodontal treatment.
- Avoid using a diversity of materials.
- Use biocompatible materials.
- Relate esthetic concerns to the patient's needs in order to create the psychologic effect that the patient has regained a complete dentition that reflects health, vitality, and physical attractiveness.

Unsightly retaining elements or the wrong tooth color must not constantly remind the patient of the mutilation of his or her dentition. Nevertheless, the form of a tooth replacement is not primarily a matter of esthetics but an expression of its placement in the functioning organic system. The optimum functional form of a tooth—based on the anatomical model—will always be the perfect esthetic form as well.

Observations on the supposed optimization of esthetic detail can only be made via analysis of the anatomical functional value. If esthetic concerns beyond the psychologic and functional value of prosthodontic work are subordinated to ideas of beauty endorsed by fashion, this will have a negative effect on functional suitability.

Cost-effectiveness analysis

The technical effort involved in fabricating the tooth replacement and anchoring elements should be kept to a level that does not jeopardize functional suitability through process and system errors.

- Choose simple and effective anchoring elements; that means rigid, prefabricated structural components.
- Technical effort should be in reasonable proportion to achievable functional value.
- The risk-benefit calculation requires systematic comparison of alternative solutions, bearing the following in mind:
  - The technical effort should be cost-effective.
  - Clasp dentures are inexpensive but have a lower functional value.
  - Prefabricated structural components are cheaper than manually fabricated components.
  - Precious metal alloys are more costly than tried-and-tested alternative alloys.
  - Aftercare, reparability, and extension possibilities must be disclosed. One aspect that may be assessed is whether the restoration loads the residual dentition during wearing to such an extent that later restorative work can no longer be done or can be done only at considerable cost.

A life-span calculation establishes which prosthodontic design offers the longest life span based on medical, materials science, and static considerations and which has the greatest functional value at the lowest cost.

Residual Dentition Situations and Design Descriptions

Design 1

This example concerns a mandibular arch shortened on one side that is broken up by an anterior edentulous gap. The dentition is further weakened by a posterior edentulous space. The residual dentition situation includes usable anchoring abutments for the prosthodontic restoration. Both canines and first premolars are still present, as well as the right second premolar and the left second molar as a terminal abutment bordering the gap (Fig 7-40).

A design with rigid anchoring and supporting elements is the first to be planned (Fig 7-41). It is advisable to place veneered full crowns on the remaining teeth; only the molar is fitted with a full-cast crown. Teeth that are close together are primarily splinted. Secondary splinting of all the teeth is achieved via the denture framework if the anterior edentulous gap is fitted with two rod-type attachments, and the free-end gap at the terminal abutment as well as the posterior edentulous gap at the molar and premolar are each fitted with a T-attachment. The left first premolar and right second premolar are given circular notches for shear distribution arms. The free-end saddle is shaped to allow for the possibility of extension and the need for reduction; the denture framework comprises a semi–drop-shaped sublingual bar that meets the requirements for periodontal hygiene, hence maintaining minimum distances from the cervical margins, the alveolar ridge, and the floor of the mouth.

Statics of the design

In this case, secondary full splinting flawlessly satisfies the demand for a rigid connection between the denture and the residual dentition. Primary splinting by bar connectors within the edentulous gaps can be dispensed with because horizontal thrusts and rotations, which would be absorbed by the bar, are adequately compensated for here by the rigid intracoronally placed attachments

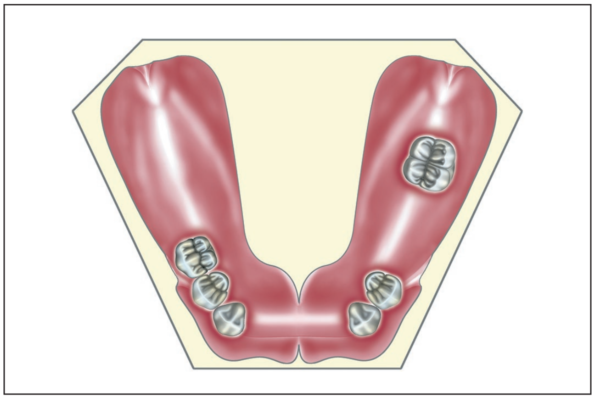


Fig 7-40 A mandibular arch shortened on one side combined with anterior and posterior edentulous gaps is a common situation requiring prosthodontic treatment. The asymmetry of the arrangement of gaps will produce uneven loading of the remaining teeth.

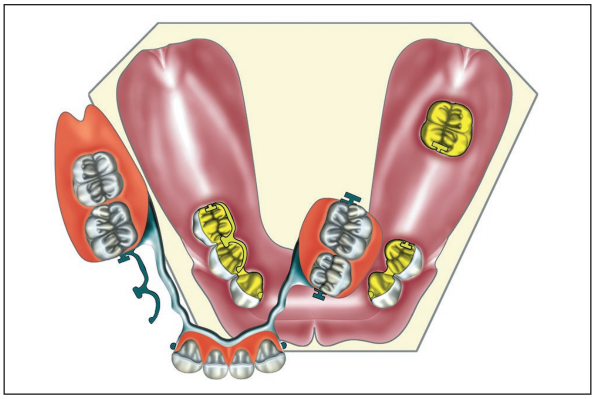


Fig 7-41 The first proposed solution involves a removable partial denture with rigid anchoring and supporting elements. All of the remaining teeth undergo coronal restoration, and teeth that are close together are subject to primary splinting. The edentulous gaps are fitted with closed, intracoronal parallel attachments, and the free-end gap is fitted with a T-attachment and a double-arch shear distributor. As a result, secondary splinting of the abutment teeth is achieved.

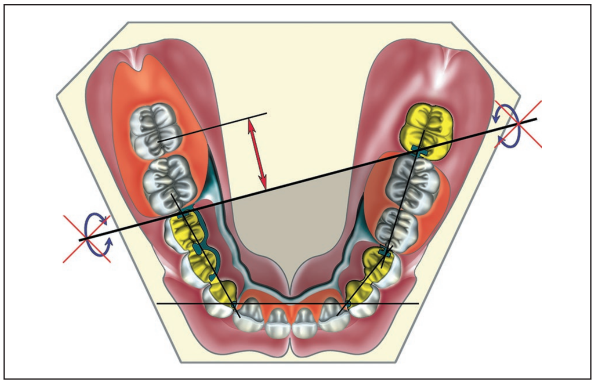


Fig 7-42 The statics of a partial denture that is combined with rigid anchoring and supporting elements are balanced. The free-end saddle may only sink by means of the periodontal resilience of the abutment teeth. All of the masticatory forces are transferred to the periodontium. The denture sits absolutely firmly, the periodontal hygiene conditions are favorable, and the result is a reliable long-term restoration.

for the anterior edentulous gap and the terminal abutments. For large edentulous gaps, bar connectors should in any case always be checked for their suitability in terms of periodontal hygiene; if other solutions offer comparable quality, they should be used instead.

The tipping line, around which the free-end saddle might be tipped, runs through the T-attachments on the mandibular right second premolar and the mandibular left second molar. Via the sublingual bar, four resistance levers of differing length and position then counteract distal tipping. The T-attachment close to the saddle with a shear distributor on the free-end part also resists distal sinking, so that sinking of the saddle is only possible by means of periodontal resilience, the elasticity of the bar, and the extremely small fit tolerance of the attachments.

The relationship of the residual dentition to the replacement teeth is shifted to the detriment of the abutment teeth, yet stresses on the interdental saddles caused by masticatory forces are readily absorbed.

By means of rigid coupling with the resistance levers, in interaction with the necessary full splinting, the free-end stresses should also be transferred to the periodontium. Although the dentition is considerably reduced, the impediment can still be remedied by prosthodontic means. The static relationships suggest that no impairment of masticatory function may be expected (Fig 7-42).

Advantages of the design

Despite the mutilation of the dentition, a rigidly anchored, periodontally supported denture is created. The secondary full splinting ensures uniform distribution of masticatory forces to all the periodontal tissues of the abutment teeth. All the attributes of a reliable denture are met:

- Secure, firm seating in the mouth
- Rigid denture–residual dentition connection
- No mucosal loading
- Worn parts can be replaced
- Excellent esthetic quality
- Favorable conditions for periodontal hygiene due to intracoronal placement of attachments

Disadvantages of the design

When the relationship of the residual dentition to the replacement teeth is unbalanced, there is a risk of permanent overloading of the abutments. This partially edentulous situation is a borderline case. The available remaining teeth are excellent abutments and lend themselves to full splinting via a rigid denture connector. The secure seating of the denture, however, misleads people into demanding too much from the restoration. In addition, handling of this construction is problematic, and only manually dexterous patients will likely be able to cope. This denture is not a good value for the money.

Design 2: Model cast-clasp denture

The same residual dentition situation is to be treated with a model cast-clasp denture. First, all of the abutments bordering the gap are provided with occlusal rests close to the saddle. The premolars on the right are fitted with a Bonwill clasp, while saddle-guided double-arm clasps are fitted around both canines and the left first premolar and second molar.

The esthetics in the anterior region can be improved by placing Bonwill clasps around the canines and the first premolar. However, clasp parts guided approximally over the dental arch are more visible in the mandible than in the maxilla. The mandibular canine is usually concealed by the substantial lower lip.

The sublingual bar joins the saddles and bears the minor connector to the Bonwill clasp. The denture saddles must be kept in extended form because masticatory forces also have to be brought to bear on the mucosa.

Statics of the design

The clasp lines, drawn according to the law of clasp lines, result in a polygonal support area that contains the two interdental saddles within its borders. In shortened dental arches, an eccentric free-end saddle will always arise. The tipping line through the rests on the right second premolar and left second molar indicates the tipping line of the action lever and establishes the length and position of the resistance levers (Fig 7-43).

Full clasping provides several effective resistance levers comprising the Bonwill clasps and double-arm clasps around the canines and the first premolar (Fig 7-44). These clasps can only prevent distal tipping of the free-end saddle by tilting toward the path of insertion. The bodily enclosure by clasps is not as effective as parallel guidance; thus, denture movements affect the free-end saddle. This gives rise to a denture with mixed support in which only the interdental saddles are supported periodontally.

Advantages and disadvantages of the design

This denture is the most cost-effective; it is easy to handle and causes no cleaning difficulties. However, mechanical loading of the enamel of the abutments as well as plaque buildup due to full clasping affect every remaining tooth—first because of the preparation of the rests required and the approximal connection to the Bonwill clasp, and second because the lingual surfaces of the abutment teeth may have to be prepared parallel for the guide arms.

Full clasping requires framework connections that jeopardize periodontal hygiene in the interface to the denture saddles and put under pressure the marginal area of the free-end abutment bordering the gap. The esthetic issues concerning full clasping are in any case indisputable. Elastic connection between the denture and the residual dentition places high stress on the severely reduced partially edentulous dental arch, which

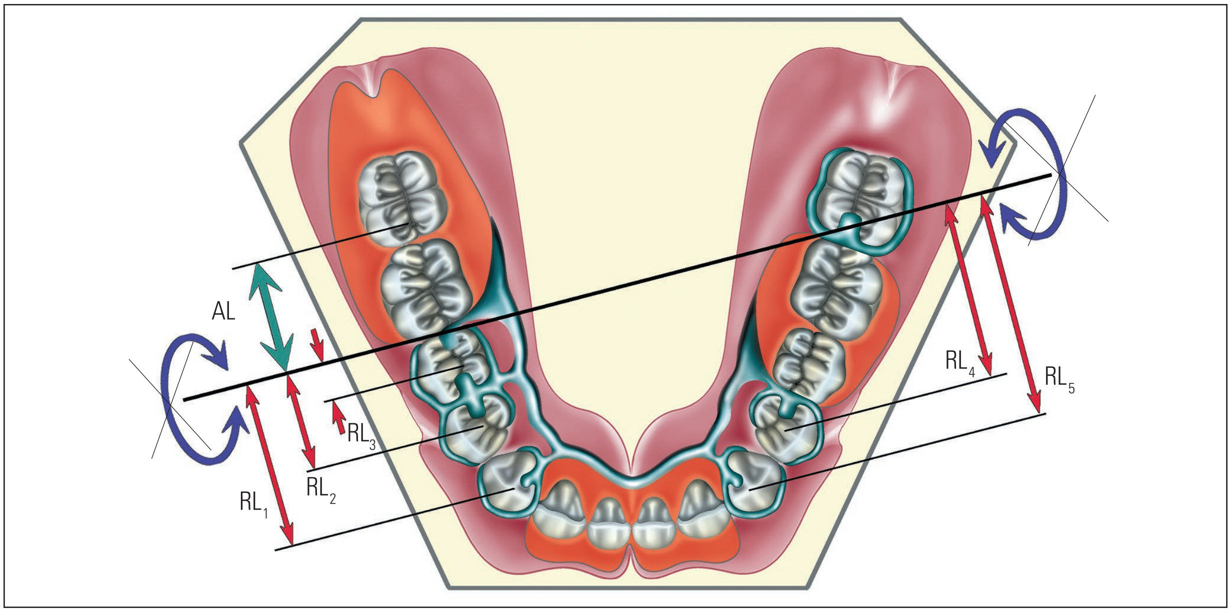


Fig 7-43 The tipping line through the rests on the left second molar and the right second premolar establishes the action lever (AL) and five active resistance levers (RL). The clasp shoulders on the canines are tilted on loading of the free-end saddle so that horizontal positional stability of the free-end saddle is effectively ensured. The interdental saddles are supported close to the saddle and are able to bear the full masticatory load. Full clasping distributes the masticatory load to the entire residual dentition and splints all the remaining teeth into an effective resistance block. Stress on the residual dentition results from mechanical wear of the abutment teeth and deficiencies in periodontal hygiene caused by cast clasps; the esthetic demands cannot be satisfied. This prosthesis is cost-effective as a long-term replacement (ie, for about 5 years).

hastens decay of the dentition after a short functioning period. If the mandibular first premolar is omitted from the clasping, the static relationships deteriorate and loading on the individual abutments is increased.

Alternative solutions

Two extravagant solutions emerge: *(1)* The edentulous gaps can be closed with veneered partial denture pontics, and the shortening of the dental arch can be remedied by an interlocked monoreducer; or *(2)* a removable partial denture can be constructed that embraces all of the remaining teeth and is secured by a lock attachment on the right second premolar. The remaining teeth should be prepared for telescopic anchoring crowns, for which support cones with a large convergence angle are suitable because a lock attachment applies the retentive force.

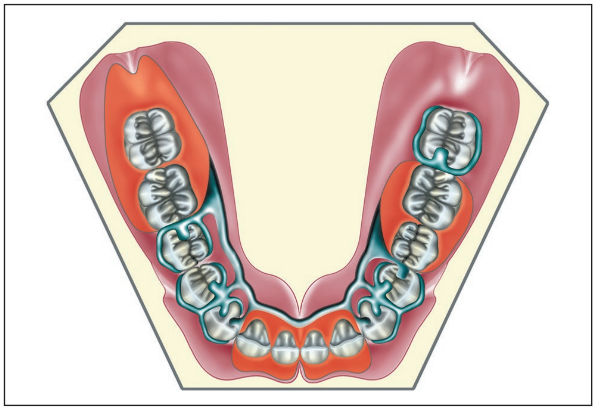


Fig 7-44 For esthetic reasons, the canines and first premolars on both sides are fitted with Bonwill clasps. The static relationships are comparable if the anterior rests close to the saddle are placed so they can tilt when the free-end saddle is loaded.

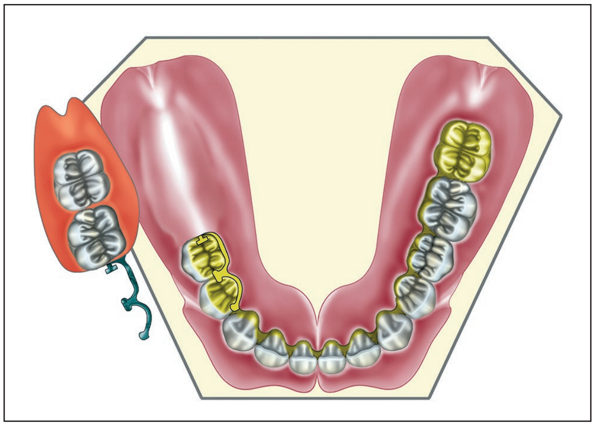


Fig 7-45 Far better wearing comfort and better esthetic effect are achieved with a fixed partial denture to which a double-arch circular notch at the free-end saddle is created for the shear distribution arm of a monoreducer. However, this solution is disproportionately more expensive.

Conical crowns can be designed to be cosmetically more favorable, and no marginal gaps are formed. As sturdy secondary parts find space on the relatively delicate conical subcrowns, the partial denture framework functioning as a denture framework can be made stable enough.

All of the replacement teeth are periodontally supported and rigidly coupled by an interlocking mechanism. Therefore, sinking of the free end only occurs via the elasticity of the partial denture framework and the periodontal resilience of the abutments.

The removable partial denture has all of the positive wearing properties of a fixed restoration and is therefore seen as an elegant solution (Fig 7-45). The real advantage, however, lies in the excellent periodontal hygiene conditions that allow all possible means of periodontal prophylaxis, which is more than a fixed replacement can offer. Handling is simple once the patient has learned to unlock the restoration. The cleaning possibilities and esthetic quality are outstanding. A removable partial denture is very cost-intensive, however, and requires considerable technical effort.

Design 3

This symmetric residual dentition situation has canines and premolars as solid abutment teeth; it is a symmetric partially edentulous dentition (Fig 7-46). Two types of denture framework are available for this common situation:

- A sectioned horseshoe connector or a broad anterior palatal strap
- A skeleton plate made of a narrow anterior and broad posterior palatal strap

The skeleton plate will leave the pressure and fricative field largely clear, while the sectioned plate fully covers the plicae palatinae, which can mean phonetic interference and impaired taste. Therefore, a model cast skeleton is chosen.

Full clasping becomes necessary because of the ratio of remaining teeth to artificial teeth. Two Bonwill clasps are placed around the canines and first premolars, and the anterior interdental saddle is supported with two additional rests close to the saddle. The second premolars are fitted with mesially open double-arm clasps with support close to the saddle (Fig 7-47).

Clearance from the periodontium of clasped teeth must be guaranteed by guiding the framework at a minimum distance of 4 mm from the periodontal margin and by running the minor connectors to the Bonwill clasps at the minimum distance. The denture base has an extended shape that encompasses the maxillary tuberosities.

Statics of the design

To lengthen the resistance levers, all of the denture saddles are supported on the marginal ridges of the teeth bordering the edentulous gap. These rests close to the saddle form the axis points of the tipping lines. If the second molars on the free-end saddle are placed outside occlusal contact, the resistance levers to the canines are longer than the action levers, which creates favorable load relationships. For the anterior interdental saddle, the resistance levers to the double-arm clasps pull on the second premolars. Horizontal positional stability is adequately secured by the full clasping.

This straightforward solution can be achieved with minimal technical effort and without elaborate preparations. This solution is an inexpensive and seemingly up-to-date construction that is frequently used today. If the clasped teeth are correctly surveyed, a relatively reliable denture is obtained that is easy to handle and keep clean.

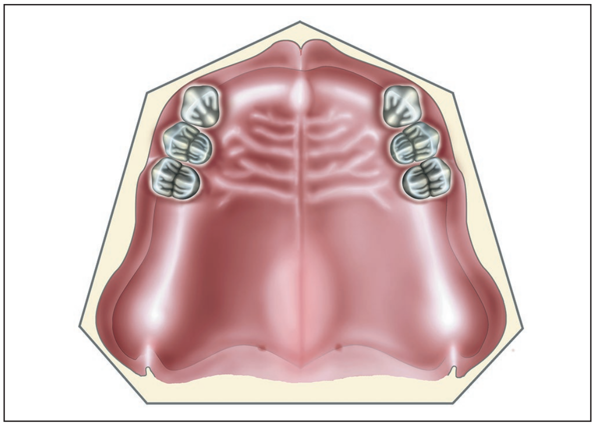


Fig 7-46 The symmetric residual dentition situation shown here comprises an anterior edentulous gap and two free-end gaps due to missing molars. Symmetric partially edentulous situations produce symmetric stresses on the remaining teeth. This situation is very common in prosthodontic care and lends itself to various possible solutions.

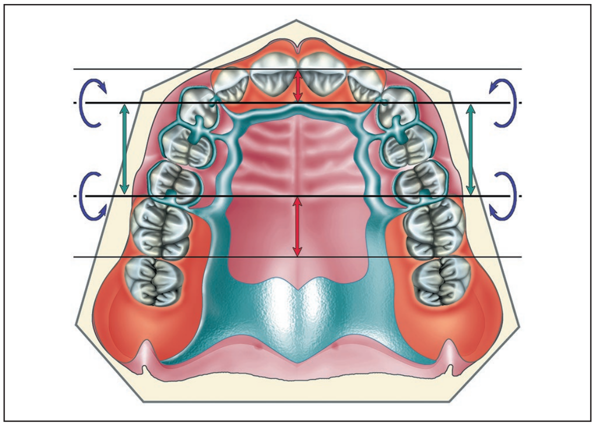


Fig 7-47 The first proposed solution to the situation in Fig 7-46 shows a removable partial denture with two double-arm clasps and two Bonwill clasps for complete splinting of the residual dentition. An anterior and posterior tipping line is formed. By means of full clasping, the saddles are adequately secured against sinking under masticatory pressure. The additional rests on the canines can tilt on free-end loading and provide positional stability.

The connection between the denture and the residual dentition is not rigid. Stresses on the free-end saddle lead to appreciable tipping and intermittent movements of the denture, which means the enamel of the clasped teeth is subject to mechanical wear.

Clasp structures are unfavorable in terms of periodontal hygiene and cosmetic appearance. They cannot be activated and require the preparation of rest surfaces.

Alternative solution

The remaining teeth are fitted with veneer crowns and splinted together. Bordering the anterior interdental gap, two rod-type attachments are integrated to secure the secondary full splinting by means of the denture framework. Two T-attachments are placed intracoronally on the second premolars and supported by shear distribution arms (Fig 7-48).

The denture framework consists of a skeleton plate that joins together the four attachment parts. The extended denture saddles make allowance for dental arch reduction needs. The requirements for denture framework and denture base design in terms of periodontal hygiene must be fulfilled.

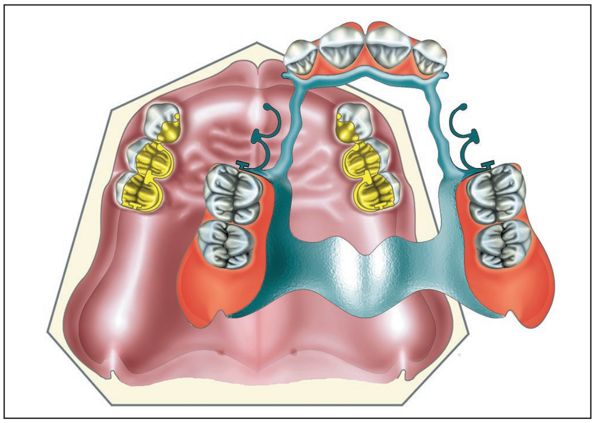


Fig 7-48 The alternative solution to the situation in Fig 7-46 involves closed parallel attachments together with double-arch circular notches with shear distributors at the free-end saddles. This anchorage provides rigid coupling to the residual dentition to secure the horizontal and vertical position and to achieve secondary splinting of the abutment teeth.

The arrangement comprising shear distributors and parallel attachments provides an absolutely rigid connection to the residual dentition. All masticatory forces and transverse stresses are absorbed as a result of rigid coupling and full splinting of the residual dentition. This is the advantage of a high degree of coupling. The static

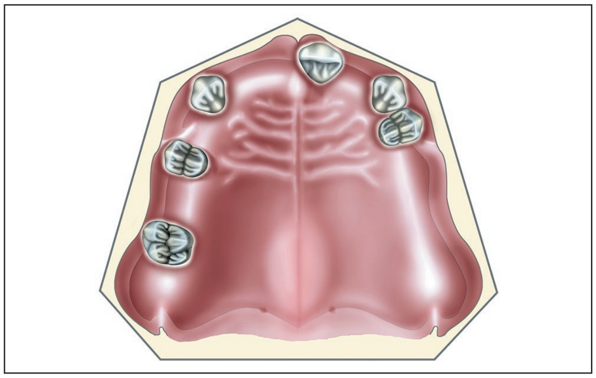


Fig 7-49 The asymmetric residual dentition situation shown here comprises two anterior and two posterior interdental gaps and one free-end gap. Six abutment teeth are available, of which only the left canine and first premolar stand together; all the others are stand-alone abutments. The first planning approach envisages a removable clasp denture. The alternative is an extensive fixed partial denture bearing a monoreducer for the free-end gap. Another alternative involves a 14-pontic removable partial denture with an implant supporting the gap.

relationships of this structure are physiologically entirely positive.

No intermittent denture movements occur; hence, the harmful suction and compressive effects on the mucosa are absent. Resorptive atrophy of dental arch segments is curbed.

This solution has esthetic advantages. The activatable retaining components are sunk into the abutment teeth and concealed. The shear distribution arms are also invisible.

However, healthy residual teeth have to be prepared for the coronal restoration. If free-end loading is considerable, the remaining teeth may be overloaded despite full splinting. This solution is technically demanding and expensive.

Design 4

This dental arch in the maxilla is shortened on one side and interrupted by alternating edentulous gaps. The lateral incisor, the second premolar, and all the molars are missing on the left; on the right, the lateral and central incisors, the first premolar, and the first molar are missing (Fig 7-49).

Model cast-clasp denture

The periodontal support of a free-end saddle is a special problem because the asymmetry of the partially edentulous dentition results in uneven loading conditions. Satisfactory anchorage can only be secured via complex full clasping. The left canine and premolar are engaged with a Bonwill clasp. The premolar is given an additional rest so that the free-end saddle is supported close to the saddle to ensure periodontal transfer of forces. The central incisor is not fitted with a clasp because of the esthetic impression; rests have to be placed mesially and distally, and two approximal minor connectors are used for splinting (Figs 7-50 and 7-51).

To secure the right anterior interdental saddle, the right canine is loaded with a mesially placed occlusal rest and fitted with a mesially open double-arm clasp with rest; the second molar receives a distally open double-arm clasp with rest. Four remaining teeth are now available as abutments for a denture to replace seven teeth. It may be practical to fit the right second premolar with a double-arm clasp and rest as well.

The denture framework is a metal skeleton with a broad posterior and narrow anterior palatal strap, which bears the interdental saddles and the free-end extension saddle. The framework is shaped according to the principles of periodontal clearance and periodontal hygiene (Fig 7-52).

Statics of the design

The tipping line goes through the rests on the second molars and the left first premolar. Various long resistance levers oppose the action lever. The periodontal support of the free-end saddle provides mixed support in which the resistance levels only act by means of tilting. The interdental saddles are secured periodontally. Horizontal positional stability is only approximately secured by the clasping because there are only mesially open clasps on the left side. Splinting of the remaining teeth is ensured.

This simple design may be preferred for cost reasons. It is convenient to handle and keep clean and sits relatively securely. The cosmetic impression is adequate if the canine clasps can be placed cervically, which is possible if only the vestibular retentive areas are used.

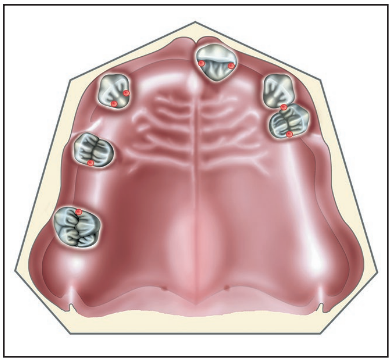


Fig 7-50 The first step in design planning is to identify the rest points. In principle, support will be close to the saddle. One rest is enough for a single-tooth gap. Double rests are possible, as with the right canine and the left first premolar.

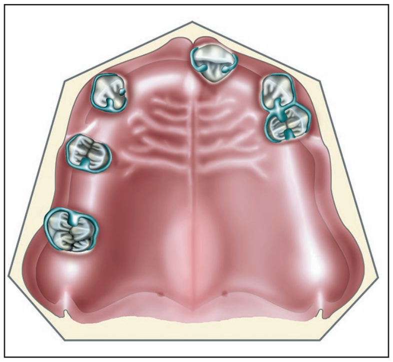


Fig 7-51 The rest points establish the path of the clasps. The central incisor must be incorporated into the splinting unit; if it is not, it will drift out of the dental arch. It is given two rests and two approximal minor connectors.

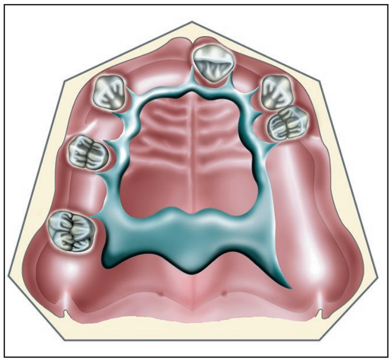


Fig 7-52 The shaping of the denture framework allows for periodontal hygiene and tongue clearance. The framework should be delicate and stable. A wide posterior palatal strap with a skeleton plate meets the requirements and is able to transfer masticatory forces to the palate.

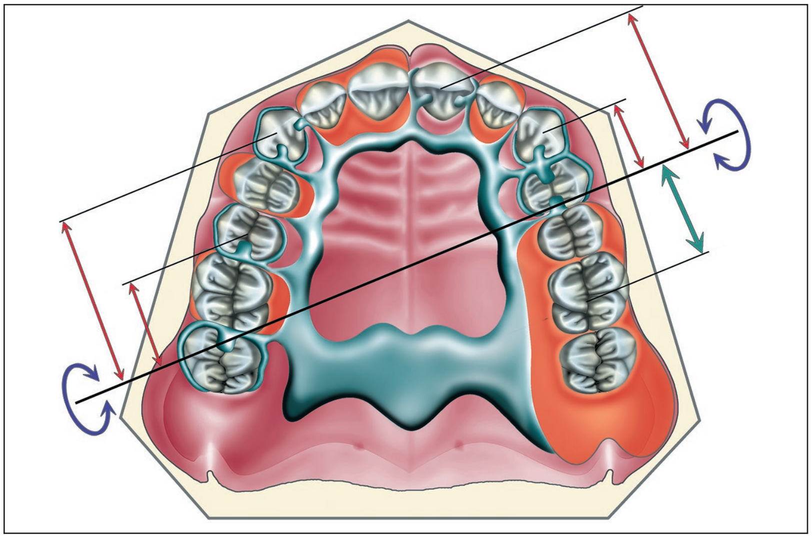


Fig 7-53 Full clasping of the remaining teeth offers good splinting effects, which primarily stabilize the central incisor, contributing to the horizontal positional stability of the free-end saddle due to tilting effects. The diagonal tipping line establishes four resistance levers, which are active against the action lever on the free-end saddle. The clasp structure offers an adequate functional replacement for medium wearing times. The esthetics are deficient, and periodontal hygiene is adequate.

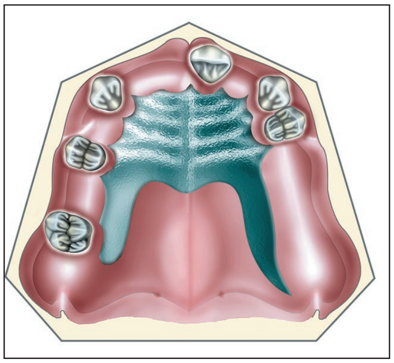


Fig 7-54 An anterior palatal strap or a sectioned plate may be designed, but it does not meet the requirement for tongue clearance. The pressure and fricative field is covered and may impede tongue function (eg, phonetics and taste); in addition, the device is less comfortable to wear.

Despite full clasping, mixed support arises, which is harmful to the underlying mucosa. Tissue breakdown can be expected. The abutment teeth are also excessively loaded by denture movements. Full clasping raises esthetic and periodontal hygiene concerns, quite apart from the traumatic mechanical stress on the enamel of the abutment tooth (Fig 7-53). The anterior palatal strap may interfere with phonetics (Fig 7-54).

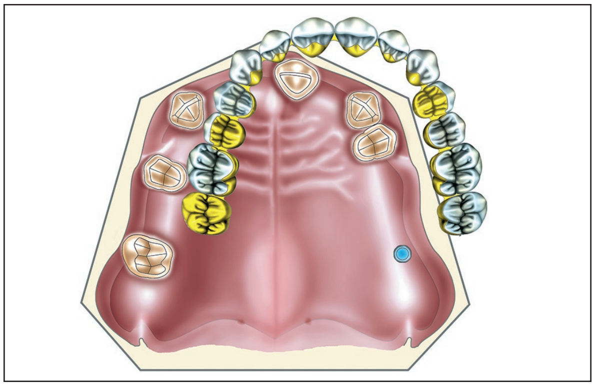


Fig 7-55 The alternative to a clasp denture is a 14-pontic partial denture in which the free-end pontics are supported on at least one implant placed in the gap. The partial denture can be designed to be removable, in which case the body dimensions must be large enough. Periodontal hygiene conditions are very favorable with removable restorations; removable partial dentures have to be so large, however, that some esthetic loss must be expected.

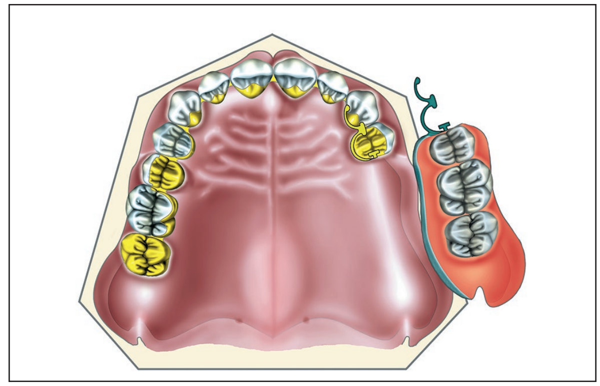


Fig 7-56 A fixed partial denture from the right second molar to the left first premolar is supplemented by a monoreducer in the free-end area, which is secured via a lock attachment and supported by a double-arch shear distributor in a circular notch. The fixed partial denture offers outstanding wearing properties and esthetic benefits; the monoreducer is advantageous in terms of periodontal hygiene.

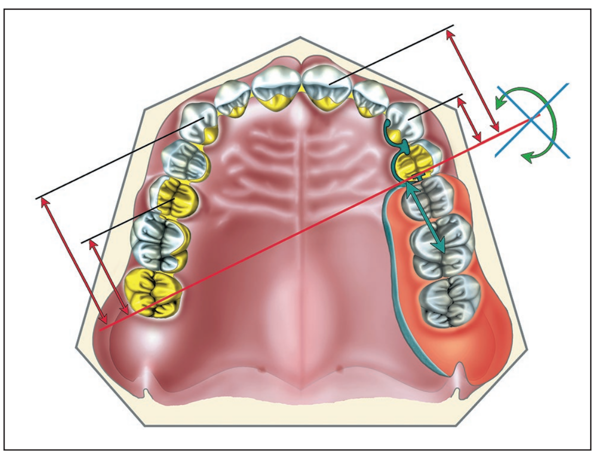


Fig 7-57 Static relationships for the monoreducer are satisfactory. The rigid coupling achieved by the lock attachment and the double-arch shear distributor secure the periodontal support of the removable restoration. The fixed partial denture combines all of the remaining teeth into an effective resistance block. The ratio between residual teeth and replacement teeth is unfavorable, so that overloading of the abutment periodontium may occur. This form of replacement may nevertheless be a practical long-term solution.

Alternative solution

A fixed partial denture for the alternating interdental gaps bears a monoreducer (Figs 7-55 and 7-56). The anchoring function for the free-end saddle is performed by a lock attachment with a double-arch circular notch around the left canine and premolars. The free-end saddle is shaped as a functionally reduced extension saddle.

The free-end saddle is rigidly joined to the residual dentition. The lock attachment prevents any movement of the saddle relative to the mucosa, unless via periodontal resilience. The entire rigid partial denture framework serves as a resistance lever for any free-end loading.

This design provides a secure and reliable restoration that largely protects the residual dentition and the supporting tissue (Fig 7-57). The free-end saddle is supported entirely periodontally and absolutely cannot perform any intermittent relative movements.

The handling, cleaning possibilities, esthetic impression, unimpeded phonetics, clear palatal area without the denture framework causing any interference, and sum of all the excellent wearing properties make this an excellent restoration. If all the teeth cannot be handled by extensive conservative measures because of caries lesions or other defects, coronal restoration of the entire dentition may be called into question; therein lies the weakness of this proposed solution. Convincing arguments are needed to justify coronal restorations for healthy teeth.

8

Complete Dentures

Complete dentures for the maxilla and mandible comprise denture bodies and artificial teeth that are inserted into the oral cavity to replace natural teeth and missing alveolar ridges. The denture bodies and teeth resemble the natural tissue parts in shape and size because they are meant to take on their functions. Use of complete dentures involves not only replacing the missing teeth and resorbed parts of the alveolar ridges but also making a radical intervention into the existing massively damaged masticatory system.

For a partial denture, it is important to find the most favorable anchorage to the residual dentition—from a technical and functional standpoint—to ensure that the prosthesis is firmly seated and masticatory forces are largely transferred to the periodontal tissues of the residual dentition. By contrast, complete dentures lie mechanically loosely on the edentulous dental arches without additional anchorage.

For tooth setup in the case of complete dentures, the anatomical and functional conditions of the variable jaw movements as well as the physical and mechanical conditions of a denture body resting on the mucosa in unstable equilibrium have to be taken into consideration. The real problem of complete dentures lies in shaping the dentures so they lie firmly on the dental arch during chewing without moving and so that masticatory forces are transferred to the underlying mucosal support over a large area.

The problems of complete dentures have been studied by many dentists since the early days of dental research, with special emphasis being placed on the relationship between scientific research and practical testing. In particular, it is a matter of interpreting the existing anatomical circumstances of edentulous jaws in light of the physical and mechanical conditions of the dynamic masticatory system so that usable models for practical fabrication of complete dentures can be developed.

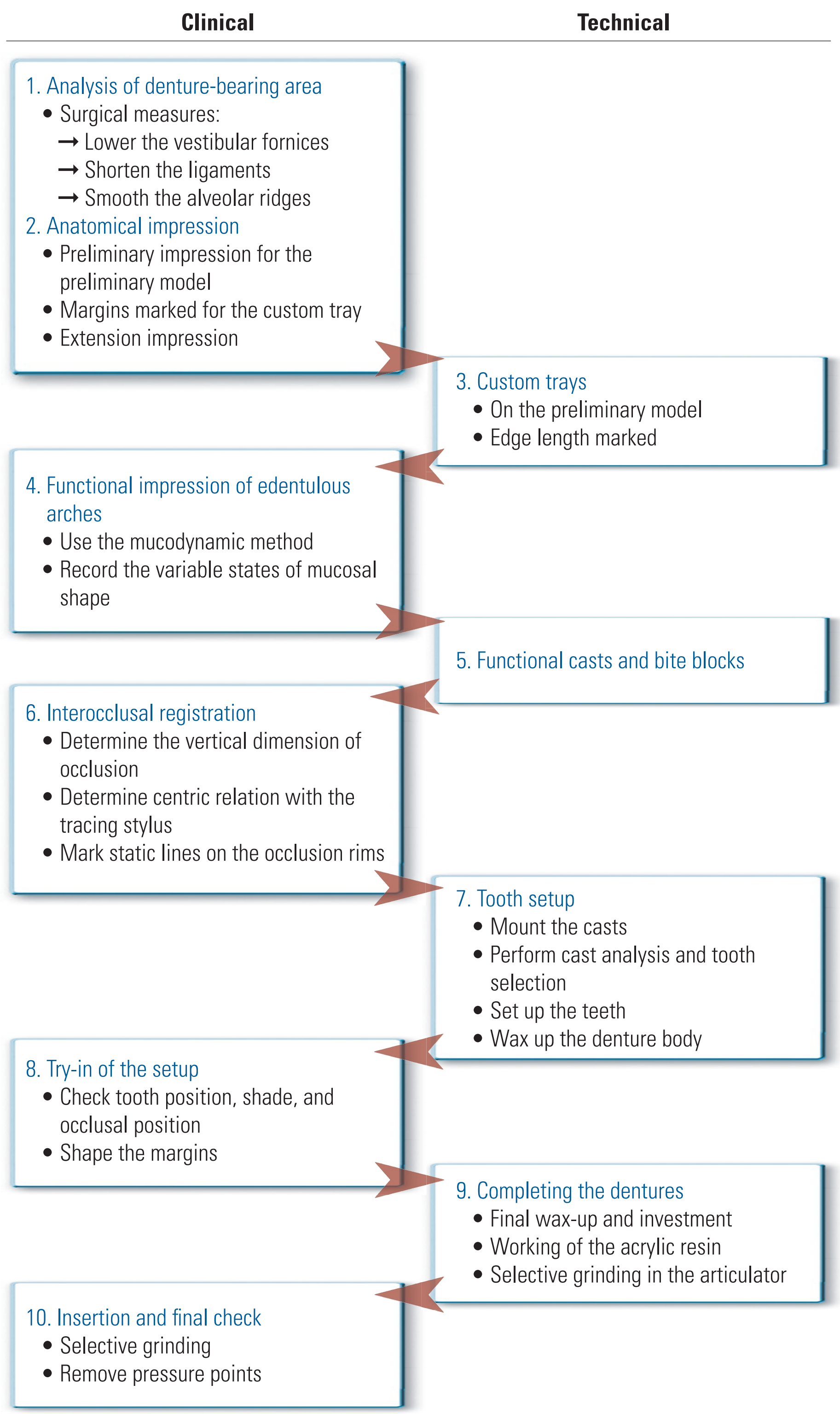


Fig 8-1 Workflow for complete dentures.

What is striking is that most of these explanatory models accentuate one anatomical or physicomechanical feature and prioritize individual measures for successful fabrication of a complete denture. For instance, the view might be put forward that the denture should be kept stable during masticatory function by means of statically favorable posterior tooth shapes. On the other hand, the premise might be that only a precise impression of the edentulous jaws will guarantee successful treatment. Techniques for interocclusal registration are available, with the appropriate articulators, facebows, and instrument kits, as well as special tooth molds for static setup of posterior teeth with detailed instructions.

The success of a complete denture, however, cannot be guaranteed by prioritizing individual measures but only by the most accurate implementation of all the individual measures. The following individual measures are involved in the fabrication of complete dentures (Fig 8-1):

1. Clinical and surgical preparation and analysis of the denture-bearing area in the maxilla and mandible
2. Functional impression as the basis for anatomically functional shaping of the denture margins and the denture base
3. Interocclusal registration with approximate determination of joint values
4. Tooth setup based on the principles of denture statics in relation to mandibular movement and taking into account esthetic and phonetic concerns
5. Contouring of the denture bodies to support the lip and cheek muscles and to increase denture retention
6. Final check of the denture while it is functioning to eliminate slip interferences in the occlusal area and pressure points on the denture base

Fundamental knowledge about the fabrication of complete dentures needs to be acquired in the aforementioned sequence of measures. This chapter therefore works through the following in detail:

- Morphologic and physiologic changes after tooth loss
- Impression-taking of edentulous jaws
- Interocclusal registration of edentulous jaws
- Tooth setup for complete dentures
- Retention of complete dentures

Various working methods for fabricating complete dentures are also presented.

Anatomical Changes After Total Tooth Loss

Normal dentition is described as functional occlusion, on the basis of which the shapes of teeth, tooth positions, jaw shapes, and inclinations in their morphology are the result of the differentiated functions that have to be fulfilled. In advanced age, the capacity for cellular regeneration declines, and physiologic wear is only poorly replaced; age-related physiologic degeneration of the tissue (senile involution) occurs. This involves continuous tooth loss with advancing age, which happens faster in the maxilla than in the mandible. Owing to their large periodontium, the canines—especially in the mandible—are the last to be lost.

As a consequence of senile osteoporosis, there is a decrease in the weight of the cranium. In edentulousness, the alveolar areas of the maxilla and mandible are almost fully resorbed because these bony parts are no longer being loaded in their original form. In principle, atrophy of disuse ensues.

Atrophy of disuse (or inactivity) means active shrinking of tissue due to impaired function or nonuse of that tissue. For example, muscles shrink when a plaster cast is used to immobilize a limb for a lengthy period after a bone fracture. This process is reversible; after healing, the tissue is built up again, provided that functional loading and proper nutrition are ensured.

Resorptive atrophy refers to shrinkage of the alveolar process after tooth loss when the stimulus provided by the tooth roots is missing and the bony sockets lose their physiologic function. This process can be delayed by suitable shaping of the denture base for extensive loading of the denture-bearing area, but it cannot be reversed.

In the maxilla, the maxillary body forms the basic framework from which the functionally orient-

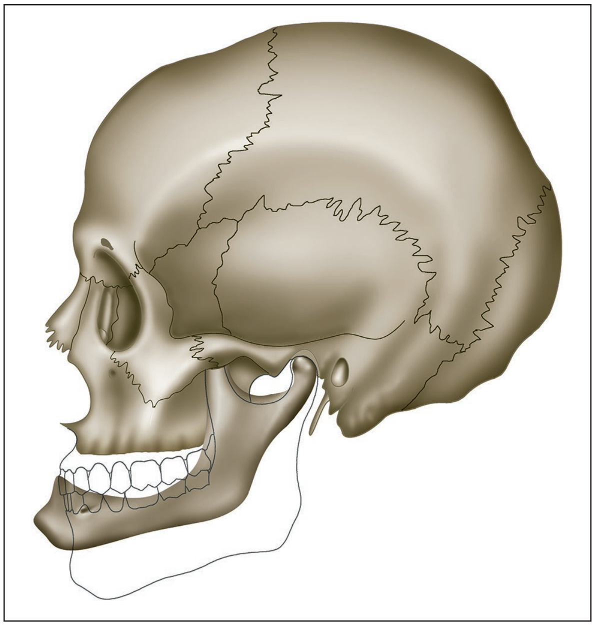


Fig 8-2 After total tooth loss, the jaw relations shift because the mandible is closer to the maxilla. If the vertical dimension of occlusion is normal, the midline of the mandibular anterior alveolar ridge lies behind that of the maxilla; the more the mandible approaches the maxilla, the more the chin shifts forward.

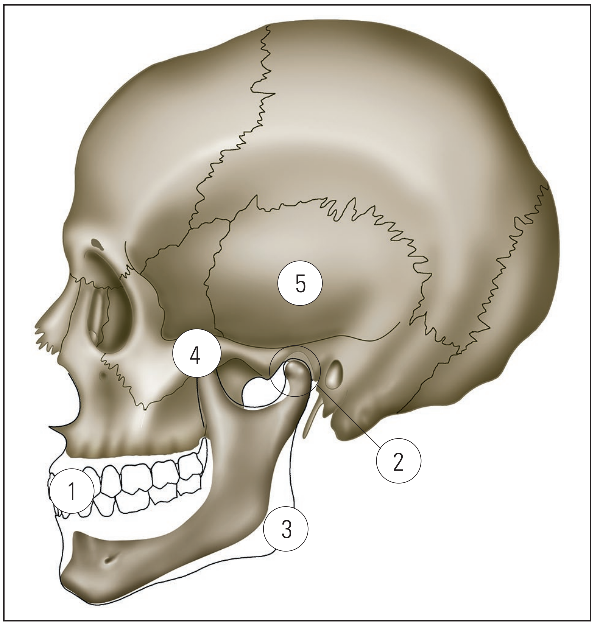


Fig 8-3 Side view of a senile skull. The outline of the fully dentate jaw shows the extent of resorptive atrophy after total tooth loss: *(1)* Alveolar processes in the mandible and maxilla shrink almost completely down to the basal bone. *(2)* The TMJ is deformed by abnormal loading. There are also changes in muscle attachments and *(3)* the angle of the mandible, *(4)* the zygomatic arch, and *(5)* the temporal fossa.

ed processes originate. The alveolar process will shrink noticeably after tooth loss; the three other processes will continue to provide static support to the upper face and will only shrink slightly. Weakening of the bone substance will take place at the muscle attachments (eg, zygomatic process).

The substance of the palatine processes of the maxilla is retained because essentially functional loading of this bony part persists because of the suction effect in the mouth. Nevertheless, in the case of the palatal bone, the posterior third of the bony palate can be paper-thin and even perforate so that the oral and nasal cavities are only separated from each other by a fold of mucosa.

In the mandible, the parts oriented by loading during masticatory function resorb after total tooth loss (eg, the coronoid process, angle of the mandible, and alveolar part). The senile mandible is hook-shaped and flattened at the angle of the jaw. If there has been severe atrophy, the mental foramen lies at the upper edge of the alveolar ridge.

As a result of atrophy, the distance between the mandibular canal and the upper edge of the alveolar ridge shortens; in rare cases, the inferior alveolar nerve may lie directly below the mucosa. The distance from the mandibular canal to the lingual and buccal wall of the mandible remains roughly constant. Jaw relations will also change; that is, the position of the mandible relative to the maxilla will shift. Initially the mandible gets closer to the maxilla due to chewing with the bony alveolar ridges (Fig 8-2).

After prolonged edentulousness, the condyles and condylar path become flattened; the condyloid process of the mandible as a muscle attachment (lateral pterygoid muscle) also loses substance and is displaced dorsally. The mandible is displaced forward. This results in structural adaptation of the temporomandibular joints (TMJs) and the neuromuscular system. Joint cartilage and the articular disc do not carry any blood vessels, so no repair process occurs, but defects (including atrophy) happen in the cartilage and the disc.

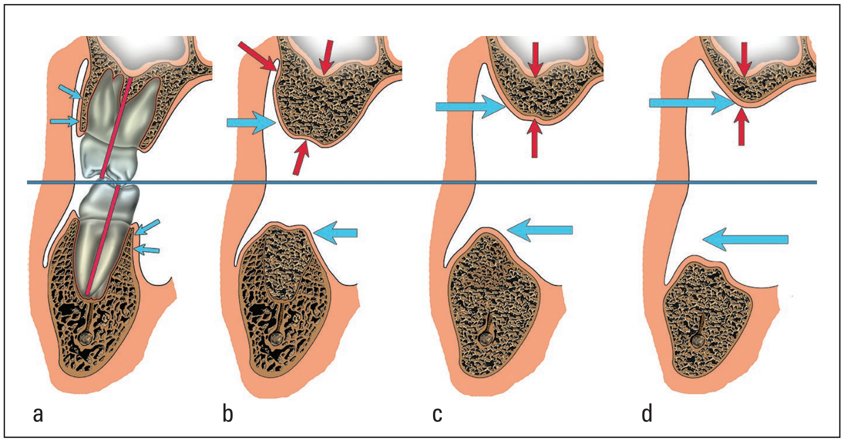


Fig 8-4 The alveolar ridges have a vestibular inclination in the maxilla and are lingually inclined in the mandible. Shrinkage happens in the direction of inclination so that the mandibular ridge line widens and the maxillary ridge line narrows. This shrinking process is further intensified by the fact that the thin walls (lingually in the mandible, vestibularly in the maxilla) shrink more than the compact walls. This results in different ridge profiles: *(a)* normal alveolar ridge; *(b)* high, wide ridge shortly after extraction; *(c)* narrow and pointed ridge; and *(d)* flat alveolar ridge without mechanical retentions.

The appearance of a senile skull illustrates the shrinkage that affects not only the alveolar processes of the jaws but also the muscle tissue and muscle attachments to the bone (Fig 8-3). When the alveolar process in the maxilla is subject to atrophy, the tip of the nose falls downward so that eventually the tip of the chin and the tip of the nose move close together in the senile skull. Atrophy of muscle mass of the masseter may make the cheeks appear hollow and the cheekbones stand out prominently. This impression is further intensified by the sunken temporal fossae in which the temporal muscle is shrunken.

Forms of Shrinkage of Alveolar Ridges

The anatomical changes in the mouth mainly relate to shrinkage of the alveolar processes or alveolar parts of the maxilla and mandible. After tooth loss, the roots leave sockets (alveoli) in which secondary bone is formed. In the maxilla, the vestibular bone lamellae of the alveolar process are thinner, while the palatal parts are relatively compact; in the mandible, the thin bone walls lie lingually and the more compact bone walls lie vestibularly. The thin bone lamellae shrink more markedly than compact ones. As a result, the alveolar ridges appear to shrink toward the palate in the maxilla and toward the vestibule in the mandible (that is, in their direction of inclination). Hence, narrowing arises due to the vestibular inclination of the maxillary ridge, and widening of the ridge lines occurs given the lingual inclination of the mandibular ridge (Fig 8-4).

In fully dentate arches, the midlines of the alveolar ridges lie vertically on top of each other. As the alveolar ridges are inclined toward each other, the mandibular central incisors are inclined lingually and the maxillary central incisors in the vestibular direction. This gives rise to a peculiar feature after tooth loss, namely that the maxilla apparently becomes smaller and the mandible larger (Figs 8-5 and 8-6). The rate of resorption of the alveolar part in the mandible can be three times greater than the shrinkage of the alveolar process in the maxilla. This means the mandibular ridge line widens considerably more than the maxillary ridge line narrows.

The interalveolar connecting line (interalveolar line) joins the centers of the shrunken alveolar ridges together (Fig 8-7). Depending on the progression of the ridge shrinkage, the interalveolar connecting line inclines toward the occlusal plane to a variable degree. The greater the incline of the interalveolar line, the more difficult it is to set up the posterior teeth. According to Gysi, the setup is in crossbite if the angle of inclination is less than 80 degrees.

In the anterior region, the widening or narrowing of the alveolar ridge lines must be viewed in a more differentiated way. In the maxilla, all the teeth show a more or less pronounced vestibular inclination so that the shape of the ridge line is preserved as a semi-ellipse. In the mandible,

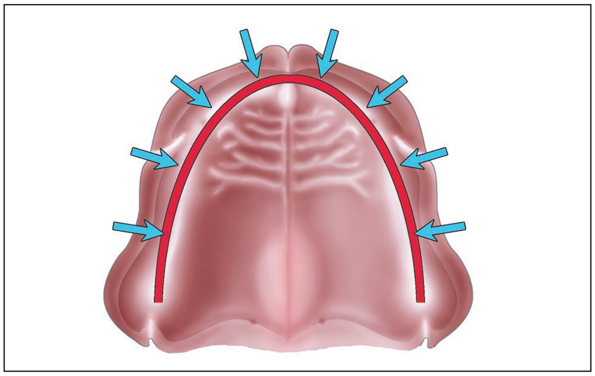


Fig 8-5 As the alveolar processes of the maxilla shrink in the direction of inclination, the maxillary ridge line narrows in the lingual direction; the maxilla becomes smaller, which has repercussions for the statics of the complete denture.

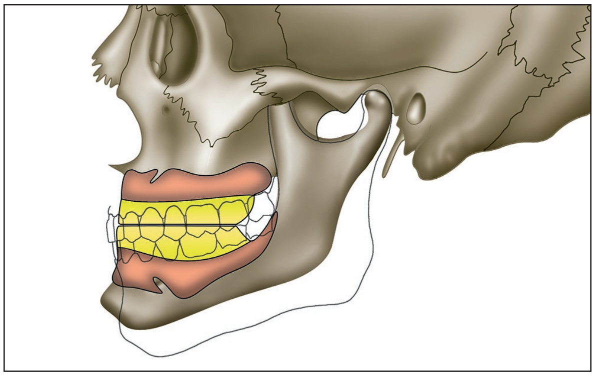


Fig 8-6 To achieve better positional stability of the denture, the vertical dimension of occlusion is reduced in complete dentures. As a result, the height of the denture body also decreases, and the mandible moves closer to the maxilla. Consequently, the midline of the mandibular anterior alveolar ridge is displaced forward.

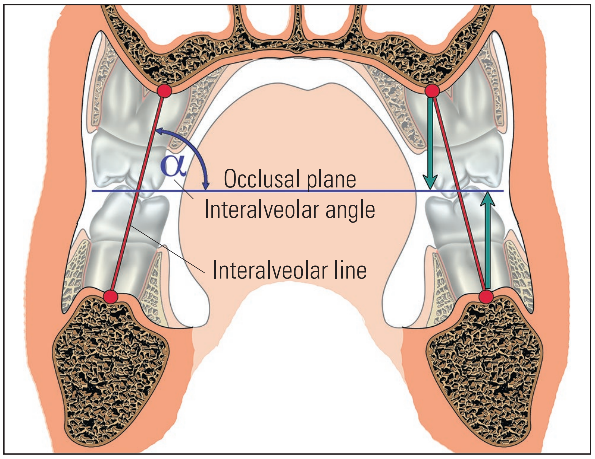


Fig 8-7 The interalveolar line is the connecting line between the centers of the ridges of the shrunken dental arches; together with the occlusal plane, it forms the interalveolar angle. The interalveolar angle changes depending on the progress of shrinkage. The more the jaws shrink, the smaller the interalveolar angle becomes.

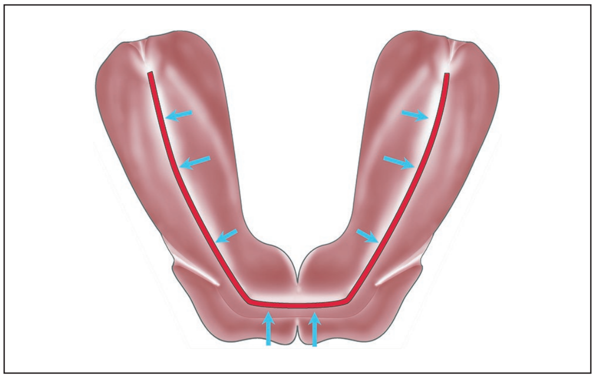


Fig 8-8 In the mandible, the posterior parts of the alveolar ridge are displaced vestibularly due to resorption, and the anterior parts are displaced lingually; the result is a roughly trapezoidal ridge-line contour.

however, only the posterior teeth are clearly inclined lingually; the canine stands vertically, and the incisors have a labial inclination. This means the ridge line changes from a parabola to a rather trapezoidal basic shape (Fig 8-8). The relationship of the parts of the alveolar ridge is maintained in the canine area; they are vertically shrunken. The anterior areas are sunken lingually, and because the central incisors are inclined more labially than the lateral incisors, the symphysis area shrinks more markedly lingually than laterally. As a result, an almost straight ridge line is formed between the canine points in the mandibular anterior region.

The ridges of the posterior teeth have a variably pronounced lingual inclination in the mandible (the tooth inclination decreases dorsally; the ridge inclination increases), which is why the ridge line widens more in the dorsal direction. Following shrinkage of the alveolar parts,

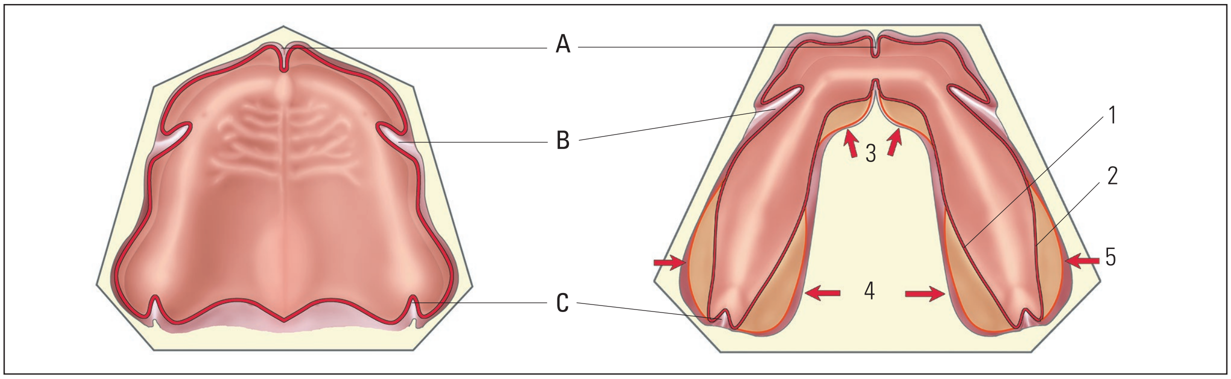


Fig 8-9 The contours of the periphery of functional trays allow for reduction needs and extension possibilities for edentulous jaws, such as all vestibularly attached ligaments, the labial frenum (A), and the buccal frenum (B). Note the pterygomandibular raphes in the maxilla and mandible (C), the path of the vibrating line in the maxilla, and the muscle attachments in the mandible, such as the mylohyoid line (1) lingually and the oblique line (2) vestibularly. Extension areas in the mandible are the sublingual areas (3), paralingual areas (4), and buccinator pockets (5).

the retromolar triangle appears to be displaced lingually. As this bony part does not shrink after tooth loss, it will retain its real position, relative to which the alveolar ridge is then displaced.

The conditions are similar for the maxillary tuberosity and the incisive papilla. The tuberosities appear to be displaced vestibularly, while the incisive papilla is shifted onto the center of the alveolar ridge contour; the tip of the papilla may lie on the anterior contour of the alveolar ridge. Depending on how much shrinkage has occurred due to the duration of edentulousness and the damage caused by faulty denture bases, different forms of jaw shrinkage will arise.

In the edentulous maxilla, the alveolar process forms the fibrous marginal zone, and the median raphe of the hard palate forms the fibrous median zone in the form of immovable mucosa. Between the fibrous median and marginal zones lie the plicae palatinae in the fatty zone, which merge dorsally into the glandular zone with serous-mucous salivary glands. Fatty and glandular zones are more resilient than the fibrous zones. The soft palate borders the hard palate dorsally.

The edentulous alveolar ridge in the mandible also develops a fibrous zone, which ends dorsally in the alveolar tubercle of the mandible, a ridge of connective tissue covered by mucosa. The immobile, fibrous ridge mucosa is bordered vestibularly by the mucosa of the vestibular fornix and lingually by the mobile floor of the mouth.

Impression-Taking of the Edentulous Jaw

Taking impressions of edentulous jaws falls within the dental practitioner's area of responsibility. The aim is to take a precise, extensive impression of the denture-bearing area, in which the transitions from the attached to the mobile mucosa are recorded in particular.

The functional impression is used to reproduce the border area individually during functional movements of the mucosa. The impression does not record the functioning of the mucosa but rather the space required by the mobile mucosa or muscles and ligaments as they function (Fig 8-9). In practical terms, a custom impression tray is used, which is first prepared from an anatomical cast or preliminary model. For this purpose, an overextended anatomical impression is taken based on the principle of mucostatic impression-taking (Fig 8-10).

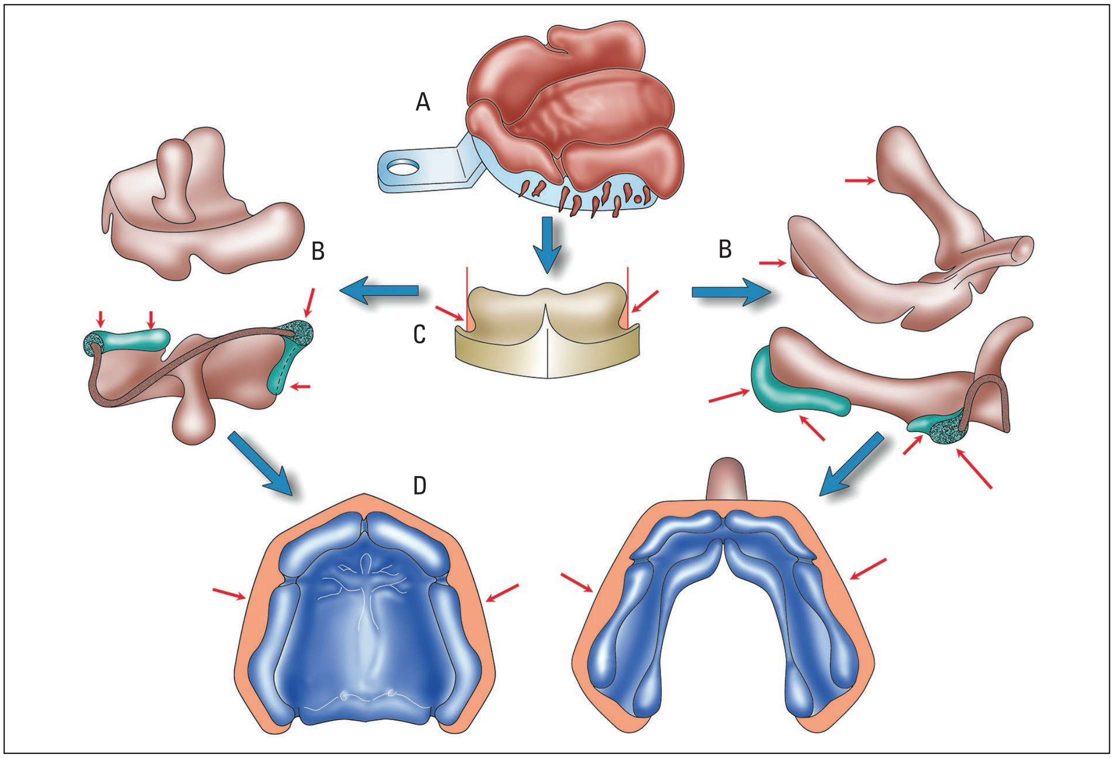


Fig 8-10 An impression of edentulous jaws is usually taken in two working steps: The mucostatic impression delivers a preliminary model (A) on which the custom functional trays are made (B). They show the path of the periphery of the eventual denture. Undercuts are blocked out on the models (C). The vibrating line area and the paralingual and sublingual areas are individually reinforced on the functional tray before impression-taking in order to exploit these important parts of the jaw for special prosthetic purposes. The finished functional impressions are given a horizontal wax rim above the impression of the valve margin (D). This produces the model rim thickness with functional margin.

The mucostatic impression is taken with the mouth relatively wide open and the mucosa in the rest position. The impression negative depicts the equilibrium position between the resting tension of the tissue and the consistency of the impression material, usually an alginate mixed to a viscous consistency. Slight movements of cheeks, lips, and tongue cause the attachments of the ligaments to stand out. This results in an extension impression in which the vestibule is widened in order to record the limits of the dental arch, including into the undercuts.

The custom tray is prepared on a preliminary model, which is derived from this impression. A felt-tip pen may be used to mark the edge of the tray on the alginate impression. This mark then appears on the preliminary model and provides a guide to the contour of the tray edge. The tray is made from a rigid plastic and has an easy-to-grip handle in the middle.

Fabrication of a custom tray varies depending on the tray material—whether thermoformed sheet or chemoplastics. What is crucial to both techniques, however, is the shaping of the tray edges. If the tray is kept slightly longer than the depth of the vestibular fornix, the edge can be individually reworked in the mouth. To do this, the edge is shortened until it does not lift off during check movements and does not create any pressure points. The edges can be reinforced with wax after correction in order to mold lip shields and buccal rests as well as the length of the sublingual roll and the paralingual wings.

Possible impression materials are heavy- and light-body silicones; thermoplastic materials allow long-term impression-taking in which the edges are harmoniously rounded in the border area. Various methods can be used to take a practical functional impression in order to record the variable contours of the mucosa.

A chewing impression is an impression of the surface of the dental arches during the muscle activity involved in chewing. This is taken to record the mucosal loading that would be caused under denture functioning conditions. A custom tray with bite planes in the correct vertical dimension of occlusion is coated with thermoplastic impression material and placed in the mouth. Chewing movements are then performed for about 30 minutes.

A swallowing impression takes an impression of the jaw's border to the floor of the mouth, which is important in recording the sublingual spaces for the sublingual roll and the paralingual wings.

An impression taken when the patient is pronouncing certain groups of vowels and consonants records the variable range of movement of the lips, cheeks, tongue, muscles of mastication, vestibule, and soft palate.

A closed-mouth impression involves taking a simultaneous impression of the maxilla and the mandible with preliminary registration of occlusal position. Prefabricated stock trays are used for the anatomical impression; they can be fixed in their position relative to each other. For this purpose, bite plate trays are prepared, which are used when determining the occlusal position for the functional impression (Fig 8-11). The functional movements can be performed actively by the patient or passively by the operator.

The functional model made from dental stone shows the functional periphery to the dimensions required for fabricating a valve margin with an adequate outer valve. To do this, the edge of the model is raised about 3 to 4 mm outward on the impression. A broad wax pad can be stuck onto the impression at that distance from the valve margin so that the base plaster can be raised up to this stop.

The vestibular fornix, the border of the floor of the mouth, and the vibrating line can be clearly identified and must not be damaged. On these functional models, the bite plates are now prepared in the dimensions of the eventual denture base and used for interocclusal registration.

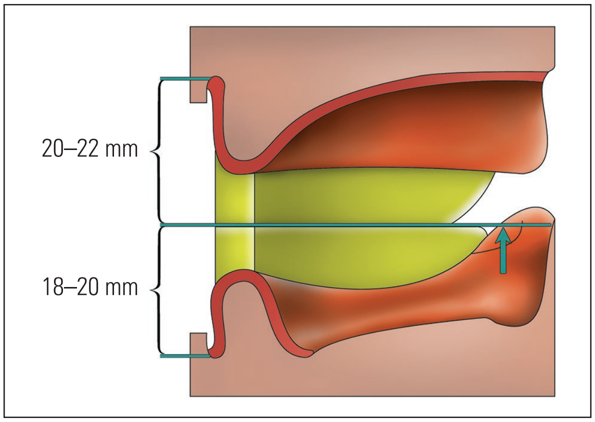


Fig 8-11 The occlusion rims are placed on firm bite plates following the course of the center of the alveolar ridge. The vertical dimension of occlusion is measured from the lowest point in the fornix to the occlusal plane. The occlusal plane runs roughly parallel to the contour of the maxillary ridge; in the mandible, it runs dorsally through the upper third of the retromolar triangle; anteriorly, the occlusion rims may be padded by the dentist to match full lip volume or in the course of the vertical anterior arch.

Interocclusal Registration

Interocclusal registration is intended to establish the positional relationship of the jaws to each other and their position relative to the joints. The aim is to regain the former centric occlusion or habitual intercuspation position in which the condyles lie pressure free and tension free deep in the mandibular fossae. In an edentulous masticatory system, the equivalent of the former centric occlusion will have to be determined in the vertical and horizontal relationships.

The vertical dimension of occlusion is measured in various ways. It can be assumed to be a statistical average, namely a 38- to 42-mm distance from the mandibular to the maxillary fornix. It can be assumed to be the position of the smallest speaking distance when pronouncing test words (eg, counting from one to ten). It can be deduced from the facial proportions as a harmonious length, whereby the facial profile lines yield three facial sections of equal length: the upper, mid-, and lower face. The distances from the root of the nose to the lower nasal point and from the lower nasal point to the tip of the chin are equal.

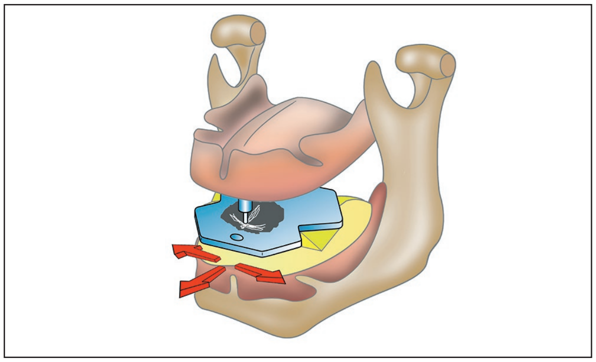


Fig 8-12 Intraoral occlusal registration involves marking the centric occlusion position by using a centrally placed tracing point to trace mandibular movement on a tracing plate in the form of a Gothic arch. The point where the arch intersects indicates the position of centric occlusion.

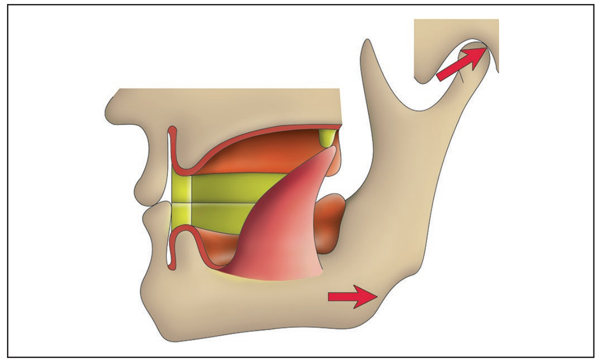


Fig 8-13 To get the mandible into centric relation, in which both condyles lie in the most retruded position, a wax bead can be placed at the dorsal edge of the plate, where it will be touched with the tip of the tongue. This means the mandible is pulled evenly into the most posterior position.

The horizontal relationship encompasses the transverse and sagittal positional relationship of the jaws. This relationship can be registered using various methods. One possibility is to get the patient to adopt the most retruded mandibular position, for example by guiding the mandible back by hand or getting the patient to swallow. However, the most retruded position of the mandible, in which the condyles are in contact with the dorsal joint limit about 1 mm behind the normal position, is a forced position in most patients.

Gothic arch tracing offers another means of determining the horizontal relationship. A tracing stylus mounted centrally on the maxillary (or mandibular) bite plate marks what is known as the *Gothic arch* on the tracing plate of the mandibular (or maxillary) bite plate. The intersection of the marked lines derived from the horizontal mandibular excursions indicates the centric horizontal relationship (Figs 8-12 and 8-13). The point of intersection lies about 1 mm in front of the arrowhead. Using the facebow and Gothic arch tracing technique, the precise position of the mandible relative to the joint points can be established and thus transferred to the articulator. The bite plate has a firm base that matches the dimensions of the denture base. The occlusion rims are placed exactly on the center of the alveolar ridge and are roughly 10 mm wide by 10 mm high. The exact height depends on the position of the occlusal plane. For instance, the mandibular occlusion rim—measured from the deepest point in the fornix (next to the labial frenum)—will be between 18 and 20 mm high, follow the occlusal plane, and pass through the upper third of the alveolar tubercle of the mandible. The maxillary occlusion rim extends from the deepest point of the fornix (next to the labial frenum) 20 to 22 mm up to the occlusal plane.

Interocclusal registration is intended to determine the relationship of the mandible to the maxilla and the joints and to provide guidance for eventual tooth setup. For this purpose, the maxillary occlusion rim to beyond the canine position is padded up to about 7 mm before the midline of the papilla, corresponding to the contour of the vertical anterior arch, until normal lip volume is achieved with wrinkles smoothed out.

The markings on the occlusion rims are also intended to provide pointers for tooth setup and tooth proportions (Fig 8-14):

- The midline is based on the middle of the face and indicates the middle of the dental arch.
- The occlusal plane runs parallel to the pupil line and Camper plane, or it is marked as the lip closure line.
- The mandibular incisal point arises as the intersection point between the midline and lip closure line and provides fixation for the incisal pin on articulators.
- The smile line is marked as the position of the upper lip when smiling or maximum raising of the upper lip. The length of the teeth is deduced from the lip closure line and smile line.

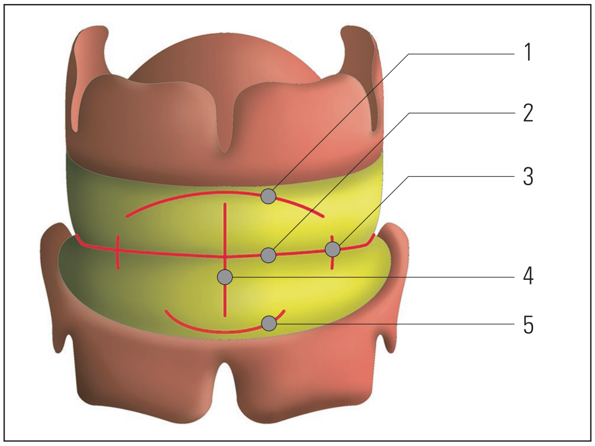


Fig 8-14 After occlusal registration, the operator can make the following markings to indicate tooth shape, tooth size, and position: *(1)* Smile line: The upper lip raised when laughing, the smile line, and the occlusal plane establish the tooth length. *(2)* Position of the occlusal plane (lip closure line). *(3)* The canine points, labial angle points, and midline points determine the tooth width. *(4)* Midline: The midline of the face is not necessarily the same as the midline of the jaw. *(5)* The lower smile line or nasal base line indicates the position of the central to the lateral incisors and establishes the length of the mandibular teeth.

- The canine points or labial angle points for determining tooth width are obtained by transferring the extension line of the width of the wings of the nose to the occlusion rims or by indicating the position of the angle of the mouth.
- The lower lip line is obtained with the mouth relaxed and open. This line may indicate the path of the maxillary incisal edges. The base of the nose line is often traced as well for this purpose.

Tooth Setup for Complete Dentures

A number of orientation guides and measures are available for reconstructing the positions of the teeth (Fig 8-15), which dental technicians must be familiar with and able to use. The descriptive models of the dental arches in a normal dentition are generally valid pointers to the position of teeth. They provide guidance for reconstructing the inclinations of axis and dental arch forms. The dental arch forms are parabolic in the mandible and ellipsoid in the maxilla. The occlusion follows the antagonist rule, an overjet being formed from overlap and overbite of the anterior teeth, and the anterior teeth forming the vertical anterior dental arch. The Bonwill circle, Bonwill tangent, and Pound lines can be used when shaping the dental arch of the mandible. The maxillary arch shows the premolar tangent.

Dentists' instructions on tooth positions are the markings on the occlusion rims that are placed during interocclusal registration. In addition, anatomical casts of the original position of the teeth or photographs of the patient may be used. Notes on the patient's physiognomy, from which individual tooth positions may be deduced, may also be provided.

Measures are taken to ensure that the static positional stability of complete dentures takes into account the position of the teeth relative to the center of the alveolar ridge, denture body height, tooth position within the compensating curves for all-round sliding contact, and balance of the tone of tongue and cheek.

Findings of model analysis are the link between anatomical fixed points and the position of teeth. They provide a symmetric grid of static lines by which the tooth positions are aligned. Tooth position instructions to take account of phonetics and esthetics can also be used.

The setup for a complete denture is done in an average-value articulator, in which the basic mandibular movements are possible. Setup in a fully adjustable simulator of masticatory movements requires individual surveying of condylar paths and cranium-related interocclusal registration for adjusting the models.

Setup in an average-value articulator after average-value adjustment of the models in the articulator can be conclusively legitimized: In most clinical cases for which a complete denture is to be prepared, there is extensive pathologic deformation

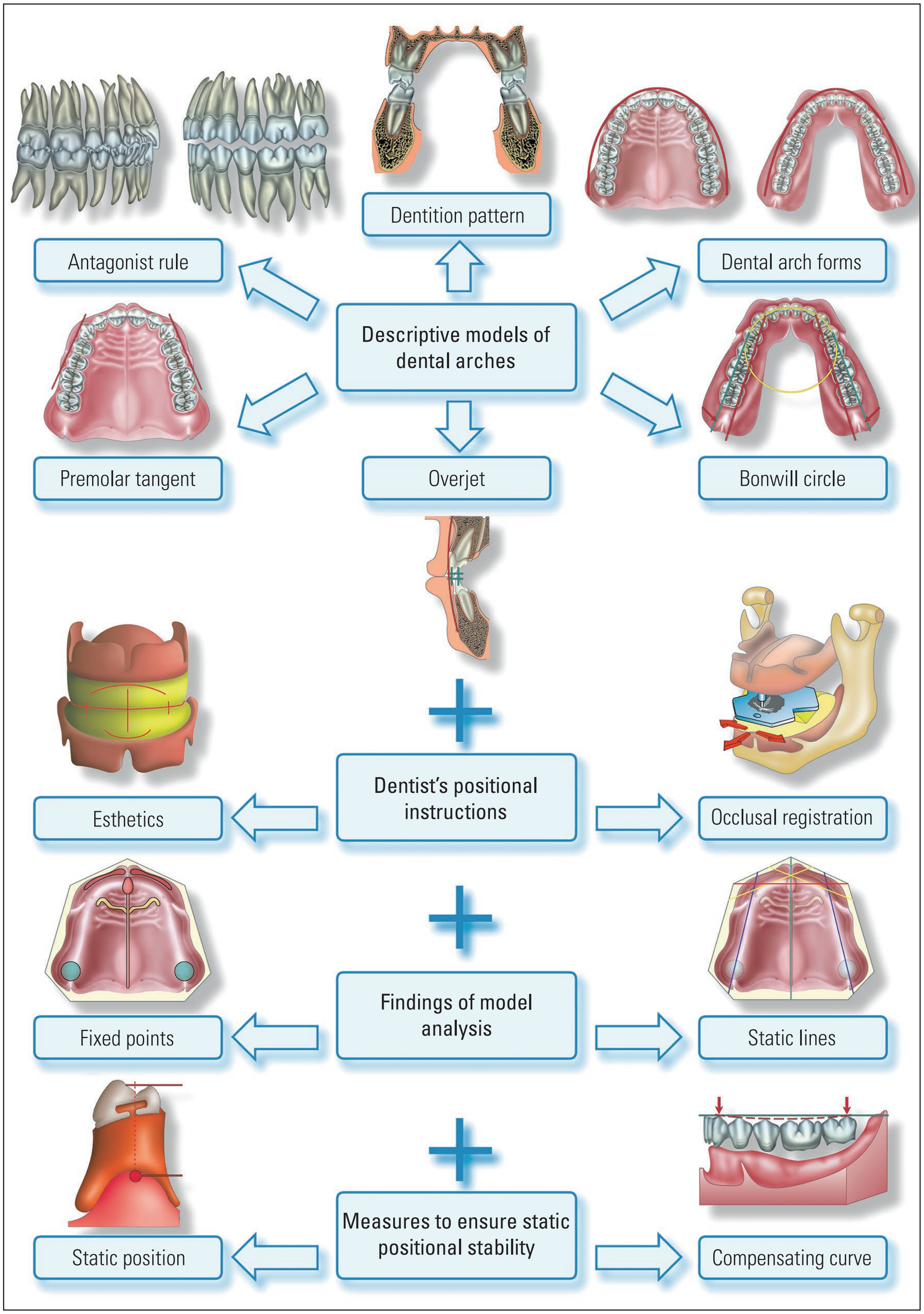


Fig 8-15 Range of orientation possibilities.

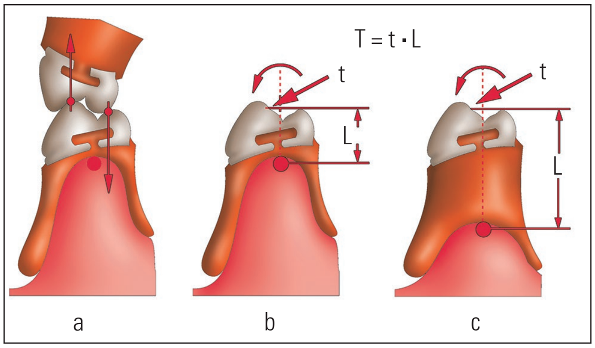


Fig 8-16 The statics of a complete denture are determined by the state of shrinkage of the alveolar ridges: *(a)* Where the ridges are well developed, even loading occurs in centric occlusion. *(b)* On transverse loading (t), the denture body acts as a lever arm (L) so that torque (T) tips the denture. *(c)* If the ridges are severely atrophied, the lever arm is longer because of the height of the denture body, and the torque is correspondingly greater. The vertical dimension of occlusion has a direct influence on denture stability.

of the TMJs, which can be treated by a standardized complete denture (ie, fabricated according to average values).

Setup aid is provided by templates (calottes) in which the radii of curvature are laid out according to average condylar paths. These average-value templates can be adjusted in an average-value articulator to the height of the occlusal plane to enable the mandibular teeth to be set up within compensating curves.

For template setup, the mandibular posterior teeth are placed with their cusp tips on the template so that the occlusal surfaces lie within the sagittal and transverse compensating curves. The exception is the mandibular first premolar, which only contacts the buccal cusp of the calotte. When the maxillary dentition is opposed according to the antagonist rule, an occlusal field may arise that exhibits all-round sliding contact during translative movements.

Template systems are available with templates showing different curves that represent different condylar path inclinations. Matching sets of posterior teeth are supplied in which slopes of cusp surfaces are referenced to different joint values.

Statics of Denture Design

A complete denture lies on the jaw without mechanical anchorage so it can be moved on the tissue foundation while functioning. Denture statics involve constructing the denture so that it lies evenly on the whole alveolar ridge under loading as well as during chewing and speaking. It would be statically unsatisfactory if the denture moved to and fro on the alveolar ridge and were tipped off during functioning. The static relationships affecting a denture are influenced by the following factors:

- The denture-bearing area of the jaws
- The height of the denture body
- Tooth position relative to the alveolar ridge (see Fig 8-17)
- Tooth position relative to the occlusal plane

The denture-bearing area influences denture statics in the described way: A minimally atrophied, firm alveolar ridge with adequate mechanical retentions is favorable; a severely atrophied jaw whose connective tissue support forms a mobile, flabby ridge without undercut retention areas is unfavorable. The form of shrinkage and progression of that shrinkage also influence the size of the denture body.

A denture body acts like a lever arm: The more the alveolar ridges have been resorbed, the taller the denture body will be. Hence, the denture body as a lever arm for occlusally acting forces becomes longer, and the resulting torque becomes greater (Fig 8-16). The conclusion is to keep the denture body flat, which can only be achieved by shortening the vertical dimension of occlusion.

The tooth position relative to the center of the alveolar ridge has a significant influence on denture statics (Fig 8-17). On one-sided masticatory loading, as a result of the tooth being positioned on the ridge center, the denture can be either pressed down on the opposite side or levered off. Three static states are identified: neutral, unstable, and stable tooth position.

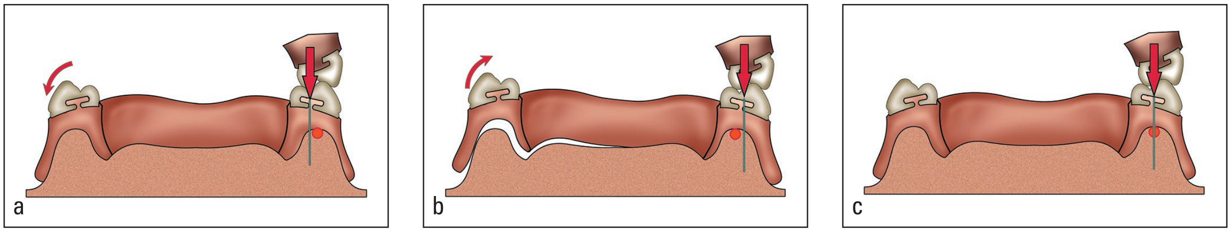


Fig 8-17 The position of the artificial teeth relative to the ridge midline has a decisive influence on the statics of a complete denture: *(a)* The stable state denotes the position of the artificial tooth inside the ridge line; here loading causes downward pressure on the opposite side because of the eccentric tooth position. *(b)* In the unstable state, the tooth is positioned outside the ridge line, which leads to the denture being lifted off on the opposite side. *(c)* The neutral state refers to the tooth position over the middle of the alveolar ridge; here only the loaded side is pressed on.

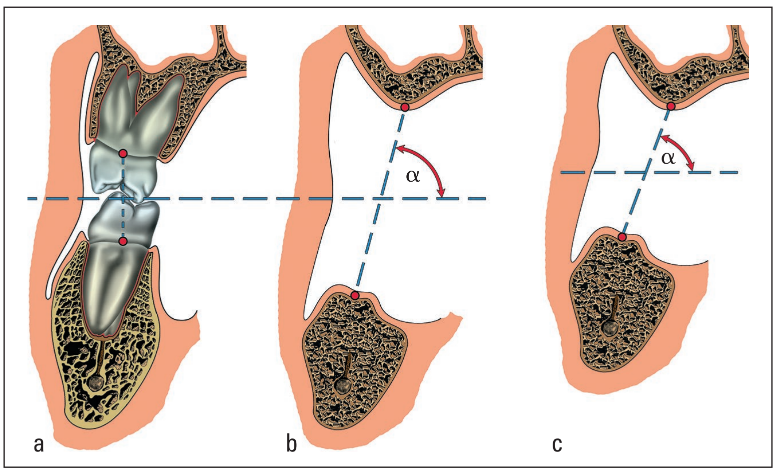


Fig 8-18 Arranging the teeth in a statically favorable position is difficult because the following anatomical features have to be taken into account: *(a)* In a fully dentate dentition, the ridge lines lie almost on top of each other. *(b)* After the jaws have shrunk, the ridge lines are displaced relative to each other, depending on how advanced the shrinkage is. The interalveolar line is inclined toward the occlusal plane at an angle α. *(c)* The inclination of the interalveolar line increases if the vertical dimension of occlusion is altered. If the teeth are arranged inside the interalveolar line, they will be displaced toward the middle of the ridge.

- *Neutral tooth position (neutral state)* shows the arrangement of the artificial teeth on the center of the alveolar ridge. On functioning, the denture is initially pressed only onto the side of the loading.
- *Unstable tooth position (unstable state)* exists if the teeth are located outside the middle of the alveolar ridge. On masticatory pressure, the denture is levered off on the opposite side.
- *Stable tooth position (stable state)* arises when the artificial teeth are positioned lingually relative to the ridge midline. A torque then acts on the denture body around a pivot on the middle of the alveolar ridge. The denture is pressed onto the opposite side by the masticatory forces. The stable tooth position guarantees secure retention of the complete denture and produces even pressure distribution to the underlying tissue.

The stable tooth position has two serious drawbacks. First, the normal processes of shrinkage widen the ridge line in the mandible while narrowing it in the maxilla. As a result, the ridge lines no longer lie one on top of each other (Fig 8-18). If the maxillary posterior teeth are now set up slightly inside the ridge line, the mandibular posterior teeth will lie well inside the ridge line if they are arranged in normal occlusion. They stand far more lingually than the natural teeth did previously. This means unacceptably severe crowding of the tongue; the patient would be constantly biting his or her tongue and having pronunciation problems.

Second, if the maxillary anterior teeth are set up in the stable position inside the ridge line, lip support is lost and the patient's facial expression is greatly altered—as in an edentulous senile face.

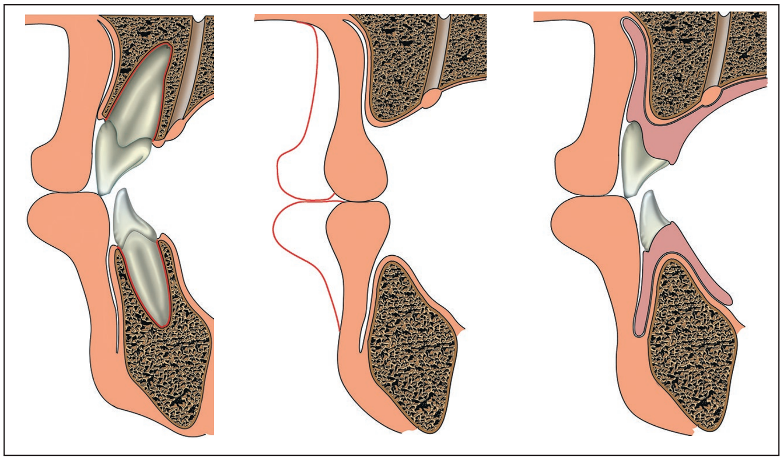


Fig 8-19 The interalveolar line can be used as a reference line for setting up teeth in the posterior region. If the teeth are arranged in normal occlusion, the mandibular central incisors are in a stable position and the maxillary central incisors are in an unstable position. If the mandibular teeth are moved closer to the middle of the alveolar ridge, taking into account the space required for the tongue, the change to the static relationships is extremely disadvantageous for the maxillary teeth.

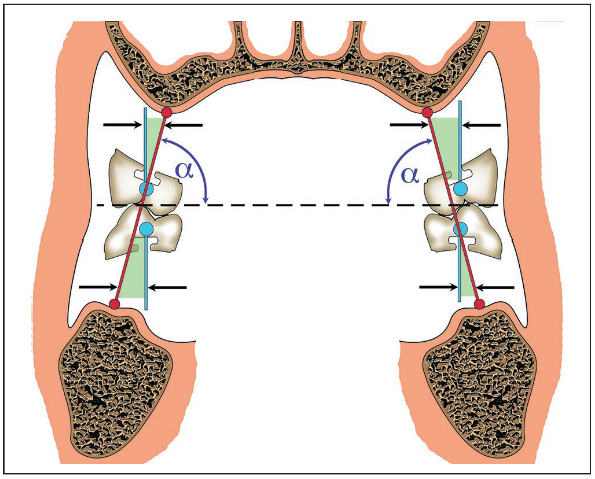


Fig 8-20 Static relationships in severely atrophied alveolar ridges can be improved by setting up the posterior teeth in a crossbite position, moving the mandibular teeth upward and the maxillary teeth downward in a crosswise fashion so that the left teeth are on the right side and the right teeth on the left side. The space for the tongue is enlarged, and the teeth are moved toward the middle of the alveolar ridge.

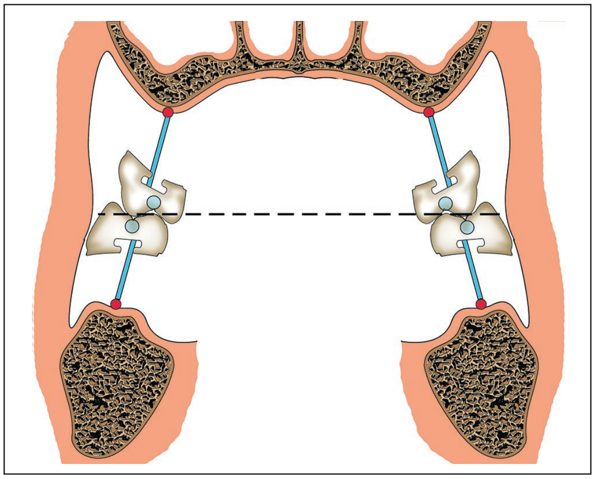


Fig 8-21 If the alveolar ridges shrink in the direction of inclination because the teeth are missing, this also has repercussions for lip volume. In the normal physiologic rest position of the mandible, the lips attain their natural fullness in a fully dentate jaw because of support from the maxillary incisors. If the mandible is brought into this position in an edentulous situation, the mouth will cave in. Thus, the anterior teeth must be brought into the original position. To do this, the maxillary anterior teeth are positioned anterior to the shrunken alveolar ridge.

Therefore, the maxillary anterior teeth are placed labially in front of the middle of the alveolar ridge for esthetic reasons.

The posterior teeth in the maxilla are positioned in the neutral position for functional reasons, thereby placing the mandibular posterior teeth in normal occlusion in a minimally stable tooth position (Fig 8-19). If atrophy is very advanced, however, the neutral tooth position in the maxilla can give rise to an extremely stable tooth position in the area of the mandibular posterior teeth, with the aforementioned drawback of crowding of the tongue.

Crossbite position becomes necessary in shrunken dental arches if the maxillary ridge is extremely narrowed and the mandibular ridge is widened vestibularly (Figs 8-20 and 8-21). This arrangement is used when the angle between the interalveolar line (the vertical line connecting the ridge midlines) and the occlusal plane is smaller than 80

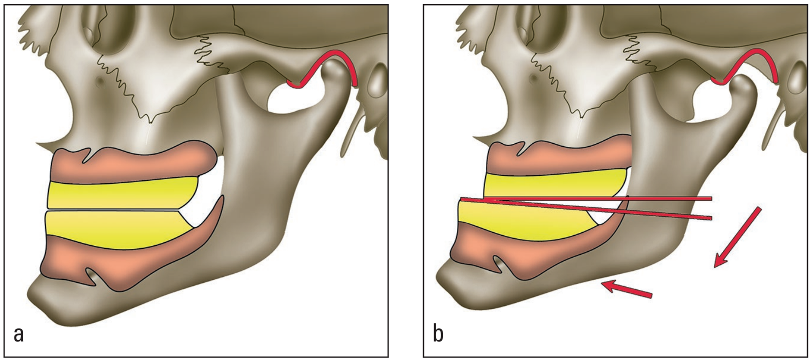


Fig 8-22 The Christensen phenomenon occurs when two occlusion rims arranged in parallel in the occlusal plane *(a)* are meant to be kept in contact during protrusive movement, but instead a large gap is created in the posterior region while the anterior teeth remain in contact *(b)*.

degrees. Practically speaking, the maxillary left incisors beyond the second premolars are moved down and to the right and reversed, and the maxillary right incisors are similarly placed down and to the left and reversed. The posterior teeth are swapped crosswise.

Position of teeth relative to the occlusal plane

The position of teeth relative to the occlusal plane also influences the statics of a complete denture, which can be depicted in relation to the Christensen phenomenon (Fig 8-22) and Bennett side shift.

On lateral movements of the mandible, the idling condyle on the nonworking side drifts down and forward on its condylar path, while the working-side condyle rotates around its vertical axis and slips outward and often backward in the direction of the lateral movement. This lateral movement of the condyle is the Bennett side shift (or laterotrusion). In a normal dentition, the posterior teeth on the working side are firmly pressed together while the posterior teeth on the nonworking side gape. This is the transverse Christensen phenomenon (Fig 8-23).

On protrusive excursions, there is a gap between the two rows of teeth while the anterior teeth are in incisal contact. This sagittal Christensen phenomenon arises because, during protrusive movements, the condyles on both sides slide downward and forward on the condylar paths and the mandible is dorsally lowered. In normal occlusion, the separation into working and nonworking sides is an expression of the functional orientation of the rows of teeth in the form of sagittal and transverse occlusal curves, whereby faulty contacts in dynamic occlusion are avoided.

Preparing plano-parallel occlusion rims for interocclusal registration at the level of the occlusal plane will give rise to an extreme Christensen phenomenon. If the teeth are set up parallel to the occlusal plane, the rows of teeth will gape on functional chewing movements; this results in the denture tilting and lifting off.

All-round sliding contact of all the teeth during lateral and protrusive movements would be advantageous because the denture would be repeatedly stabilized against possible tipping off (Fig 8-24). How can such all-round sliding contact be achieved?

In the normal dentition, complete and firm occlusal contact between posterior teeth occurs during a lateral movement on the working side, while anterior teeth and the opposite side remain without contact. This firm and complete occlusal contact of the posterior teeth on the working side comes about because the occlusal surfaces are inclined inside a gently arched sagittal and transverse occlusal curve (Fig 8-25); on the opposite side, however, these occlusal curves prevent tooth contact. It is worth checking whether or not the shape of the occlusal curves might be exploited to gain all-round sliding contact with complete dentures because full occlusal contact or selective tooth contact arises at least on the working side because of the occlusal curves.

With strongly arched curves, all-round sliding contact can be achieved, and the Christensen phe-

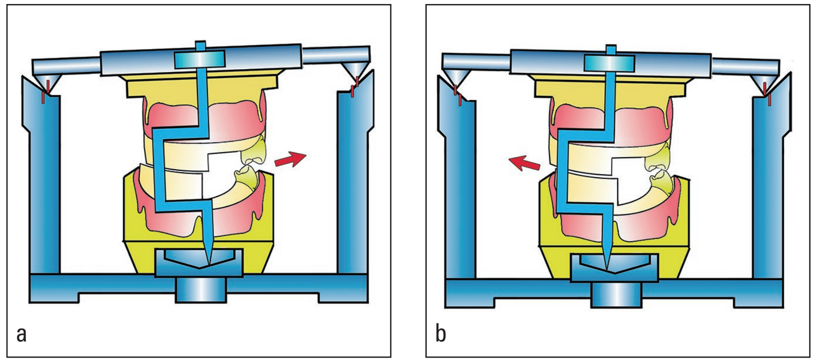


Fig 8-23 During lateral movements and the transverse Christensen phenomenon, the Bennett movement also influences the curvature of the compensating curve. The teeth should be positioned so that tooth contact exists in the balancing position *(a)* and the working position *(b)*.

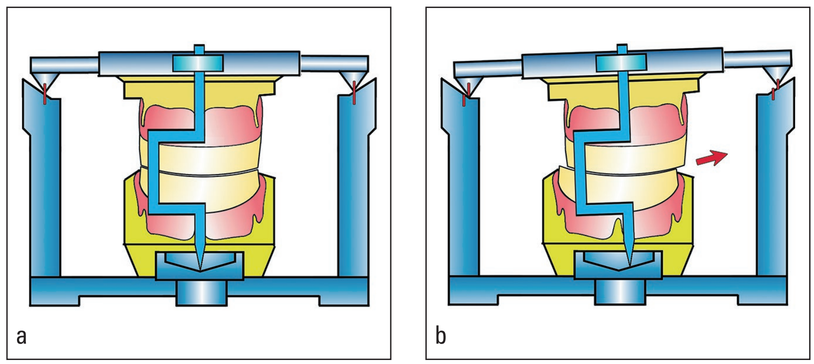


Fig 8-24 All-round sliding contact can be ensured in the transverse plane by means of a compensating curve arched caudally. From the central articulator position *(a)*, the maxilla is moved relative to the mandible to the side *(b)* so that the calotte-shaped, curved occlusion rims move against each other in sliding contact.

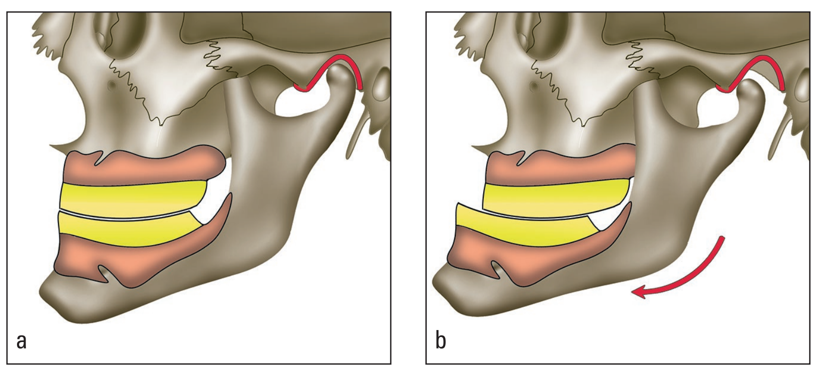


Fig 8-25 The occlusal plane can take on a curved shape *(a)*, which favors sliding contact on mandibular excursions *(b)*. The arrangement of the occlusal curves in space may result in a calotte shape.

nomenon and the positional defect of the Bennett side shift can be compensated for. This is why these curves are called *compensating curves*. They have basically the same shape as the familiar occlusal curves but are more strongly arched.

Disturbances in the occlusal plane move the denture against the mucosal base, which may accelerate resorption of the bony foundation. For instance, a one-sided increase in the vertical dimension of occlusion—if it is not remedied—will cause that side to be particularly stressed via reflex movements, which may lead to deformation of the TMJ.

In this context, a similar aspect applies to guidance from groups of teeth, for example canine guidance in the case of complete dentures. The maxillary canine—including those in complete dentures—can guide the mandibular denture into centric occlusion but only in interaction with the cusps of the posterior teeth (Fig 8-26). If necessary, the canine must be ground back to allow for the individual movement pattern.

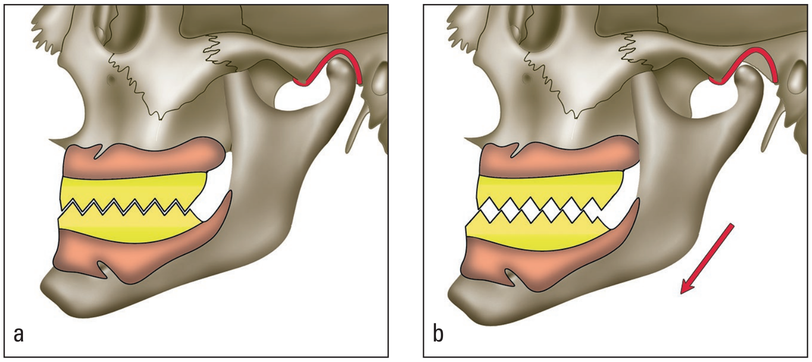


Fig 8-26 If teeth whose occlusal surfaces have slanting cusps *(a)* are mounted, these slanting cusp surfaces will find sliding contact on protrusion *(b)* while the mandible can be moved without tilting.

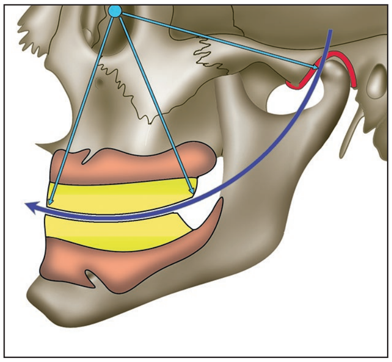


Fig 8-27 Increasing the curvature of the compensating curves in the sagittal plane so that the condyles and teeth move on a shared arc of a circle is in line with Ferdinand Graf von Spee's diagrams. The curve of Spee (or anteroposterior curve), which is named for him, is often used as a synonym for the occlusal and compensating curves. The curve of Spee is a special type of sagittal occlusal curve in that occlusal curves typically follow a flatter course. The compensating curves are also not so sharply arched that extension of the curves touches the condyles. More importantly, the condylar path—as a guide variable for the condyle—is not arched in the path of the curve of Spee.

In summary, the following may be concluded regarding denture statics: The artificial teeth should be set up over the middle of the alveolar ridge, the mandibular posterior teeth may be placed slightly inside the ridge line, and the maxillary anterior teeth must be placed in the original tooth position (hence anterior to the alveolar ridge) for esthetic reasons and to aid pronunciation. To secure denture statics, the posterior teeth should be set up inside the sagittal and transverse compensating curves (Fig 8-27). In the process, the denture body should be kept as flat as possible. The artificial teeth should exhibit a statically stable form to avoid transferring horizontal shearing forces to the denture.

Artificial Teeth for Complete Dentures

Modern artificial teeth are precisely matched to their natural counterparts in terms of shape and color. This acknowledges the fact that the natural tooth represents the optimum functional form with which the functions of the masticatory system can be best performed. These tooth shapes, reproduced according to the natural model, are in themselves stable and more functionally reliable (Fig 8-28). For the anterior region, a vast array of different tooth shapes are available, enabling individual restoration of any possible case.

Posterior teeth are supplied in a few selected shapes and sizes. The occlusal surfaces are anatomically precisely shaped, which makes it easy to locate their position in centric occlusion and produces a favorable esthetic impression. Some manufacturers include a certain theory of occlusion; for example, the Physiodens from Vita has simultaneous and uniform point contacts with occlusal clearances.

Abrasion surfaces on the occlusal surfaces are re-created in a few forms. These surfaces are related to condylar paths based on variable values. This makes setting up the teeth easier, based partly on average values but also on individual joint values. Using these teeth, problem-free setup is

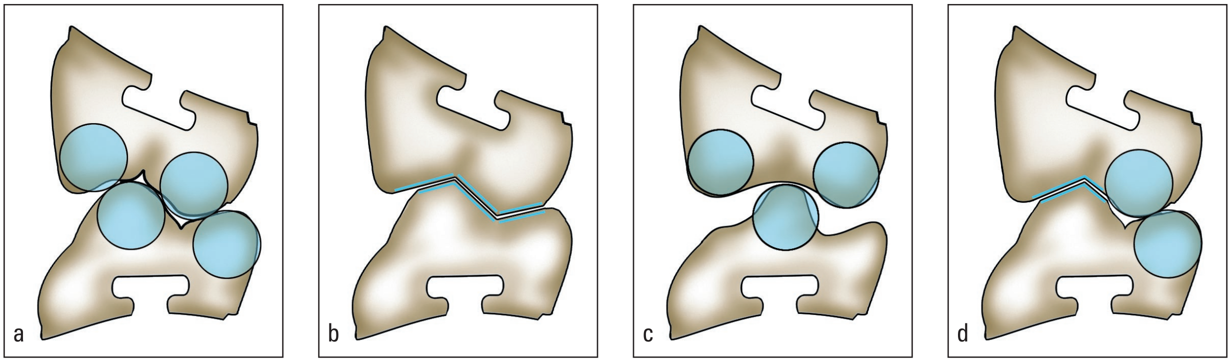


Fig 8-28 Artificial posterior teeth differ from natural teeth, especially in terms of static suitability. Manufacturers usually offer a smaller form that meets the special static demands placed on a complete denture. The process starts with replication of punctiform occlusal contacts of natural tooth shapes *(a)* and moves on to pronounced abrasion of occlusal surfaces with variably inclined cusps, which are derived from average condylar paths *(b).* Modification into a trough-shaped tooth in which a pestle-like occlusal surface engages *(c)* then leads to a different form in which the condylar path–related parts of the abrasion surface are combined with mortar-and-pestle sections *(d).*

Fig 8-29 Modern posterior teeth have cusp slopes that relate to different types of occlusion, as is the case here with the posterior tooth from Ivoclar Vivadent. The cusp groove angles relate to the condylar forward glide path; there is a difference between deep bite (approximately 29 degrees), normal occlusion (26 degrees), and crossbite (25 degrees). The cusp surfaces have punctiform contacts.

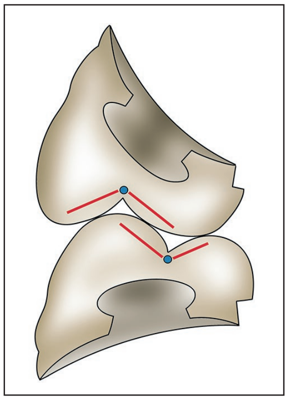
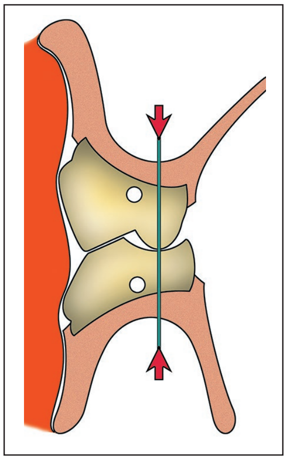


Fig 8-30 In the case of Gerber Condyloform molars and premolars, the maxillary posterior teeth have a palatal occluding cusp in the form of a pestle, which engages in the mortar-like occlusal surface of the mandibular teeth; these cusps involved in chewing are positioned inside the middle of the alveolar ridge. The vestibular cusps have a stabilizing effect on chewing; the bulbous buccal tooth surfaces have cheek contact.



possible in multipoint contact during functional chewing movements.

Variations from the natural tooth shape can be found in the ranges of posterior teeth supplied by certain manufacturers (Fig 8-29). These are usually modifications of the original shape down to statically more favorable reduced forms. During the development of artificial tooth forms, attempts have been made to diverge from the natural functional form and develop greatly reduced forms that are intended to support the statics of the denture.

Hiltebrandt's mortar-and-pestle tooth is the most successful modification of the natural tooth shape, which was further developed into a differentiated form such as the Condyloform teeth developed by Gerber. According to this principle of form, the punctiform occlusal contacts of natural teeth are simplified into a flat mortar-and-pestle contact in which the contact surfaces are displaced lingually and the vestibular contacts are designed merely as supporting and balancing contacts to position each individual posterior tooth so that it is statically stable (Fig 8-30); no balancing contact is required on the opposite side.

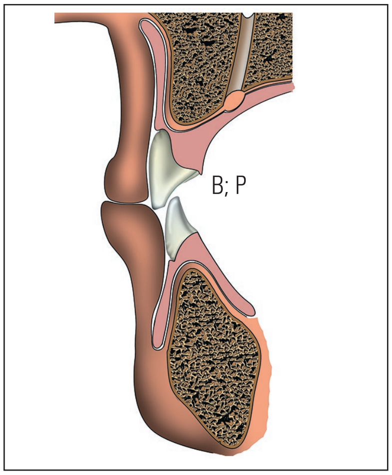


Fig 8-31 Bilabial sounds (B and P) are impeded if the lip position is altered by incorrect tooth positioning. If the anterior teeth are placed too far lingually, the lips will cave in and the consonants will be poorly formed.

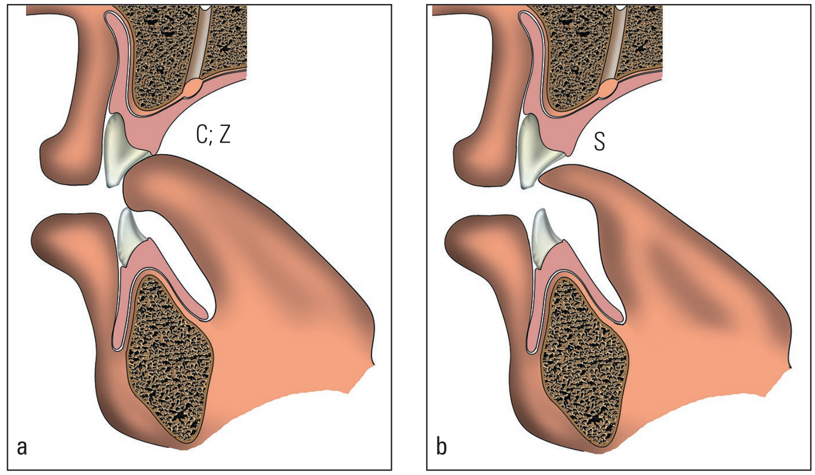


Fig 8-32 Apart from the position of the teeth, the shape of the denture base also influences pronunciation. In the case of large faults, malpositioning of teeth, and incorrect denture shape, the patient may never get used to the denture and may always retain a speech impediment. The tongue's position relative to the anterior teeth when pronouncing various consonants shows the area in which the most common problems occur due to denture design: *(a)* The voiced consonants C and Z are formed when the tip of the tongue is pressed against the maxillary anterior teeth and lies close to the mandibular incisal edges. *(b)* S also arises as a fricative when air is squeezed through the narrow gap formed by the tip of the tongue and the palatal surfaces of the maxillary incisors. Incorrect tooth positions often result in lisping.

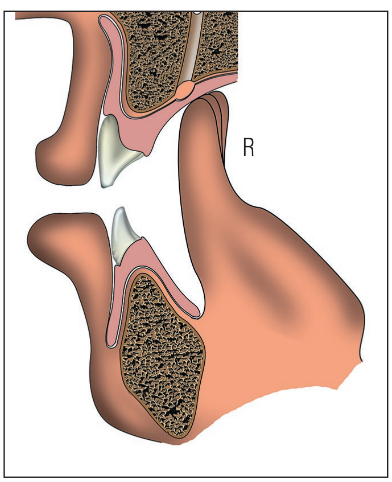


Fig 8-33 A forward rolled R is formed when the tongue is moved behind the anterior teeth in a powerful tremolo and produces a vibrating plosive sound. Errors in tooth position and incorrect denture base shapes impede the formation of this consonant.

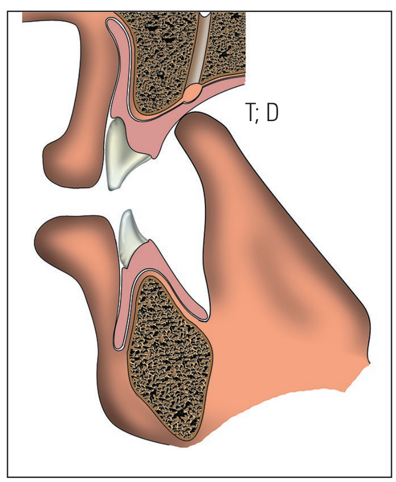


Fig 8-34 The tongue lies on the palatal plate directly behind the anterior teeth when pronouncing T and D. If the base is too thick or angular in this area, the tongue will shift and T or D will become a G.

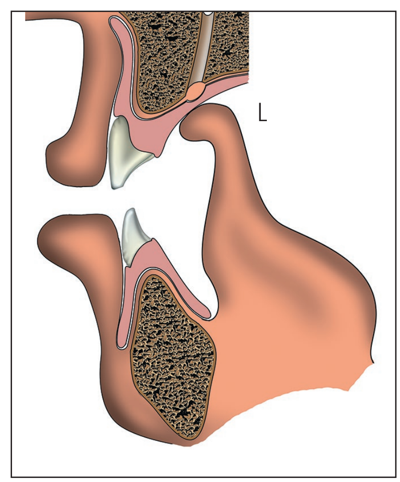


Fig 8-35 The same applies to the consonant L, which is formed in the same place, with the tongue also lying against the premolar region. Replication of the plicae palatinae will make it easier to orient the tongue.

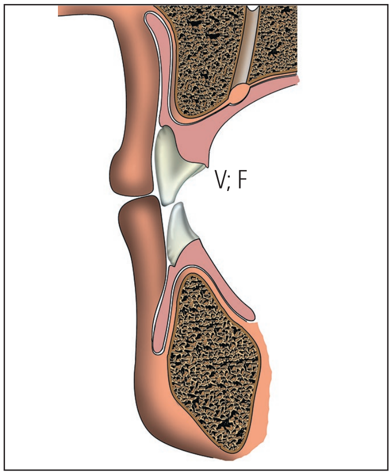


Fig 8-36 If the maxillary anterior teeth are too short or the occlusal plane is displaced, the weak fricatives (V and F) are distorted into a blurred glottal stop.

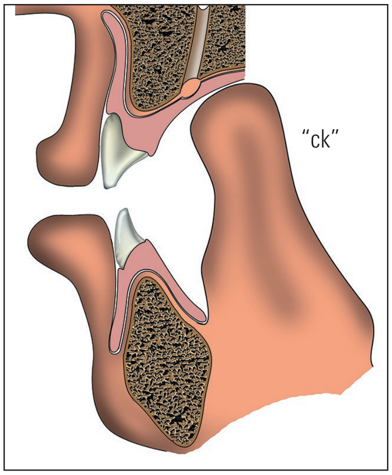


Fig 8-37 The "ck" consonant group is palatally formed. This fricative is impeded if the dental arch is too narrow.

Position of Teeth and Phonetics

The unstable tooth position must always be chosen for the maxillary anterior teeth for esthetic reasons. Restoring the natural lip volume is the primary aim so that the patient is not identifiable as a denture wearer. However, the functional importance of the natural position of the maxillary anterior teeth is also closely linked to the patient's speech. The formation of sounds is a complex interplay between tongue, lips, and teeth. Most consonants are influenced by the teeth and their position during the sound. It is not uncommon for patients to complain of having difficulty forming certain sounds with their new teeth.

Bilabial sounds, such as B, P, and M, become possible on normal lip closure (Fig 8-31). The correct position of the anterior teeth and hence the correct lip position have functional significance for pronunciation. If the vertical dimension of occlusion is too big, lip closure is prevented; if the maxillary anterior teeth are placed too far palatal, the lips will cave inward. In both cases, this leads to weak formation of bilabial sounds.

Sibilants (dentoalveolar sounds), such as C, S, and Z, are formed when the tongue is pressed against the palatal surfaces of the maxillary anterior teeth and the anterior palate. Gaps between the teeth lead to spluttering; if the teeth are tipped in the oral direction or if the transition from denture base to the teeth is too thick or worked too smoothly, the patient will lisp (Fig 8-32). Reproduced plicae palatinae provide orientation for the tongue (Fig 8-33).

Glottal stops (palatoalveolar sounds), such as D, T, or L, arise when the tongue is pressed onto the palate behind the teeth. If the teeth are tipped orally or placed too far lingual, a glottal stop is not possible (G instead of D); a thick base will press the tongue downward and prevent pronunciation of these sounds (Figs 8-34 and 8-35).

Fricatives (labiodental sounds), such as V and F, arise when the lower lip contacts the maxillary incisal edges. If the maxillary anterior teeth are too short, the sounds V and F will be distorted into B (Fig 8-36).

Postpalatal sounds, such as J, K, and G, arise when the tongue is supported on the posterior teeth. If the dental arch is too narrow, this will impede tongue movements (Fig 8-37). If the transition from the denture base to the teeth is too rough, too angular, or worked too thickly, the space for the tongue will be impeded and narrowed.

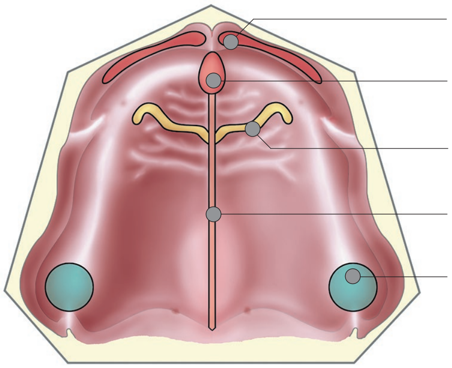


Fig 8-38 The reference points of model analysis must be present on each dental arch, must always be located at the same place and be unaffected by resorptive atrophy of the jaws, and must be clearly visible and clearly related to tooth position. The figure shows the fixed points in model analysis.

Model Analysis of Edentulous Jaws

Points and lines can be fixed on the dental arches, allowing individual tooth positions relative to anatomical landmarks to be located later. The purpose of model analysis is to locate and trace points on the edentulous jaws that remain unaffected by the normal atrophy that occurs after tooth loss. From these, a symmetric grid is created from static lines, and this grid is used when setting up the teeth and shaping the dental arches.

Statics analyses have shown the relationship between these points and normal tooth position. Based on these lines and fixed points, the original tooth position can be reconstructed. The setup for complete dentures can then be clarified with the aid of topographic features from the description of the normal dentition. The position and form of the model analysis fixed points are presented here; their references to natural tooth position are explained, and other prosthetic references are identified.

Model analysis of the maxilla

Figure 8-38 shows the fixed points in model analysis of the maxilla. The median palatine suture fixes the middle of the jaw or the model midline. The symmetry axis of the maxillary dental arch along the median palatine raphe is generally the first to be traced on the model. On this midline, the labial frenum is located in the anterior vestibular area, while the dorsal end is formed by the posterior nasal spine of the palatine bone.

The incisive papilla appears to be labially displaced in an edentulous jaw because the alveolar ridge is resorbed in the palatal direction. The raphe-papillary cross-line runs transversally through the middle of the incisive papilla (about 2 mm from the tip backward) through the canine tips and in the fully dentate jaw touches the lingual edges of the maxillary central incisors. The labial contours of the incisors are located approximately 7 mm labially.

The first pair of large plicae palatinae end about 2 mm anterior to the palatal edges of the maxillary canines. In an edentulous jaw, the canine points can therefore be fixed on the alveolar ridges (ie, approximately 5 mm from the plicae palatinae toward the raphe-papillary cross-line) (Fig 8-39). This value is variable, depending on the extent of ridge atrophy.

The maxillary tuberosity marks the dorsal end of the alveolar ridge, which is not resorbed after tooth loss. The middle of the tuberosity is indicated by the attachment of the pterygomandibular raphe.

The centers of alveolar ridges in the posterior region are identified by the canine points and the midpoints of the maxillary cusps. The middle of the ridge in the anterior region can be drawn from the canine point to the tip of the incisive papilla.

Model analysis of the maxilla therefore encompasses the following steps:

1. Mark all the fixed points (incisive papilla, first large pair of plicae palatinae, median palatine suture, and midline of the maxillary tuberosity).

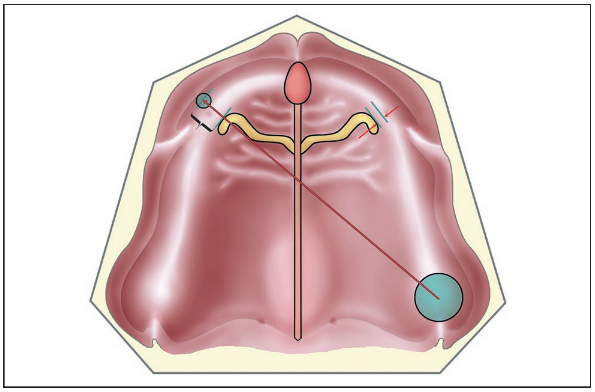


Fig 8-39 The canine point is constructed with the aid of model analysis fixed points. The model midline is first drawn through the median palatine raphe; then the maxillary tuberosity and the first pair of large plicae palatinae (which can clearly be seen) are selected. A diagonal line is drawn from the center of the maxillary tuberosity over the tip of the opposing first large plica. The canine point lies on this line approximately 5 mm vestibularly. The found canine point is reflected over the axis of symmetry.

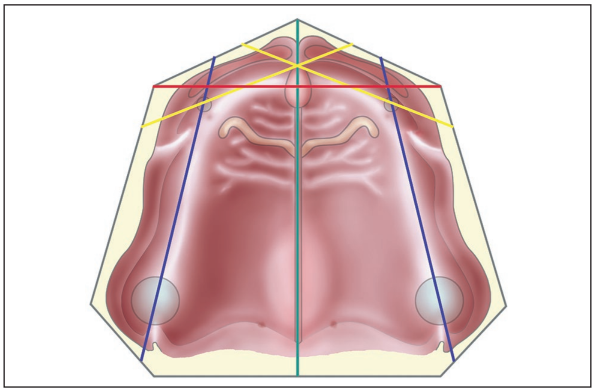


Fig 8-40 The static lines through the model analysis fixed points are the model midline over the median palatine raphe, the raphe-papillary cross-line through the middle of the papilla, the midlines of the anterior alveolar ridges through the canine points and to the tip of the papilla, and the midlines of the posterior alveolar ridges through the center of the maxillary tuberosities and the canine points.

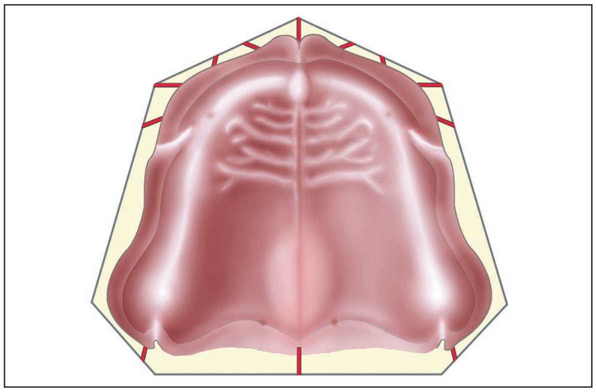


Fig 8-41 The static lines are carried over to the model edges so they can still provide orientation during setup on a nontransparent base. Twelve markings must appear on the edge of the maxillary model, and these produce a symmetric grid.

2. Mark the middle of the model and extend the tracing onto the edge of the model.
3. The canine point must be constructed: Draw a diagonal from the midline of the maxillary tuberosity through the tip of the opposing first large plica palatinae. To do this, select the fixed points that are clearly visible. To obtain a symmetric grid, reflect the clear fixed points and the found canine point over the axis of symmetry.
4. Trace the centers of the alveolar ridges in the posterior and anterior region and extend the tracing onto the model edges.
5. Draw the raphe-papillary cross-line and extend it to the model edges. On the model edges, this produces a typical image of model analysis markings.

Application of model analysis findings

The static reference lines (model midlines, centers of ridges) as well as the position points for the canines and maxillary central incisors are found by means of model analysis (Figs 8-40 and 8-41); this also establishes the position of the maxillary lateral incisors. The position of the posterior teeth is located via the center of the alveolar ridge. The lines of the central developmental grooves of the posterior teeth lie over the middle of the ridge. To ensure that the mouth does not look overfull and that the buccal corridor is created, the premolars are placed inside the premolar tangent (ie, the connecting line between the labial marginal ridge of the canine and the mesiobuccal cusp ridge of the first molar).

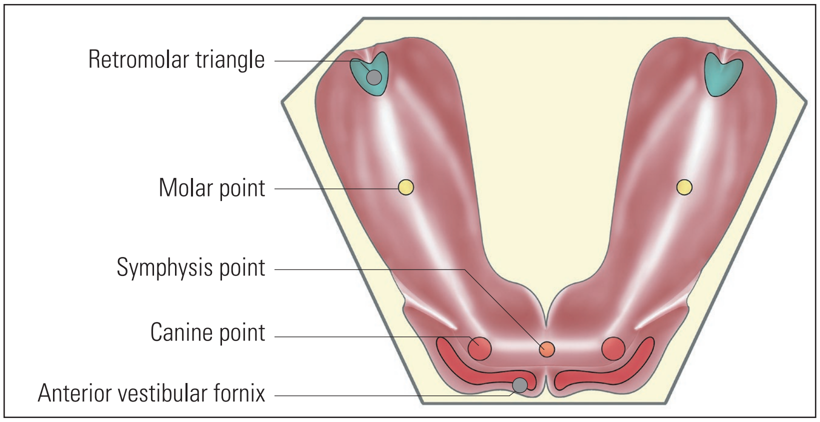


Fig 8-42 The model analysis fixed points on the mandible must have the same quality as those in the maxilla. They must always be present in the same place on each jaw, remain unaffected by resorptive atrophy, be clearly visible, and be clearly related to tooth position. The figure shows the fixed points in a model analysis.

Model analysis of the mandible

Figure 8-42 shows the fixed points in model analysis of the mandible. The retromolar triangle or pad can be used for constructing various static lines. It is not resorbed after tooth loss, so half the height (or the upper third) of the triangle continues to indicate the dorsal position of the occlusal plane. Half the height of the triangle serves in many template setup devices and average-value articulators as a fixed point for the appropriate calibration keys, which are adjusted to the triangles and the mandibular symphysis point.

The symphysis point is located directly on the center of the alveolar ridge and is the equivalent of the mandibular incisal point. (Assuming that the anterior apex of the Bonwill triangle tips downward at the mandibular incisal point after tooth loss, this apex will describe a section of an arc and, after shrinkage of the alveolar ridge, will lie on the middle of the ridge, namely on the symphysis point, without the length of the sides of the Bonwill triangle having changed.) The symphysis point is found on the middle of the alveolar ridge contour where labial and lingual frena attachments can be joined.

The axis of symmetry of the mandibular dental arch or the jaw midline runs through the symphysis point and half the distance of the triangle (Fig 8-43). To put it another way, a triangle is spanned through the centers of the retromolar pads and the symphysis point; its midline drawn through the symphysis point indicates the middle of the model or midline of the jaw.

Canine points on the mandible lie clearly on the corner of the edentulous alveolar ridge, which is resorbed into a trapezoidal basic shape because of its direction of inclination.

The alveolar ridge centers in the posterior region run through the centers of the triangle and the canine points (Fig 8-44). In the anterior region, the center of the ridge runs through the canine points.

Vestibular fornices in the anterior region of the maxilla and mandible are fixed points for the vertical anterior arch, which touches the labial surfaces of the maxillary central incisors; this arc of a circle runs 7 mm away from the middle of the papilla. The labial surfaces of the incisors thus give the upper lip its necessary volume, while the cutting edges of these maxillary teeth support the lower lip.

The inferior vestibular fornix is a reference point for the position of the occlusal plane, which lies about 18 to 20 mm above the deepest point of the vestibular fornix directly next to the labial frenum. In addition, this lowest point of the fornix is used as the approach for some calibration keys.

Molar points can be seen in the posterior region as a clear depression in the region of the mandibular first molar, from where the ridge profile increases very steeply dorsally and relatively gently ventrally. This depression arises because of the natural shape of the dental arch inside the sagittal occlusal curve and is further accentuated by severe resorption of the bone material after loss of the largest posterior tooth.

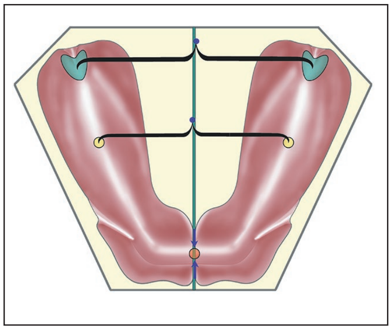


Fig 8-43 The midline of the model has to be constructed in the mandible: The fixed points are first traced, then the distances between the molar points and the retromolar triangles are halved. The midline runs from the symphysis point between these arithmetically averaged points.

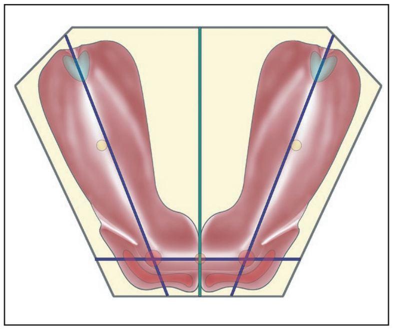


Fig 8-44 The centers of the alveolar ridges run anteriorly between the canine points and posteriorly between the canine points and the middles of the retromolar triangles. The actual ridge contour deviates in a vestibular direction at the molar points. The midlines of the alveolar ridges form a trapezium.

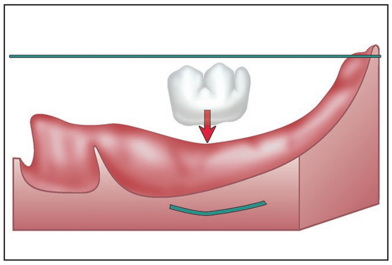


Fig 8-45 The mandibular alveolar ridge shrinks most around the position of the first molar so that the profile of the ridge dips most here from the vestibular view. This point, known as the *molar point*, serves as a reference point for calibration keys in average-value articulators and helps to reconstruct the original tooth position as the mandibular first molar is set up directly above this lowest point.

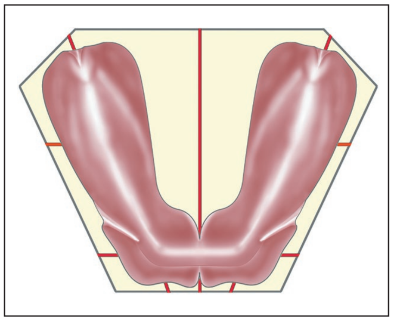


Fig 8-46 In the mandible, the static lines have to be carried over to the model edges so that they can be used for orientation during setup. Ten markings are made, including the position of the first molar, which identifies the deepest point of the alveolar ridge contour.

This deep point in the profile of the alveolar ridge serves as a reference point for calibration keys by the average-value technique in order to align mandibular jaw models in an average-value articulator (Fig 8-45). This also provides a direct reference for reconstructing original tooth positions: the mandibular first molar is set up above this lowest point.

Model analysis of the mandible therefore encompasses the following steps*:*

1. Trace all the model analysis fixed points again (symphysis point, retromolar triangle, and canine points).
2. Construct the model midline and continue to the model edge. To do this, halve the distance of the triangles and draw a connecting line to the symphysis point. The halved distance between the molar points can also be used for locating the midline.
3. Mark the ridge centers in the posterior and anterior region and extend them to the model edges. On the model edges, this again produces the typical picture of the model analysis markings.

Application of model analysis findings

Once again, the static reference lines (model midlines, centers of ridges) as well as the position points for the canines and the first molars are found (Fig 8-46). The posterior teeth lie with their central developmental grooves exactly over the middle of the ridge.

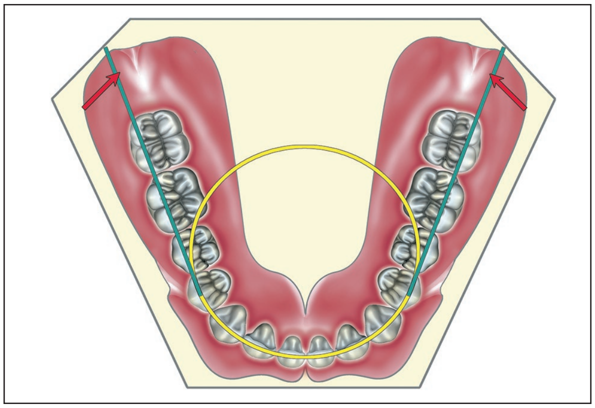


Fig 8-47 The mandibular dental arch can be described by the Bonwill circle *(yellow)*, where the mandibular anterior teeth and the first premolar lie on an arc of the circle. Tangents *(teal)* placed at the first premolars intersect the buccal cusps and buccal border of the triangle. The central incisors are positioned slightly lingually inside the arc of the circle if the alveolar ridge is severely atrophied.

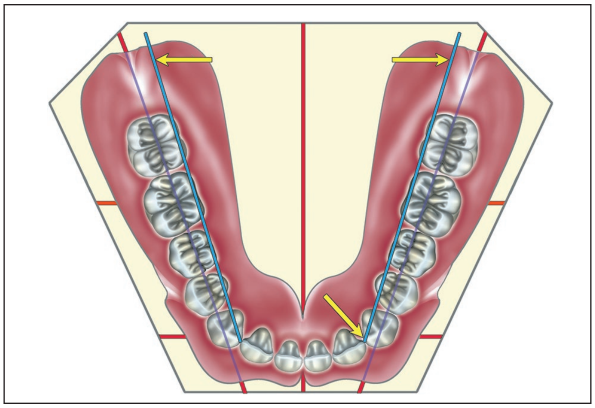


Fig 8-48 The Pound line touches the lingual border of the triangle and runs over the lingual cusps of the posterior teeth up to the mesial edge of the canine. The simplest and most reliable method of setting up the posterior teeth is to align the central developmental grooves with the middle of the alveolar ridge.

The mandibular parabolic dental arch can be described by the Bonwill circle and its premolar tangents. The size of the Bonwill circle is fixed by the canine points; the buccal boundary of the triangles establishes the path of the tangents (Figs 8-47 and 8-48).

General Setup Rules

Comparison of different descriptions and illustrations of complete dentures shows that there are a few fundamental rules governing the setup of artificial teeth. These fundamentals, drawn from the various interpretations, are applied here. No particular method is given priority, but essential advice is taken from all the depictions of tooth setups. As most setup compendia relate to specific tooth shapes, no single method can claim to be universally valid.

An average-value articulator is the minimum requirement for setting up two complete dentures in order to perform check movements and arrange the teeth inside the compensating curves. A setup in a fully adjustable articulator would require the condylar path to be surveyed in the patient. Whether it is appropriate to carry out time-consuming condylar path surveying for complete dentures is a matter for the dentist to decide, especially because determination of an average-value occlusal field can also be used therapeutically for the TMJs.

The findings of model analysis are the primary orientation guides and the static lines that the dentist draws in place. On the other hand, the familiar descriptive models of normal occlusion can also provide orientation.

Static positional stability of the denture is achieved if the artificial teeth are positioned on the center of the alveolar ridge. If they are placed outside the ridge middle, that is called *vestibular placement*, and adverse lever effects will arise in response to eccentric mandibular movements. Instead, the mandibular posterior teeth can be placed slightly lingually, provided that they do not crowd the tongue. The maxillary anterior teeth are the exception to this principle; these teeth are placed anterior to the alveolar ridge to provide support to the lips (Figs 8-49 to 8-54).

The compensating curves have to be created. The teeth should be set up inside sagittal and transverse compensating curves. The term *three-point contact* clarifies this point: On lateral and protrusive movements, the denture may be levered off on the nonworking side if tipping is not avoided by means of antagonist contacts on the nonworking (balancing) side.

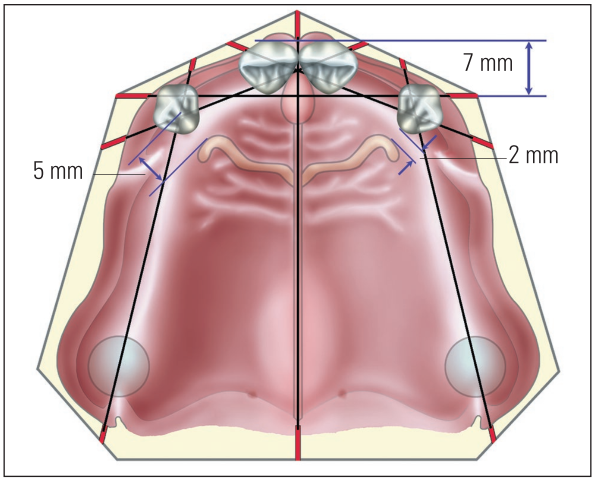


Fig 8-49 The maxillary anterior teeth can be reconstructed in their original arrangement with the aid of model analysis to improve the esthetic impression. The central incisors are placed with the labial contour about 7 mm in front of the raphe-papillary cross-line. The canines can be brought into their original position with relative accuracy by reference to the first pair of large plicae palatinae; in the process, the canine tips touch the raphe-papillary cross-line.

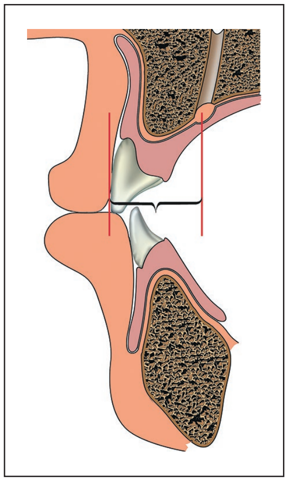


Fig 8-50 The labial contours of the maxillary incisors should be about 7 mm in front of the middle of the papilla so that a natural lip volume is created.

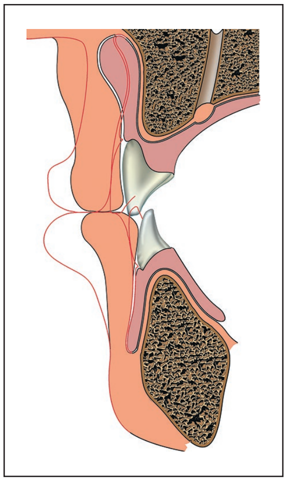


Fig 8-51 The lips will cave in if the maxillary incisors are placed on the center of the ridge. The impression of an aging face is accentuated if the vertical dimension of occlusion is reduced.

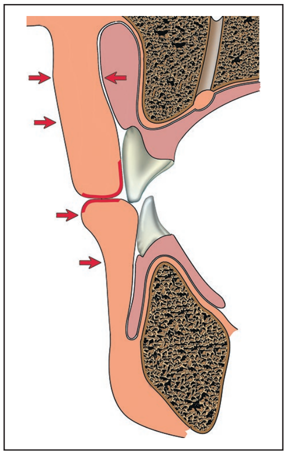


Fig 8-52 If the denture body is reinforced to tighten the wrinkles around the mouth, the vermilion of the lips is pulled inward and the lips appear very thin.

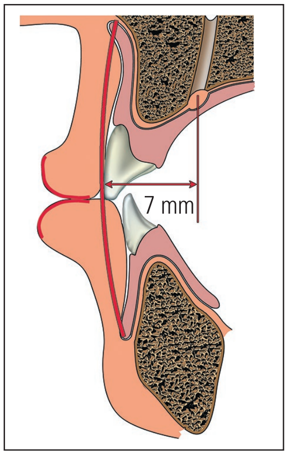


Fig 8-53 The natural lip volume with adequate vermilion is restored if the maxillary anterior teeth are arranged inside the vertical anterior arch approximately 7 mm in front of the middle of the incisive papilla and the denture body only compensates for the atrophy of the alveolar ridge. The vestibule is a capillary gap in a fully dentate dentition, but this is widened by the denture base so that this part of the mouth is altered.

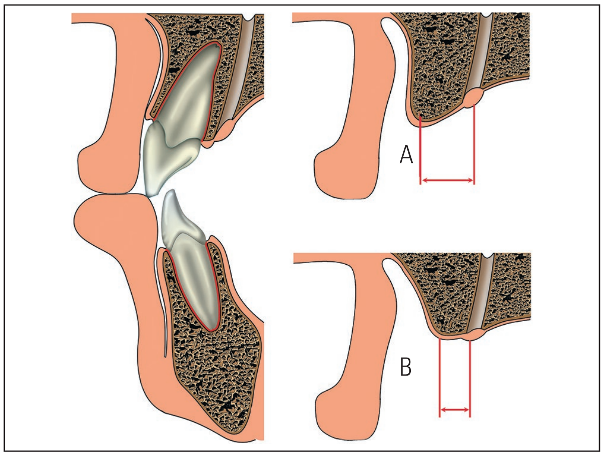


Fig 8-54 The incisive papilla in conjunction with the raphe-papillary cross-line is used as a fixed point in model analysis. In a fully dentate dentition, it is clearly located behind the alveolar ridge. It apparently drifts as far as the center of the alveolar ridge, depending on how advanced the atrophy is (A and B).

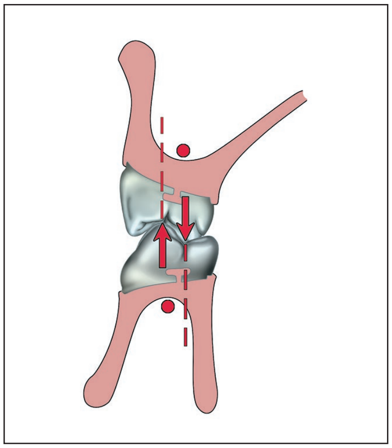


Fig 8-55 In terminal occlusion, it does not matter what path is followed because the opposite side is also in tooth contact. Patients adapt their movement habit when chewing so masticatory forces stabilize the denture. Biting-off movements and reflex-checking movements are critical.

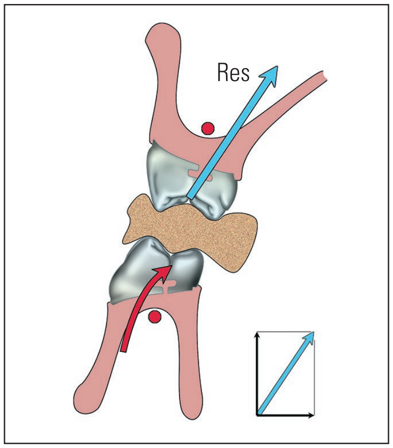


Fig 8-56 The chewing cycle in the final phase is directed toward the palate. The mandible presses the food in that direction against the maxillary teeth. In the maxillary denture, the resultant force (Res) passes the center of rotation on the middle of the alveolar ridge, and the denture is stabilized on the opposite side.

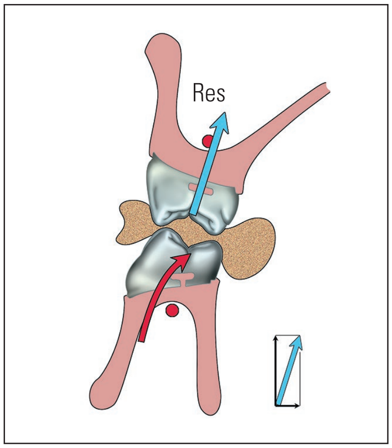


Fig 8-57 Shortly before terminal occlusion, when masticatory force is greatest and is applied rather vertically, the resultant directed palatally goes past the center of rotation. As a result, the denture is pressed onto the opposite side.

When chewing food, there is no guarantee that the balancing side will have contact. The highest masticatory pressure and hence the risk that the denture will be levered off occurs immediately before gliding into terminal occlusion, or directly before tooth contact on the balancing side; stabilization is then instantly possible.

The direction of movement when sliding into terminal occlusion can also help stabilize the denture (Fig 8-55). During chewing, the movement stroke is always guided into centric occlusion coming from the vestibular toward the lingual; the direction of movement is then toward the palate (Fig 8-56). Hence the maxillary denture presses on the dental arch on the opposite side (Fig 8-57). If the mandibular teeth lie slightly inside the alveolar ridge line, the force vector passes inside the center of rotation and the denture presses onto the jaw.

During speaking and normal play movements, the teeth are also moved against each other under contact, and the denture might be levered off if teeth have not been set up inside the compensating curves. If the teeth are placed inside these curves, however, the patient can readily be guaranteed stabilization. The embarrassment of insecure denture retention is particularly highlighted when the wearer is speaking, which is why a denture should have balancing contacts for this purpose.

Canine guidance (or guidance from a group of teeth), which lifts the posterior teeth out of occlusal contact when protrusive or lateral movements are performed, is inappropriate for complete prosthodontics because even the best functional impression and positional stability provided by the mechanical retentions of undercuts can never offer the type of secure retention a fixed restoration can provide. Even if canine guidance would not lever off the denture, the dentures will still be moved transversally against the underlying mucosa. Over the long term, these usually transverse, forced movements will damage the tissue base and accuracy of fit will be lost, which in turn means dynamic loading increases on the mucosa (Figs 8-58 and 8-59). Relining becomes necessary, but it is often not done promptly enough, resulting in remarkably fast breakdown of the bony foundation; the necessary denture-bearing area is lost.

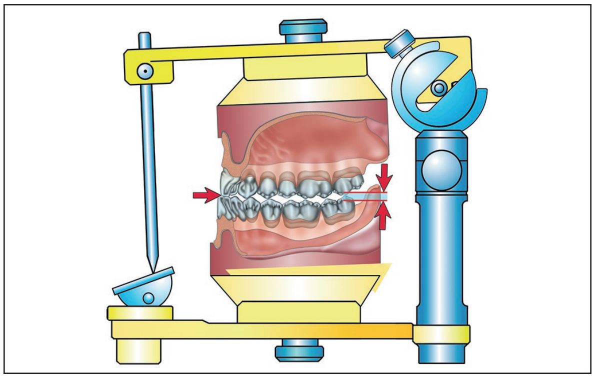


Fig 8-58 Guidance for a group of teeth in the anterior region can be constructed for complete dentures if adequate mechanical retentions are available; these are recorded by an accurate functional impression. In the posterior region, occlusal contact is broken on eccentric movements of the mandible. However, transverse forced movements of the denture occur that non-physiologically load the denture-bearing area and damage it.

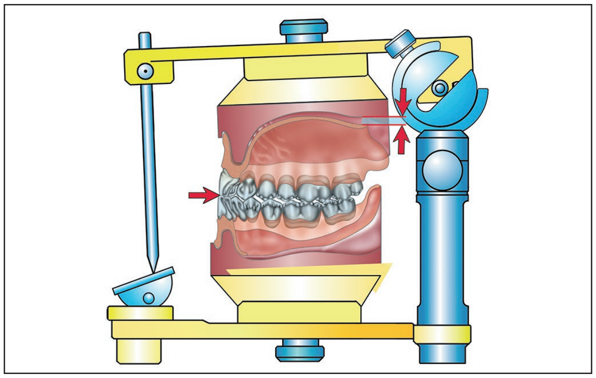


Fig 8-59 If the mechanical retentions are inadequate, the dentures will be levered off their rest area by guidance from a group of teeth. This positional instability lessens the dentures' functional value and leads to dynamic stresses on the underlying tissue. Progressive breakdown of the bony foundation occurs, which further reduces positional stability. For complete dentures, bilaterally balanced occlusion should be attempted.

Ways to Check Tooth Positioning

The teeth are set up tooth by tooth while check movements (lateral and protrusive excursions) are constantly performed to ensure that all-round antagonist contact exists. The incisal guide pin must always maintain contact with the incisal guide plate, especially when a certain plate slope is specified.

On lateral movements, the buccal cusps of the posterior teeth on the working side lie on top of each other, while the cutting edges of the anterior teeth on this side have edge-to-edge contact. The anterior teeth on the balancing side have no antagonist contact, while the buccal cusps of the mandibular posterior teeth on this side lie on the palatal cusps.

On protrusive movements, the anterior teeth have edge-to-edge contact, and in the posterior region individual cusp tips on the molars touch each other. In some circumstances, the incisal guide pin may lose contact with the guide plate.

The position of the individual teeth is checked in three spatial directions: from the occlusal, vestibular, and approximal directions. From the occlusal aspect, rotation inside the dental arch should be checked and corrected. The reference point is the central developmental groove for posterior teeth and the incisal edge for anterior teeth. The central developmental grooves form a straight line that lies directly over the alveolar ridge. The incisal edges form the dental arch.

From the vestibular aspect, the mesial or distal inclination of the axis is checked and corrected. This involves checking the height of the tooth relative to the adjacent tooth; a correct interdental embrasure must result, in which the antagonist contacts are evenly distributed to both teeth. On lateral movements, the antagonist cusps glide along in these embrasures.

From the approximal aspect, the lingual inclination of axis of the alveolar ridge is checked. In the mandible, the teeth are inclined lingually in keeping with the tooth inclination; in the maxilla, the teeth have a vestibular inclination, which gives rise to the transverse curve.

The length of the maxillary anterior teeth is definitely dependent on the length of the upper lip. The safest way of establishing this length is for the dentist to make markings on the occlusion rims. If the lip closure line is marked, the anterior teeth should project 1 to 2 mm beyond it.

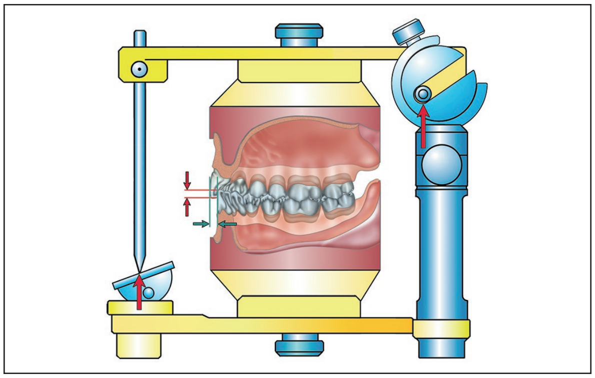


Fig 8-60 The term *overjet* defines the overbite and is equivalent to the amount of protrusive occlusion; that is, the incisors are placed in relation to each other so that the maxillary incisal edges reach beyond the mandibular teeth by the amount to which the maxillary teeth stand anterior to the mandibular incisal edges.

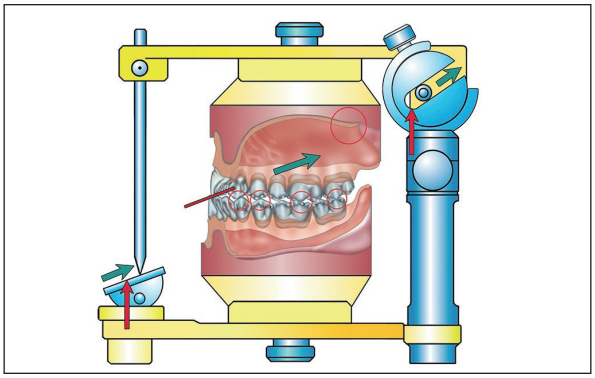


Fig 8-61 The degree of overjet should ensure that, on protrusion, the anterior teeth glide past each other while the posterior teeth simultaneously remain in sliding contact. With this balanced occlusion, the dentures are stabilized on the denture-bearing area and are not levered off.

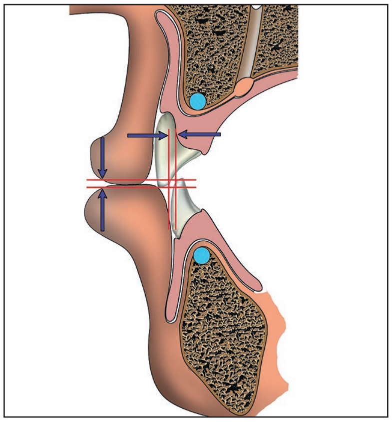


Fig 8-62 The position of the dental arches relative to each other influences the overjet: If the mandible lies in front, a small amount of overjet is selected. As a result, the anterior teeth achieve sliding contact after only short movement deflections.

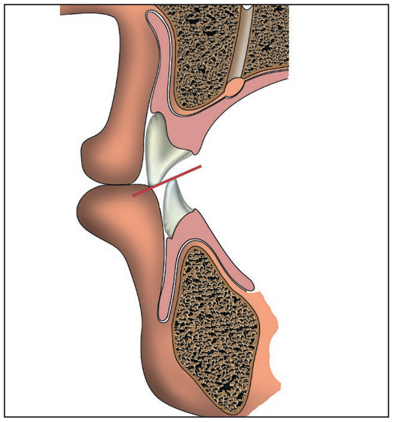


Fig 8-63 Abrasion edges can be ground into the anterior teeth, along which these teeth glide during eccentric movements. Many prefabricated teeth already have abrasion edges; canines usually have to be ground in.

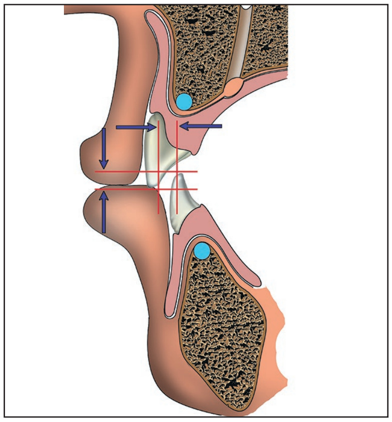


Fig 8-64 The overbite may be extended if the upper lip is long. As a result, the mandibular teeth must be placed far back or the maxillary teeth placed far forward to achieve a balanced amount of overjet. This jeopardizes positional stability.

In principle, an overjet is formed; that is, the anterior teeth, including the canines, have no antagonist contact in centric occlusion (Figs 8-60 to 8-62). If this overjet is not formed, the denture may lever off when biting off food or during protrusive movements.

Individual tooth positions are always positive if they are prepared according to the dentist's instructions or based on an anatomical model of the original tooth positions, with any extreme positional anomalies obviously being alleviated. An individual tooth position must not impede the statics of the denture (Figs 8-63 to 8-68).

It is advisable to carry out individual variations from normal tooth position after setup of all the teeth has been fully completed; a better overview is then possible because dynamic occlusion already functions with all-round sliding contact. Then interferences only need to be sought on the repositioned teeth. The following variations from normal tooth position may be selected:

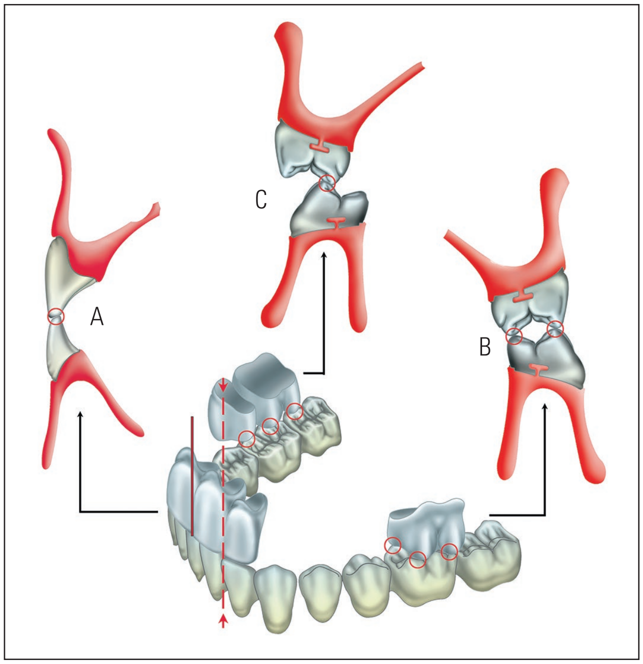


Fig 8-65 For checking purposes, the lateral movement is executed until the approximal edges between the central and lateral incisors of the maxilla and mandible lie above one another. Then the incisors on the working side have edge-to-edge contact (A). On the working side, the posterior teeth then have cusp-to-cusp contact (B), while on the balancing side the palatal mandibular cusps have sliding contact with the buccal cusps of the mandibular teeth (C). The incisal guide pin will not lift off the guide plate.

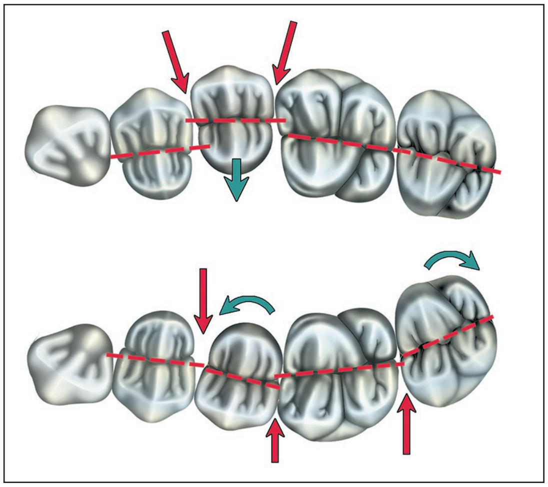


Fig 8-66 Rotation of the posterior teeth from the occlusal view. As a basic principle, the central developmental grooves form a line. If this criterion is applied, it is noticeable when a tooth tips out or is twisted out of the arch. This indicates that the interdental niche is disrupted and the dental arch form is defective, which has esthetic drawbacks, especially in the case of the premolars.

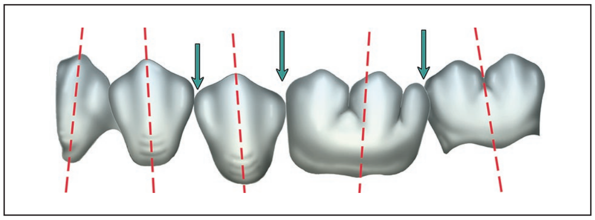
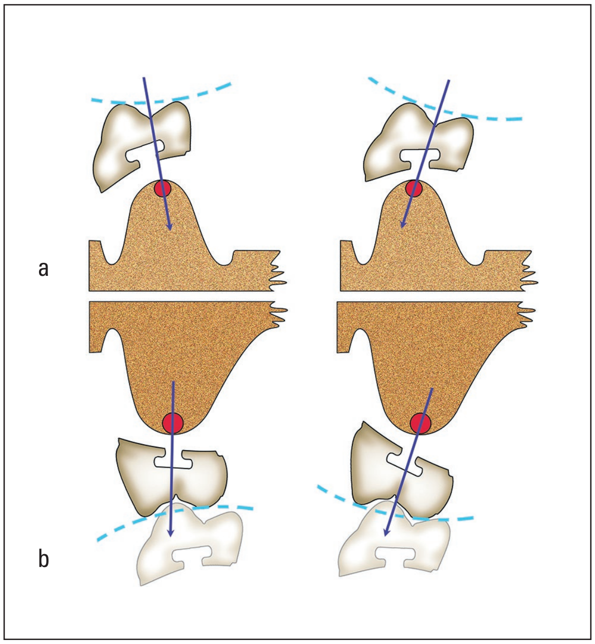


Fig 8-67 The position of the tooth axes can be checked when viewed from the vestibular aspect. Although more esthetic aspects come to the fore in the anterior region, in the posterior region it is a matter of shaping the interdental embrasures because this is where the contact areas of the antagonist cusps lie. Otherwise, gliding interference may arise in the embrasure area on lateral excursions.

Fig 8-68 *(right)* It is important to check the approximal inclination of the teeth because it determines the position of the teeth relative to the occlusal curves. *(a)* If a mandibular tooth is tipped in the vestibular direction, an inverted curve rather than a transverse compensating curve will arise. *(b)* If a maxillary tooth is tipped lingually, the palatally placed occlusal contacts will be lost; however, if it is placed too far vestibularly, this will lead to static and esthetic disadvantages.



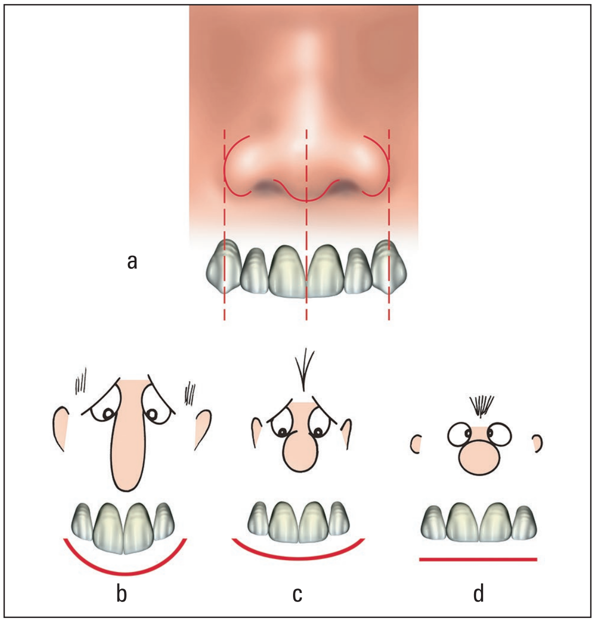


Fig 8-69 The shape of the nose can be used to determine the width of the anterior teeth: *(a)* The vertical tooth axes of the canines line up with the outer edges of the wings of the nose. *(b)* The incisors can be aligned with the baseline of the nose; a long, pointed nose invites stepped positioning of the anterior teeth. *(c)* A normally curved base of the nose allows harmonious positioning of the anterior teeth. *(d)* A relatively uniform line of incisal edges fits well in a patient whose nose has a broad base.

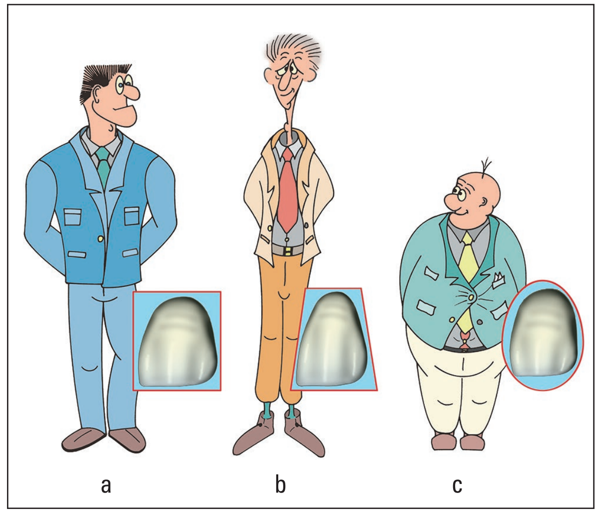


Fig 8-70 The Kretschmer constitutional typology is reflected in the shape of the maxillary central incisors, as illustrated here: *(a)* The athletic constitution is well balanced, powerful, and represented by an angular, almost square tooth shape. *(b)* The leptosomic or asthenic type, rather lanky, nervous, and panicky, is characterized by a triangular tooth shape. *(c)* The round and trusting pyknic type is best represented by an oval basic tooth shape.

- The contour of the incisal edges of the anterior teeth follows the lower lip contour or the nasal baseline. The dentist can mark both lines on the occlusion rims. The shape and width of the wings of the nose can be used to select the width of the anterior teeth (Fig 8-69).
- The anterior teeth can be rotated within the dental arch. For instance, the central incisors can be twisted with their distal edges out of the dental arch or conversely with their mesial edges twisted out of the dental arch. The anterior teeth can also be moved with their vestibular axes so that the teeth partly overlap at the incisal edges. Spaces between individual teeth can also be set up, although the central incisors are excluded from this if the patient experiences vocalization problems afterward.

The dentist chooses the tooth color, taking into consideration the patient's age, complexion, lip color, and facial hair. The shape of the anterior teeth should be established by the dental practitioner in order to select the basic shapes that match the patient's physical type (Fig 8-70).

Position of Mandibular Anterior Teeth

There is no hard and fast rule about which teeth to start with in a complete denture setup. If starting from the model analysis markings on the maxilla, supplemented by the markings and padding of the occlusion rims, it makes sense to begin by setting up the maxillary teeth. If this padding is absent and an average-value template is used for the setup, it is advisable to set up the mandibular teeth first, for which the static lines from the model analysis of the mandible provide reliable guides. In any case, the parabolic dental

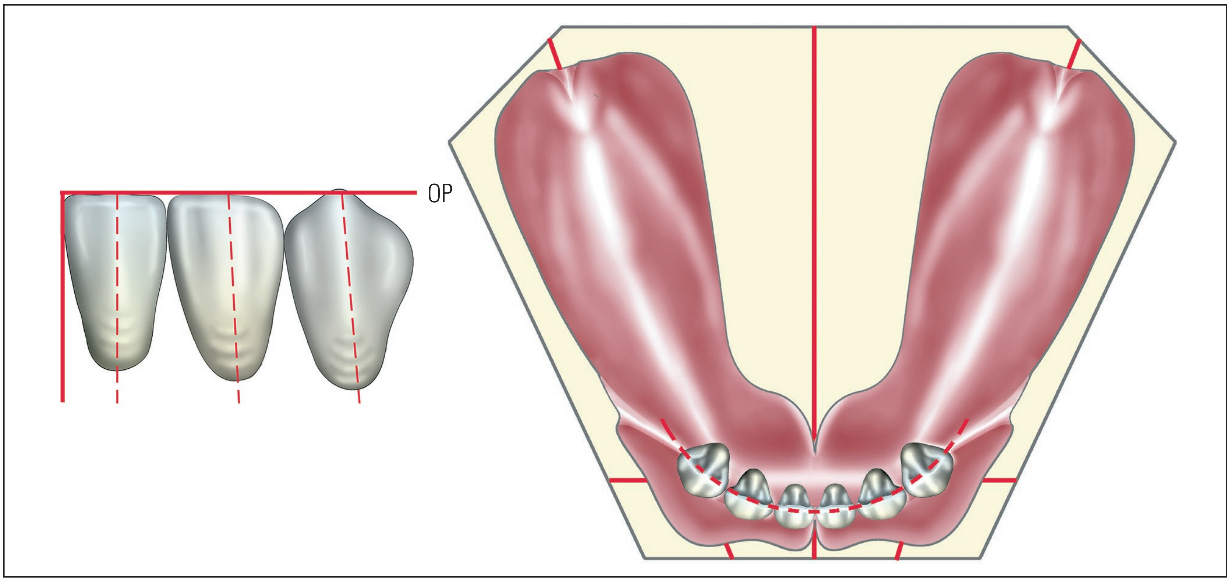


Fig 8-71 The mandibular anterior teeth stand exactly on the occlusal plane (OP), and their incisal edges form a straight line. The tooth axes display a mesial tendency when seen from the labial aspect. The dental arch, seen from the occlusal aspect, forms the Bonwill circle with the canines positioned over the canine points.

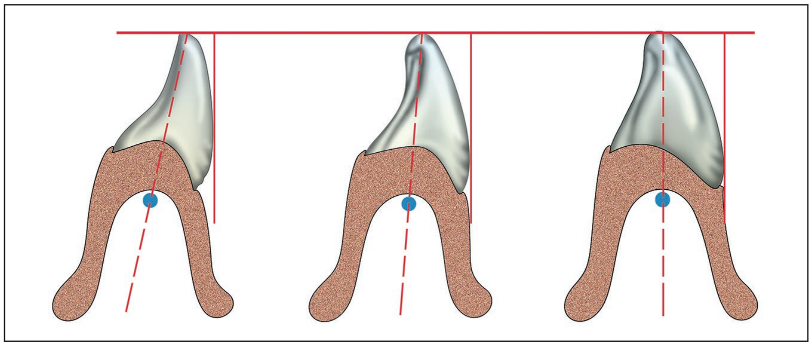


Fig 8-72 The approximal inclinations are varied to form the dental arch in keeping with the Bonwill circle. All the anterior teeth stand on the center of the alveolar ridge. The approximal inclination can be checked by looking at the path of the labial contour: The labial contour of the central incisor stands vertically, that of the lateral incisor is inclined slightly lingually, and that of the canine shows a pronounced lingual inclination. These match the correct inclinations of the tooth axes.

arch shape is easier to reproduce than the semi-ellipse in the maxilla.

The procedural approach to setup being adopted here starts with the mandibular anterior teeth, followed by the maxillary anterior teeth and shaping of the overjet. The posterior teeth are set up in fixed pairs of antagonists (tooth to tooth): mandibular premolars and maxillary first premolars in order to determine possible tooth spacing between canines and the first premolars. This is followed by the mandibular first molar and the opposing maxillary second premolar, then the mandibular second molar and finally the maxillary molars.

The mandibular anterior teeth invariably stand on the alveolar ridge. Seen from the incisal aspect, they form the start of the Bonwill circle, the arc of the circle whose tangents form the reference lines for the posterior teeth (Figs 8-71 and 8-72). As the alveolar ridge of the mandible is generally straight in the anterior region, the arc must be created by the approximal inclination of the anterior teeth and by rotation around the tooth axis. It is inadvisable to use the tooth axis for aligning in the approximal inclination; the labial contours of the anterior teeth provide better orientation.

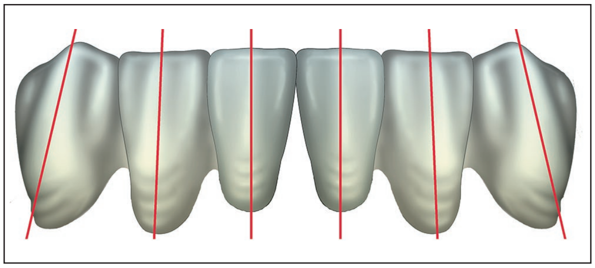


Fig 8-73 From the labial view, the incisal edges form a straight line corresponding to the occlusal plane, beyond which the tips of the canines protrude slightly. In a symmetric setup, the mandibular anterior teeth appear to be inverted because of the aforementioned approximal inclinations.

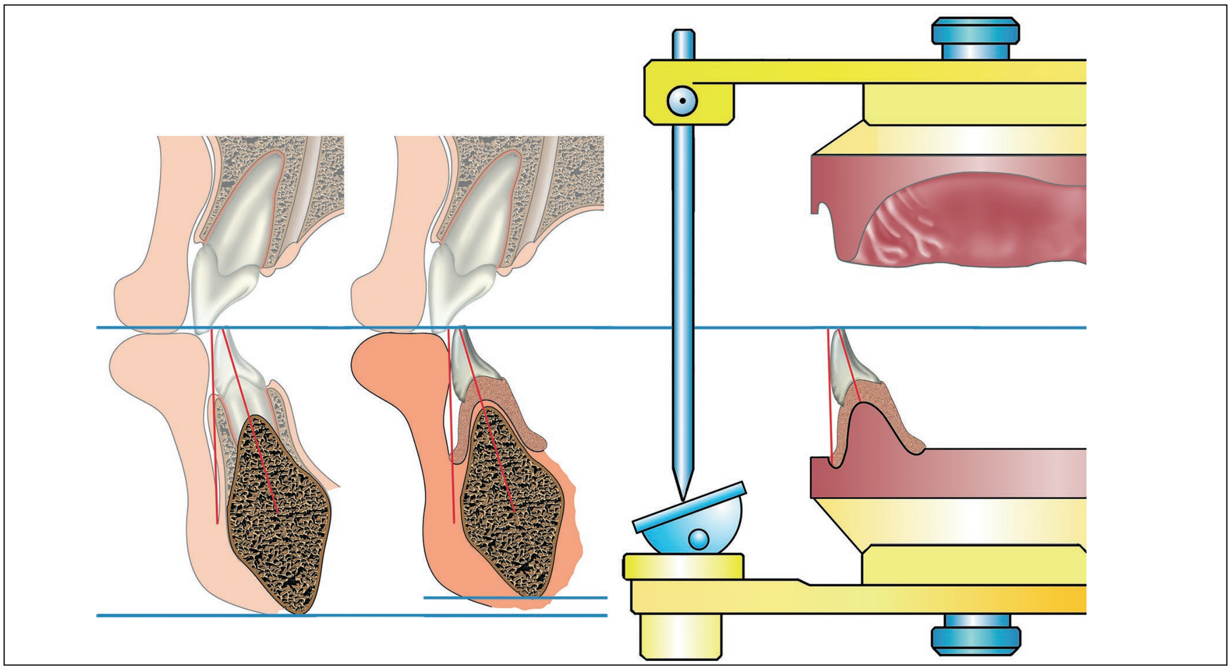


Fig 8-74 *(left)* The mandibular central incisor has a vestibular inclination in a normal dentition; its labial contour, extended vertically, points into the mandibular vestibular fornix. On total tooth loss, the vertical dimension of occlusion is reduced so that the middle of the anterior alveolar ridge of the mandible is displaced forward. If the mandibular central incisor is brought into its original position, it stands slightly in front of the center of the ridge.

Fig 8-75 *(right)* When setting up the central incisor in the mandible, the mandibular vestibular fornix may provide good orientation: The labial contour points vertically downward into the depth of the vestibular fornix, and the incisor stands slightly in front of the middle of the alveolar ridge and displays the necessary vestibular inclination. The maxillary vestibular fornix is not suitable for orientation because the shift in the jaw relation will also shift the relationship of the maxillary vestibular fornix to the position of the mandibular teeth.

The incisal edges of the mandibular anterior teeth form a straight line congruent with the lip closure line (occlusal plane), while the canine may exceed this line slightly at its tip (Fig 8-73). From the vestibular view, the central and lateral incisors stand perpendicular with a slight mesial tendency, while the canine is inclined mesially.

The mandibular central incisors stand with their tooth axis inclined strongly toward the vestibular aspect; the labial contour runs vertically, and its extension points into the mandibular vestibular fornix (Figs 8-74 and 8-75). The mandibular lateral incisors stand with their tooth axis almost perpendicular on the center of the ridge; the labial contours are inclined slightly in the lingual direction. The mandibular canines stand with their tooth axis vertical and slightly toward the lingual aspect, while the labial contours show a marked

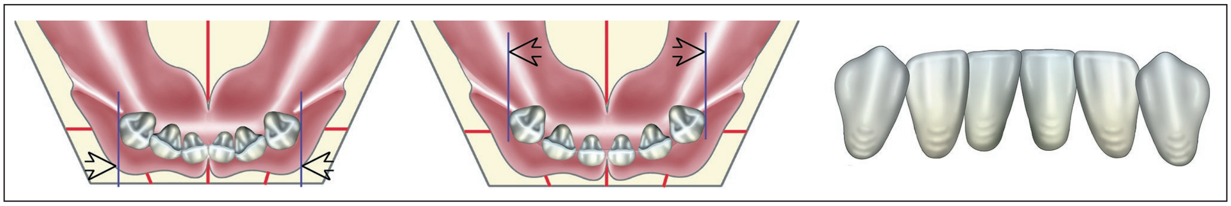


Fig 8-76 The mandibular anterior teeth can be set up irregularly to create a favorable esthetic impression. If the teeth are rotated in their vertical tooth axes and pushed together so that they partly overlap, the anterior width from canine to canine may be reduced. Spacing the mandibular anterior teeth can enlarge the anterior dental arch, which can also create a favorable esthetic impression.

lingual inclination. The position of the canines is determined by the canine point, as defined by model analysis.

An individual tooth position caused by rotation and overlapping is permissible and should be formed so that no interference in occlusion occurs and sliding contact is always maintained during lateral movements. The mandibular anterior teeth can be set up irregularly to create a favorable esthetic impression (Fig 8-76). If the teeth are twisted in their vertical tooth axes and pushed together, the anterior width from canine to canine may also be reduced. The anterior width can be increased by leaving spaces between the mandibular anterior teeth.

Error analysis

It is difficult to make proper use of the orientation lines and positional guidance provided. The requirement for tooth positioning on the center of the alveolar ridge is difficult to carry out. When is an inclined incisor actually on the ridge middle? Must the cervical margin and the ridge contour show, or should the incisal edge lie above the ridge middle, or should the base overlap the ridge contour? For static reasons, the incisal edges should be placed over the middle of the ridge, but then it is not possible to form the Bonwill circle.

By way of compromise, the cervical margins of all the mandibular anterior teeth form a roughly straight line parallel and approximately 2 mm in front of the ridge middle; the dental arch is shaped by the previously described vestibular inclination of the teeth and their rotation around the tooth axis. The advice to let the extension of the labial contour of the mandibular first incisor point into the vestibular fornix is a good guide. This advice also allows considerable leeway. The labial contour can point into the depth of the fornix at the outer or the inner edge; another variation will arise if the contour does not lie vertically. A ruler held against the contour can show this variation clearly.

Position of Maxillary Anterior Teeth

The maxillary anterior teeth should form the overjet. Thus, the mandibular anterior teeth are placed up to the lip closure line, while the maxillary anterior teeth overhang this line by about 2 mm. The maxillary anterior teeth lie in front of the mandibular anterior teeth by the same amount. If the mandibular anterior teeth have been set up first, the maxillary teeth can first be placed with the appropriate overbite to the mandibular anterior teeth, and provided the wax is still soft, a lateral movement can be performed until edge-to-edge contact is achieved, which means pressing the maxillary incisor in the vestibular direction. If the maxillary anterior teeth are allowed to glide back into centric occlusion, normal overjet to the correct extent will emerge, and protrusive occlusion will be equivalent to overbite.

The maxillary central incisor stands in front of the alveolar ridge, in keeping with the occlusion rim padding or, based on the average from model analysis, 7 mm from the center of the papilla as far as the contour of the labial surface (Fig 8-77). The vestibular inclination, checked from the approximal aspect, shows the following: It is vestibularly inclined with the neck of the tooth at the alveolar ridge, and the labial contour follows the vertical anterior arch. The incisal edge overhangs the lip

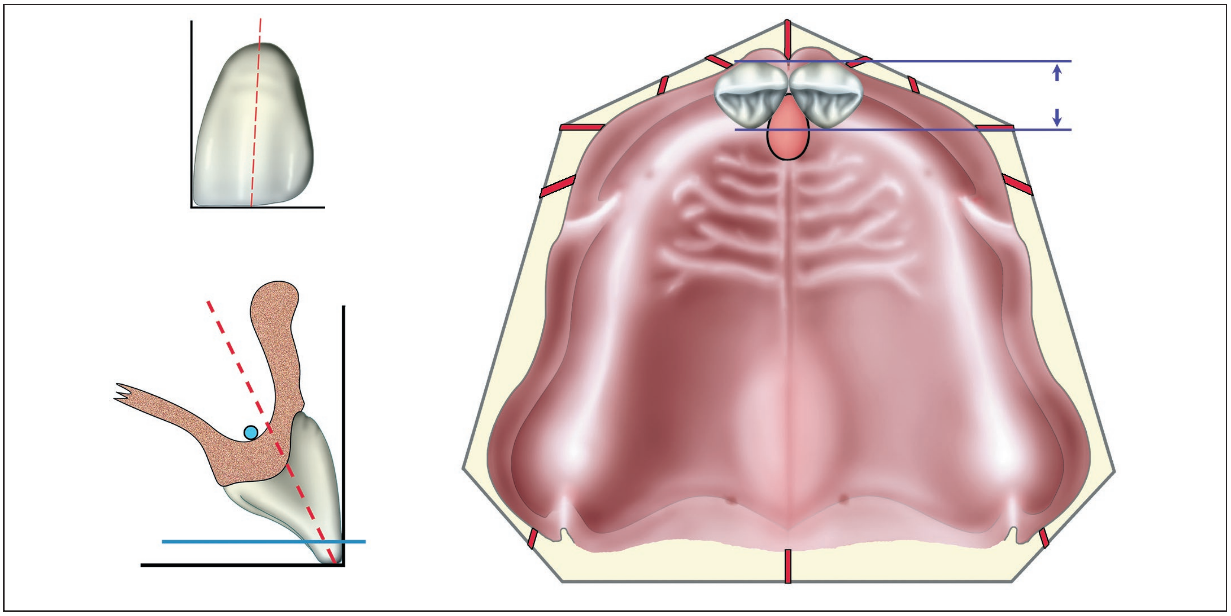


Fig 8-77 The maxillary central incisor stands in front of the alveolar ridge so that the labial surface is about 7 mm in front of the middle of the incisive papilla. It has a vestibular inclination. When seen from the labial aspect, the mesial inclination of axis can be seen. The tooth projects about 1 to 2 mm beyond the occlusal plane or the lip closure line. Seen from the occlusal aspect, both central incisors stand in the dental arch.

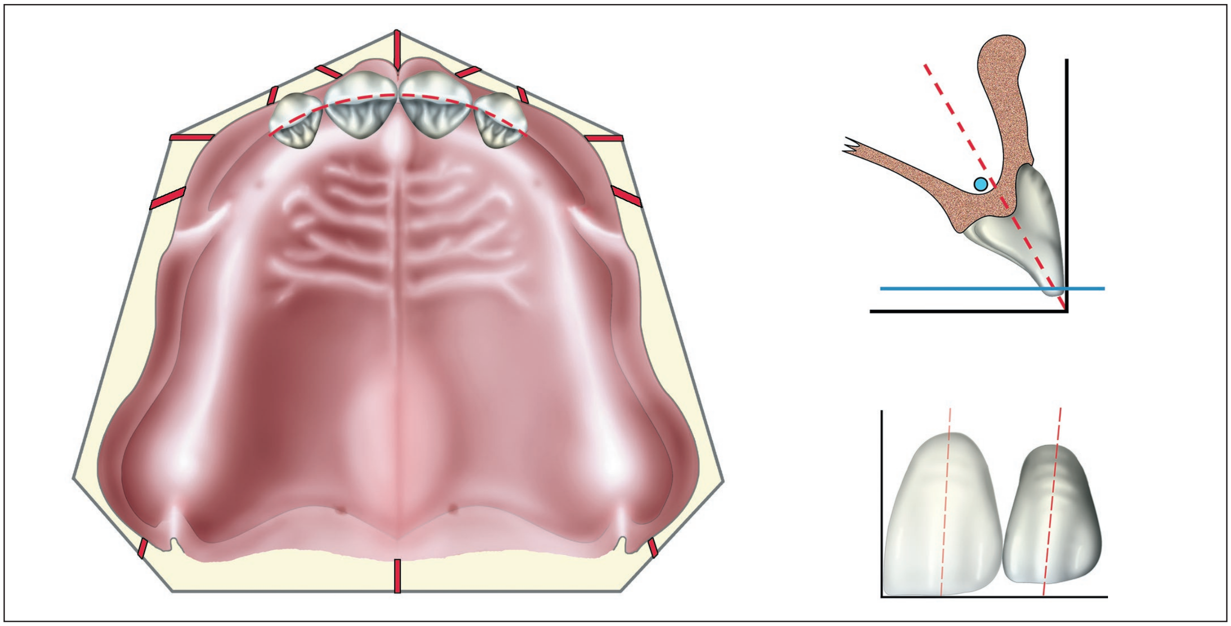


Fig 8-78 The lateral incisor has a more pronounced approximal inclination, is set up to be slightly shorter, and is tipped more mesially. The lateral incisors stand anterior to the alveolar ridge and continue the dental arch.

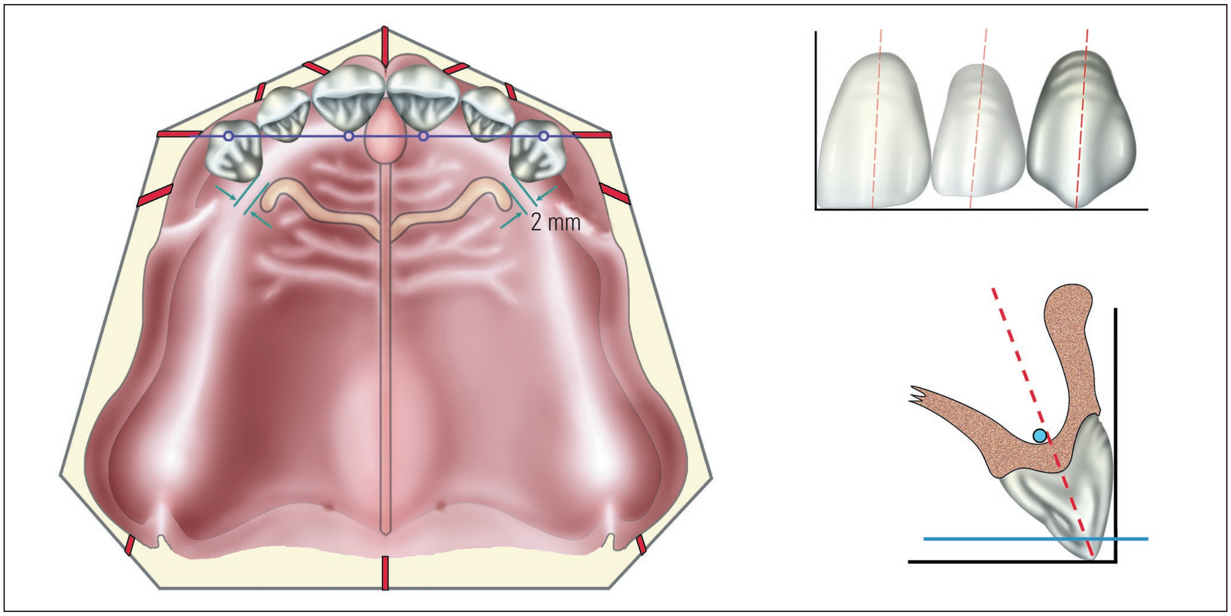


Fig 8-79 The canine is also located in front of the alveolar ridge. The canine point is fixed by the first pair of large plicae palatinae. The canine, like all the anterior teeth, displays a vestibular tendency and is inclined slightly mesially. Its length corresponds to that of the central incisor. From the occlusal view, the canine must be given an exposed position. It is the corner in the dental arch, 2 mm in front of the first pair of large plicae palatinae.

closure line by about 2 mm, and hence an overbite over the mandibular anterior teeth is formed that corresponds to the overjet. The mesial axis of inclination is checked from the vestibular aspect, although this inclination is very weak. From the occlusal aspect, there must already be a suggestion of the dental arch when looking at the incisal edges of both central incisors.

The maxillary lateral incisor also stands anterior to the alveolar ridge, like the central incisor, and hence is in keeping with the vertical anterior arch or follows the occlusion rim contour (Fig 8-78). The inclinations of axes are more pronounced: seen from the labial aspect, there is a stronger inclination, but from the approximal aspect, the neck of the tooth shows more at the alveolar ridge. The lateral incisor is shorter than the central incisor but still projects beyond the lip closure line. From the incisal aspect, the dental arch is visible.

The maxillary canine also stands in front of the alveolar ridge (Fig 8-79). The canine point has been located by model analysis or fixed by markings on the occlusion rim. The canine is inclined mesially. Its approximal inclination is in the vestibular direction, which means the tip of the canine and the cervical margin lie roughly vertically on top of each other; as a result, the bulbous canine appears very dominant. The canine is not longer than the central incisor, which is checked with a flat plate parallel to the occlusal line. Canine guidance is not attempted. At best, antagonist contact exists with the mandibular first premolar, hence distally; the mandibular canine has no contact in centric occlusion. It may become necessary to prepare the maxillary canine for interference-free lateral movement.

The incisal edges of the maxillary anterior teeth can be ground in, as they are beveled labially to palatally and abrasion surfaces are created. This may even become necessary if the flash on factory teeth is not adequately buffed. Usually, it then becomes necessary to bevel these areas of flash toward the labial aspect in the case of the mandibular anterior teeth. This results in a regular sliding contact.

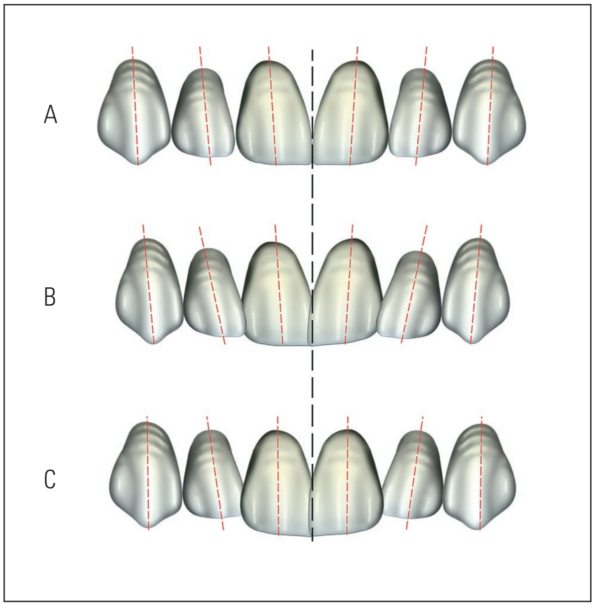


Fig 8-80 Subtle, deliberate irregularities in tooth position enhance the natural effect of the dentures. Based on this knowledge, it is possible to deviate from regular positioning (A) and create a harmonious individuality seen from the labial aspect by means of convergence and divergence of the tooth axes (B and C).

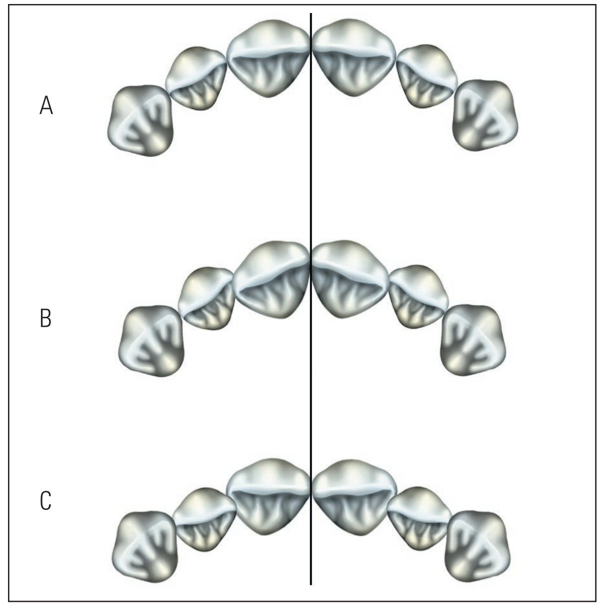


Fig 8-81 Positional changes achieved by rotation around the vertical tooth axis, so that some of the teeth may overlap, will also increase the natural impression (B and C).

Individual tooth positions

Subtle, deliberate irregularities in tooth position enhance the natural effect of dentures (Fig 8-80). Based on this knowledge, it is possible to deviate from regular positioning and create a harmonious individuality seen labially by convergence and divergence of the tooth axes. Positional changes achieved by rotation around the vertical tooth axis, so that some teeth may overlap, will also increase the natural impression (Fig 8-81).

Error analysis

The canine is often placed with the neck of the tooth facing vestibularly for esthetic reasons. However, inverted placement of a canine, where the cutting edge is tipped inward, causes massive interference in lateral movements; as a result, the canine will be pressed out in the vestibular direction by forced movements. The canine is deformed by corrective preparation. Therefore, the canine should be set up so that the neck and incisal edge overlie each other vertically. The degree of overjet has esthetic aspects and functional value. The sagittal distance of all the teeth must be uniform. The distance often increases on the lateral incisor and canine. This error arises if the artificial teeth have the wrong vestibular inclination or are placed inverted; this error will also arise if the maxillary teeth are placed too close together.

Position of Mandibular Posterior Teeth

For static reasons, the mandibular posterior teeth are placed on the middle of the alveolar ridges. Provided that the tongue is not crowded, it is possible to move the posterior teeth slightly lingually. The compensating curves are formed by the position of the posterior teeth. The curves are achieved in an average-value articulator with a template (calotte) by placing the teeth against the mounted template. If the posterior teeth are set up without accessories—hence without tem-

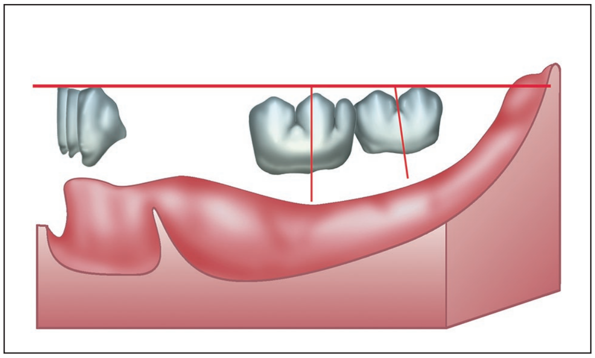


Fig 8-82 The second molar is set up with a mesial inclination inside the compensating curve, and its distobuccal cusp tip touches the occlusal plane.

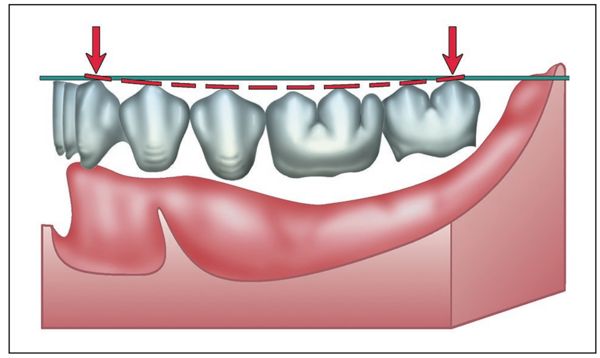


Fig 8-83 The occlusal plane is fixed by half the height of the retromolar triangle and by the lip closure line, which in turn is represented by the incisal indicator on the articulator. The compensating curve intersects the occlusal plane at the canine and at the distobuccal cusp of the second molar. The curve arises because the first premolar lies lower than the canine, the second premolar lower than the first premolar, and the first molar lower than the second premolar, while the second molar is tipped so steeply that it touches the occlusal plane again.

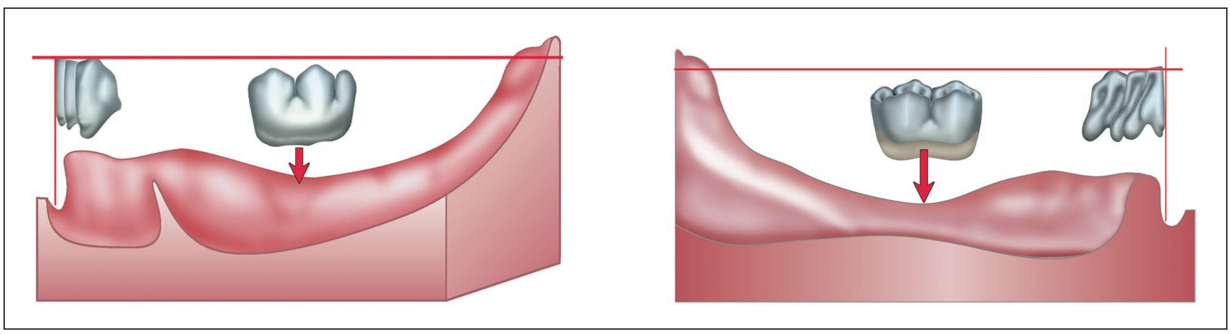


Fig 8-84 The first molar is placed at the lowest part of the sunken alveolar ridge, where the center of masticatory force is located.

plates—the following points should be kept in mind.

Setup starts with the mandibular posterior teeth, and the maxillary posterior teeth are set against them. This is because the static lines in the mandible are clearer when the anterior teeth are in place, which makes setup easier. Setup is done tooth by tooth in antagonist pairings; the necessary corrections always relate to all the teeth involved.

The mandibular second molar stands with its distobuccal cusp at the same height as the tip of the canine, which means level with the occlusal plane. This occlusal plane runs from the mandibular incisal point to half the height of the retromolar triangle (Figs 8-82 and 8-83). This occlusal plane is marked in every average-value device so that this plane can be readily identified by simple placement of a ruler. Stretching a rubber band is not accurate because it can be shifted by the standing teeth or the occlusion rim.

The sagittal compensating curve must emerge when viewed from the vestibular aspect: Only the canine and the distobuccal cusp of the second molar touch the occlusal line. The premolars stand below this line. The first molar stands perpendicular and is the lowest within the curve (Fig 8-84).

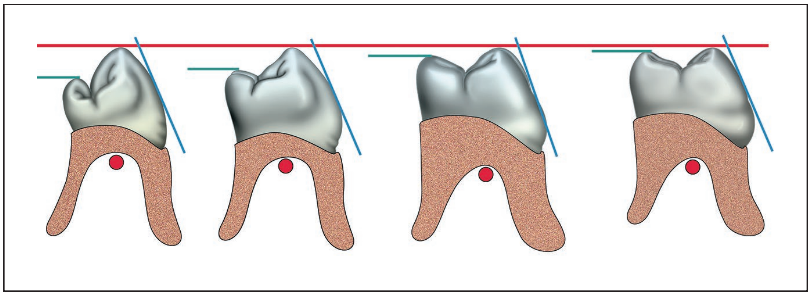


Fig 8-85 The approximal inclinations of the mandibular posterior teeth in the lingual direction produce the transverse compensating curve. This inclination can be found in a tooth-by-tooth setup by the check movements in which sliding contacts have to exist. The transverse curve decreases distally; that is, the first premolar is the most strongly inclined lingually and the second molar the least inclined.

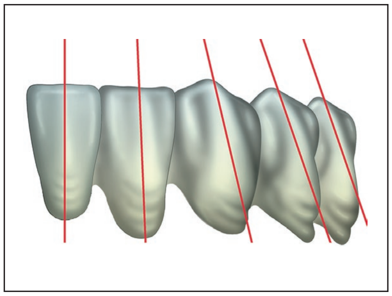


Fig 8-86 The premolars are fitted inside the compensating curve; their vestibular contours display the same inclination as the canine.

The transverse compensating curve is formed when the tooth inclination of the mandibular posterior teeth is reproduced; that is, all the posterior teeth are inclined lingually (Fig 8-85). The central developmental grooves of the mandibular posterior teeth form a straight line that aligns with the middle of the alveolar ridge; as a result, the buccal cusps lie on the tangent of the Bonwill circle. The lingual cusp tips lie on the Pound line. Check movements show whether an antagonist contact exists with the maxillary canine, without the incisal guide pin lifting off.

The mandibular first premolar stands with its buccal cusp tip slightly lower than the canine. This cusp tip should point exactly to the interdental embrasure between the canine and first premolar in the maxilla. Inclination of axis from the vestibular view is slightly distal (Fig 8-86).

A space between the first premolar and the canine becomes necessary to compensate for the differing widths of the anterior teeth. To do this, the two mandibular premolars and the maxillary first premolars are fixed in their approximate position to determine where the space is needed. If the maxillary set is too wide or the overjet is too small, a space is needed in the mandible; if the maxillary set is too narrow or the overjet is very wide, the space will arise in the maxilla.

The mandibular second premolar stands with its buccal cusp again slightly lower than the first premolar, approximately 0.75 mm below the occlusal plane; the sagittal curve is formed. From the vestibular view, the tooth axis is perpendicular, which supports the shape of the curve. So that a precise interdental embrasure is created, the mesial edge of the second premolar lies at the same height as the distal edge of the first premolar. The approximal inclination shows the tooth inclination, whereby the transverse curve arises. In the tooth-by-tooth setup, the maxillary first premolar is now set up to correct the sliding contacts during check movements.

The mandibular first molar in the vestibular view stands vertically at a distance of about 1 mm from the occlusal plane. It forms the lowest point on the sagittal compensating curve. Its central developmental groove forms a straight line with the first and second premolars, running parallel to the ridge line. It stands with a slight tooth inclination lingually in order to shape the transverse curve. In the tooth-by-tooth setup, the maxillary second premolar must be set up to correct the sliding contacts during check movements.

The mandibular second molar, seen from the buccal aspect, stands inside the sagittal compensating curve and is tipped mesially so that it forms a correct interdental embrasure with the first molar and touches the occlusal plane with its distobuccal cusp. The transverse curve is very weakly developed at the terminal molar. In the tooth-by-tooth setup, the antagonists are now set up, and complete sliding contact is corrected.

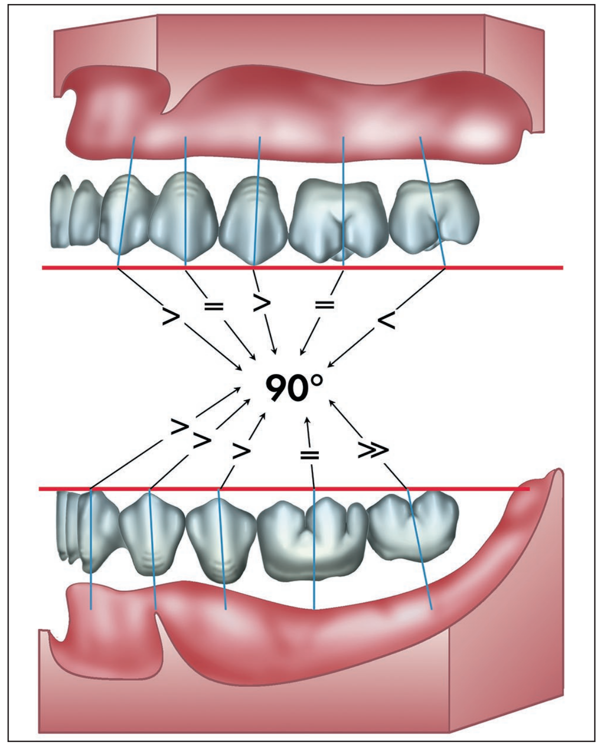


Fig 8-87 *(top)* In a complete denture setup, the inclinations of the tooth axes of the maxillary (and obviously the mandibular) posterior teeth deviate from the natural inclinations of axis because the sagittal compensating curve is more curved than the natural occlusal curve. The first and second molars are tipped markedly in the distal direction. In addition, the posterior teeth project beyond the occlusal plane because of the shape of the curve.

Fig 8-88 *(bottom)* The axes of the mandibular posterior teeth are inclined so that the sagittal compensating curve arises: The first molar stands perpendicular, and the second molar is tipped mesially; the first and second premolars have a slight distal tendency to the alveolar ridge.

Position of Maxillary Posterior Teeth

For static reasons, placement of the maxillary posterior teeth on the middle of the alveolar ridge is compulsory. Slight deviations in the vestibular direction may arise because of the inclination of axis inside the transverse compensating curve (Figs 8-87 and 8-88). Nevertheless, secure retention of the complete denture can be ensured by means of the functional impression and the mechanical retentions.

The dental arch is shaped into a semi-ellipse; the premolars stand inside the premolar tangent in order to shape the buccal corridor, for which the canine and first molar serve as fixed points (Figs 8-89 and 8-90). It makes sense to set up the mandibular pair of posterior teeth first and then to align the maxillary antagonists accordingly (Fig 8-91). It is important to ensure that the posterior teeth are placed in normal occlusion according to the antagonist rule, where the cusp tips always lie in the interdental embrasures of the antagonists (Figs 8-92 and 8-93).

If the mandibular teeth are set up, the maxillary antagonist can be fixed with a little wax in its correct intercuspation position on this row of teeth (Figs 8-94 and 8-95). It is then pressed into the maxillary softened wax rim by closing the articulator. The maxillary and mandibular occluding cusps each engage in their antagonist contact areas. The correct sliding contact is checked by lateral and protrusive movements.

The maxillary premolars stand perpendicular, and their lingual cusps touch the antagonists in the interdental embrasures. The correct position should also be checked intraorally. The palatal cusps appear longer than the buccal cusps and form the transverse compensating curve. The premolars have only a slight overbite buccally and glide past each other in antagonist contact without interference and without losing the sliding contact of the anterior teeth.

The maxillary first molar is brought into the correct intercuspation position by resting the mesiolingual occluding cusp in the central develop-

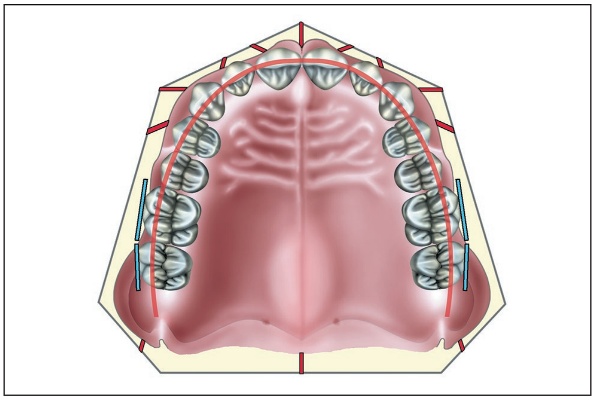


Fig 8-89 The maxillary dental arch forms a semi-ellipse. To achieve this, the second molar is twisted distally into the dental arch. Ellipsoid shaping of the dental arch is necessary so that the cheek is not pulled between the rows of teeth on mastication in the narrow buccal vestibular space.

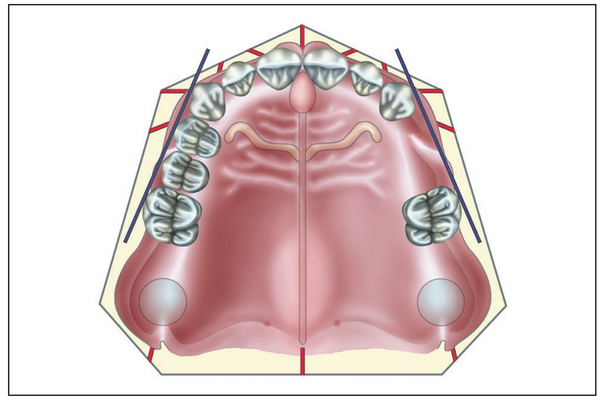


Fig 8-90 Two principles apply to setting up the maxillary incisors: placement on the center of the alveolar ridge and following the premolar tangent. The vestibular edges of the first molar and the canine are touched by a straight line, behind which the premolars stand; the buccal corridor should emerge.

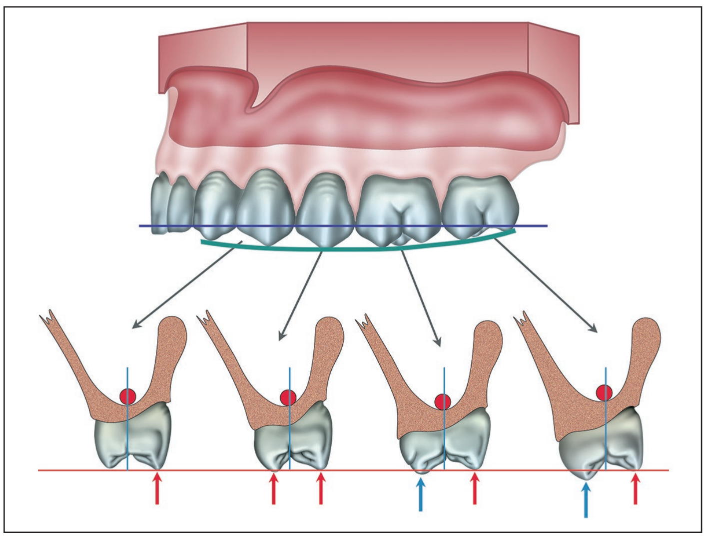


Fig 8-91 The approximal inclinations of the maxillary posterior teeth should be selected so that the palatal occluding cusps have occlusal contact in the central areas of the mandibular teeth. The first premolar stands over the ridge line so that its palatal cusp is shorter than its buccal cusp; in the case of the second premolar, both cusps are at the same height; the occluding cusp of the first molar is longer than the buccal nonsupporting cusp (shear), a relationship that is further accentuated on the second molar. From the vestibular view, the buccal cusps follow the compensating curve and project beyond the occlusal plane caudally.

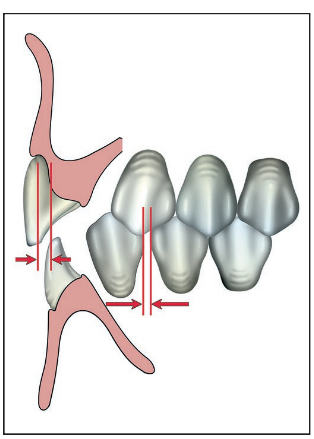


Fig 8-92 If the overjet is small but the maxillary anterior width is large, a space between the mandibular canines and first premolars will become necessary on both sides. If the anterior teeth are set up first, the mandibular premolars and the maxillary first premolar must be placed in an antagonist pairing to identify where and how much of a space needs to be left.

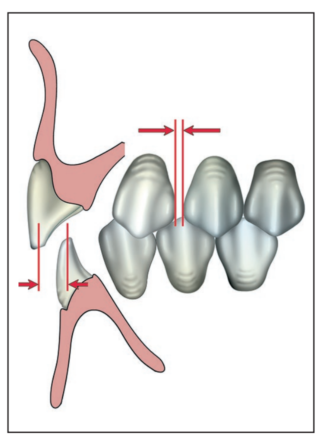
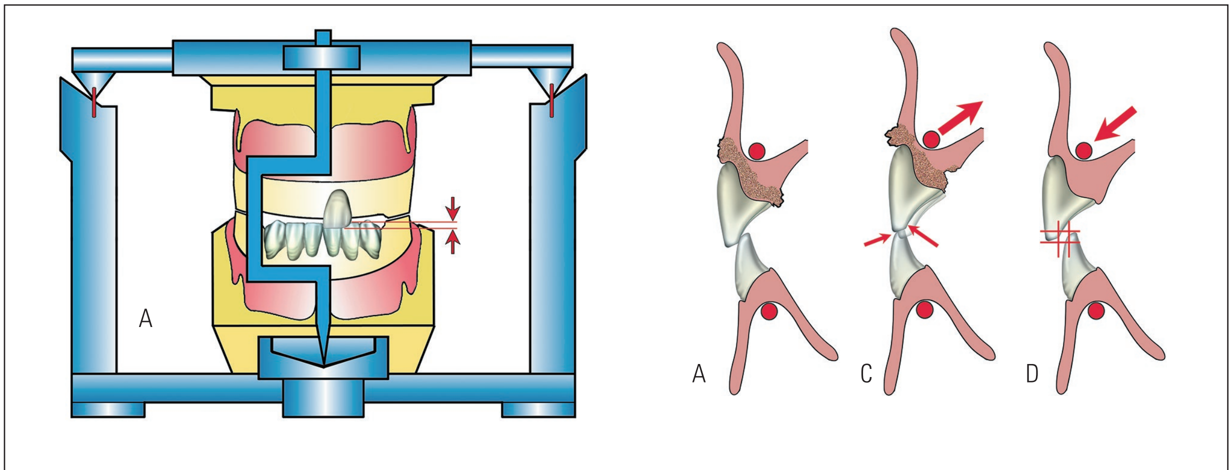


Fig 8-93 If the maxillary anterior teeth are too narrow and the overjet is very wide, a space will form between the maxillary canine and the first premolar. This space is often referred to as a *primate space*. In any case, it is advisable to leave a slight gap between the posterior teeth during setup so that the individual antagonist pairings can be placed in an interference-free intercuspation position.



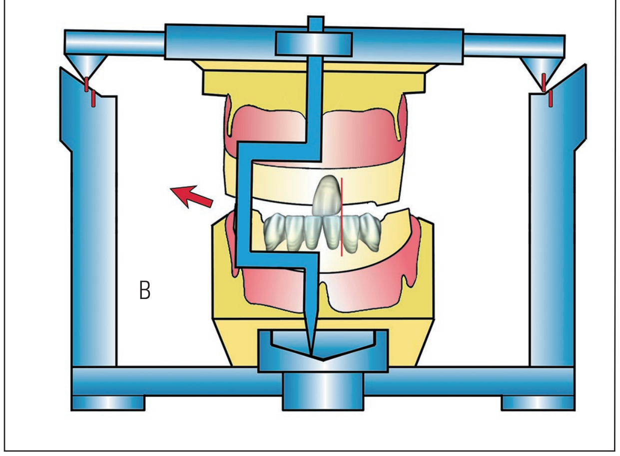


Fig 8-94 The overjet is constructed by reference to a defined excursion: Once the mandibular anterior teeth have been set up, the maxillary central incisor is placed in the soft wax in its position, precisely on the midline with an overbite (approximately 2 mm) (A). A lateral movement guided by the incisal guide table is then performed until the distal approximal edges of the maxillary and mandibular central incisors are in alignment (B). In the process, the maxillary central incisor is pressed in a vestibular direction; in this lateral position, it is pressed to the edge-to-edge position in the soft wax (C). If the excursion is reversed, the maxillary central incisor will lie in the correct overjet (D).

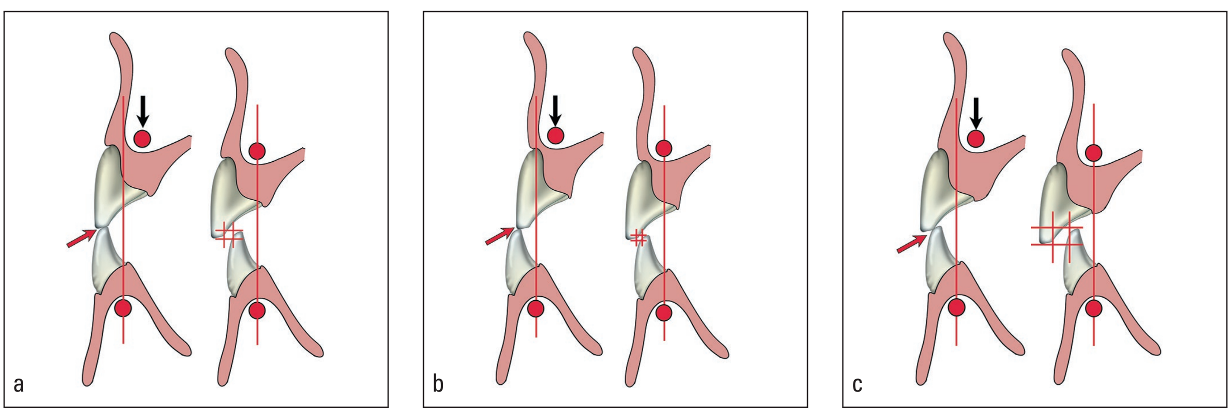


Fig 8-95 The size of overjet can vary within the aforementioned excursion if the contact situations of the abraded incisal edges are altered: *(a)* Setting the abraded incisal edges exactly to edge-to-edge contact will produce an average amount of overjet. *(b)* If the maxillary central incisor is placed with the vestibular edge of its abrasion facet on the lingual edges of the abraded cutting edges of the mandibular antagonists, a very small overjet will be created. *(c)* If, on the other hand, the maxillary central incisor is placed with the lingual edge of its abrasion facet on the vestibular edges of the abraded cutting edges of the mandibular teeth, a wide overjet will result.

mental groove of its antagonist. Its distolingual occluding cusp lies in the interdental embrasure between the mandibular first and second molars. The mesiobuccal facet with the labial contour of the canine forms the premolar tangent on which the premolars lie.

The second molar is fitted into its correct intercuspation position. Keeping the second molar inside the ellipsoid dental arch can pose problems. If a buccal overbite is dispensed with and an edge-to-edge position is chosen instead, the correct position within the dental arch can be achieved. The compensating curves are determined by the position of the mandibular teeth. If a complete antagonist contact is created, the transverse compensating curve is clearly identifiable from the maxillary teeth.

The central developmental grooves of the maxillary posterior teeth—as in the mandibular dentition—form a roughly straight line that lies over the middle of the alveolar ridge.

As a departure from tooth-to-tooth setup, the mandibular dentition can be set up and ready, and then the maxillary first molar can be placed in its position so that the premolars can be brought into the space. This gives rise to a space between the canine and first premolar if the occlusion or the different widths of the anterior teeth demand it; if a space becomes necessary in the mandible, the setup of the mandibular posterior teeth must be repeated.

Error analysis

To check tooth position, lateral and protrusive movements are executed, during which the described sliding contacts must arise without the incisal guide pin lifting off the guide table. Each antagonist pairing is checked and corrected until sliding contact exists during all eccentric movements; only then is another antagonist pairing set up. The interdental embrasures, the oral and vestibular intercuspation, and the curvature of the compensating curves are checked and corrected.

If balancing contacts are missing, the oral intercuspation may be defective, or the transverse compensating curve will have to be strengthened. If working-side contacts are missing, the vestibular intercuspation may be defective, or both compensating curves are too pronounced. The first antagonist pairing (mandibular premolars and maxillary first premolars) may already point to this error. If the buccal cusp of the maxillary first premolar glides into the interdental embrasure, it should retain contact with both antagonists. If the sagittal curve is too pronounced, a gap with the mandibular second premolar will occur, which should be raised by exactly the width of the gap. In this way, the sagittal compensating curve can be corrected.

Retention of Complete Dentures

The main problem when restoring edentulous jaws lies in ensuring that the complete denture has secure enough retention when in the rest position and when functioning. Complete dentures are supported on the dental arch without mechanical anchorage, whereby static relationships and dynamic processes influence functioning capability. Retention of the complete denture is affected by anatomical and physical realities, including the quality of the underlying tissue (Fig 8-96). Adequate retention must be provided against withdrawal forces.

These withdrawal forces may be lever forces arising from masticatory function, traction forces due to sticky foods, or the weight of the denture itself. Denture retention onto the dental arch can usually be achieved without additional aids, purely by the effect of suction, forces of adhesion and cohesion, and mechanical retentions from undercut parts of the jaw.

The denture margins and body can be prepared with such accuracy of fit by means of a precise functional impression that the denture is firmly retained. The quality of the retention can be measured by the way in which the denture rest area—the tissue of the jaw—is protected and how effectively the denture is protected against withdrawal forces.

The following physical factors influence retention of a complete denture:

- Adhesive and bonding effect
- Accuracy of fit
- Stable support
- Mechanical retentions

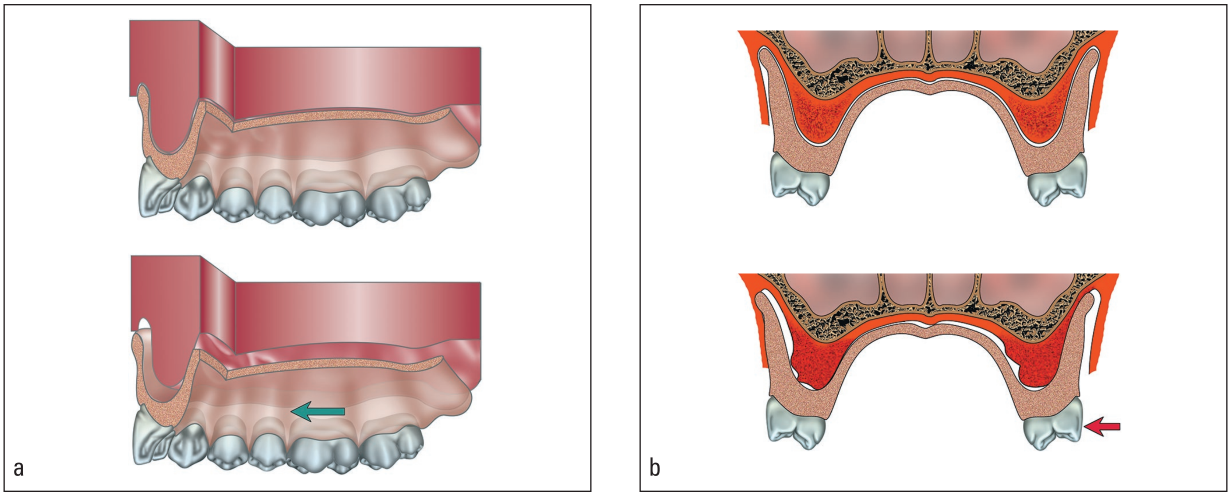


Fig 8-96 Horizontal positional stability depends on the underlying tissue. In the case of flabby ridges *(a)*, where the ridges consist of tough connective tissue only, the dentures can be displaced transversally and sagittally on very strong compression of the mucosa. High, well-preserved alveolar ridges are the prerequisite for good denture retention. This is because the denture can still be shifted when the bony support with uniform mucosal covering is not high and its shape offers no mechanical retentions *(b)*. Denture movements and compression of the mucosa will accelerate bone resorption.

- Effect of suction
- Statics of denture design

Adhesive and bonding effects due to forces of adhesion and cohesion are crucial to retention of a complete denture. There is saliva in the gap between the mucosa and the denture base, which creates adhesive forces to the denture acrylic on the one hand and to the tissue on the other. This form of retention can be illustrated by the example of two glass microscope slides.

Adhesion refers to the forces of attraction between the molecules of two bodies. The closer these two bodies are brought together, the greater the force. The size of the gap between the bodies can usually be filled with the easy-to-move molecules of a liquid substance, so that the adhesive effect happens via these molecules and, as shown by two wet glass slides, can produce enormous forces. The adhesive force of the denture base is consequently greater if the gap is very small (that is, the accuracy of fit of the denture is very great).

Cohesion refers to the force of attraction between the molecules of a substance. Cohesive force arises through the saliva. This cohesive force is relatively strong with a thick viscous saliva but can be further increased by suitable adhesive agents (adhesive powder). Adhesive and bonding effects always act together, namely adhesive force between saliva and the denture or tissue and cohesive force in the saliva.

Accuracy of fit increases the capillary action of the aforementioned forces due to adhesion and cohesion. The more tightly the denture base fits to the mucosa, the more effective is the capillary action and the effect of suction. Good accuracy of fit also prevents any adverse dynamic behavior of the denture while functioning; that is, during chewing function or when the wearer is speaking, a very accurately fitting denture will not slip to and fro on the mucosal support as much as an ill-fitting denture, which will produce sore spots.

Stable support from a relatively firm denture-bearing area is necessary for secure retention of a complete denture. A bony alveolar ridge with minimally resilient mucosal covering is best suited as support for a denture. On a mobile support (flabby ridge) comprising tough connective tissue, a denture will be displaced and levered off. Denture movements counter to jaw movements produce areas of opposing pressure loading, leading to substantial pressure sores.

Mechanical retentions are undercut areas of the alveolar ridge on the jaws into which the denture bases have to be extended. In the maxilla, these

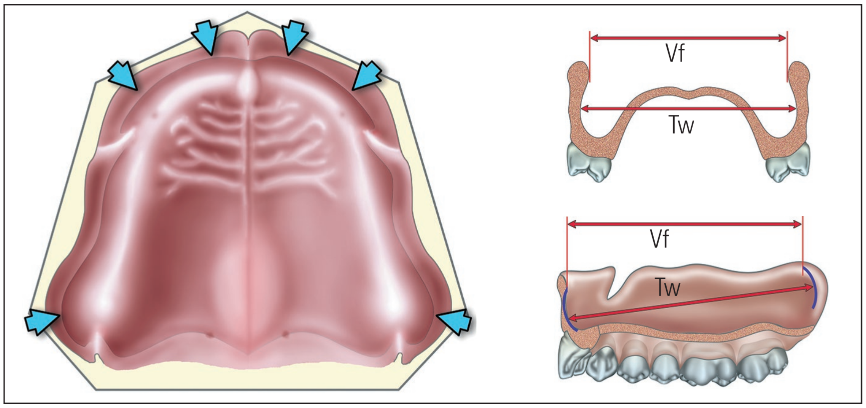


Fig 8-97 In the maxilla, the mechanical retentions on well-preserved alveolar ridges are found in the undercut anterior vestibular areas and the buccal vestibular areas. These areas act as mechanical retentions but only interact when the width of the vestibular fornix (Vf) is less than the tuberosity width (Tw); therefore, the anterior areas do not become effective until the dorsal retentions are also present.

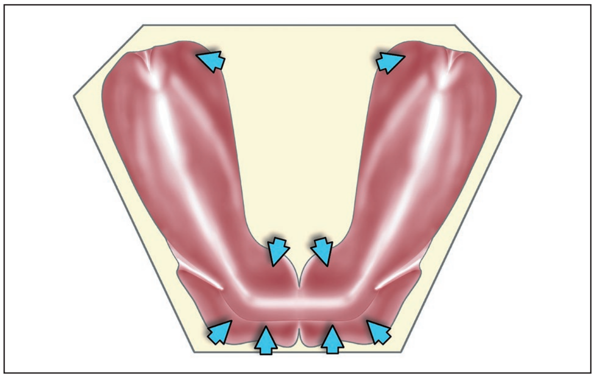


Fig 8-98 In the mandible, well-preserved alveolar ridges in the anterior vestibular area are undercut and offer mechanical retentions. If the denture base is extended into the sublingual areas, the downward pressure of the tongue may serve as mechanical retention. The paralingual areas are always undercut and can be used as mechanical retentions if appropriate impressions are taken.

areas include parts of the left and right tubercles, between tubercle and anterior alveolar ridge, and sometimes the entire vestibular area (Fig 8-97). In the mandible, the undercuts include the anterior parts of the alveolar ridge and the retromolar wings (Fig 8-98). These morphologic features of the jaws can be described as extension options.

Suction Effect

A suction effect arises because a space filled with rarefied air gets smaller because of the effect of normal atmospheric pressure. The effect can be illustrated by a suction pad: If a rubber pad is pressed onto a smooth surface, its edges offer a tight marginal seal. The pressure difference arises because the rubber pad that is deformed when it is pressed will try to upright itself because of its elasticity. Hence a small gap of rarefied air is formed between the pad and smooth surface. Atmospheric air pressure presses the edges of the rubber pad onto the smooth surface. If the pad is pulled perpendicular to the surface, the rarefied air space and hence the pressure difference will get bigger and the pad will stick more.

The functional margin in a denture acts like the edges of the suction pad, producing a space that is closed on all sides (Fig 8-99). To achieve this suction effect with a denture requires this closed space on all sides, which can be made bigger by withdrawal forces and gives rise to the rarefied air space. Atmospheric air pressure becomes effective because of withdrawal force as it tries to restore the original spatial dimensions. If the denture is pulled off vertically, the space between the jaw and the denture base will increase. In the small amount of air found in the saliva within this space, a pressure difference occurs in response to higher outer pressure and creates a suction effect. This suction effect is greatest when subject to axial forces (withdrawal forces perpendicular to the suction surface); in other words, flat jaws

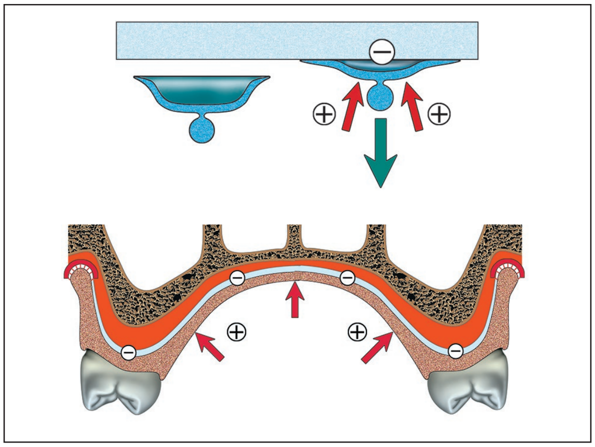


Fig 8-99 In the same way as a normal suction cup, the suction effect of a complete denture arises as the space between the denture and tissue is enlarged when the denture is pulled off its support. In the case of a suction cup, pre-tension caused by the elasticity of the pressed-on rubber holds the cup onto the smooth surface. In the case of a denture, the suction force only ensues when external pulling forces increase the size of the space. The denture margin in the vestibular fornix must provide an airtight seal, as with a suction cup. It therefore becomes necessary to shape the functional margins as valve margins.

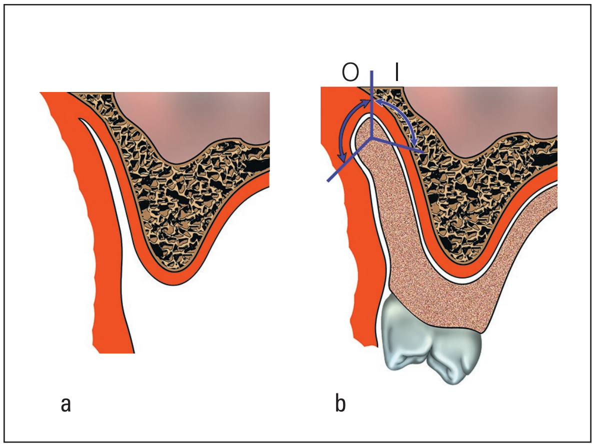


Fig 8-100 In the rest position, the vestibular fornix is a narrow space in which the mucosal parts touch each other *(a)*. The entire functional margin of the denture *(b)* must be shaped as a valve margin. A distinction is made between the outer valve and the inner valve. The outer valve (O) arises when the mucosa is displaced out of the rest position in the vestibular direction by the wide denture margin and is stretched around the functional margin. The inner valve (I) is the area of immobile mucosa from the depth of the vestibular fornix up to the alveolar ridge.

are not unfavorable but need to be better protected against axial forces.

A valve-type margin is a specially shaped functional margin to a complete denture base. The vestibular fornix in the rest position is a narrow space in which the mucosal parts touch each other (Fig 8-100). Therefore, a denture margin in the transitional area from attached to mobile mucosa, having been shaped, smoothed, and rounded according to a functional impression, may slightly displace the mucosa that is pulling toward the vestibule. The mucosa is slightly stretched and remains at the denture margin during denture movements. The denture margin forms the valve-type seal throughout its course, with a distinction being made between an outer valve and an inner valve. The inner valve is the area of the immobile mucosa from the depth of the vestibular fornix up to the alveolar ridge. The outer valve is formed when the mucosa is displaced out of the rest position toward the vestibule by the broad denture margin and is stretched around the functional margin. The denture margins should not be so wide that they cause pressure points to develop on loading because of the space they occupy.

The more accurately and more extensively the valve margin (especially the outer valve) is shaped according to the functional impression, the more effective the valve margin. The surface of the outer valve can be enlarged by suitable shaping of the outer surface of the denture so that the pressure-equalizing air travels a longer distance. The inner valve can be effectively created if the mucosa in this vestibular fornix area is also displaced out of the rest position toward the bony support and is thereby placed under tension.

Etched lines marking the vibrating line on the dorsal edge of the baseplate of the maxillary denture complete the valve margin (Fig 8-101). The vibrating line is etched in place so that the edge of the plate presses into the mucosa. The etching can be shaped in various ways. To prevent retching by the patient, the contour of the etching should ideally be adapted to the bony support; that is, it should be flat, should rise dorsally, and then should be sunk into the transition from hard to soft palate. The etching should be about 2 to 3 mm wide and about 1 to 1.5 mm deep. The acrylic resin plate can be gently tapered so that a smooth, dorsal transition is formed from den-

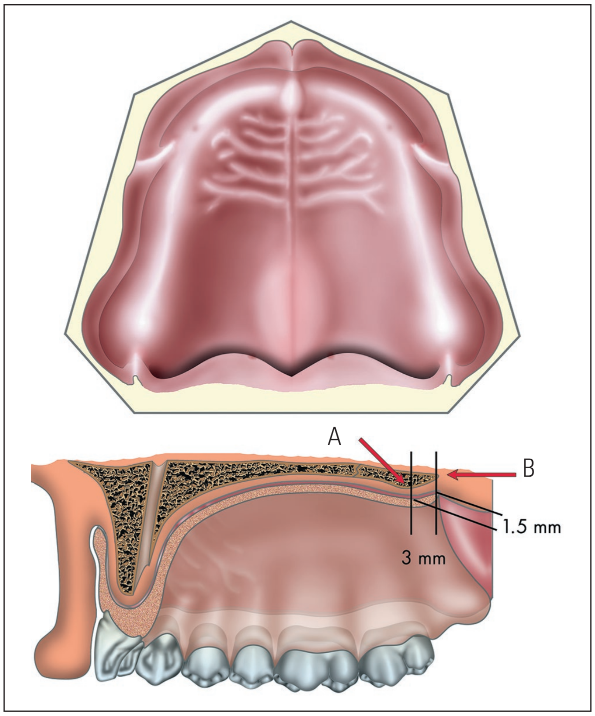


Fig 8-101 The dorsal edge of the maxillary complete denture is etched to complete a circumferential valve margin. As in the vestibular area of the margin, the mucosa must be displaced out of the rest position. For this purpose, a 3-mm-wide and 1.5-mm-deep groove falling continuously in the dorsal direction is etched directly at the transition to the soft palate. The path of the vibrating line becomes visible in the functional impression if the soft palate is moved during impression-taking by the patient's swallowing or pronouncing "ah" or by the nose-blowing effect. As a result, the position of the posterior nasal spine of the palatal bone becomes visible; this should definitely be taken into account because the palatine suture is thickened here (A). This etching of the vibrating line (ah line) must follow the dorsal edge of the bone precisely to avoid pressure points. It is worth noting that the dorsal edge of the bone is beveled cranially and ends in a sharp edge (B), which meets the etching of the vibrating line.

ture to mucosa. Etching of the vibrating line, as well as the effect of the valve margin, should also compensate for any inaccuracy of fit of the dorsal plate edge caused by shrinkage of the acrylic resin. Even if shrinkage is largely offset by re-pressing devices for acrylic polymerization and accuracy of fit is improved, it is still advisable to etch a vibrating line to complement the valve margin.

Additional etchings on the surface of the palate can increase retention of the maxillary denture base. Etching additional ridges will divide the entire retentive surface into several compartments with their own separate retentive effect. Tools with different profiles may be chosen for this purpose. Etched lines should be placed so that the bony support is not damaged.

Extension Options

Extension options are the design principles involved in extending denture bases into mucosal areas so that masticatory forces are distributed according to the snowshoe principle and additional retention is created for the denture base.

In the maxilla, it is mandatory to encompass the entire vestibule with the denture base right into the buccal vestibular spaces. This includes the maxillary tubercle, which is not affected by atrophy after tooth loss and can offer excellent support. In individual cases, the denture body may be extended buccally into the cheek area to accommodate the posterior teeth, so that the buccal mucosa creates additional retention for the denture.

Shaping the outside of the denture to ensure denture retention includes the sparing, smooth reproduction of the alveolar eminences as well as the creation of a circumferential channel directly above the valve or functional margin. Allowing for reduction needs, the buccal and labial mucosae, along with their muscle bundles, can settle here and support the denture. The outer surface of the denture body in the anterior region is shaped to grip muscle; this is done by constructing lip shields for the orbicular muscle of the mouth. In the posterior region, buccinator rests should be created, and the muscle tracts to the buccal frena should be traced (Figs 8-102 and 8-103). Due regard should be given to reduction needs (Fig 8-104).

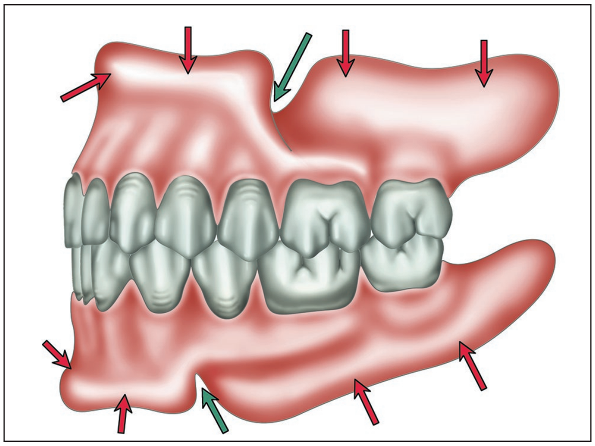


Fig 8-102 The outer surfaces of the denture body are shaped to grip the muscles; that is, lip shields are prepared for the orbicular muscle of the mouth, in the posterior region buccinator rests are created, and the muscle tracts to the buccal frena are traced. Reduction needs should be taken into consideration.

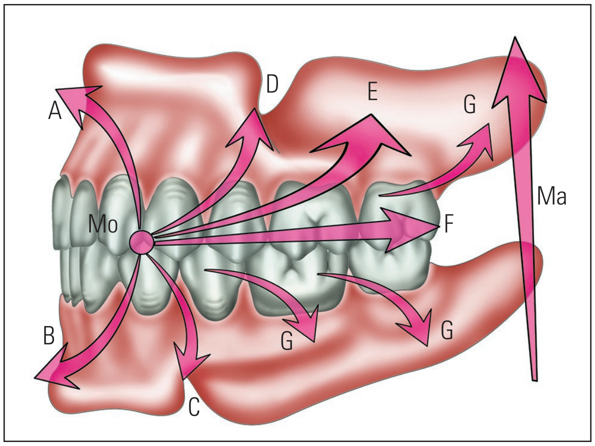


Fig 8-103 The course of the muscle tracts originating from the modiolus (Mo) allows shaping that grips the muscles: The tract of the orbicular muscle of the mouth (A + B) engages in the lip shields. The levator and depressor anguli oris (C + D) pull toward the buccal frena. The major zygomatic muscle (E) pulls with parts of the buccinator (G) toward the zygomatic crest. The risorius muscle (F) also runs with parts of the buccinator (G) backward and toward the oblique line. The masseter (Ma) overlays the buccal vestibular space.

In the mandible, the retromolar triangle or the mandibular tubercle is enclosed on both sides to support the denture and enlarge the base. These dorsal ridge areas can be slightly restricted by a well-developed pterygomandibular raphe, which is tightened when the mouth is opened and levers off the denture. Therefore, the dorsal limit of the margin must be suitably reduced here.

Sublingual pockets (in the anterior sublingual space) can be covered with a so-called sublingual roll (Figs 8-105 and 8-106). This is a horizontal extension of the denture margin under the tongue into the area of the premolars. Vertical extension would have the opposite effect and would actually cause the denture to lift off during tongue movements. Horizontal extension of the margin considerably increases the retentive effect of the denture. The functional impression involves taking an extension impression of the anterior sublingual space without impeding tongue movement and while sparing the lingual frenum.

Paralingual pockets (posterior sublingual spaces) are located on both sides in the dorsal lingual area under the retromolar triangle. These are usually undercut areas behind the mylohyoid line into which retromolar wings of the denture base engage and, as mechanical retention in combination with the undercut ridge parts of the anterior region, can secure retention of the mandibular denture (Fig 8-107). The size and the shape of this retromolar region are limited by the movement of the root of the tongue.

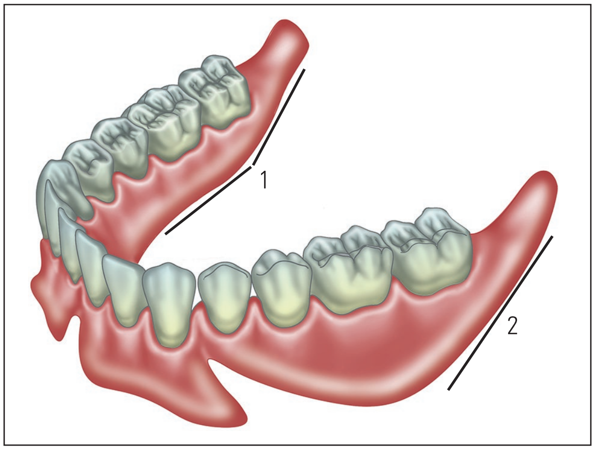


Fig 8-104 A normally shaped mandibular denture that makes allowance for reduction needs ([1] mylohyoid line, [2] oblique line) has a slim mucosal rest. If the denture base is enlarged into the extension spaces, excellent mechanical retentions are achieved in undercut areas of the jaw.

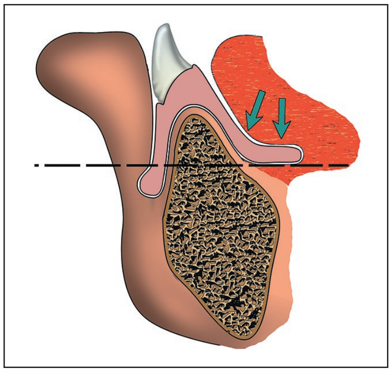


Fig 8-105 The sublingual space can be filled by an extended denture margin so that the tongue can stabilize the mandibular denture by its own weight. It is inadvisable to extend the denture margin vertically because this will displace the floor of the mouth and impede movement of the tongue.

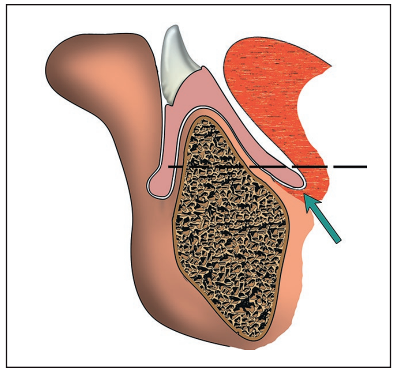


Fig 8-106 Extending the denture margin in the horizontal plane under the tongue does not impede the floor of the mouth and therefore fulfills the function of an additional retentive aid because the weight of the tongue can press the denture downward. A denture margin extended in this way is known as a *sublingual roll*.

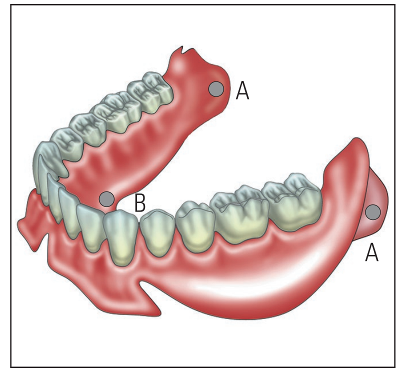


Fig 8-107 An individual impression must be taken of the paralingual areas (A), which provide space for the retromolar wings on the denture. The vestibular undercuts on the anterior ridges form usable supports for the retromolar wings. The sublingual spaces (B) can be used for the sublingual roll.

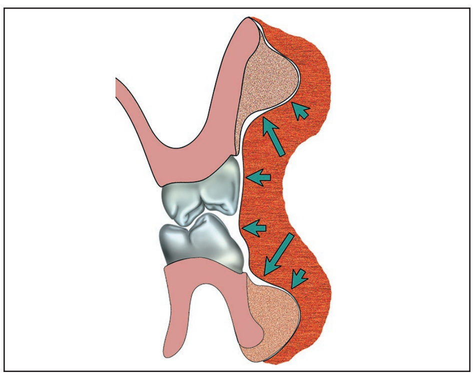


Fig 8-108 In the posterior region, the denture body can be extended into the buccal space so that the cheek can lie on these convexities and give the denture additional retention. The buccinator support starts above the vestibular fornix. In the mandible, the buccinator support can be extended vestibularly over the oblique line. A suitable impression is always the foundation for shaping these accessory retentive aids.

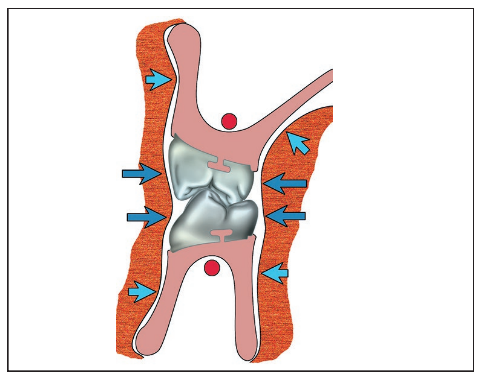


Fig 8-109 The posterior teeth are placed so that they do not impede the cheeks or tongue. Thus, they are positioned over the middle of the alveolar ridge and are accompanied by balanced tongue and cheek tone. Balanced tone is the position of equilibrium between the resting tension of the tissues of the tongue and cheek. When the posterior teeth are accompanied by balanced tone, the patient cannot bite the cheeks or tongue.

Buccinator pockets are the posterior buccal spaces into which the denture margin can be extended by buccinator supports. In the same way as the sublingual roll, a horizontal extension can be created above the plate edge that has been trimmed in keeping with the oblique line; this extension takes the form of a rest for the cheeks, whereby the denture is pressed onto the dental arch (Fig 8-108).

Balanced muscle tone between the tongue and the cheek can aid retention of the mandibular denture if the teeth are set up so that the denture cannot be moved by these muscles and so that the patient does not bite his or her tongue or cheek (Fig 8-109). Typically, the teeth stand further lingually than they did before tooth loss for static reasons. Therefore, the space for the tongue is always slightly restricted. This is why manufac-

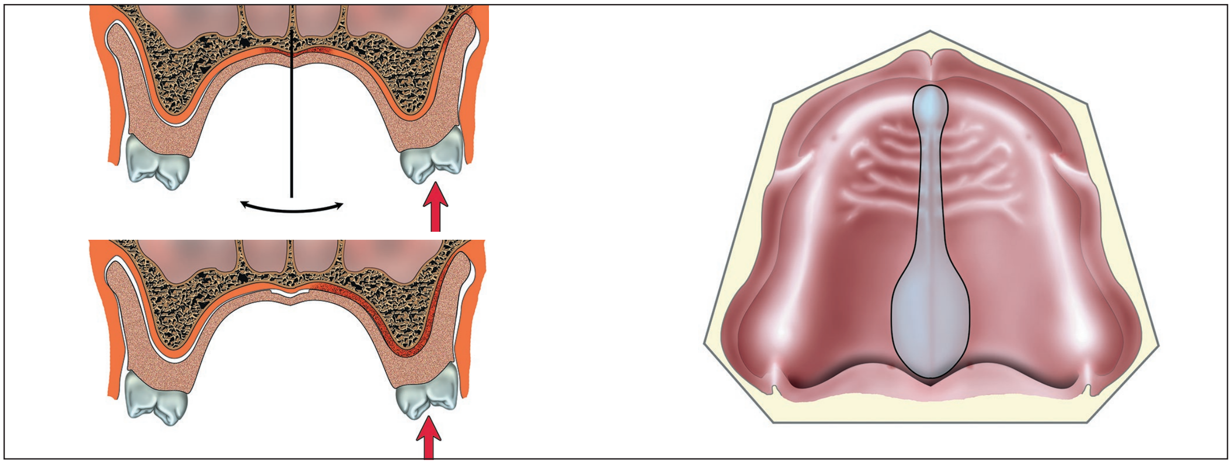


Fig 8-110 In the fibrous median area (palatine raphe and palatine torus), a rocking movement around the median palatine suture can occur when the denture is loaded on one side, and the denture margin may be lifted off on the unloaded side. Therefore, it may be advisable to hollow out this area so that the denture sinks in evenly and can be more heavily loaded. If the denture base is hollowed out in the area of the median palatine suture, an additional suction effect may arise because a vacuum chamber has been created. This effect is lost after a short time because the mucosa proliferates into the chamber.

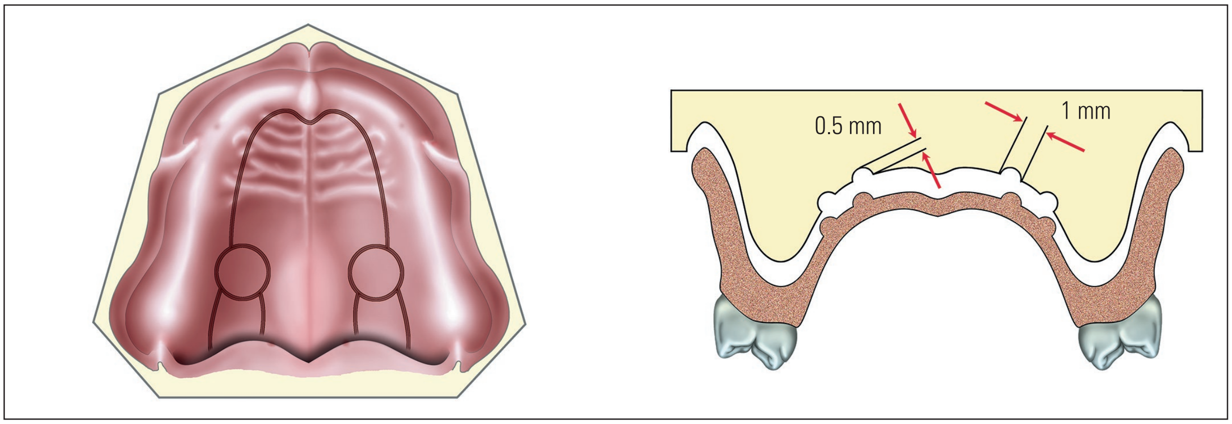


Fig 8-111 Retention of a maxillary complete denture can be improved by etching lines. The retentive surface is divided into areas of different sizes, forming separate retentive compartments. If air gets under the denture at the valve margin, the denture will still hold because the individual compartments can still have adequate negative pressure. The etching, in this case Frankfurt etching, is preferably done in the glandular and fat pad area. Vertical band etching is another method in which the whole alveolar ridge is encompassed by a circumferential ridge. The ridge is angular and about 1.5 mm deep. A vibrating line etching is also created. This form of etching has been used for flabby ridges and is not recommended for normal dental arches.

turers supply artificial teeth that have a smaller vestibular-lingual breadth than normal teeth.

Hollowing out the papilla, the palatine raphe, and the torus can increase the suction effect of a maxillary complete denture in the short term (Fig 8-110). A kind of suction chamber is formed, but this closes after a short wearing time due to proliferation of the mucosa. If lines are etched and hollowing out is done at the same time, the foils are guided over the etched lines up to the hollowed-out area.

The retentive force of the denture—due to the suction effect, the force of adhesion, and cohesion—is between 70 and 100 N if the accuracy of fit is good and the valve margins are functioning properly (Fig 8-111); on vertical withdrawal, this force may be considerably higher.

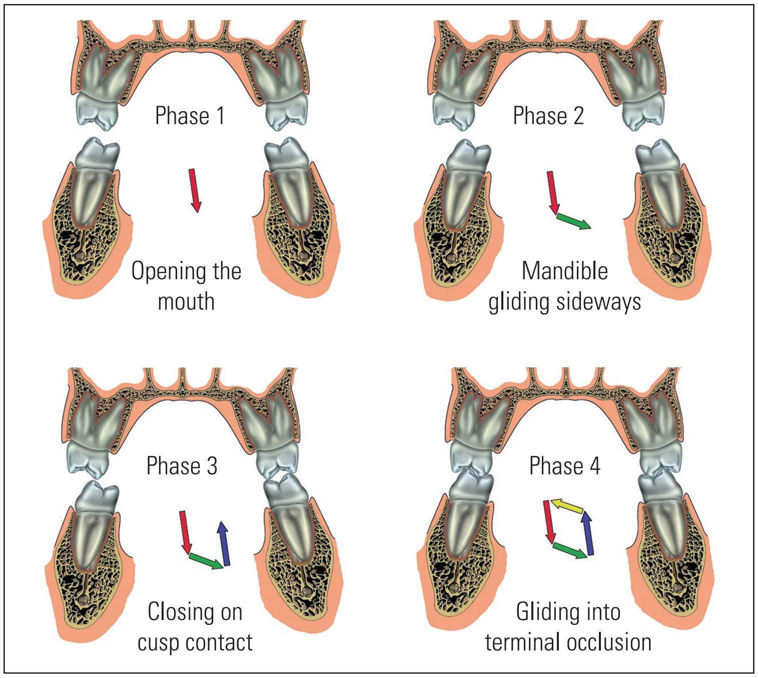


Fig 8-112 The movement sequence of the chewing cycle is described by Gysi as a four-phase round bite. The sequence of movements follows a fixed principle but is dependent on the consistency of the food and is therefore variable. Four phases are identified. The phases merge seamlessly. The fourth phase is of interest: gliding into terminal occlusion under masticatory force, during which balanced articulation is required for a complete denture according to Gysi.

Gysi's Working Method

The term *articulation theory* is closely linked to the name of Professor Gysi because he presented what he called the "articulation problem" in a 1908 publication. In that and subsequent publications, as well as through his teaching work, he studied and was the first to prove the functional relationship between tooth shape and tooth position, the TMJ, and mandibular movement. The proof was provided by long-term studies, experimental research, and statistical analyses, all of which laid down the principles of modern dental research.

Based on his research findings, Gysi developed a comprehensive and, in the truest sense, complete theory, which was applied to create instructions for the practical fabrication of dentures. According to Gysi, the chewing cycle involves a movement habit that depends on the consistency of the food and varies between individuals but follows a fixed principle: Food is crushed as sliding occlusal surfaces grind against each other. To do this, the mandible is brought into a slightly lateral position from which a grinding, sliding movement takes place into terminal occlusion.

According to Gysi, the four-phase round bite is the movement sequence involved in masticating food (Fig 8-112):

1. The first phase is opening the mouth to take in the food.
2. The second phase is a slight sideways gliding of the mandible to the chewing side to grasp the food.
3. The third phase involves closure of the mouth into approximate cusp-to-cusp contact, whereby the food is crushed but not ground.
4. The fourth phase involves gliding out of the lateral position into terminal occlusion, when the food is broken down into small pieces by the constant increase in masticatory force.

The single phases flow seamlessly into each other. Only the fourth phase is of interest, when the teeth on the chewing side glide into centric occlusion in full tooth contact and the mandible is guided not only by the joints but also by the occlusal pattern of the teeth. This tooth guidance becomes even clearer when looking at the process of biting off food: The mouth is opened and the mandible pushed forward to grip the food. If the

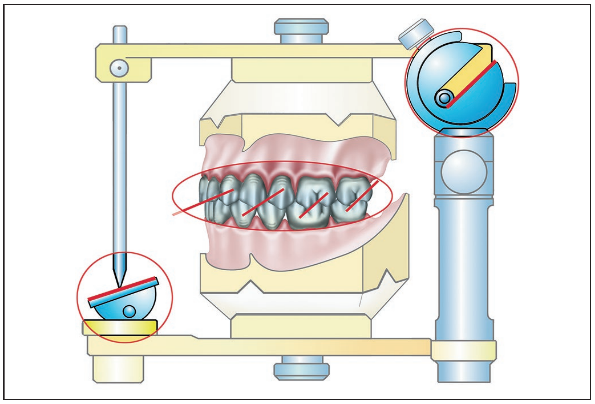


Fig 8-113 The guiding elements of mandibular movement, according to Gysi's mechanical explanatory model, are the joints and occlusal patterns of the teeth; the musculature is ignored. The occlusal patterns are combined in incisal guidance. With the joints, this forms a three-point support on which the upper arm of the articulator can be moved relative to the mandible. If the three guides are individually adjustable, each occlusal area can be reconstructed.

food now has to be sheared off, the incisors glide into centric occlusion under contact. To glide into terminal occlusion, the anterior teeth and canines guide the mandible into the correct position.

Guiding elements in mandibular movement are the TMJs and the occlusal patterns of the teeth (Fig 8-113). The occlusal patterns of all the teeth can be presented as a combined virtual guide plane: the incisal guide (surface).

The mandibular movements can be understood from the condyles and a fixed point on the incisors. It is noticeable that the condyle moves on a fixed path both forward and to the side, namely on the sagittal and lateral condylar paths. In the process, the fixed point on the mandibular incisors moves on the palatal surfaces of the maxillary incisors within what is known as the *sagittal and lateral symphysis path*. (The *symphysis point* and *mandibular incisal point* are considered synonyms for the anterior Bonwill triangle point.)

Gysi describes the sagittal and lateral symphysis path and condylar path as a functional unit with the cusp slopes of the posterior teeth and the inclinations and positions of the teeth inside the occlusal curves. In this context, these curves continued to be called curves of Spee, even though there was already evidence that the ideal form of the Spee curve, according to Spee's description, must be regarded as a special case.

Certain conclusions necessarily arise from these connections. If the chewing cycle involves fixed, recurring movements and the mandible is guided by the TMJs and the tooth shapes and positions, fabricating a fully functioning denture should follow these steps:

1. Initiate the mandibular movement.
2. Precisely reproduce the anatomical tooth shapes.
3. Position teeth relative to mandibular movement.

To put it simply, Gysi proved that precise reproduction of specific parts of the functioning masticatory system ensures the success of a denture.

Articulators according to Gysi

Gysi developed articulators for copying mandibular movements, which made it possible to simulate a close approximation of individual movements. The Simplex articulator is the best-known average-value device developed by Gysi (Fig 8-114). It allowed the essential mandibular movements to be executed on condylar paths with a sagittal inclination to the occlusal plane of about 33 degrees and a Bennett angle of roughly 15 to 17 degrees. Joint-related mounting of the models was possible in the average-value articulator. A key factor was that the incisal guide plate could be variably inclined between 0 and 55 degrees to handle patients' asymmetric condylar path inclinations.

Gysi's Trubyte articulator enabled the sagittal condylar path inclination to be set between 0 and 55 degrees, based on individual values, and an individual Bennett angle to be chosen between 0 and 20 degrees. These individual joint values had to be measured with a specially developed facebow and special tracing plates.

The tooth shapes Gysi went on to develop emulated the anatomical pattern and had cusp surfaces with a slope that was adapted to the condy-

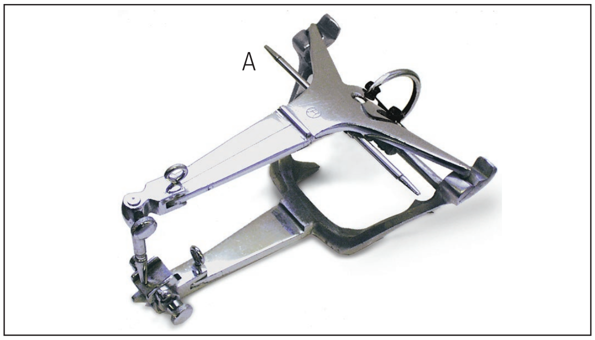


Fig 8-114 The Simplex articulator is an average-value articulator in which the Bennett movement is produced by dorsally positioned joints; the crosspiece located on the upper arm in front of the joint surfaces serves as the marking of the hinge axis (A).

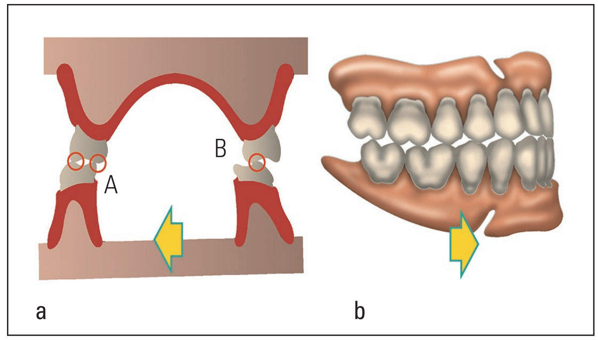


Fig 8-115 The term *balanced articulation* in the fourth phase of Gysi's round bite defines the working side (A) and the balancing side (B). The working side is the side into which the mandible is pushed, while there are tooth contacts on the balancing side that should prevent the unloaded parts of the dentition from being levered off *(a)*. When biting off food, sliding contacts on the posterior teeth in the protrusive position must prevent any tipping of the denture *(b)*.

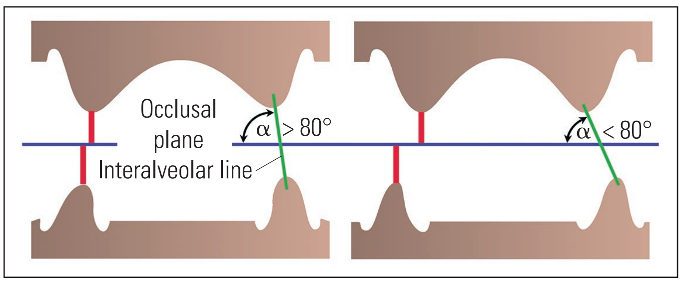


Fig 8-116 The varied shrinkage of alveolar ridges can pose a problem when setting up the posterior teeth. If the teeth have to be arranged on the ridge line according to the law of ridge lines, normal intercuspation may be disrupted. According to Gysi, a normal occlusion should be set up if the inclination of the interalveolar line to the occlusal plane is greater than 80 degrees, and a crossbite should be set up for inclinations less than 80 degrees.

lar path inclination. The Anatoform artificial teeth had a sagittal inclination of 32 degrees and a buccal and lingual inclination between 10 and 20 degrees; the molars based on Gysi had a sagittal inclination of 20 degrees and a lateral inclination of 3 degrees.

Gysi described tooth positioning relative to mandibular movement with the term *balanced articulation*, dividing the rows of teeth into the working side and the balancing side (nonworking side) during chewing (Fig 8-115). During chewing, the working side is the loaded side; Gysi described the nonworking (idling) side as the balancing side because the tooth contacts on that side were supposed to prevent the denture from being levered off or tipping during the fourth phase of chewing.

On protrusive movements, tooth contact in the anterior region is meant to be compensated for by balancing contacts on the terminal molars. The teeth must therefore have both a sagittal and a transverse occlusal curve, thereby compensating for the Christensen phenomenon. These dental arch forms that Gysi called compensating curves also had to be replicated when setting up the teeth. The aim was to achieve three-point contact during lateral and protrusive movements, which, distributed over the entire dentition, had one contact in the posterior region on each side and one contact in the anterior region.

The static conditions affecting the denture body in relation to the shrunken alveolar ridges had to be taken into account during setup of the teeth. In the law of the ridge line, Gysi required the artificial teeth to be set up over the center of the alveolar ridges in a statically stable position to prevent lever effects caused by the denture body (Fig 8-116).

Crossbite setup in the posterior region becomes necessary if the lines connecting the ridge centers are at an angle less than 80 degrees to the occlusal plane. This connecting line and angle are known as the *interalveolar line* and the *interalve-*

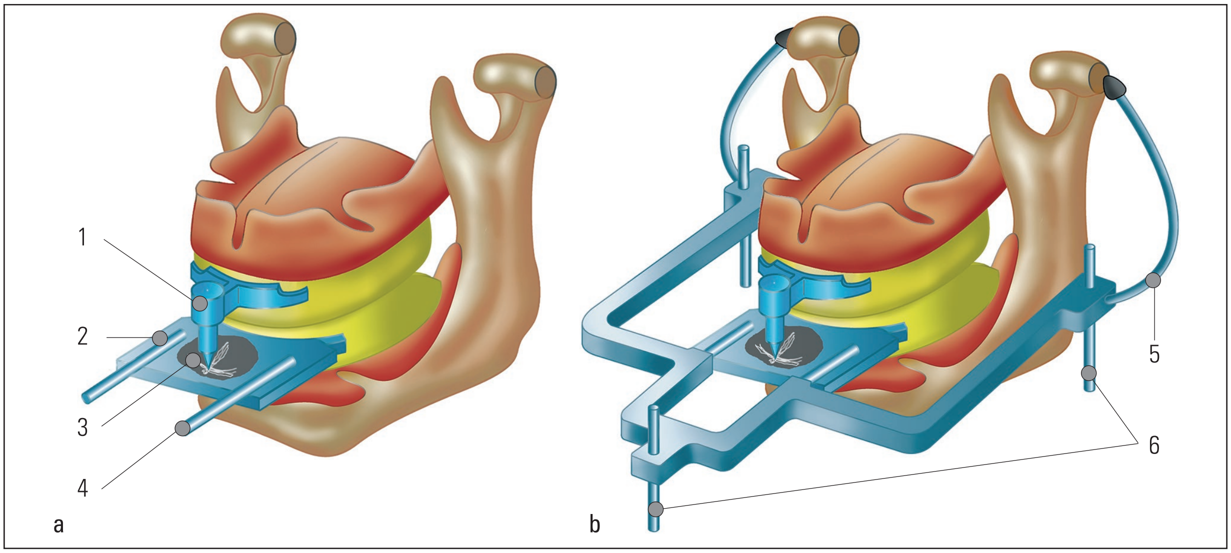


Fig 8-117 Extraoral occlusal registration is an attempt to regain centric occlusion with suitable registration kits and, using a facebow, to carry out joint-related mounting of the casts in the articulator as well as survey the condylar paths. *(a)* The tracing pin (1) is mounted on the maxillary occlusion rim and the tracing plate (2) on the mandibular occlusion rim; the registration wax (3) for tracing mandibular movement is located on the mandibular tracing plate with the facebow mounting pins (4). *(b)* The facebow is mounted on the pins, and the flexible condyle indicators (5) are aligned with the condylar points of the patient. Adjusting pins (6) are fitted onto the facebow; these are height adjustable so that the bite plates can be brought into the correct height when plastering up in the articulator.

olar angle, respectively. In conclusion, Gysi gave working instructions for fabricating complete dentures. A functional impression with custom trays is first required, and then a precise interocclusal registration.

Gysi described and recommended extraoral occlusal registration (Fig 8-117). This involved molding occlusion rims out of stent material (thermoplastic impression material) and setting them onto the bite plates over the center of the alveolar ridge to the exact vertical dimension of occlusion so that they contact in the occlusal plane. A tracing plate was then mounted on the mandibular occlusion rim and the tracing pin onto the maxillary occlusion rim.

The tracing plate and tracing pin protruded out of the mouth and enabled mandibular movements to be checked, during which the Gothic arch was traced into the registration wax. The tip of the Gothic arch indicated the position of centric occlusion. The bite plates were fixed in this position.

As positional indicators for the teeth, the occlusion rims had to be padded to reflect natural lip volume so that the middle of the face could then be traced on the occlusion rims as well as the lip closure line, the canine points, and the smile line of the upper lip, thereby establishing tooth length and width (Fig 8-118). These tracings then had to be transferred to the models, and the tracing of the sagittal inclination of the posterior mandibular ridge had to be added.

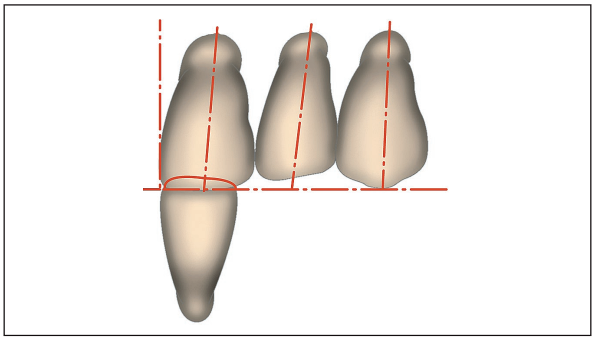


Fig 8-118 The maxillary anterior teeth are placed on the occlusal line and stand with their labial contours on the outer contour of the wax occlusion rim, which has been padded to reflect lip volume. The inclinations of axis are located. The mandibular central incisor should be in contact with its antagonist without an overjet.

Surveying the condylar path

It was possible to fit a facebow onto the tracing plate of the mandibular bite plate in order to allow joint-related mounting of the models in the articulator. The flexible ends of the facebow were aligned with the patient's condylar points and represented the spatial relationship between the condyles and the occlusal plane. The facebow could be adjusted in the articulator with the tracing plate, bite plate, and mandibular model in such a way that the flexible ends pointed to the condyles of the device and the mandibular incisal point on the bite plate coincided with that of the articulator.

The facebow technique permitted individual surveying of the condylar paths and occlusal registration, the sagittal course of the condylar paths actually being traced with the flexible ends of the facebow during Gothic arch tracing. To do this, two tracing plates were placed on either side of the patient's head, and the black lead pencils on the flexible ends of the facebow traced the sagittal course of the condylar path onto the tracing plates. The inclination of the condylar path to the occlusal plane could then be determined by simply measuring the angle.

This description of Gysi's articulation theory only provides a historical perspective but also illustrates his thoroughness, consistency, and systematic working method, which remains exemplary to the present day. After phases of hostility and defamation, expert opinion now asserts the importance of his theory. The methods commonly used today for fabricating complete dentures—in terms of their compendium-type setup rules and their explanatory constructs—represent a refinement of Gysi's ideas or partial concentration on certain working methods based on this theory.

The criticisms of Gysi's articulation theory arose because certain anatomical facts allow for other interpretations. For instance, Gysi considered the balancing contacts to be the ideal form, including in natural dentitions, and interpreted missing contacts as a degenerative deformation of the dentition. Critics deduced from this that the theory was incorrect. The high-cusp teeth were criticized because they lacked the physiologic and functional abraded grinding surfaces. The position of the maxillary anterior teeth and the lack of overjet were also criticized because this supposedly gave rise to unsatisfactory esthetics and statics of the maxillary denture.

Setup instructions

Gysi developed precise instructions for fabricating complete dentures, among which the setup rules are of interest to dental technicians. They establish the position of the teeth and the setup sequence:

1. The maxillary anterior teeth are placed on the occlusal line and stand with their labial contours on the outer contour of the wax occlusion rim, which has been padded to reflect lip volume. The inclinations of axis visible from the vestibular aspect are identified.
2. The mandibular anterior teeth should stand in contact with their antagonists without overjet. Once again, the inclinations of axis visible approximally and vestibularly are established.
3. The approximal inclination of the maxillary anterior teeth is also established. Accordingly, the labial contours of the canines stand vertically, and their tooth axes have a clearly vestibular inclination (Fig 8-119).
4. The first premolar in the maxilla contacts the occlusal line with its buccal cusp; this line is simulated by a glass plate. A small space is possible between the canine and the first premolar (Fig 8-120).
5. The maxillary second premolar contacts the occlusal line with both cusps (Fig 8-121).
6. The maxillary first molar touches the occlusal line with its mesiopalatal cusp (Fig 8-122).
7. The second molar has no contact with the occlusal line, in keeping with the compensating curve (Fig 8-123).
8. The mandibular anterior teeth are placed on the ridge midline with their incisal edges at the same height. The labial inclination of axis shows a mesial tendency, and the approximal inclinations are established. The mandibular dental arch is thus developed (Fig 8-124).
9. The mandibular first molar is first placed in its correct position (Fig 8-125).
10. Only then are the remaining teeth set up (Fig 8-126).

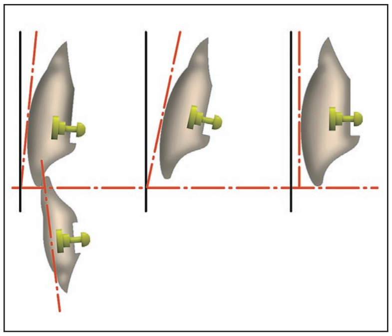


Fig 8-119 The approximal inclination of the maxillary anterior teeth is also established, Gysi referring to the labial contour in their inclination and not the tooth axis. Accordingly, the canines stand with their tooth axes showing a clear vestibular inclination.

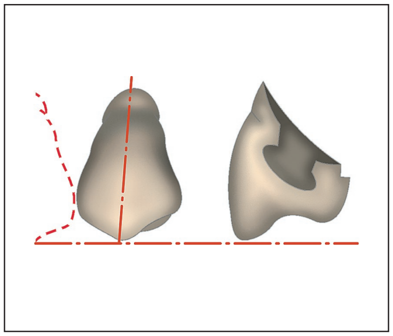


Fig 8-120 The maxillary first premolar touches the occlusal line with its buccal cusp. A small space between the canine and first premolar is possible.

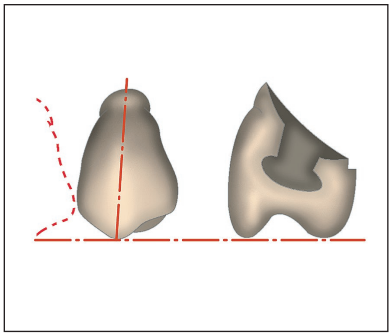


Fig 8-121 The maxillary second premolar contacts the occlusal line with both cusps.

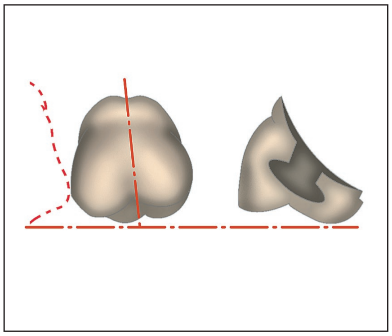


Fig 8-122 The maxillary first molar touches the occlusal line with its mesiopalatal cusp.

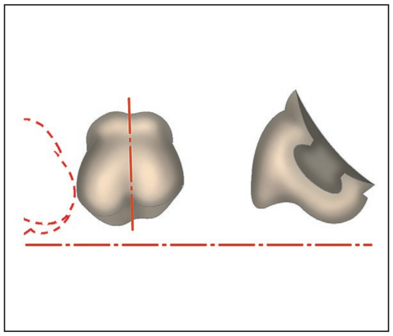


Fig 8-123 The second molar has no contact with the occlusal line, in keeping with the curve of Spee.

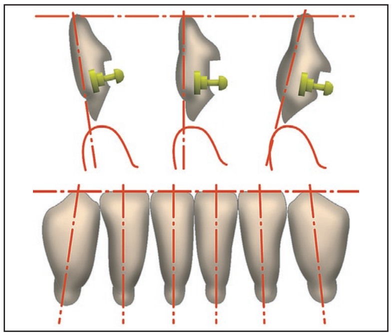


Fig 8-124 The mandibular anterior teeth stand on the center of the ridge with their incisal edges in a straight line. The labial inclination of axis shows a mesial tendency, and the approximal inclinations are established. The mandibular dental arch is thus developed.

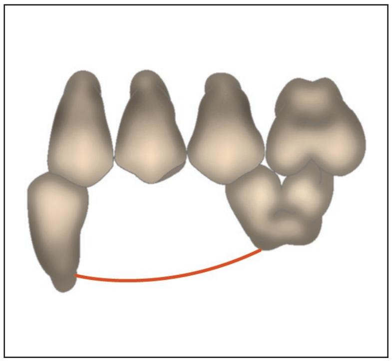


Fig 8-125 The mandibular first molar is first placed in its correct position.

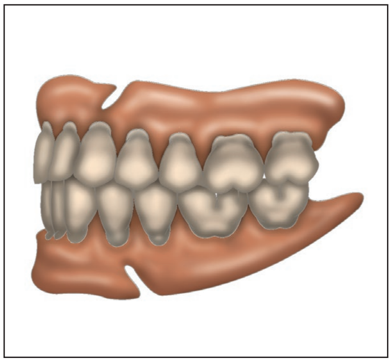


Fig 8-126 The remaining teeth are then set up.

Hiltebrandt's Working Method

The interpretations by Dr Carl Wilhelm Hiltebrandt offer a cohesive theory with working instructions for fabricating complete dentures. In this case, the law of form and function is used to interpret the relationship between functional mandibular movements and the form of the masticatory system, thereby qualifying Gysi's approach. According to Hiltebrandt's view, form and function make up a harmonious unit in which the form can adapt to functional disturbances. Mandibular movements are guided solely by the musculature, which does not follow fixed pathways. The TMJs and occlusal patterns of the teeth have no significance as elements that guide such movement.

The purpose of the condylar path inclinations is to separate the rows of teeth during protrusive and lateral movements in the area where no chewing activity is performed. The separation into working side and balancing side does not exist in a healthy, complete dentition. Only the canine guides the mandible into centric occlusion and is therefore referred to as the *anterior jaw joint*.

Occlusal curves are interpreted according to the law of the smallest unit of force. The stepped positioning of the molars aids the stability of the alveolar bone.

Mandibular movements are described as regulatory control movements or as a crushing and grinding movement in the occlusal field. Regulatory check movements are slight lateral movements under tooth contact, whereby slight irregularities on the cusps standing in the way of articulation are ground off and the position of the teeth and dentitions are kept in constant balance. Crushing and grinding movement is the actual chewing movement with which food is broken down into small pieces. It is guided from the centric to lingual aspect and takes place on one side only. According to Hiltebrandt, this results in the inclination of the teeth: vestibular at the top and lingual at the bottom.

Physiologic abrasion arises because of the crushing and grinding movement and the regulatory check movements. As a result, the teeth are ground down into trough-shaped and dome-shaped functional forms.

The occlusal field is the functional area of the chewing surface that is formed and extended by abrasion. The effective chewing movements take place in the occlusal field as crushing and grinding movements; it is the area of complete tooth contact. All movements outside the occlusal field are termed *articulation*; all movements within the field are termed *occlusion*.

Molar roots are aligned so that the masticatory forces are absorbed axially and transferred to the jawbone. The mandibular first molar stands inside a line that runs as an axis through the palatal root of the maxillary first molar. The maxillary first molar stands perpendicular to the occlusal plane (Fig 8-127). The ideal axis between the mandibular and maxillary first molars is the physiologic connecting line, which is at an angle of about 160 degrees to the occlusal plane. The occlusal field lies within this axis.

The basic statics law states that the maxillary first molar stands perpendicular to the occlusal plane on the ridge midline and that the mandibular molar stands with its longitudinal axis along the physiologic connecting line at an angle to the occlusal plane.

Hiltebrandt's conclusions include the following (Fig 8-128):

- Chewing movements abrade the teeth into flat functional forms; anatomically shaped, high-cusp posterior teeth are unfavorable.
- Compensating curves are not necessary because:
  - The stability of the denture is ensured by static tooth shapes
  - The chop bite is the effective chewing movement as a form of functional adaptation in denture wearers
- The TMJs have no guiding functions; surveying joint values and their transfer to articulators is unnecessary, so:
  - Occlusion is merely reproducible
  - Setup of the teeth is done in an occluder with stable tooth positions and without support contacts on the opposite side
- Guidance of effective chewing movements takes place in the occlusal field; therefore, physiologically domed and trough-shaped teeth are used.
- For esthetic reasons, maxillary anterior teeth are placed in front of the alveolar ridge with an in-

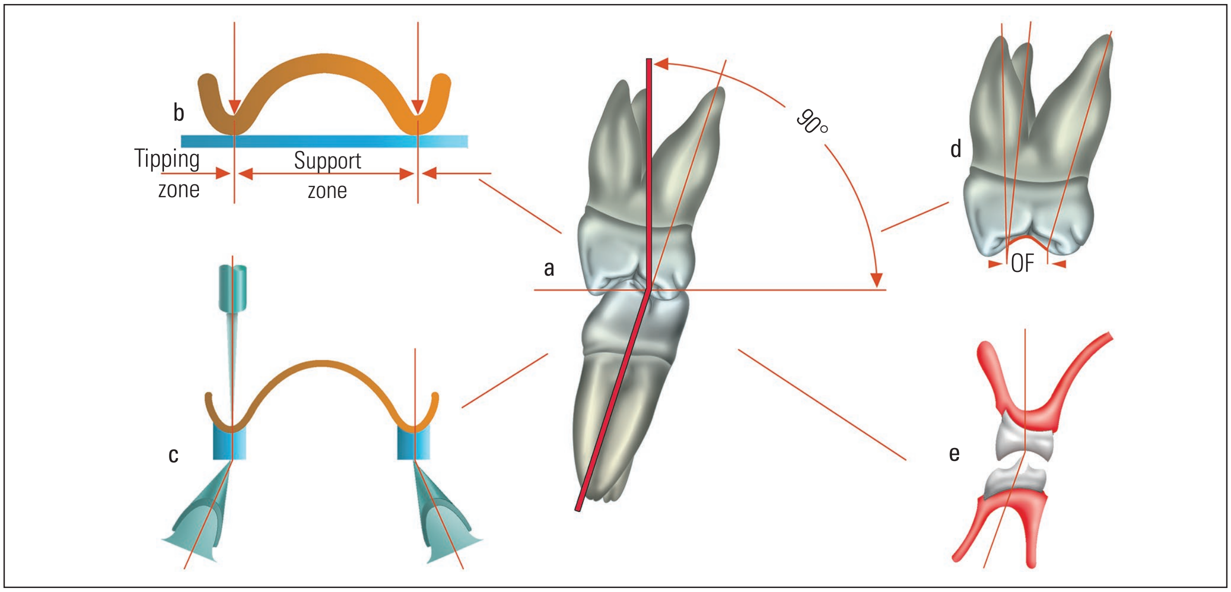


Fig 8-127 According to Hiltebrandt, the maxillary first molar stands perpendicular to the occlusal plane. The ideal axis of the mandibular molar runs parallel to the palatal root axis of its antagonist. *(a)* The physiologic connecting line is derived from the ideal axes of the two first molars and is bent at an angle in the occlusal plane. *(b)* The basic law of statics requires the posterior teeth to be placed on the alveolar ridge so that the ideal longitudinal axes intersect the ridge line. Tipping will occur outside the ridge line. *(c)* The occlusion rims already have a statically favorable position inside the physiologic connecting line. *(d)* The occlusal field (OF) is a limited area of the occlusal surface with a fixed relationship to the root arrangement. *(e)* The physiologically shaped posterior teeth have an enlarged occlusal field into which the sagittally placed ridge of the antagonist engages. The mortar-and-pestle principle becomes clear here.

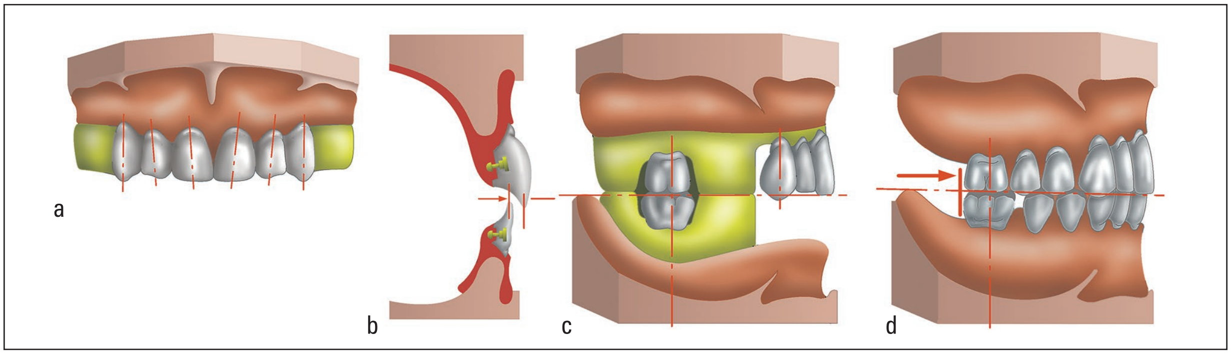


Fig 8-128 According to Hiltebrandt, the setup rules are simpler and easier to understand: *(a)* Based on esthetic considerations, the anterior teeth are set up in the appropriate inclinations of axis. The canine stands perpendicular. *(b)* An overjet is left, and the anterior teeth support the lips. *(c)* The mandibular first molar is placed at the lowest point of the alveolar ridge to contribute to the positional stability of the mandibular denture. The antagonist is precisely aligned with it. *(d)* The remaining teeth are accommodated in the space from canine to first molar. The row of teeth ends at the first molar. According to Hiltebrandt, any dorsally placed tooth could push the mandibular denture forward on the inclined plane of the sloping alveolar ridge.

cisal gap from the mandibular anterior teeth for effective chewing movements.
- Posterior teeth are stable in themselves because of the typical inclination to the occlusal plane.
- Setup inside the physiologic connecting line makes crossbite positioning unnecessary.

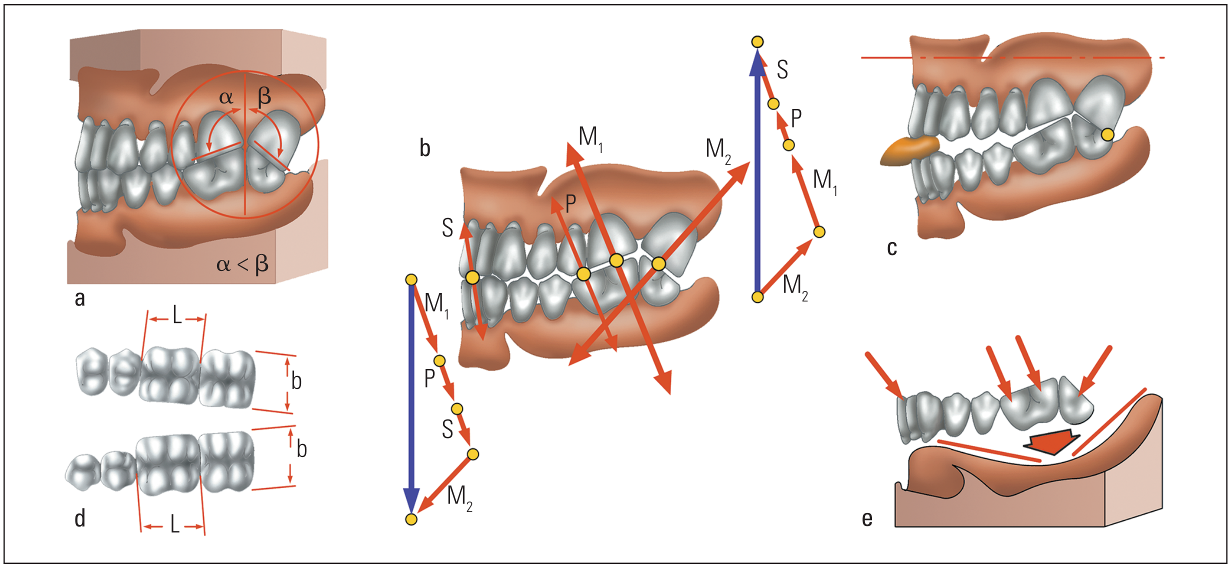


Fig 8-129 According to Haller, a denture can be stabilized on the edentulous jaw (and in a partially edentulous dentition) by special positioning of the molars. *(a)* The four molars are set up in an exaggerated notch position to each other. In this positioning, the second molars are more inclined toward the occlusal plane than the first molars. Angle α is smaller than angle β. *(b)* The force vectors at the molars, premolars, and incisors run centripetally, hence toward the middle of the denture or the denture-bearing area. The force diagram should yield a resultant that stands vertically on the jaw. *(c)* On biting off food, the notching of the molars prevents the denture from being completely levered off. The patient can immediately stabilize the prosthetic appliance. *(d)* The specially molded Haller molars are wider and longer than natural teeth and are entirely flat on their occlusal surface. This produces a very large field of action. *(e)* The force paths on the mandibular dentition show that the notching presses the denture against the dental arch and the ascending dorsal alveolar ridge. The mandibular denture should therefore sit stably.

Haller's Working Method

Ludwig Haller's working method is not a self-contained theory of masticatory function but deals with partial aspects of tooth positioning in prosthodontics. Certain distinct, individual measures are intended to enhance the functionality of complete and partial dentures. The recommended measures specifically relate to a tooth positioning that improves the statics and hence the retention of a complete denture.

Haller calls his setup method a centripetal system for keying dentures. Retention of a complete denture is improved by the fact that the posterior teeth are notched within the occlusal line. The very flat and wide molars (Haller molars) of the mandibular posterior regions are placed rooflike against each other so that they form a roof ridge that fits into a notch inside the maxillary row of teeth. The incorporated notch is intended to key both dentures with each other and hold them in the right position on the dental arches (Fig 8-129).

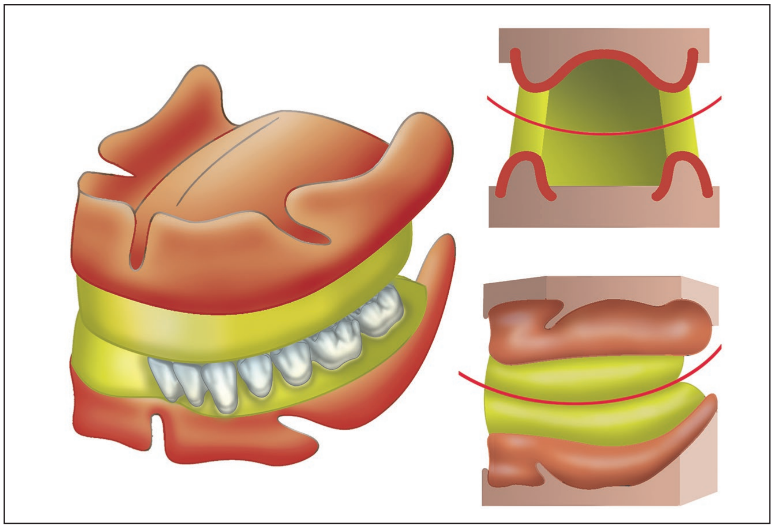
Functional performance is expected to increase as the patient gains confidence in bringing the denture into the correct position by regulative movements.

The TMJs are supported orthopedically by the centripetal setup as favorable stimuli during chewing function; this leads to regeneration of atrophic processes in the joints as a result of the securely fixed centric occlusion. The keying ensures retention of the denture to such an extent that greater chewing efforts are possible, which strengthen the muscles of mastication.

The principle of keying is preferred to a setup inside compensating curves. This is because the denture would be pushed dorsally against the ascending ramus of the mandible as a result of the curves. Furthermore, true three-point guidance over the excessively flat cusps of anatomical teeth is not considered possible.

Notching of the posterior teeth and a pronounced anterior overbite give rise to centripetal force paths that are directed at one point and fix

Fig 8-130 According to Fehr, if occlusion rims have a calotte-like shape in the occlusal plane in maximal intercuspation and a suitable instrument is used to rework mandibular lateral and protrusive movements individually until the bite plates can be moved against each other without interference and without tipping, the mandibular teeth can be placed against the calotte-shaped occlusion rim. As a result, they are positioned inside an individual occlusal curve. At try-in in the mouth, lateral and protrusive movements can be performed without interference while maintaining complete denture stability.



the denture in a stable position. On the mandibular denture, these force lines run directly to one point; on the maxillary denture, by parallel translation, a force diagram fixed at one point can be constructed.

For better retention of a complete denture, Haller recommends reinforcing the labial edge of the denture directly in the vestibular fornix with ridges that are set against the denture body by a pronounced notch. The mucosa of the lip area fits into this notch or onto the ridge and protects the denture. Furthermore, a peripheral denture anchor can be created on the mandibular denture. This roughly 5-mm-high, rounded ball anchor is placed vestibularly level with the second molars at the denture margin and is intended to wedge in the cheek muscles.

Fehr's Working Method

Fehr's working method is not a new approach to clarifying the static relationships; here the views about mandibular movements are stated in Gysi's terms. For the interocclusal registration, the occlusion rims are shaped to the correct vertical dimension of occlusion in keeping with the compensating curves. The occlusion rims are then modeled to such a length that all-round surface contact exists during all translative movements and the bite plates lie stably on the dental arches. In other words, a smooth, curved, and individual occlusal field is modeled with the occlusion rims that fully compensates for the Christensen phenomenon.

The Fehr method uses a template (calotte) for interocclusal registration. A simple occluder and flat-cusped teeth are used for the setup. Canines are trimmed at their tips, and the anterior teeth are arranged at a sagittal distance of about 1 mm. The working principle stipulates that the mandibular teeth should first be placed on one half of the jaw precisely against the individually molded occlusion rim, then the antagonists should be placed against them (Fig 8-130). Afterward the other half of the jaw is set up in the same sequence. This produces a tooth setup that in principle will exhibit all-round sliding contact in the sense of three-point support.

Other authors also offer concepts for setting up teeth using calottes (eg, Eichner, Monson, Hall, and Faber), and articulators with average-value calottes or calotte-shaped setup templates are available. All of these methods are based on the realization that the positional stability of a denture is achieved by three-point support and not by extreme keying of the dentures.

Schreinemakers's Working Method

Another working technique for improving the retention of complete dentures is analysis of the denture-bearing area to ensure functional efficiency by individual contouring of the denture base. Analysis of the denture-bearing area, which is set against articulation theory, involves drawing up an individual treatment plan. Based on this plan, the shape of the denture body and the marginal contouring in the vestibule, on the floor of the mouth, and at the vibrating line are established. A form of denture is then produced that secures the positional stability of the prosthetic appliance. Tooth setup is performed based on static aspects: in the posterior region on the ridge midline and in the anterior region in front of the ridge for esthetic reasons.

The working method of J. Schreinemakers is based on a theoretical model demonstrating what marginal contour, marginal length, and marginal thickness the denture should have (Figs 8-131 to 8-136).

The action limit defines the transition from attached to mobile mucosa. No advice about the resilience of the movable mucosa is given here, but this is deemed to be noncompressible. The denture margin should extend beyond the action limit on all sides so that the tension of the close-fitting mucosa is bound to create a valve margin that ensures negative pressure in the liquid layer under the denture base. Accordingly, a denture retained by suction is produced for each dental arch.

By means of the functional impression, a denture margin is designed that creates a balanced state between tissue tension at the valve margin and levering muscle tension. The course of the muscle attachments is accurately established underneath the vestibular fornices, on the floor of the mouth, and in the soft palate. The direction of force and pull is also described to indicate the dimensions of margin thickness.

The marginal depth in the lingual area of the mandible at the tongue and floor of the mouth must be determined with the utmost accuracy. The marginal depth of the labial vestibular fornix area requires great accuracy as it must support the lip parts in a tension-free way during functioning. The path of the fornices and the position and extent of muscle attachments coincide with the described denture-bearing area in the maxilla and mandible.

The anterior sublingual area is analyzed in detail so that the lingual groove around the genioglossus muscle, measuring about 2 mm long and 3 mm deep, can be used for the sublingual roll. The seating for the tongue beyond this sublingual roll can be enlarged by hollowing out the lingual surface of the denture body from the teeth up to the denture margin. The aim is to create functional clearance for the tongue that improves denture retention. In the buccal posterior region, however, the denture body should bulge outward to enable self-cleaning; a buccinator support is not attempted.

The border of the denture margin with the soft palate is placed at the vibrating line, where a groove about 2.5 mm deep and 2.5 mm wide is etched from the pterygomandibular raphe around the palatine processes of the maxillary tuberosity to the transition from hard to soft palate. The palatine foveae are indicated as reference points. The etched line must be probed individually with an instrument in the mouth.

The retromolar triangle (pad) is also finished at its dorsal border by an etching that is 1 mm deep by 1 cm long. This means the plate edge ends toward the pterygomandibular raphe.

In terms of the practical procedure, Schreinemakers offers a semi-individualized tray set for the first impression. Custom trays are prepared on the anatomical casts from the first impression. Occlusion rims to the exact vertical dimension of occlusion are simultaneously placed on the custom trays. A functional impression is taken after rigorous marginal checks at the action limit and extremely accurate marginal correction of the bite plate. The custom trays/bite plates should already have a certain suction effect. An impression material is used that allows subsequent corrections to be made. The functional impression is therefore taken in various stages.

The anterior setup is based on esthetic considerations. The Pound line is used for aligning the posterior teeth. If the mandibular posterior teeth are aligned with their lingual surfaces on this line, they will stand almost exactly over the ridge midline.

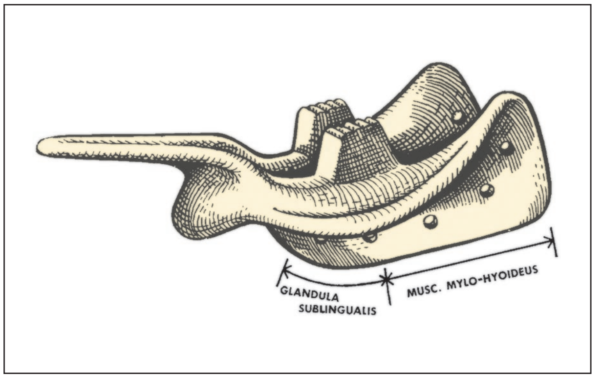


Fig 8-131 For Schreinemakers trays, the working instructions relate to impressions of the dental arches. The first impression is taken with prefabricated Clan-Trays, which are closely matched to the anatomical circumstances of edentulous arches.

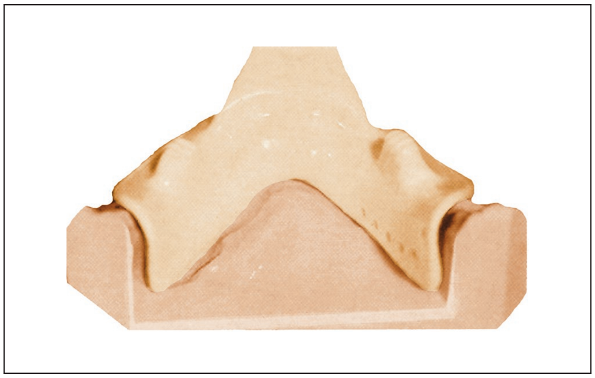


Fig 8-132 The mandibular Clan-Tray extends deeply into the floor of the mouth area to allow an impression to be taken of the sublingual area and the mylohyoid line.

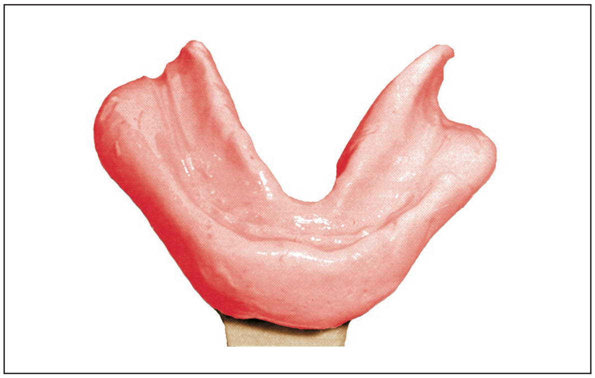


Fig 8-133 An initial impression with viscous-consistency alginate yields an extended representation of the mandibular denture-bearing area.

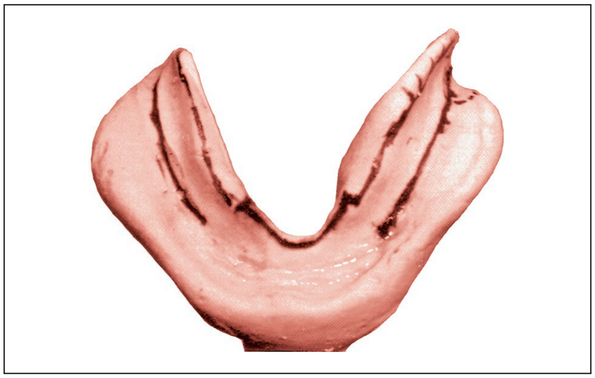


Fig 8-134 The course of the lingual margin of the custom tray is traced in the first impression and will appear on the plaster cast.

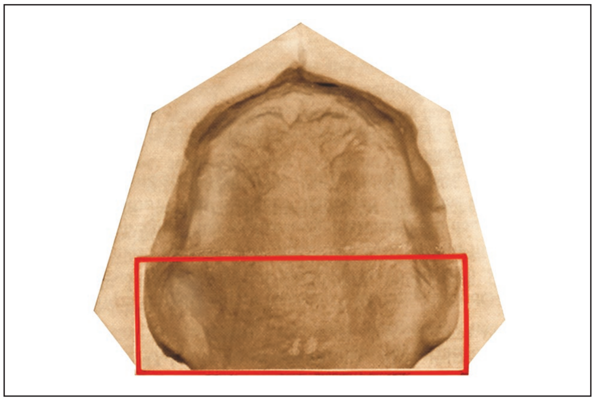


Fig 8-135 An impression is taken of the dorsal palatal area into the soft palate. The denture margin should also pass in the soft palate area.

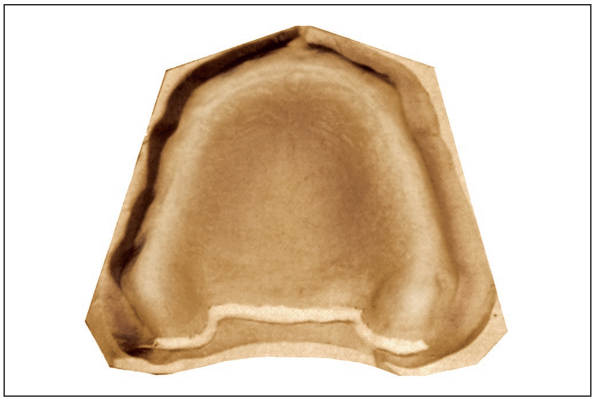


Fig 8-136 The dorsal margin of the bony mass of the jaw is probed and etched into the jaw model as a semicircular, 2-mm-deep groove that extends into the tuberosity processes.

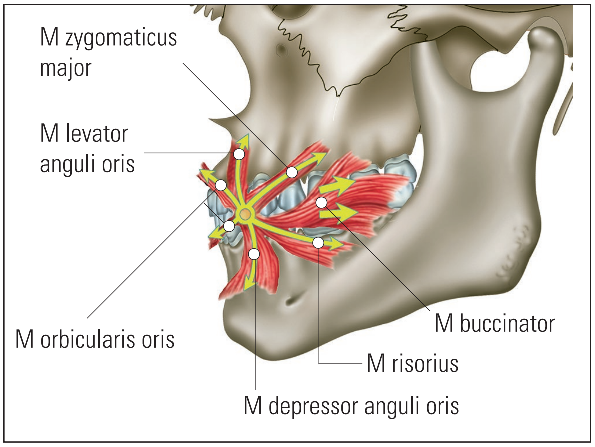


Fig 8-137 The anterior teeth, especially the canines, are positioned in front of the alveolar ridge to support the lips. Padding of the labial vestibule to tighten the upper lip must be rejected as inadequate. The canine position anterior to the ridge determines the position and shaping of the angle of the mouth as the modiolus (insertion site for the illustrated muscles) is supported. For this purpose, the mandibular canine must also be precisely mounted to tighten this tissue area. If the canines are placed too far lingually, the corner of the mouth will descend (as it does if the vertical dimension of occlusion is too small), saliva will leak, and the corner of the mouth may become inflamed.

Uhlig's Working Method

The working method of Professor Horst Uhlig sets the analysis of denture-bearing areas against Gysi's articulation theory. Analysis of the denture-bearing area is put forward as the only essential requirement for fabricating a complete denture.

Denture retention on the dental arch is presented as the interaction of capillary forces (adhesion and cohesion effect) and forces caused by pressure differences (suction effect), where the saliva acts as an adhesion promoter. The marginal seal comprises an inner and outer valve as well as the mechanical locking between the edge of the denture and the undercut areas of the jaw. The functional margin displays an inner valve at the outer surface of the jaw and an outer valve at the cheek; it also exploits all of the mechanical retentions, such as the maxillary tuberosity and anterior alveolar ridge areas. Hollowing out of certain areas of the palate, Frankfurt etching, and etching of the vibrating line are recommended as accessory retentive aids.

In practical terms, a formalized procedure for analyzing the denture-bearing area is proposed in which the tissue condition; the position of ligaments, muscle attachments, and bony ridges; and the shape of the alveolar ridges are described and entered on a form. Based on this analysis, necessary surgical measures, such as tightening of a flabby ridge, lowering of vestibular fornices, separation and movement of ligaments, or smoothing of sharp-edged ridges, are undertaken. The resilient areas of the palate and the path of the vibrating line are then traced.

For precise marginal locking of the denture base, a custom tray is prepared and used to take the functional impression. For tooth setup, taking an impression of the "denture accommodation" is recommended to establish the position of the cheeks, lips, and tongue so that the teeth can be set up while these tissues are in balance. In a "technique of individual fine adjustment," the outer surfaces of the denture bodies should be adjusted to the position, shape, and dimensions of the cheeks and the tongue; that is, a circumferential chamfer should be formed into which the mucosa settles. The result can be described as a dimensionally accurate dental prosthesis shaped to grip the muscle.

In the maxillary labial area, the denture can be thickly padded to tighten the upper lip and compensate for the shrinkage of the jaw. The maxillary anterior teeth are positioned in front of the alveolar ridge to support the upper and lower lips (Fig 8-137). In the posterior region, a crossbite position is presented to stabilize the position of the maxillary denture, together with a sagittal occlusal curve that is not constructed relative to the TMJ but emerges from the positioning of the teeth inside the interalveolar line.

Jüde's Working Method

Professor Jüde established the course of the margin of a mandibular prosthesis based on extremely accurate studies. In particular, an extension into the retromolar area is specified to provide mechanical retention to the mandibular denture.

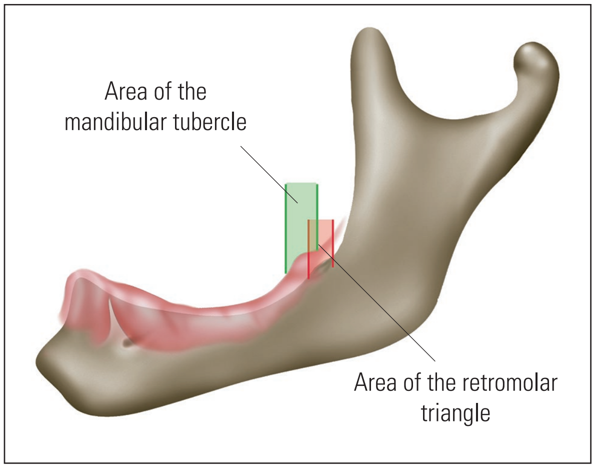


Fig 8-138 The position and shape of the mandibular tubercle is described as a tough mucosal ridge located in front of, but not above, the bony retromolar triangle. Therefore, the tubercle and triangle are not in the same position, but the mandibular tubercle on an edentulous jaw is located roughly at the position of the third molar and should be contained.

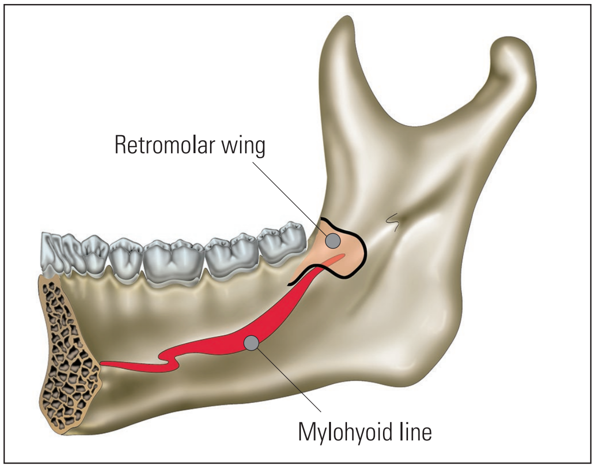


Fig 8-139 The line of origin of the mylohyoid muscle indicates the border of the mobile floor of the mouth. Jüde described the limit of the floor of the mouth using a variety of shapes for the areas of origin. The most commonly found line of origin is depicted here. Any extension of the denture margin is supported on the mylohyoid muscle in the paralingual region. It therefore becomes necessary to avoid pressing the retromolar wings against the mandible and instead to provide the mylohyoid muscle with the space it needs to function.

The muscle movements of the retromolar region are determined by the activity of the tongue and can often give rise to an undercut mucosal pocket into which the retromolar wings of a mandibular denture can engage. These wings should be dorsally guided caudally without impeding the activity of the myloglossus muscle.

The genioglossus muscle described by Jüde originates below the mandibular tubercle on the inside of the mandible (Fig 8-138). The muscle bundle runs from there to the root of the tongue and thereby covers the posterior area of the mylohyoid muscle. This limits the size of the retromolar wings inferiorly.

The retromolar (paralingual) areas should be individually determined by a functional impression taken during tongue activity. The functional movements of the tongue for taking an impression of the sublingual area are usually the same as those performed for defining the paralingual area.

In practical terms, the length of the margin is incorporated into the custom tray before the functional impression is taken. In the process, the lingual edge of the tray follows the border of the floor of the mouth (Fig 8-139); trimming along the mylohyoid line is carried out, followed by extension into the paralingual area and sublingual lengthening for the sublingual roll. In the oral vestibule, the tray edge is guided along the vestibular fornix (Fig 8-140), trimmed in keeping with the oblique line, and spared at the ligaments.

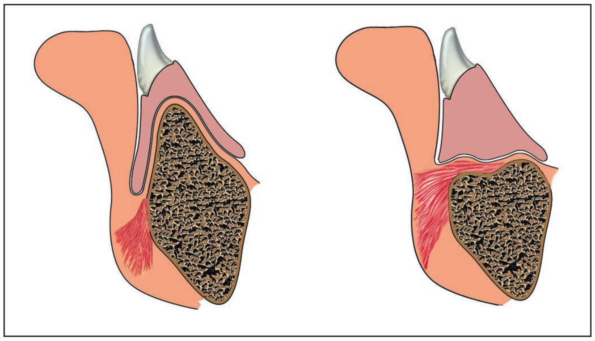


Fig 8-140 The attachment of the mental nerve lies below the vestibular fornix; in the case of severe atrophy, it may shift to the middle of the anterior alveolar ridge in the denture-bearing area and may impair the positional stability of the mandibular denture.

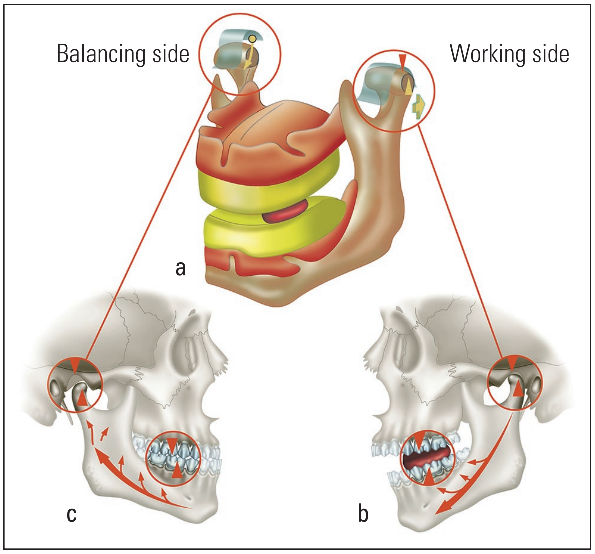


Fig 8-141 According to Gerber, the chewing cycle follows fixed pathways: *(a)* The mandible moves out of centric occlusion into the loading position. The condyle on the balancing side slips forward and downward. The condyle on the working side moves backward and outward in the Bennett movement and remains unloaded. *(b)* Out of the loading area, the active masticatory pressing and protrusive action occurs on the working side. This involves the condyle slipping forward and inward into the fossa. In this active chewing phase, the maxilla moves in the direction of anterior contact and makes a contact-free change of position to the balancing side in order to glide back into centric occlusion. *(c)* During the active chewing phase, sliding balancing contacts occur on the balancing side in the molar region close to the joint.

Gerber's Working Method

In recent years, the working method of Professor Gerber has gained in significance because it brings together the methods and theoretical principles outlined in the previous sections to create a successful synthesis that also incorporates the latest research findings. Over the years, this has led to an almost closed, mechanically based theory of masticatory function with practical instructions on fabricating complete dentures.

The functional mandibular movements are analyzed using varied analysis methods, including radiographic sequences of joint movements and film recordings of the chewing cycle in order to develop an articulator and static functional shapes of artificial teeth. First, the relationship of the TMJs to tooth shapes and tooth positions is established and defined. Maximum tooth contact exists in centric occlusion in a normal dentition. The two condyles are located in the depth (zenith) of the mandibular fossae entirely pressure and tension free. In this position, masticatory forces are not transferred via the condylar heads.

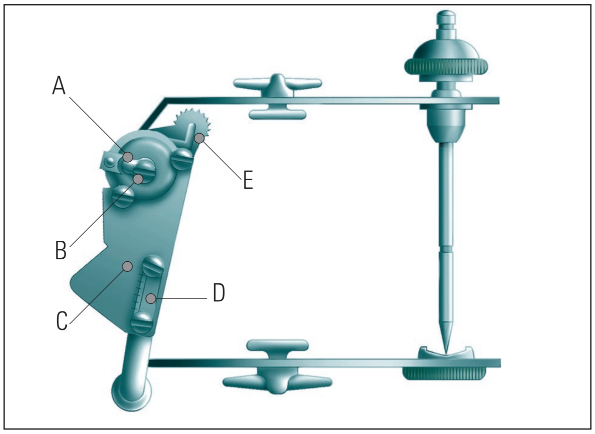
According to Gerber, the chewing cycle follows fixed pathways (Fig 8-141). The loading phase is the start of the chewing cycle, for which the mandible is guided to the chewing side to grasp the food. In the process, the condyle on the chewing side floats freely in the joint and can be pulled dorsally and laterally by the musculature. A Bennett movement is performed. In the loading phase, the mandible is pushed out of the retruded lateral position forward and centrically to grind the food. Then the mandible can be seen to change position to the opposite side (balancing side) and to the anterior teeth before gliding back into the centric hinge position.

Analysis of the chewing cycle demonstrates the basic movement sequence of the Bennett movement, but it also shows the position of the condyles during the movement sequence. In addition, it becomes clear that the functional chewing movement, in contrast to the four-phase round bite, does not happen two-dimensionally in the transverse plane but three-dimensionally to the side and dorsally, after which it swerves over to the balancing side.

Lip, cheek, and tongue activities during the chewing process prevent food particles from slipping down into the vestibule, while the tongue repeatedly presses the food between the rows of teeth. This muscle activity is one of the factors determining the excursions during mastication. Based on observations regarding functional mandibular movements, Gerber sets out the following requirements:

- The mandibular movement must be imitated in suitable articulators in order to fabricate dentures.

Fig 8-142 The Gerber Condylator is an articulator in which the inclination of the condylar path is adjustable between 0 and 60 degrees. The Condylator aperture (A) is curved in keeping with the natural condylar path. The Condylator body (B) has a double-cone shape and takes on guidance in all lateral-eccentric movements. On the joint plate (C), the articulation can be raised from 0.3 to 1.0 mm using the Vario device (D). The fixed table (E) opens the joint movements in the raised state but otherwise blocks the Condylator body, so only hinge movement is possible.



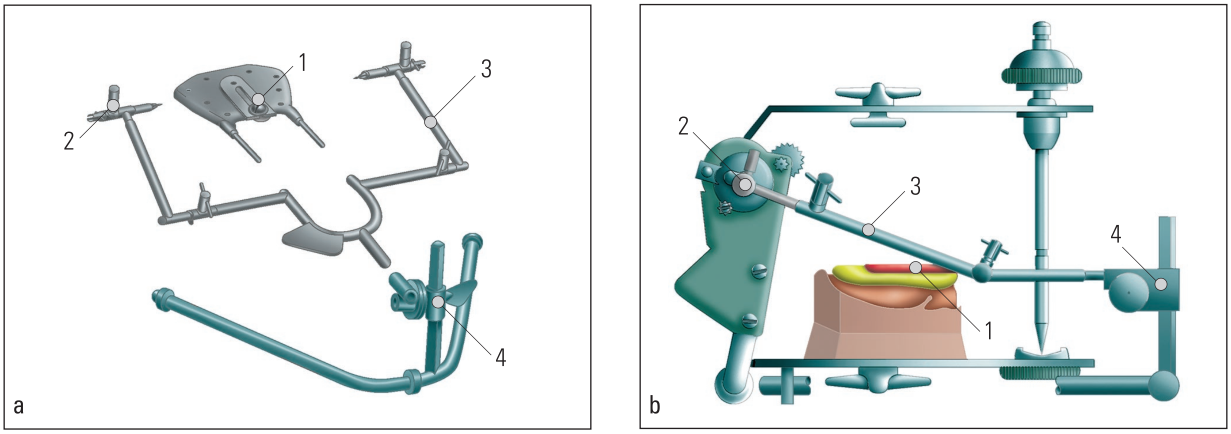


Fig 8-143 A facebow (3) is available for the Condylator, with which the inclinations of the condylar paths can be surveyed. *(a)* The facebow is fitted onto the tracing plate (1), and the tracing tips (2) trace the mandibular movements as condylar path tracings on registration flags. *(b)* The facebow can be used for joint-related mounting of the casts in the articulator. To do this, the facebow is fixed onto the stand (4) and propelled around the articulator until the tracing tips point to the midpoint of the Condylator body.

- During occlusal registration, the centric, pressure-free position of the condylar heads in the zenith of the articular fossae must be relocated.
- The condylar path must be surveyed so that individual values can be transferred to the articulator.
- The artificial teeth must be referenced to the mandibular movement and satisfy static requirements.
- Tooth positioning on complete dentures must secure the positional stability of the appliance.
- The denture body must be shaped to enable the muscles to support denture retention without impeding muscle activity.

Gerber Condylator

The Condylator is a semiadjustable articulator in which the condylar paths are adjustable from 0 to 60 degrees (Figs 8-142 and 8-143). The mandibular fossa (Condylator aperture) and the condylar heads (Condylator body) take on the functions of guidance and limiting movement in all mandibular excursions. They permit retral movement out of centric occlusion. This backward movement is not straight but curved in the Condylator aperture, in keeping with the natural hinge range. The Condylator body has a double-cone shape; the 17-degree inward-facing cone and the 13-degree

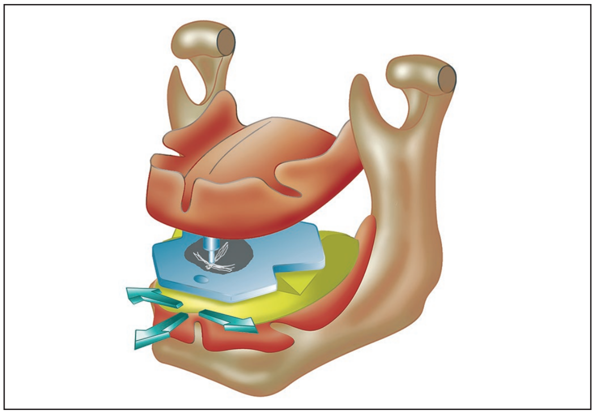


Fig 8-144 The intraoral occlusal registration described by Gerber follows the same principle as the Gysi extraoral registration. In this case, however, the registration kit is mounted centrically over the dental arches so that tilting is ruled out. During mandibular movement, a Gothic arch also appears on the tracing plate. A perforated plexiglass disk is fixed over the intersection point. The tracing stylus engages in the hole on the disk, and the mandible is established in centric occlusion.

outward-facing cone undertake guidance of the Bennett movement.

The incisal guide plate has an 18-degree incline for complete prosthodontics, but dentate arches can be modeled into an individual guide plate with self-curing acrylic resin by means of the intact incisal guidance of the arches. An optimized registration kit is recommended for the intraoral occlusal registration (Fig 8-144).

Condyloform teeth

The Condylator articulator was developed on the basis of observations of mandibular movements as well as TMJ shapes and movements. According to Gerber, this functional relationship also exists between joint and tooth shapes. During development of the dentition, there is a progressive adaptation between the sliding surfaces of the TMJs and tooth surfaces. This wearing process produces abraded surfaces on the molars, which have a shape similar to that of the articular fossae.

The articular fossae and condyles fit together like a mortar and pestle. It was based on this mortar-and-pestle principle that the maxillary palatal cusps and the mandibular occlusal surfaces on Gerber's Condyloform posterior teeth were created (Fig 8-145). The palatal cusps form microcondyles, and the lingual chewing depressions on the mandibular posterior teeth form microfossae.

The static principle of mortar-and-pestle teeth according to Hiltebrandt is combined with the anatomical cusp slopes according to Gysi's interpretation. The chewing surfaces are shaped as upside-down microjoints, in which one part of the joint is fixed and the other is mobile. The microjoint chewing surfaces display guide surfaces with the same slope and shape as real joint surfaces (Fig 8-146).

The chewing surfaces on the mandibular posterior teeth have their mortar-shaped occlusal fossae shifted lingually, while the buccal cusps have a noticeable abrasion surface that slopes down toward the vestibule.

The palatal cusps of the maxillary teeth engage pestle-like into the mandibular occlusal fossae, while the maxillary buccal cusps engage with their adapted abrasion surfaces over the mandibular teeth. In their eventual shape, the occluding cusps resemble microcondyles that articulate in the microfossae.

The condylar path inclinations and the movement patterns of the mandible are in the sloping surfaces of the buccal cusps in the sagittal and transverse direction, as reflected in the curvatures of the mortar-and-pestle cusps. Thus, protrusive movements on the long working facets and retrusive movements on the short balancing facets of the occlusal surfaces can be performed under tooth contact.

The mortar-and-pestle teeth permit slight mandibular movements under tooth contact in centric occlusion but do not result in dynamic denture movements or the need for slight changes to be made to mouth opening. In the case of normally shaped anatomical forms of abrasion, translative movements are only possible if the mouth is opened slightly and the teeth are lifted out of centric occlusion.

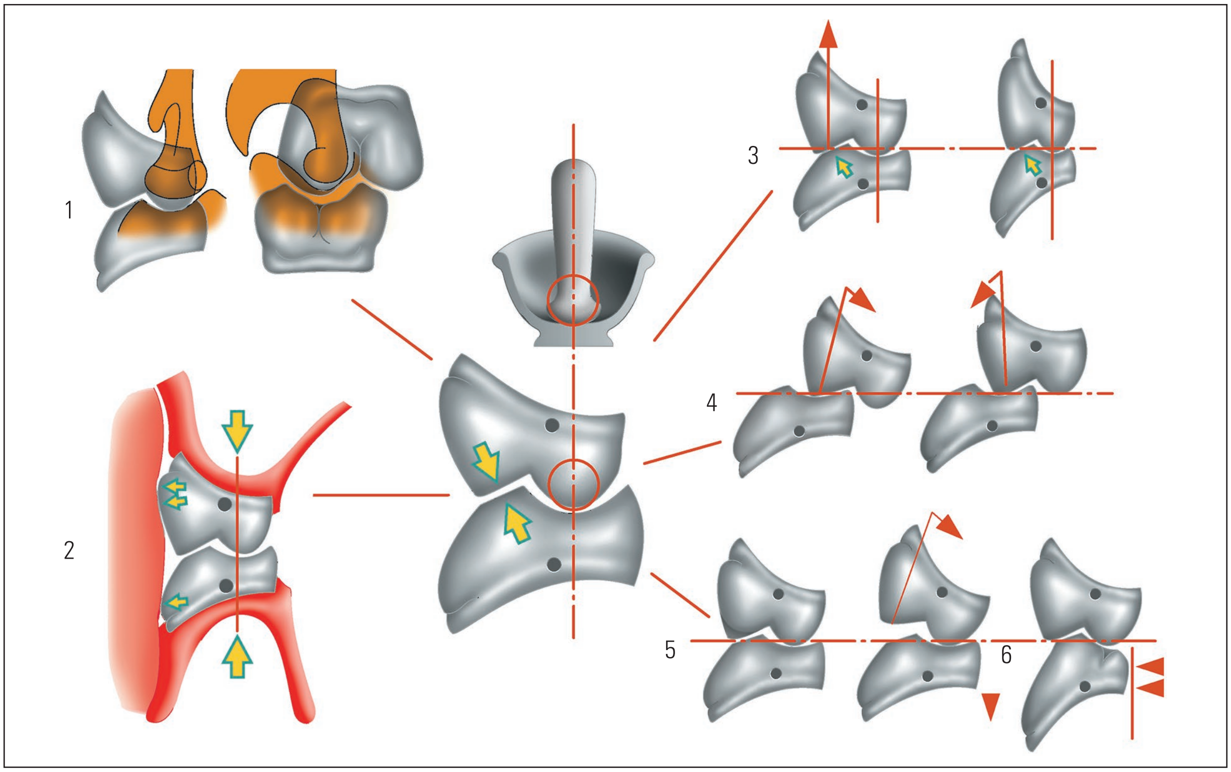
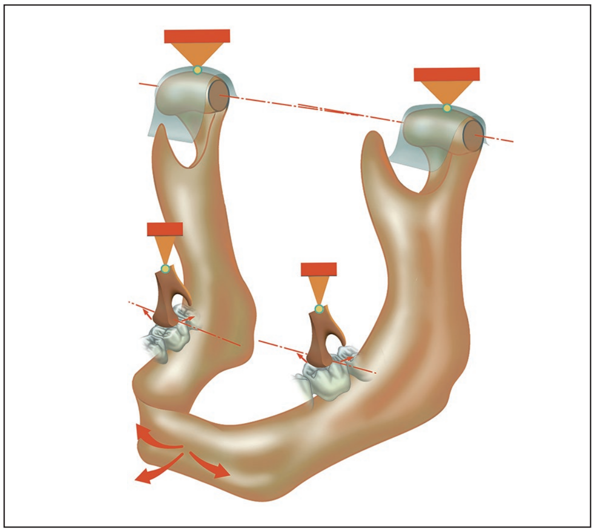


Fig 8-145 On the Condyloform posterior teeth, the maxillary occluding cusps engage like a mortar in the pestle-like occlusal surface of the mandibular teeth. *(1)* Occluding cusps resemble microcondyles that articulate in the microfossae. *(2)* Active masticatory microcondyles and microfossae are located in the lingual part of the teeth: The bulbous buccal tooth surfaces have cheek contact and stabilize the denture; positioning the active masticatory parts on the center of the alveolar ridge leaves adequate clearance for the tongue; and functional elements lie markedly lingually, so the teeth can be positioned more vestibularly. *(3)* The abraded buccal cusps aid statics and stability during mastication. *(4)* In crossbite, the molars are not swapped but the buccal cusps of the maxillary molars become active masticatory cusps; the palatal cusp must not impede chewing movement. *(5)* The buccal cusps can be ground back or placed out of contact. *(6)* To enlarge the space for the tongue, premolars can be used instead of molars in the mandible.

Fig 8-146 The basic idea of interpreting the occlusal surfaces of the posterior teeth as microfossae and microcondyles is illustrated in this diagram. The sliding movements of the real joints are also possible on the posterior teeth. The occlusal surfaces are interpreted as upside-down microjoints in which one part of the joint is fixed and the other is mobile. The microjoint occlusal surfaces have the same guide surfaces as the real joints; this is the desired relationship.



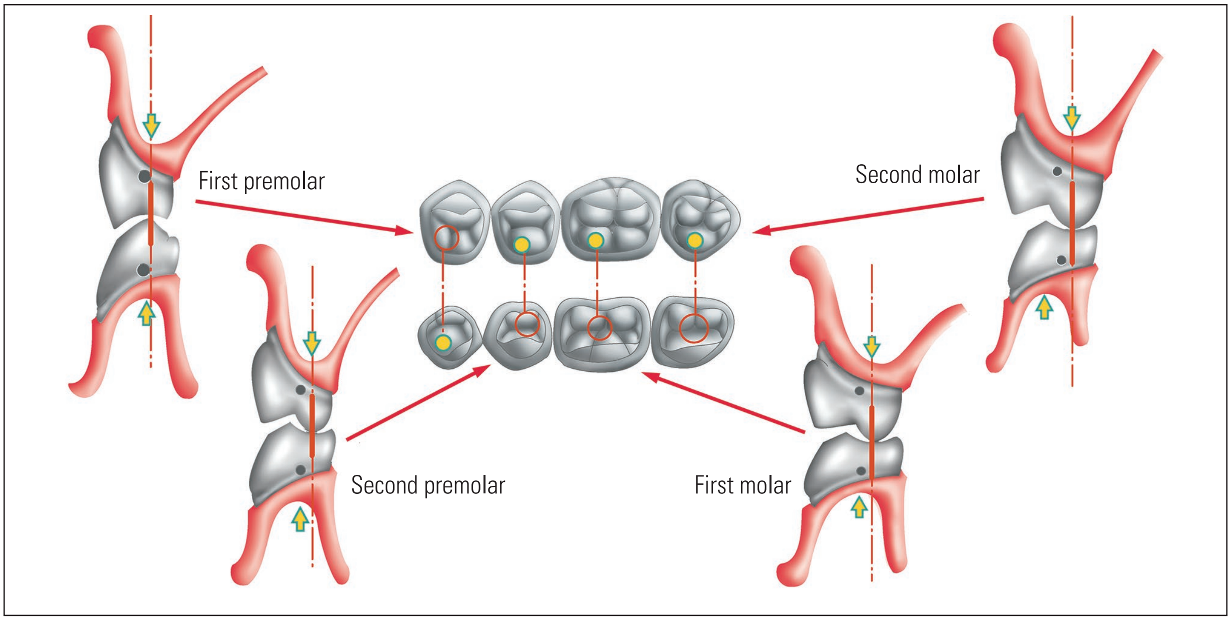


Fig 8-147 Gerber also addressed the principle of placing the posterior teeth on the center of the alveolar ridge. In the case of Condyloform teeth, the active masticatory lingual parts of the surfaces must be positioned over the ridge line. In the mandible, because of the buccally overhanging shape, the tooth can be moved slightly lingually, which benefits the statics of the mandibular denture but does not crowd the tongue. In the case of the first premolar, the mortar-and-pestle principle is turned on its head. This aids masticatory stability and tooth shape in this area. The buccal cusps of the subsequent teeth are placed far enough out of contact that they do not interfere with denture statics but still provide balancing contact on lateral excursions. The maxillary second molar can usually be omitted, while the mandibular second molar can be the shape of a premolar that serves merely as a secondary antagonist to the maxillary first molar.

The lingually shifted occlusal fossae on the mandibular teeth and the abraded buccal cusps contribute to positional stability because these functional elements (microcondyles and microfossae) are displaced from the middle of the teeth in a pronounced lingual direction.

The balanced tone of the tongue and cheek can be used because the teeth are kept wider in the lingual/vestibular direction. The anatomically shaped vestibular surfaces show a pronounced curvature, which makes good cheek contact possible. Denture wearers are able to guide and stabilize their dentures with their cheeks and tongue.

Condyloform teeth can be set up on the center of the alveolar ridge, leaving their antagonists independently stable on chewing (Fig 8-147). As the functional elements are actually moved in a distinctly lingual direction, the teeth can be placed very vestibularly. Positioning the active masticatory parts on the center of the alveolar ridge leaves adequate clearance for the tongue. To enlarge the space for the tongue, premolars can even be used instead of molars in the mandible without impairing chewing activity.

A crossbite, necessitated by advanced atrophy of the jaws, is not created by swapping the molars. Instead the buccal cusps of the maxillary molars are turned into active masticatory cusps, while the palatal cusps must not impede articulation movement. This is why the teeth are tipped very buccally, whereby cheek contact is also restored. The buccal cusps can be ground back or placed out of contact if they hamper denture stability or articulation.

Stability during mastication

According to Gerber, positional stability depends on tooth shape, the contouring of the denture body, and the positioning of the artificial teeth relative to the alveolar ridges (Fig 8-148). The posterior teeth stand on the middle of the ridges. As

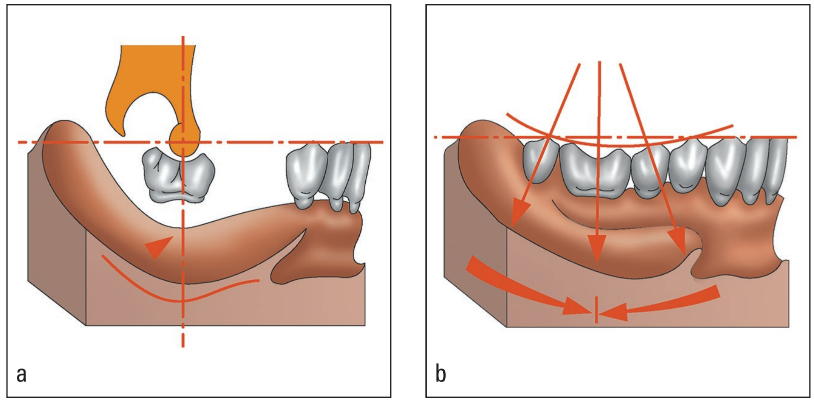


Fig 8-148 According to Gerber, stability during mastication (or masticatory stability) is linked to two facts: *(a)* The mandibular first molar must be placed at the lowest point on the shrunken mandible. The molar then stands between two inclined planes whose contrary effect cancels itself out. This stable position can be compared with a saddle, which is securely seated in the dip of a horse's back. *(b)* The posterior teeth are set up inside a steep occlusal curve. This is supposed to compensate for positional defects due to the Christensen phenomenon and Bennett movement, but it also reinforces the contrary effect of the inclined plane.

stipulated by Gysi's law of the ridge line and by Hiltebrandt's basic static law, this condition also applies to Gerber. If tooth positions are outside the ridge line, the denture may be levered off. On Condyloform teeth, the functional elements, such as the occlusal fossa and the lingual occluding cusp, are moved markedly toward the lingual aspect. If these functional mortar-and-pestle parts are set up exactly over the ridge center, the buccal cusps will extend far in the vestibular direction.

A crossbite position is only rarely necessary, as the space for the tongue is almost normal and not crowded and cheek contact can be used extremely well for positional stability. All the teeth stand with their independently stable antagonists and permit slight movements under tooth contact. The requirement to position the teeth on the center of the alveolar ridge does not become a problem with Condyloform teeth, thereby satisfying the first criterion for positional stability of a complete denture.

The instability of mandibular dentures on an alveolar ridge rising dorsally can be contained by special tooth positioning. Hiltebrandt thought the solution was to shorten the dental arch up to the first molar, and Haller recommended an upward notching of the posterior teeth. Gerber's solution synthesizes these two views. The contour of the alveolar ridge in the mandible is deflected downward and is generally at its lowest at the first molar. This is where the masticatory center of a complete denture must lie, which is why Gerber describes this area as the stable center during mastication. This lowest point is marked on the edge of the cast, and the first molar is arranged there.

So that the masticatory center also remains on this stable center during mastication, the maxillary row of teeth stops at the first molar, and the denture baseplates are kept a sufficient distance from each other. One premolar is now placed behind the mandibular first molar, ending the arched curve as a secondary antagonist for the maxillary first molar. The posterior teeth are set up in a steep curve deflected downward, which produces a steep sagittal occlusal curve. The aim of this notching, shortening of the dental arch, and special tooth shape is to prevent the mandibular denture from slipping on the inclined plane of the alveolar ridge during mastication.

To create balanced contacts on the nonworking side, the posterior teeth should be inclined inside the transverse curve. If no balancing contacts are possible when crushing food, these contacts will be achieved on functional mandibular movements during the swerve toward the balancing side. Furthermore, these balancing contacts protect the jaws and joints during normal functional movements (eg, when speaking). According to Gerber, the posterior teeth should be set up inside the transverse and sagittal curves, and these curves should create balancing contacts during mandibular movements. Therefore, strictly speaking, these are compensating curves.

Another aspect of securing masticatory stability is supporting the denture in a particular way in the canine region. Denture wearers often bite food with the canines and premolars because the

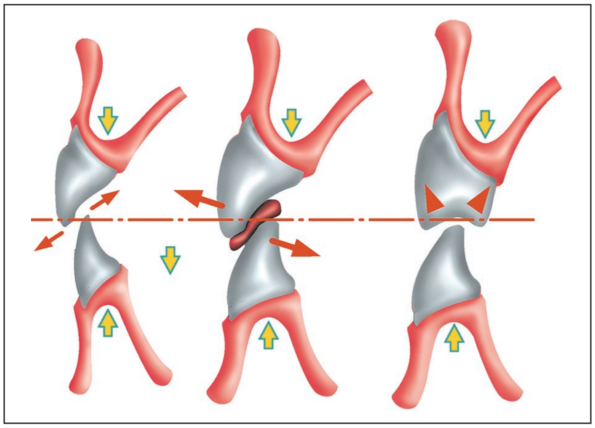


Fig 8-149 The masticatory stability of the maxillary denture is jeopardized primarily by the canine because anterior contact is always sought in a chewing cycle. Gerber first proposed setting up the incisors and canines so they could glide past one another. If the maxillary canine is replaced by a broad premolar, into whose chewing fossa the mandibular canine glides centrally, the effect of masticatory force could be used to stabilize the denture. The "canine premolars" exhibit a particular positional stability.

denture is usually more securely seated in this area than in the region of the incisors. If broad premolars are set up instead of maxillary canines, the mandibular antagonists in the occlusal fossa of the maxillary canine/first premolar can produce an excellent cutting effect without pressing the maxillary denture outward and thereby levering it off (Fig 8-149). This is because the mandibular antagonists split up the food, like a knife between two parallel cuts would do.

Finally, the positional stability of a complete denture should be supported by the contouring of the denture body. Schreinemakers, Uhlig, and Jüde recommend a thorough analysis of the denture-bearing area, whereas Gerber suggests molding lip shields on the maxillary and mandibular dentures for mucosal support, based on a muscle relief impression of the perioral muscles, as well as modeling narrow channels in the direction of function of the ligaments for the buccal frena.

Tooth setup according to Gerber

Gerber explains the special tooth positioning for complete dentures by the special shape of the Condyloform teeth (Fig 8-150). The antagonist pairs of posterior teeth form harmonious masticatory units that are meant to be independently stable in their position in the dentition. This means that the teeth have only occluding cusp contact, and the abraded buccal cusps touch in order to increase masticatory stability. The maxillary antagonists are centered in their antagonists and do not have multiple cusp contact.

Setup calls for four phases:

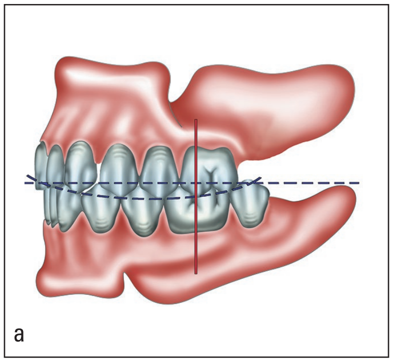
1. Anterior teeth
2. Mandibular posterior teeth
3. Maxillary second premolar
4. Rest of the maxillary posterior teeth

The anterior teeth are set up by reference to the model analysis markings, tracings on the occlusion rims, and static considerations. The incisors have a sagittal distance of 1.5 to 2 mm; the cutting edges are abraded so they glide into an unimpeded edge-to-edge occlusion on protrusive movements.

The canines are never placed with a pronounced overlap but permit free articulation movements. If necessary, the tips of the canines inhibiting movement should be trimmed. The canines stand slightly outside the dental arch, hence in a dominant position. The decisive canine stability is achieved by placing a premolar instead of the maxillary canine. The tip of the mandibular canine engages in the mortarlike concavity of the maxillary canine/premolar, pressing the denture onto the dental arch.

The broad posterior teeth are intended to gain cheek contact with their bulging buccal surfaces. The occlusal concavities and occluding cusps stand over the center of the alveolar ridge.

The mandibular posterior teeth are first set up, a gap being left between canine and first premolar. The curve of Spee is distinctively shaped by imitating the occlusal line as a fixed locator on the articulator using a ruler or a rubber band.



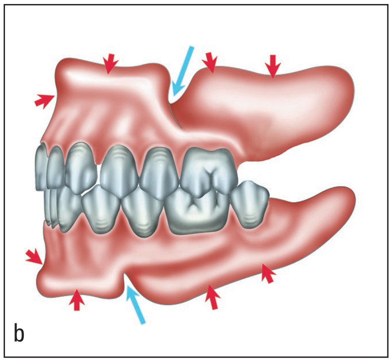


Fig 8-150 *(a and b)* According to Gerber, the finished denture displays the following features: The mandibular first molar has its occlusal concavity at the lowest point of the trough-shaped alveolar ridge; the posterior teeth stand inside the occlusal curves; the posterior teeth end at the first molar, and the mandibular premolar/second molar is a secondary antagonist; and the maxillary canine/premolar engages centrally over the mandibular canine. The outer surface of the denture body is shaped to grip muscle, with anterior lip shields for the orbicular muscle of the mouth. In the posterior region, buccinator rests are created and the muscle tracts at the buccal frena are traced. Reduction needs are taken into consideration.

The position of the maxillary posterior teeth is referenced to the maxillary second premolar. This tooth is the first of the maxillary teeth to be set up, then the two teeth still missing are inserted. An oral check is done to see whether the pestle cusps have full mortar contact and whether the sloping abrasion surfaces permit unimpeded sliding movements.

The maxillary second premolars stand with their lingual occluding cusps over the center of the ridge, while the maxillary antagonists stand with their markedly lingually displaced masticatory concavity in the middle. A comparable tooth setup is also adopted for the first molars. This position also applies to the second molars, provided that they can be arranged while maintaining favorable ridge relationships.

For the mandibular first premolar, it is important to position the buccal cusp tip over the ridge midline, which means the maxillary first premolar then has to stand with its central developmental groove over the ridge middle.

The mandibular first molar should lie centrally over the deepest point of the ridge profile. This point is marked on the edge of the model, which fixes the position of the first molar. This tooth is also set up first, and the other teeth are then aligned with it.

Reoccluding the dentures is done so that errors in tooth position caused by wax stresses and shrinkage during polymerization can be compensated for after completion. This involves selective grinding of the finished dentures on the casts in the articulator. Carbon paper is used to identify gross interferences from a possible vertical increase of occlusion during functional lateral and protrusive movements, and these interferences are remedied with an abrasive stone. Correction is only done on the mandibular teeth.

This is followed by selective grinding with a paste made from carborundum powder and glycerin. Under gentle pressure, the teeth are moved against each other with minute circular motions alternately to the right and left, the movements being guided by the joints and incisor guidance.

The palatal cusps of the maxillary posterior teeth must not be ground off because the occlusion-fixing functions of these cusps need to be preserved. Selective grinding on an average-value articulator produces a chewing pathway that can stabilize the denture but imposes a specific movement on the joint. Such movements are actually adopted after a brief period of habituation so that this relationship can be used for therapeutic purposes.

Biologic Prosthetics

A *biologic prosthetic* is defined as a diagnostic depiction of the occlusion and articulation of a natural, intact, healthy, normal dentition that can be applied equally to fixed tooth replacements, partial dentures, and complete dentures.

The field of biologic prosthetics postulates neuromuscular mandibular guidance, while the classic concepts suggest mechanical tooth and

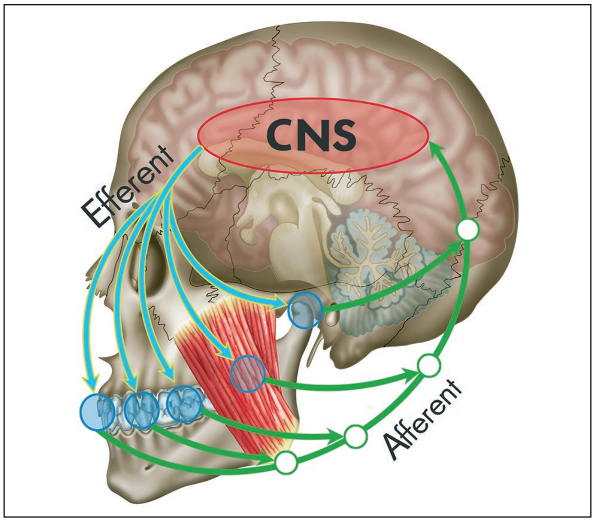


Fig 8-151 The masticatory system works according to a cybernetically controlled feedback cycle to maintain all of its components. Physiologic centric and habitual intercuspation come together in an interference-free masticatory system. The chewing cycles are learned in childhood and are memorized and maintained via feedback mechanisms. The field of biologic prosthetics postulates, as an overarching concept, neuromuscular mandibular guidance in which no canine guidance, guidance from groups of teeth, or bilateral balancing can be established. No tooth guidance is seen in the masticatory system, merely neuromuscular guidance.

condylar guidance. Dr E. End asserts that no canine guidance, guidance from a group of teeth, or bilateral balancing can be established in the natural dentition for all physiologic movements. In the masticatory system, there is no tooth guidance, only neuromuscular guidance (Fig 8-151). Thus, biologic prosthetics presents an overarching concept.

In a healthy dentition, the habitual intercuspation coincides with a loose, relaxed centric occlusion adopted by neuromuscular methods. This contact position is the physiologic centric occlusion, which can be adopted by the patient at any time out of the mandibular rest position. According to End, the physiologic centric occlusion of the natural dentition displays the following characteristics (Fig 8-152):

- Uniform and simultaneous point contacts are on the occlusal surfaces in the posterior region in a typical distribution.
- Contact points mainly lie on the inner slopes of the working cusps, on the lingual cusps in the maxilla, and on the buccal cusps in the mandible.
- There are only a few marginal ridge contacts (10% of contacts on posterior teeth).
- There are only a few contacts on shears (nonworking cusps).
- Anterior teeth have full or only partial, slight contact simultaneously with the posterior teeth.
- The sagittal overbite has a vertical range of 1 to 8 mm and a horizontal range of 1 to 6 mm.
- There is no point and surface support in the sense of a long centric occlusion.
- The terminal occlusion position is an unstable balance of contacts with occlusal clearances.

Functional analysis of natural dentitions by clinical and instrumentation methods shows that unimpaired functioning maintains the physiology of the natural teeth. Physiology does not lead to self-destruction but maintains the structure. Physiologic, neuromuscularly guided mandibular movements during chewing, swallowing, speaking, or reflex probing movements do not produce abraded surfaces on the teeth. Only nonphysiologic movements of the mandible (parafunctions) produce abraded states; tooth-guided movements of the mandible are nonphysiologic.

In this respect, the axial loading of the teeth is seen to be physiologic, while eccentric nonaxial loading has atrophic and destructive effects. Only when the feedback cycle of the masticatory system is disrupted will faulty movements and faulty loading that have a pathologic impact occur.

Chewing movements are performed in a reflexive, unconscious fashion. They are conditioned, which means they have to be learned in childhood and are sustained via feedback mechanisms. An individual chewing style will develop. Only the closing phase of chewing cycles is the same in all

Fig 8-152 According to End, in a natural dentition there is no tripodization (three-point support) over the whole dentition and no long centric occlusion with point-and-surface support. Only physiologic centric occlusion exists that has the following characteristics: even and simultaneous point contacts with occlusal clearances, contact points predominantly on the inner slopes of the working cusps, few marginal ridge and shear contacts, anterior teeth with minimal touch contact, and sagittal overbite. (Illustration from Vita.)

humans. Thus, when the mandible is moved back into terminal occlusion, the movement is stopped just before or on contact in centric occlusion.

The chewing cycles take place out of and end in this physiologic centric occlusion. The typical chewing movement starts with the movement to open out of centric occlusion with immediate separation of the rows of teeth. The closing movement again meets in physiologic centric occlusion in the middle. In the process, the mandible moves to the working side, where the food is meant to be chewed between the teeth.

In conventional articulators, centric occlusion is the only contact that can be physiologically imitated. All other contact positions and contact movements are nonphysiologic and are arbitrarily performed by dentists and dental technicians. Chewing movements differ between individuals, are dependent on the food being consumed, and cannot actually be simulated in an articulator.

It may therefore be concluded that anterior guidance or sequential lateral guidance by groups of teeth cannot offer an articulation concept that maintains the system. No standard dentition guarantees intactness and physiologic function. An individual physiologic dentition works without interference by means of neuromuscular tooth guidance and physiologic centric occlusion.

Tooth setup in biologic prosthetics

Tooth setup for a complete denture according to the concept of biologic prosthetics is outlined here. Taking for granted the laws applicable to natural dentitions, setup has to be done in physiologic centric occlusion without bilateral balancing or tooth-group guidance. If a sufficiently punctiform centric occlusion exists, without enforcing posterior or anterior balances in the masticatory system, parafunctions can largely be eliminated or prevented.

Tooth contacts during the chewing cycles only occur in centric occlusion where the grinding work takes place. Canine guidance, one-sided group guidance, or bilateral balancing are not necessary in the natural dentition and hence are not required in the complete denture.

Retention of complete dentures outside occlusion depends on the coordinated neuromuscular interaction between intraoral and extraoral structures and the denture. Therefore, the teeth should also be placed so that there is neuromuscular equilibrium of all the involved structures. In physiologic centric occlusion, uniform loading of the denture without tipping moments is achieved by the punctiform occlusal contacts meeting simultaneously.

The occlusal plane is aligned parallel to the Camper and bipupillary planes on the midlines of the retromolar triangles in the therapeutic vertical dimension of occlusion. The therapeutic vertical dimension of occlusion is measured from the speech distance of 1 to 2 mm and from reconstruction of the patient's profile.

The transverse and sagittal occlusal curves are shaped. These are not compensating curves with

Fig 8-153 Vita's bodily, esthetic anterior tooth shapes that function in mastication are based on the concept of biologic prosthetics and can therefore be used equally for partial and complete prosthodontics. The Vita 3D shade selection system is shown in these sets of teeth. (Illustration from Vita.)

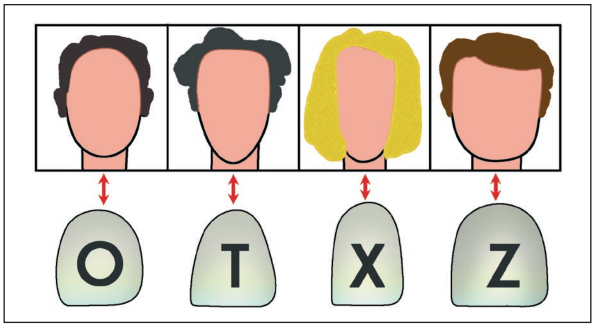


Fig 8-154 The classification of a patient's physiognomy—oval (O), triangular (T), rectangular (X), and square (Z)—forms the basis of the systematization of types of tooth shape. (Illustration from Vita.)

which balancing is to be achieved, but they optimize the force vector of the muscles of mastication. The individual occlusal curves do not balance or guide the dentures but facilitate the stereotypically recurring chewing movements.

After the usual functional impression and model fabrication, the physiologic centric occlusion of the jaws is established using facebow registration. The working models are mounted in an average-value articulator.

The dentist shapes the mandibular anterior region in the patient's mouth, taking into account esthetics and phonetics because the esthetics of the face depend on the shape and positioning of the anterior teeth. A plaster key that reproduces the occlusion rim contour and length determines the position of the maxillary teeth. The mandibular anterior teeth are aligned after the maxillary anterior teeth.

The overjet results from esthetic and phonetic considerations. The maxillary anterior teeth are clearly positioned in front of the ridge contour, and the mandibular anterior teeth are placed slightly in front of or on the alveolar ridge. The labial contours of the mandibular anterior teeth and first premolars are usually located over the vestibular fornix. After the anterior teeth, the mandibular posterior teeth are fully set up.

The other mandibular posterior teeth should be positioned centrally over a straight line from the canine tips to the retromolar triangle, while the maxillary posterior teeth should be placed on an elliptical connecting line between canine tips and tuberosities. The static positioning on the ridge midlines would lead to a crossbite situation.

The setup limit is deemed to be the middle of the retromolar triangle. If the second molars are not set up, the flow of saliva to the pharynx is interrupted. The tongue and cheeks press into the free space and push the dentures forward, which means atrophic stresses on the alveolar ridges. In addition, pressure points may occur in the sublingual area and at the incisive papilla.

Physiodens teeth from Vita are designed for the concept of biologic prosthetics and can be set up in physiologic centric occlusion, which can be repeatedly adopted as the neuromuscular contact position (Fig 8-153). These teeth allow tooth setup with the following (Figs 8-154 to 8-161):

- Uniform, simultaneous point contacts
- Freedom in occlusion
- Contact points on the inner slopes of the working cusps
- Few contacts of shears or marginal ridges
- Slight touch contacts on the anterior teeth
- Positioning of anterior teeth optimized in functional, phonetic, and esthetic terms
- Individual overbite without anterior guidance or bilateral balancing

The naturally shaped occlusal surfaces and their nonbalanced setup prevent parafunctions. Excursions out of and into centric occlusion remain neuromuscularly free of interference and become possible due to the occlusal clearances.

Fig 8-155 The posterior teeth from Vita Physiodens/Posteriores were developed by End according to natural laws and by reference to physiologic centric occlusion; they have occlusal clearances with uniform occlusal point contacts. (Illustration from Vita.)

Fig 8-156 Setup of the maxillary posterior teeth is done in the sagittal and transverse occlusal curve, which starts at the first premolar and continues with the subsequent teeth. (Illustration from Vita.)

Fig 8-157 The oral view of the maxillary posterior teeth shows the sagittal and transverse incline of the occlusal surfaces for individual shaping of a helicoid torsion curve. (Illustration from Vita.)

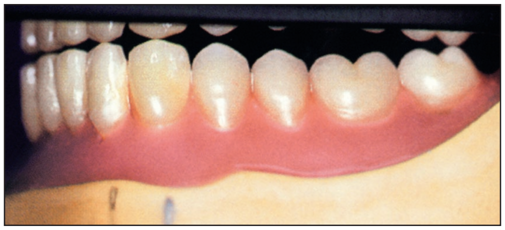


Fig 8-158 The mandibular posterior teeth are also set up in the sagittal and transverse occlusal curve, but this is not intended to take on the function of compensating curves. (Illustration from Vita.)

Fig 8-159 The occlusal plane, represented here by a flat mirror, provides the orientation plane for tooth setup. The occlusal curves are distinctly arched. (Illustration from Vita.)

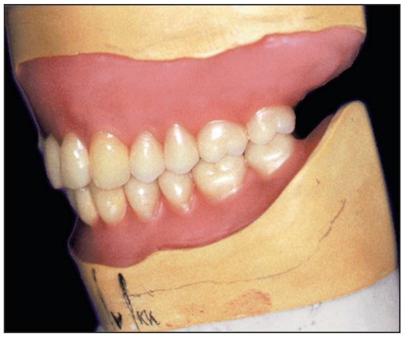


Fig 8-160 The intercuspation visible from the vestibular aspect follows the antagonist rule in tooth–to–two-tooth occlusion. (Illustration from Vita.)

Fig 8-161 Oral intercuspation follows the antagonist rule. The anatomically shaped Physiodens do not occlude very closely but exhibit occlusal clearances for excursions out of physiologic centric occlusion. (Illustration from Vita.)

Fig 8-162 A stabilizing splint is placed in the silicone (Lutesil, Bisico) for the preliminary functional impression; the impression is taken in a nonperforated prefabricated tray.

Fig 8-163 The limit defined by the vestibular fornix is marked in the finished preliminary functional impression, and the impression is removed from the tray.

Fig 8-164 A knife can be used to trim the stable silicone into a temporary custom tray.

Fig 8-165 The preliminary impression, trimmed to form a custom tray, is coated with light-body silicone (Perfekt), and an impression is taken of the mandibular denture-bearing area during functional movements. This creates the foundation for a custom tray.

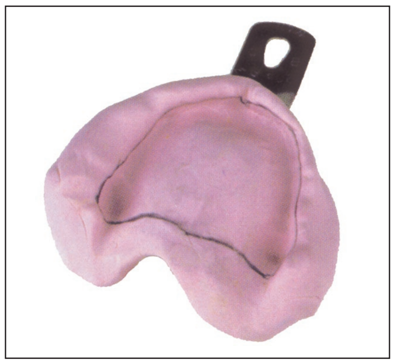


Fig 8-166 The maxillary preliminary functional impression is handled in the same way: The limit of the margin is marked in the vestibule and in the course of the vibrating line.

Fig 8-167 The preliminary impression is taken out of the tray and trimmed back to the marked margin. This preliminary impression, as a custom tray, is used to perform a correction impression of the maxillary denture-bearing area.

Ludwig Technique

Ludwig's method is a technical approach to fabricating complete dentures that does not claim to offer a self-contained articulation theory. In this method, priority is given to a perfected impression technique and physiologic shaping of the denture base, especially in the case of severely resorbed mandibular rest areas.

The technique starts with a preliminary functional impression, for which stable silicone is used (Figs 8-162 to 8-164). This preliminary impression records the function-related denture margin in a dynamic process and is keyed by means of an impression of the vestibule to produce a provisional interocclusal record. The vestibular impression records the inner lip closure line, from which the type of occlusion and path of the occlusal plane can be deduced.

These keyed preliminary impressions are used to prepare the individual bite plates based on jaw relation in an adjusting and leveling device (Lutemat), by means of an integrated kit for intraoral occlusal registration. The integrated functional tray/bite plates—used to take the impression and register the occlusion—are functionally shaped and leave freedom of movement for the tongue and jaw muscles (Figs 8-165 to 8-167). The registration kit is removed for the functional impression.

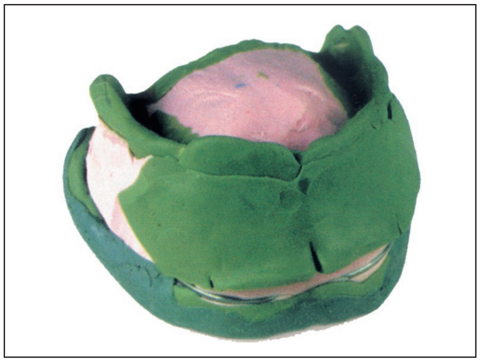


Fig 8-168 The two preliminary functional impressions are aligned with each other by means of a provisional interocclusal record, and a vestibular impression is added. Based on these impressions, casts are made, and all the information is available for preparing custom bite-plate impression trays onto which a registration kit for intraoral occlusal registration is fixed. Using these bite-plate impression trays, the final impression and final interocclusal registration are performed, again with a vestibular impression.

Fig 8-169 The final impression with interocclusal registration and vestibular impression reproduce the precise lip volume; cuts are made to indicate the midline and canine points, and the inner lip closure line stands out.

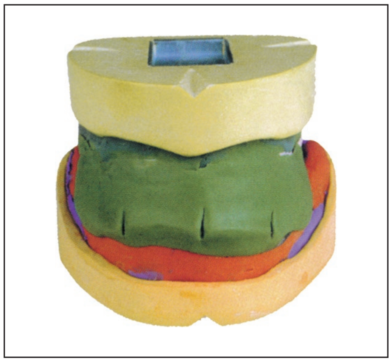


Fig 8-170 Casts are fabricated by the split-cast method and prepared for mounting in the articulator.

Fig 8-171 A matrix is prepared from the vestibular impression; this is meant to indicate the limit and extent of the vestibule.

The definitive functional impression is taken again with a vestibular impression to depict the inner shape of the lip. The aim is to establish the lip closure line, correct lip volume, type of occlusion, overjet, and occlusal plane (Figs 8-168 and 8-169).

Gothic arch tracing is performed by the usual method. The keying of the definitive functional impressions to form a record and the vestibular impression provide the necessary information for correct positioning of the models in an average-value articulator. The average-value position for the articulator is ascertained and fixed with the Lutemat adjusting and leveling device.

The template designed for the Ludwig technique is used for tooth setup; it can be integrated into any type of articulator and adjusted to individual occlusal plane inclinations (Fig 8-170). A matrix is prepared from the vestibular impression, and this provides important orientation for the subsequent anterior setup (Fig 8-171). The maxillary anterior teeth are set up in the path of

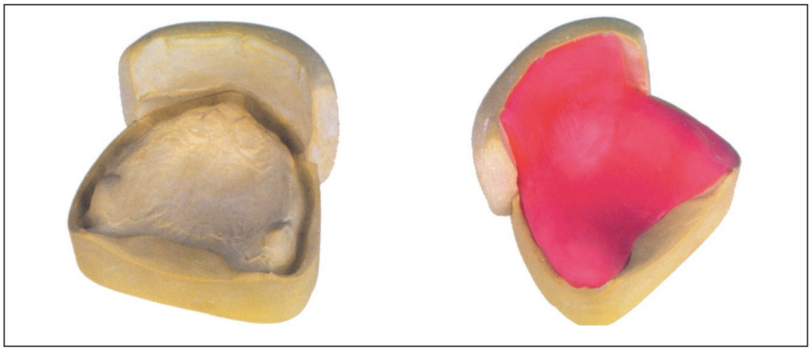


Fig 8-172 The matrix on the mandibular cast shows the dimensions of the vestibule. The matrix is lined with wax for setting up the maxillary anterior teeth; the outer contour of the wax rim provides orientation for the labial contours of the maxillary anterior teeth.

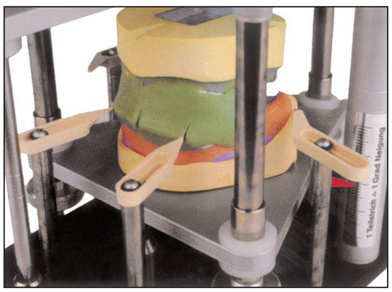


Fig 8-173 The finished casts are set up with the record in the Lutemat. This additional device is referenced to the geometry of the articulator.

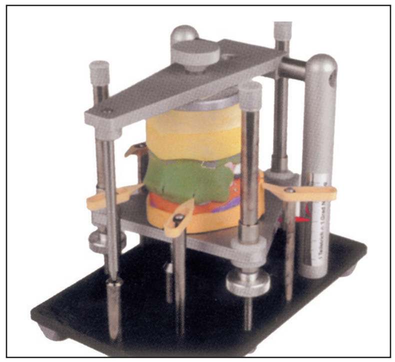


Fig 8-174 The maxillary cast is fixed to the cast holder and transferred to the compatible articulator, where the mandibular cast is inserted next.

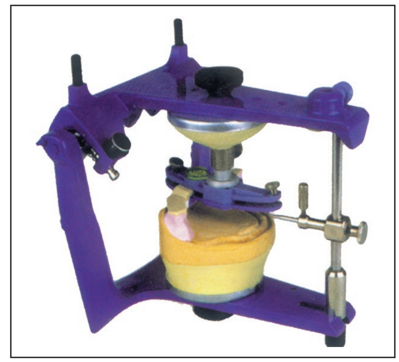


Fig 8-175 The template is adjusted to the reference planes of the articulator and plastered onto a cast holder. It is fitted with one template tooth and a transparent template window.

the individual vertical anterior arch for the individual overjet to achieve natural lip volume (Fig 8-172). The posterior teeth are set up on the ridge midlines based on static considerations. The aim is to achieve a bilateral balanced occlusion upon completion (Figs 8-173 to 8-175).

A nonhardening denture base, primarily for a severely atrophied mandible, is another key aspect of the Ludwig technique. The softly cushioned surface of the denture base is integrated into the physiologic movement patterns of the jaw and relieves potential pressure points. The physiologic functional denture is fabricated in three steps:

1. An individual steel reinforcement to receive the nonhardening base material is first prepared (Fig 8-176).
2. The nonhardening base material is partly vulcanized and finished. This base material (Lutemoll 40, Bisico) has a hardness of 40 Shore A; areas particularly susceptible to pressure points can be worked with a softer material (Lutemoll 25) with hardness of 25 Shore A.
3. The wax-up is done on the finished denture base, and the denture is subsequently completed in acrylic resin.

Durability of the special nonhardening base materials is achieved after vulcanization at approximately 150°C for 1 hour and subsequent tempering at 200°C for 4 hours (Fig 8-177). It is not possible to work the material directly joined to the denture acrylic resin because this, as well as the artificial teeth, will depolymerize at the high working temperatures. Therefore, an individualized steel reinforcement is first prepared, and the nonhardening base material is partly vulcanized, tempered, and finished. Then the wax-up can be done on the denture base. It is advisable

Fig 8-176 A metal reinforcement is first produced by the model casting technique to carry the elastic, nonhardening base material.

Fig 8-177 The metal reinforcement is lined with the nonhardening material, which is vulcanized at approximately 200°C.

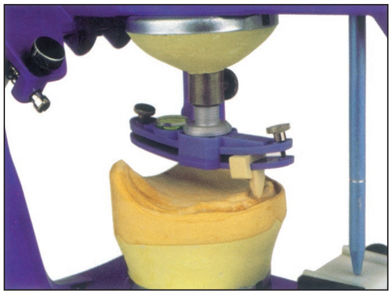


Fig 8-178 Tooth setup starts by placing the sagittally movable template tooth onto the middle of the mandibular alveolar ridge.

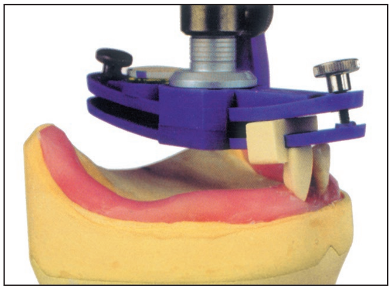


Fig 8-179 The first mandibular central incisor is then placed onto the finished metal base next to the template tooth in wax.

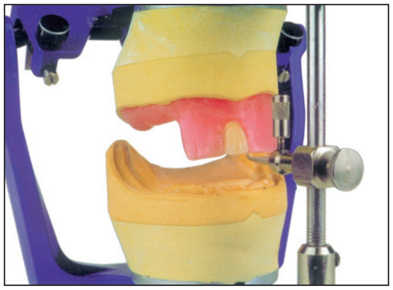


Fig 8-180 The first maxillary central incisor is aligned with the articulator marking and with the wax rim created from the vestibular impression.

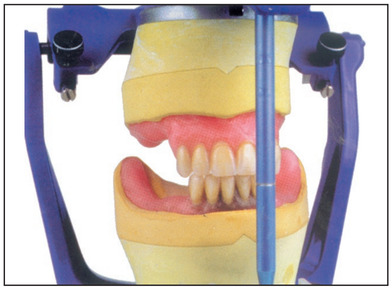


Fig 8-181 The anterior teeth are set up according to the vestibular impression, thereby satisfying esthetic requirements.

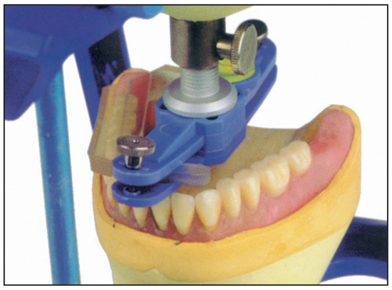


Fig 8-182 Starting from the mandibular central incisor, the mandibular dental arch is reconstructed; the marked lines on the template provide orientation.

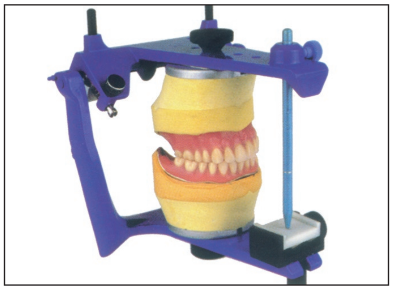


Fig 8-183 The try-in is done on the finished Lutemoll base.

Fig 8-184 In the finished denture, the margins of the metal reinforcement extend precisely into the vestibular fornix and support the highly elastic, nonhardening base material.

to perform final completion of the denture by the injection method, but the tamp-press technique may also be used.

The fact that excellent fracture resistance is achieved due to the steel reinforcement is another reported advantage of the physiologic functional denture. This method is also recommended for implant-supported complete dentures.

Tooth setup according to the Ludwig technique is presented in Figs 8-178 to 8-184.

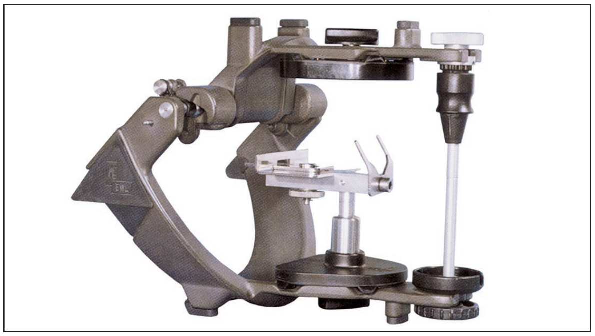


Fig 8-185 For systematic mounting of casts, a model positioner is provided that is height adjustable and has a movable fork for anterior fixation and a slider for the tuberosity starting points. This mounting device allows average-value positioning of the maxillary cast.

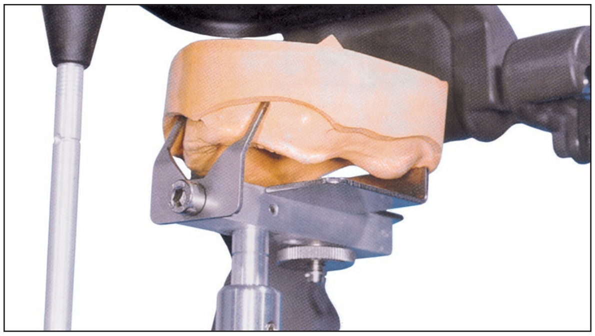


Fig 8-186 The metal prongs of the fork are aligned with the anterior support points in the depth of the anterior fornix and the starting points of the tuberosities.

Fig 8-187 The occlusion inclination indicator is used as a setup aid for the posterior teeth. The setup aid is fixed in the Protar articulator from KaVo with the mounting bracket.

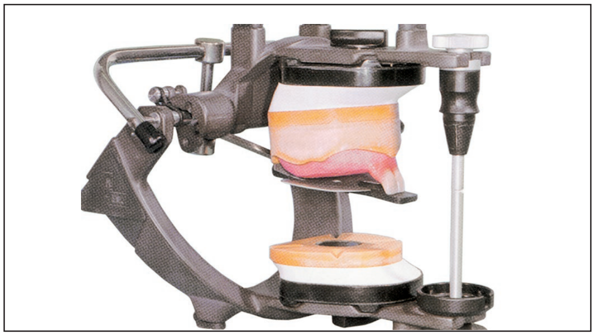


Fig 8-188 Before aligning the occlusion inclination indicator with the start of the tuberosities and the incisal edges, the maxillary central incisors must be set up.

APF_{NT} System

The APF system ([**A**]esthetics, **P**honetics, **F**unction) has been supplied since 1975 by Dentsply as a teaching, checkable setup guide. To enhance the practical relevance of this system, the APF_{NT} system (**N**ew **T**echnology) was developed and introduced in 2001. The new system is intended not only to satisfy training requirements but also to improve the standard of the fabrication of average-value complete dentures.

The APF_{NT} system describes four comprehensive measures for preparing a patient-related tooth setup:

1. Mounting the model with the model positioner for the Protar articulator from KaVo.
2. Determining the occlusal plane with the occlusion inclination indicator from the same KaVo system.
3. Performing model analysis to determine the setup areas on the bony base of the jaws.
4. Establishing tooth-to-tooth setup in lingualized occlusion.

Average-value mounting of the maxillary cast is done with the model positioner. The mandible is matched to the maxillary cast with an intraoral occlusal record. The maxillary model positioner is a height-adjustable mounting device that has a slider that rests in the starting points of the two tuberosities and a movable fork for the deepest points in the maxillary anterior vestibular fornices (Figs 8-185 and 8-186).

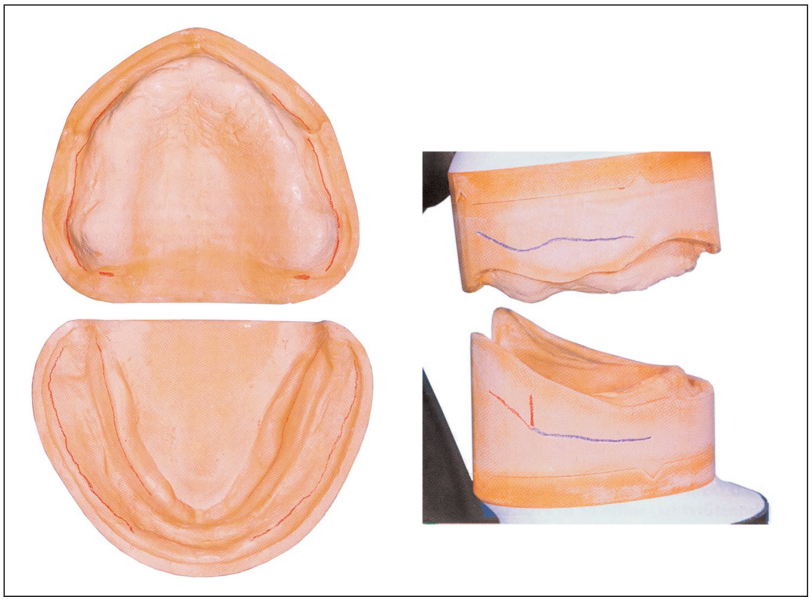


Fig 8-189 Model analysis is confined to tracing the alveolar ridge contours, the depths of the fornices, and the mylohyoid line in order to limit the setup area within which the antagonist contacts are supposed to lie.

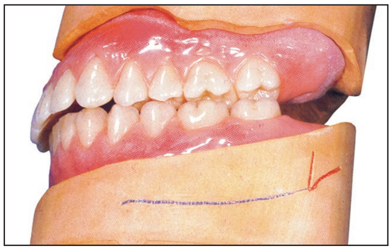


Fig 8-190 Tooth-to-tooth setup in lingualized occlusion and with individual overjet allows intermediate movements at a maximum of 1 mm wide; these movements are not excursion movements. The basic setup objective is centric relation.

The occlusal plane as a reference line for posterior setup is referenced to the starting points of the two tuberosities and the incisal edges of the maxillary anterior teeth. The mandible is defined as not belonging to the skull and thus does not provide any orientation for the occlusal plane. This is because the occlusal plane, which runs from the mandibular incisal point to the upper edges of the retromolar pads, slopes downward and backward and destabilizes the mandibular denture.

The occlusion inclination indicator (setup aid) from KaVo is aligned with the starting points of the two tuberosities and the maxillary incisal edges and shows how the occlusal plane is oriented in the interalveolar space (Fig 8-187). The occlusal plane rises backward so that the mandibular posterior teeth project above the upper edge of the retromolar pad. The occlusion inclination indicator set comprises the mounting bracket, setup aid with anterior table, and operating tool.

To align the setup aid, tooth setup must start with the maxillary anterior teeth, which are placed in muscular equilibrium of the lips and tongue to support the functional areas of speech and the patient's physiognomy (Fig 8-188). Optimized positioning of the anterior teeth is found with a physiognomic check template that should be individualized by the dentist. The overjet, as an individual patient-specific measurement, is also determined with the check template.

Marking of the ridge midlines is omitted in the model analysis of edentulous jaws (Fig 8-189). Instead the bony foundation of the jaw is defined as the setup area for the posterior teeth. This setup area lies inside the deepest points of the vestibular fornix in the maxilla; in the mandible, it lies between the inner border of the mylohyoid line and the outer border of the oblique line. It is assumed that the teeth positioned inside these lines safely transfer all the forces to the denture-bearing area; even though the teeth are not on the middle of the alveolar ridge, the denture remains stable.

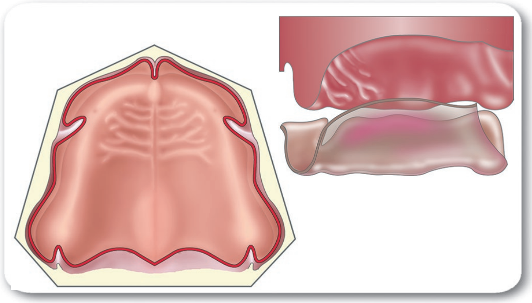
The posterior teeth are set up in a tooth-to-tooth relationship (Fig 8-190); that is, only one pair of teeth ever has contact with each other, and each antagonist pairing of teeth stands alone. No mesial or distal partners are needed for stability in centric occlusion or during intermediate movements in dynamic occlusion. Corrective grinding should be performed for intermediate movements. The intermediate guide paths are a maximum of 1 mm wide and do not represent excursion movements.

The concept of lingualized occlusion, in which the teeth are moved buccally, is stipulated to create more space for the tongue but without destabilizing the teeth. In lingualized occlusion, the lingual occluding cusps of the maxillary denture teeth engage in the central contact areas of the mandibular denture teeth (central fossae). The buccal cusp segments are markedly out of antagonist contact. However, they must be placed inside the bony borderline. In centric occlusion, there must be no anterior tooth contact.

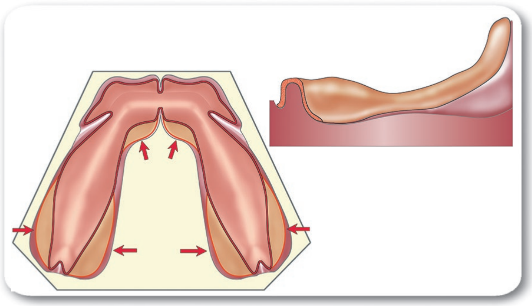
Planning, Fabricating, and Assessing Complete Dentures

The working steps of creating a complete denture are the following:

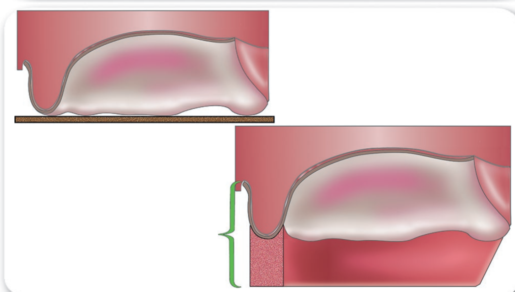
1. Create a normal interocclusal registration (Fig 8-191).
2. Perform model analysis of the maxilla (Fig 8-192).
3. Perform model analysis of the mandible (Fig 8-193).
4. Adjust the models in the articulator (Fig 8-194).
5. Set up the mandibular anterior teeth (Fig 8-195).
6. Set up the maxillary anterior teeth (Fig 8-196).
7. Set up the mandibular premolars and the maxillary first premolar (Fig 8-197).
8. Set up the posterior teeth (Fig 8-198).
9. Wax up the denture body (Fig 8-199).



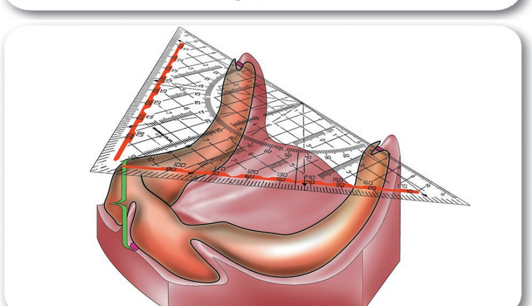
Adapt the maxillary baseplate and establish the marginal border of the maxillary baseplate:
- Trace the marginal border.
- Etch the vibrating line and hollow out the plicae palatinae.
- Isolate the model surface.
- Adapt the baseplate material.
- Cut out the baseplate margin and smooth.
- Fill out the valve-type margin.



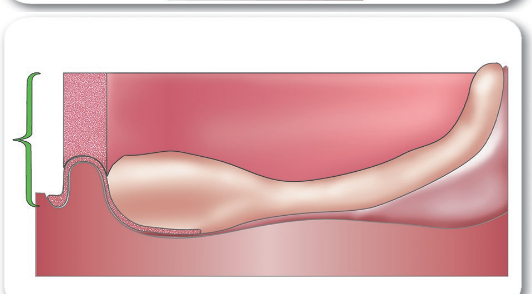
Adapt the mandibular baseplate and establish the marginal border of the mandibular baseplate:
- Trace the marginal border.
- Isolate the model surface.
- Adapt the baseplate material.
- Cut out the baseplate margin and smooth.
- Create clearance around the mylohyoid line/oblique line.
- Fill out the valve-type margin and enclose triangles.



Set up the occlusion rim in the maxilla and shape the occlusion rim in wax or use occlusion rim bars:
- Place on the middle of the alveolar ridge.
- Raise to the occlusal plane.
- Ensure that the distance from the vestibular fornix to the occlusal plane is a minimum of 24 mm.
- Make sure the maxillary alveolar ridge contour is roughly level.
- Set the occlusion rim parallel to the ridge contour.
- Bevel the occlusion rim to the maxillary tuberosity.



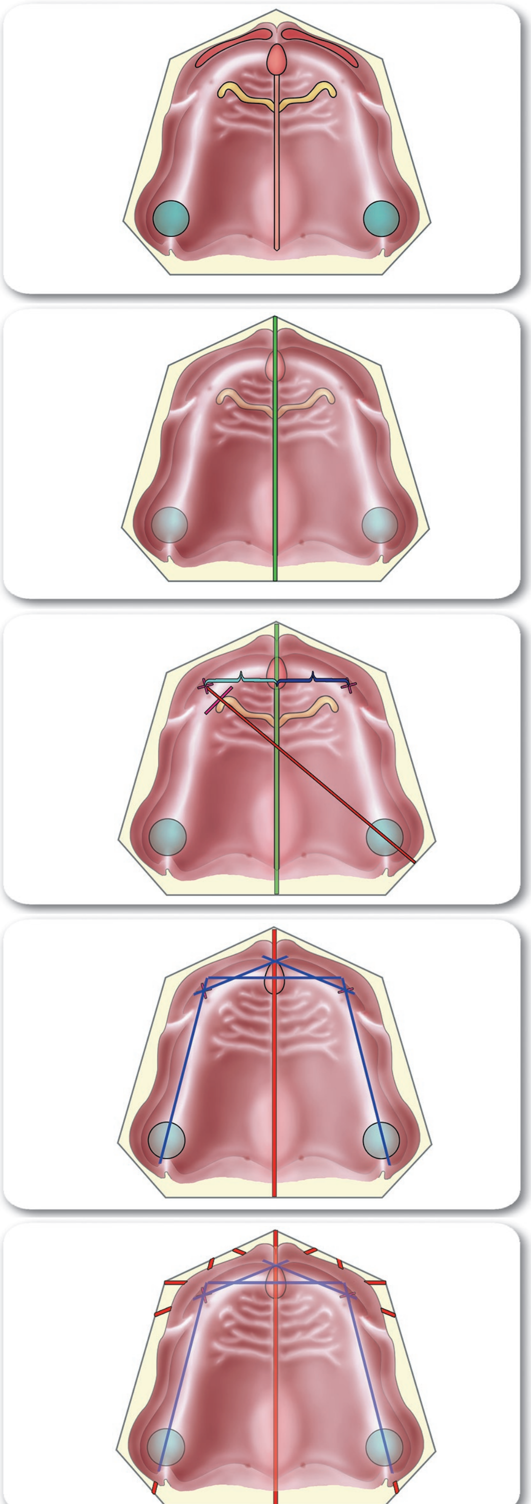
Establish the occlusal plane and mark the occlusal plane with a protractor:
- Ensure that the distance from the vestibular fornix to the occlusal plane is a minimum of 20 mm.
- Fix the occlusal plane to the upper edge of the triangle.
- Set the upper edge of the triangle on one side.
- Reflect the triangle and bring to a symmetric height.
- Trace the occlusal plane markings on the base margins.



Set up the occlusion rim in the mandible and shape it in wax:
- Use occlusion rim bars.
- Place on the middle of the alveolar ridge.
- Raise the occlusion rim to the occlusal plane.

(Note: The occlusion rim is dimensioned high enough to provide sufficient space for the setup without having to grind the teeth at the base.)

Fig 8-191 Step 1: Create a normal interocclusal registration.



Establish the model analysis fixed points in the maxilla:
- Anterior vestibular fornices
- Incisive papilla
- First large pair of plicae palatinae
- Median palatine raphe
- Maxillary tuberosities

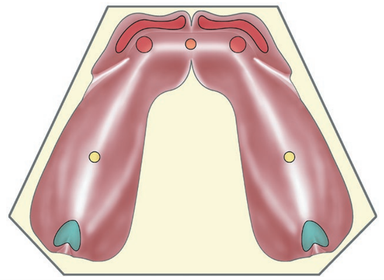
Establish the axis of symmetry in the maxilla:
- Construct it from the model analysis fixed points.
- Form a symmetric grid from static lines.
- Include clear references to tooth position.
- The middle of the model is the median palatine raphe, which is the axis of symmetry.

Construct the canine point in the maxilla:
- Canine points lie on the diagonal from the tuberosity, over the first large pair of plicae palatinae, and approximately 5 mm in front of that.
- Reflect the second canine point across the axis of symmetry.

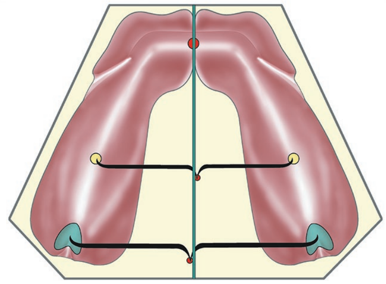
Trace the midlines of the alveolar ridges:
- Mark the midline of the anterior alveolar ridge.
- Mark the canine point to the tip of the papilla.
- Mark the midline of the posterior alveolar ridge (middle of the maxillary tuberosity to the canine point).
- Mark the raphe-papillary cross-line at right angles to the model midline through the middle of the papilla.

Mark the static lines:
- Static lines must be transferred to the model margins.
- These lines include 12 markings in the maxilla.

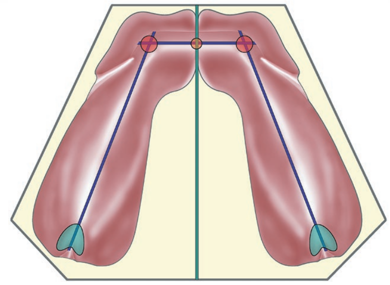
Fig 8-192 Step 2: Perform model analysis of the maxilla.



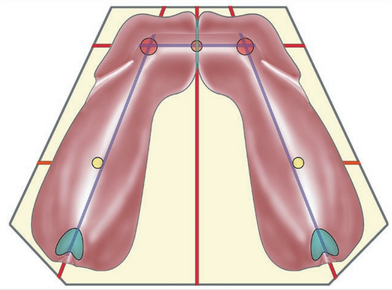
Establish the model analysis fixed points in the mandible:
- Anterior vestibular fornices
- Mandibular symphysis point
- Canine points
- First molar point
- Molar triangle



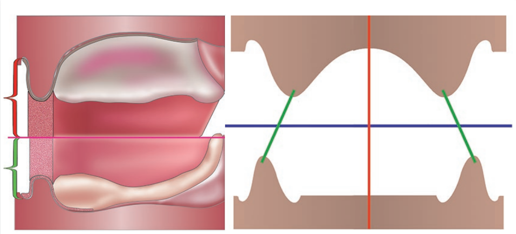
Establish the axis of symmetry in the mandible:
- Mark the middle of the mandibular model.
- Mark from the symphysis point to the arithmetic mean between half of the line connecting the triangles and half of the line connecting the first molar points.



Trace the ridge midlines:
- Mark the midline of the posterior alveolar ridge from the middle of the triangle to the canine point.
- Mark the midline of the anterior alveolar ridge as a line connecting the canine points, which usually lies behind the ridge contour.

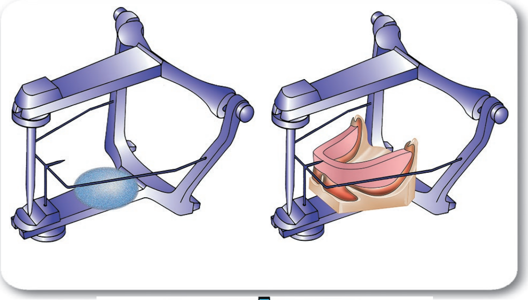


Transfer the static lines to the model margins:
- Twelve markings in the maxilla and eight in the mandible are produced as a symmetric grid.



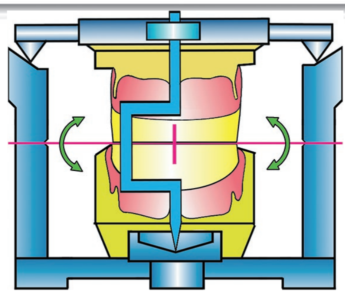
Adjust the models in centric relation:
- Fix the models according to the model analysis grid.
- Align the axes of symmetry.
- Place the midlines of the anterior alveolar ridges so that the maxilla protrudes 2 mm.
- Place the midlines of the posterior alveolar ridges so that the interalveolar lines are symmetrically inclined.

Fig 8-193 Step 3: Perform model analysis of the mandible.



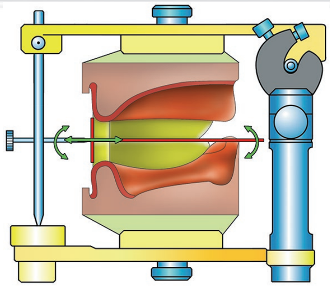
Position the models with plasticine. The models are inserted in two stages—first the maxillary model and then the mandibular model:

- Set the mandibular model on plasticine.
- Line up the occlusal plane marking on the articulator with the occlusal plane of the interocclusal registration.
- Check the occlusal plane from the front, behind, and side.
- String the occlusal plane markings with a rubber band.



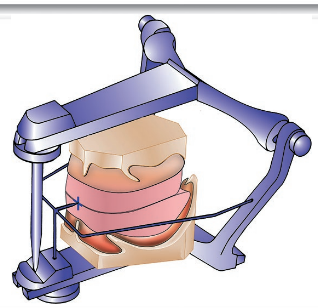
Adjust the model midline/articulator midline, viewing the models from the front and back:

- Adjust the model midline to the articulator midline.
- Pay attention to occlusal plane fixation; do not tilt.
- Open the upper articulator arm and line up the midline of the model with the articulator midline (the model midline must point to the floor of the maxillary base).
- Line up the model midlines with the articulator midline.



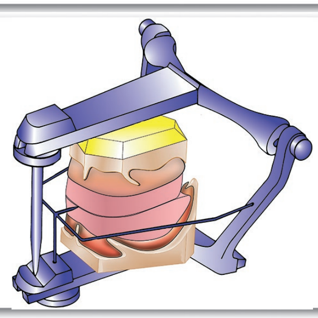
Adjust the models/sagittal plane; view the models from the lateral position:

- Set the models to the incisal point based on the Bonwill triangle.
- Measure the intercondylar distance with dividers.
- Project this distance onto the occlusal plane as the incisal point.
- Make sure the occlusal planes do not tilt.
- Check the position of the models.



Fix the maxillary model with plaster, isolate the model base, and fit the base with a magnet capsule:

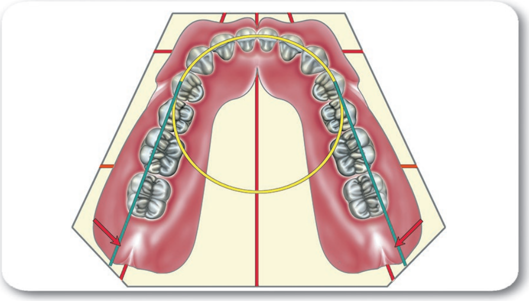
- Mix plaster in the correct mixing ratio.
- Apply plaster to the maxillary model base and maxillary model holder.
- Gently close the upper articulator arm.
- Push plaster into the depressions in the base.
- Let the plaster set before trimming.



Fix the mandibular model with plaster, isolate the model base, and fit the base with a magnet capsule:

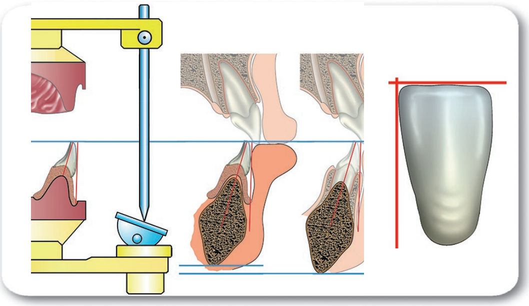
- Mix plaster in the correct mixing ratio.
- Turn over the articulator and open the lower arm.
- Apply plaster to the model base and model holder.
- Gently close the lower articulator arm.
- Push plaster into depressions in the base.
- Let the plaster set before trimming.

Fig 8-194 Step 4: Adjust the models in the articulator.



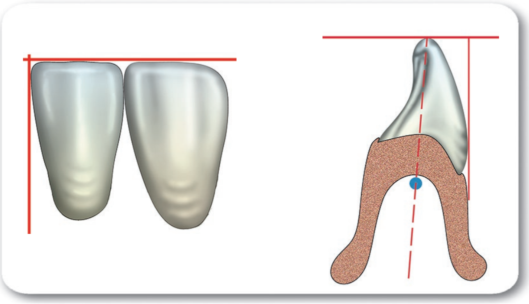
Check the reference and orientation planes and lines. Setup starts with the mandibular anterior teeth and reference lines for the mandibular anterior teeth:

- Mark the midline of the alveolar ridge.
- Create the Bonwill circle with the diameter referenced to tooth widths.
- Mark the mandibular vestibular fornix.
- Mark the position of the occlusal plane.



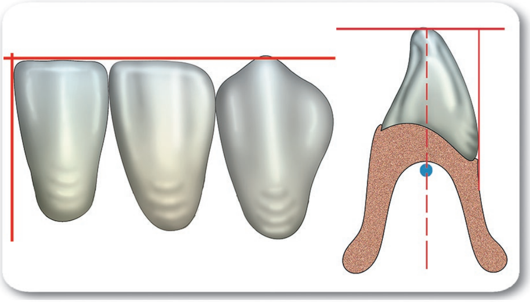
Position the mandibular left central incisor:

- It should stand with its base on the ridge midline and its incisal edge exactly on the occlusal plane.
- Position it approximally.
- Tooth axes have a vestibular inclination.
- The labial contour is perpendicular and shows in the vestibular fornix.
- The tooth axis viewed from the vestibular aspect is perpendicular.
- Its incisal edges form the start of the Bonwill circle.



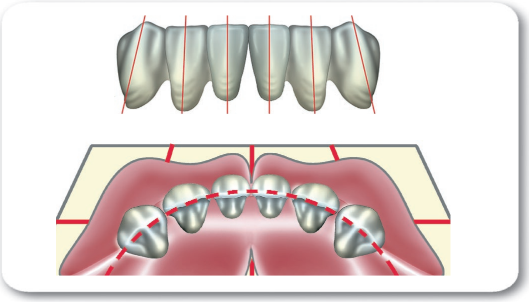
Position the mandibular left lateral incisor:

- It should stand with its base on the ridge midline and its incisal edge exactly on the occlusal plane.
- Position it approximally.
- Tooth axes have only slight vestibular inclination.
- The labial contour has a slight lingual inclination.
- The tooth axis viewed from the vestibular aspect is perpendicular.
- Viewed occlusally, the incisal edge lies in the Bonwill circle.



Position the mandibular canine:

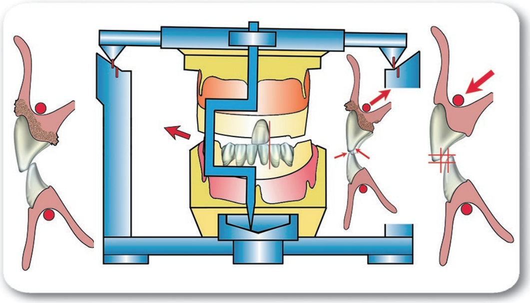
- It should stand with its tooth axis vertical, its base on the canine point, and its incisal edge exactly on the occlusal plane.
- Tooth axes have a slight mesial inclination from the vestibular aspect.
- The labial contour has a pronounced lingual inclination.
- Viewed occlusally, the incisal edge forms the Bonwill circle.



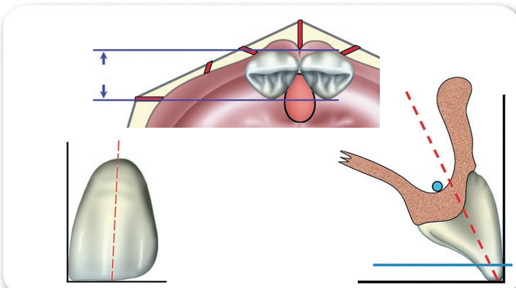
Position the mandibular right anterior teeth:

- They should stand with their base on the ridge midline.
- The dental arch is formed by approximal inclinations.
- The labial contour of the central incisor is vertical, the labial contour of the lateral incisor is slightly lingual, and the labial contour of the canine shows pronounced lingual inclination.
- The incisal edges rotate into the Bonwill circle, with the incisors vertically positioned and the canine slightly mesially inclined.

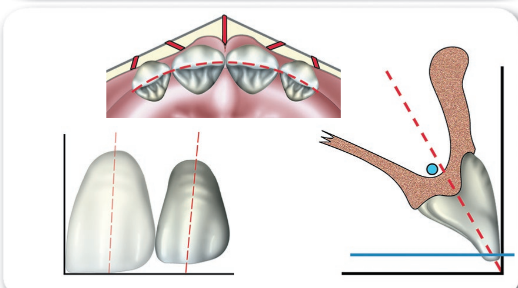
Fig 8-195 Step 5: Set up the mandibular anterior teeth.



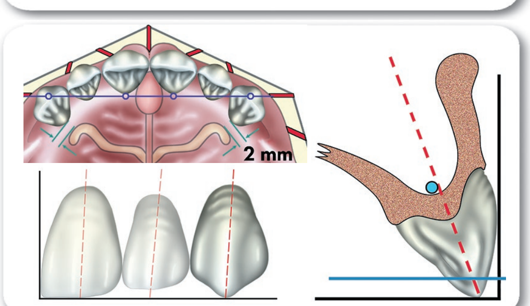
Construct the overjet:
- Place the central incisor with the necessary overbite without protrusion and the correct mesial inclination exactly at the midline of the dental arch.
- Make lateral movements in soft wax until the approximal edges of the maxillary and mandibular central incisors are pressed out labially.
- Maintain the lateral position and push the central incisor into edge-to-edge position.
- In terminal occlusion, the central incisor is in exact overjet.



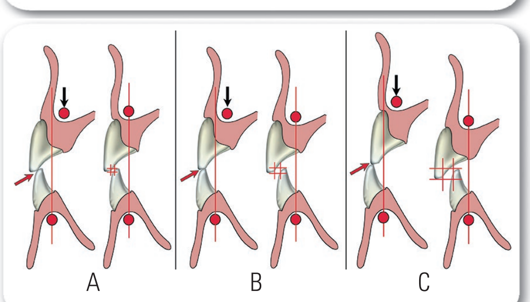
Position the maxillary left central incisor:
- It should stand with its base in front of the ridge midline.
- It forms the vertical anterior arch.
- The labial contour stands vertically approximately 7 mm in front of the papilla midline.
- Viewed labially, there is a slight mesial inclination.
- It protrudes approximately 2 mm beyond the occlusal plane.
- Viewed occlusally, the dental arch is formed.



Position the maxillary left lateral incisor:
- Viewed labially, it has a pronounced mesial inclination and protrudes only about 1 mm beyond the occlusal plane, shorter than the central incisor.
- Viewed approximally, the labial contour has a slight vestibular inclination, and the tooth axis has a pronounced vestibular inclination.
- Viewed occlusally, the dental arch is formed.

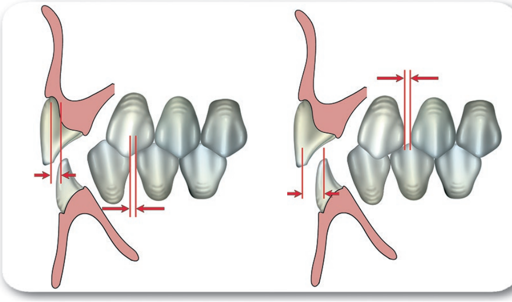


Position the maxillary left canine:
- Viewed labially, it has a slight mesial inclination and protrudes about 2 mm beyond the occlusal plane, as long as the central incisor.
- Viewed approximally, the labial contour stands perpendicular.
- The tooth axis has a pronounced vestibular inclination.
- If it stands vertically, it will interfere with lateral movements.
- Viewed occlusally, the canine stands in front of the canine point.
- The raphe-papillary cross-line runs through the canine tips.

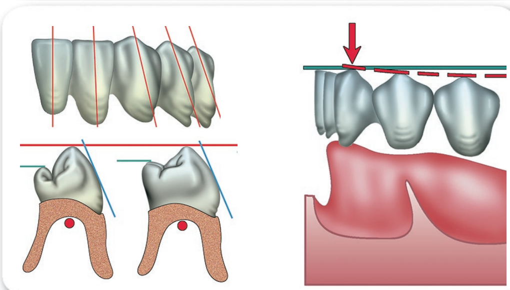


Construct the overjet. The size of the overjet depends on the edge-to-edge position when the approximal edges of the maxillary and mandibular central incisors are in alignment:
- If the incisal edges touch labially, there is a small overjet (A).
- If the incisal edges are in full edge-to-edge contact, there is a medium overjet (B).
- If the incisal edges touch lingually, there is a large overjet (C).

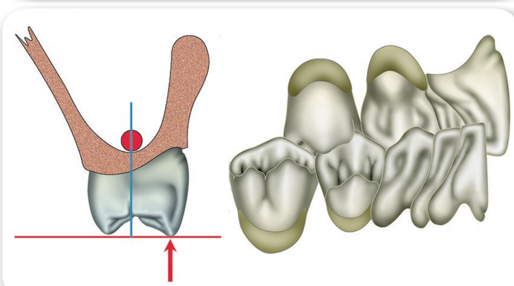
Fig 8-196 Step 6: Set up the maxillary anterior teeth.



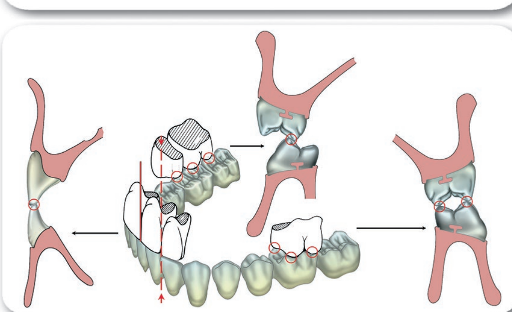
Temporarily position the premolars:
- The gap between the canine and the premolar depends on the size of the overjet and the tooth widths, so the position of the premolars must be set up temporarily to see where the gap arises.
- With a small overjet or wide maxillary anterior teeth, there is a gap between the mandibular canine and first premolar.
- With a large overjet and set of narrow maxillary teeth, there is a gap between the maxillary canine and first premolar.



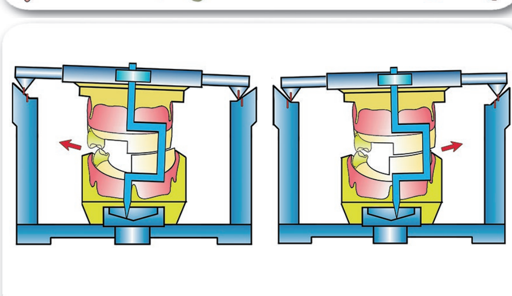
Position the mandibular left premolars:
- Align the central developmental grooves with the ridge midline.
- The first premolar should stand inside the compensating curves, approximately 1 mm below occlusal plane, with a slight mesial inclination.
- The second premolar should have a pronounced tooth inclination, with its central developmental groove over the ridge line, approximately 1 mm lower than the first premolar.



Position the maxillary left first premolar:
- Set the normal occlusion to the mandibular premolars.
- Check the occlusion from the vestibular and oral direction.
- It has a slight mesial and vestibular inclination.
- Its lingual occluding cusp lies in the interdental embrasure and extends onto the buccal cusps to the balancing side.
- Its nonsupporting cusp lies approximally between the first and second premolars and extends through the interdental embrasure to the working side on movement.

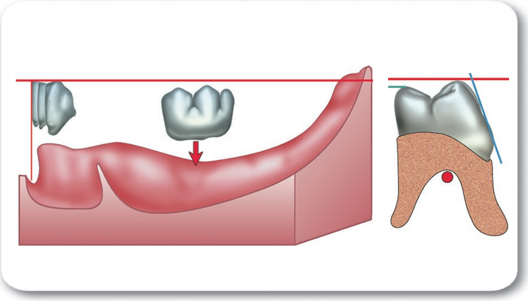


Check the lateral movements:
- For sliding contacts on the balancing side, a transverse compensating curve must be formed.
- For sliding contacts on the working side, a sagittal compensating curve must be formed.
- There will be no sliding contacts if the sagittal curve is too pronounced, the lateral incisor is underdeveloped, the occlusal plane has not been adhered to, or the canine is too long or has too strong a mesial/inward inclination.

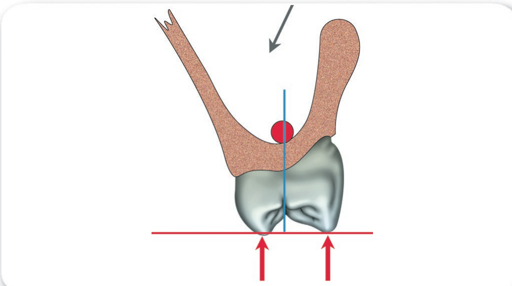


Set up the right pair of antagonists; for three-point or multipoint contacts during lateral and protrusive movements, the following are required:
- Sagittal compensating curve
- Transverse compensating curve
- Overjet of the anterior teeth
- Completely closed intercuspal position of the posterior teeth vestibularly, lingually, and approximally

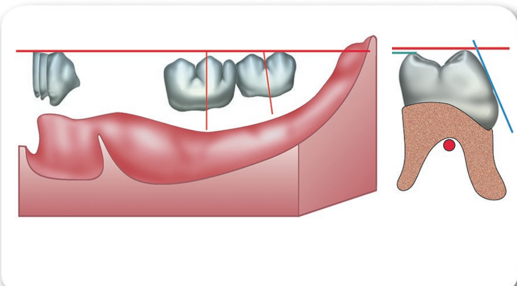
Fig 8-197 Step 7: Set up the mandibular premolars and the maxillary first premolar.



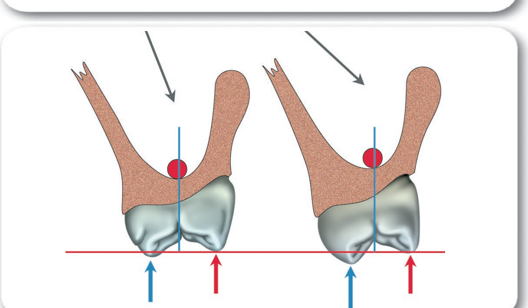
Position the mandibular first molar:
- It forms the lowest point of the sagittal compensating curve.
- It stands perpendicular, from the vestibular view.
- It has its central developmental groove over the ridge midline.
- It shows a slight lingual inclination.
- It forms a weak transverse compensating curve.



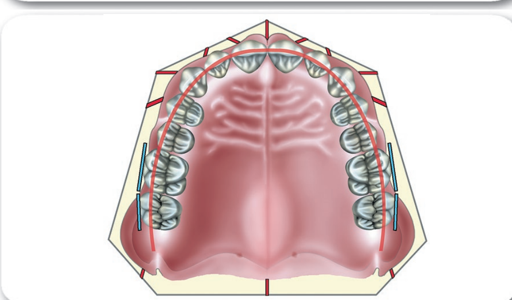
Position the maxillary second premolar:
- It should stand inside the premolar tangent on the ridge midline.
- Its vestibular contour is roughly perpendicular.
- Both cusps are the same height.
- Its lingual occluding cusp lies in the interdental embrasure and extends on the buccal cusp of the maxillary first molar to the balancing side.
- Its nonsupporting cusp lies approximally between the second premolar and first molar and extends through the interdental embrasure to the working side on movement.



Position the mandibular second molar:
- It shows a pronounced mesial inclination.
- It touches the occlusal plane with its distobuccal cusp.
- It has its central developmental groove over the ridge midline.
- It may be rotated slightly into the dental arch.
- The mandibular dental arch is parabolic.
- Viewed approximally, it stands perpendicular (no tooth inclination).

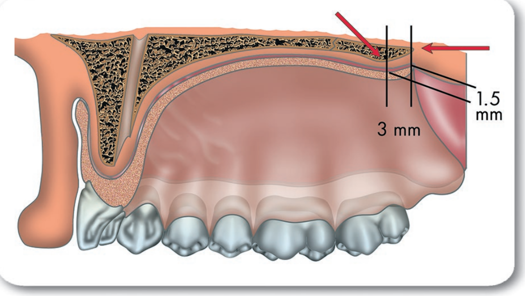


Position the maxillary molars:
- Ensure precise intercuspation on the ridge midline.
- Place them in the sagittal and transverse compensating curve.
- The first molar with the canine forms the premolar tangent, and its occluding cusp is placed in the central developmental groove of the mandibular first molar.
- The second molar is rotated distally in the dental arch, which forms a semi-ellipse, and its occluding cusp is placed in the central development groove of the mandibular second molar.
- The buccal overbite is reduced to edge-to-edge position.

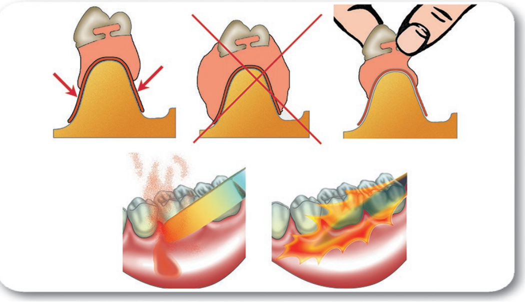


Set up the posterior teeth:
- Place them on the ridge midline.
- Shape the dental arch to form a semi-ellipse.
- The premolars should stand in the premolar tangent.
- Perform check movements for balancing and working contacts.
- Make corrections to antagonists.
- Sliding contacts arise due to precise shaping of the compensating curves.

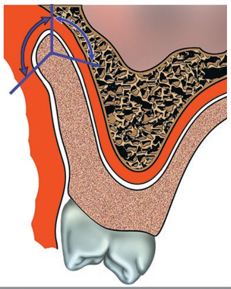
Fig 8-198 Step 8: Set up the posterior teeth.



Prepare the models:
- Prepare the maxillary model first.
- Etch a vibrating line in the double arch from tuberosity to tuberosity and enclose the posterior nasal spine of the palatine bone.
- Hollow out the median palatine raphe and palatine torus.
- Isolate both models (possibly steep).
- Plaster against wax.

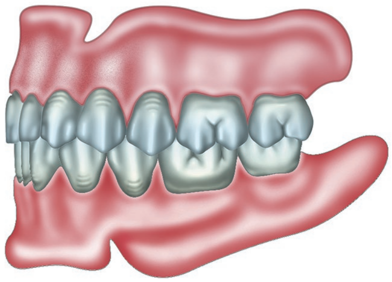


Apply alternating wax appropriately:
- Apply wax without producing wax stresses.
- Alternate application of wax so that the setup wax is not heated through.
- Smear wax layers with underlying wax and keep bubble-free for a homogenous wax structure.



Shape the denture margins:
- Completely fill the denture margins in the vestibular fornix area for a ridge-shaped valve-type margin.
- Hollow out the denture body above the valve margin as a lip shield for the musculature.
- Allow for necessary reductions.
- Create extension possibilities.

Wax up the anterior denture body:
- Reproduce the gingival sulcus.
- Reproduce alveolar eminences as far as the first premolar.
- Close interdental spaces and hygienically shape the interdental papillae.
- Anatomically shape the gingival structure.
- Smooth the wax-up.



Wax up the posterior denture body:
- Extend the denture body toward the necks of teeth.
- Close interdental spaces and hygienically shape the interdental papillae.
- Ensure that the denture body is smooth.
- Do not reproduce any alveolar eminences.
- Do not shape the gingival structure.
- Shape a valve-type margin in the maxilla.
- Avoid the oblique line and mylohyoid line.

Fig 8-199 Step 9: Wax up the denture body.

9

Implant Terminology

The term *implant* refers to a material introduced into the body to replace or reinforce an organ or tissue, such as bone chips or endoprostheses (eg, artificial blood vessels and joint replacements). Thus, in dentistry the term *implantology* refers to the placement of dental implants (parts to replace tooth roots) in the maxilla and mandible to receive tooth replacements. These tooth root replacement parts are implanted from alloplastic (foreign to the body) materials into the jaw area to anchor individual teeth or an extensive fixed or removable prosthesis.

Closed implants are surrounded on all sides by the body's own tissues, for example closed magnetic implants, joint replacements, or heart valves. *Open implants* are tissue replacement components sunk into the body that permanently protrude through the surface of the body and can form a constant entry portal for germs. The root replacement parts commonly used in dentistry for affixing dentures are open implants (Fig 9-1).

Implant placement takes place in several stages, starting with history taking, clinical examination, and radiographs and concluding with the actual surgical procedure. Depending on the timing, a distinction can be made between one-stage (single-phase or one-step) and two-stage (dual-phase or two-step) implant placement.

In one-stage implant placement, the implant is inserted so that the exostructure (implant post/abutment) protrudes through the mucosa during the healing phase and is functionally loaded by an implant-supported denture immediately after implantation. No prosthetic replacement is worn for about 2 weeks to ensure that wound healing of the mucosa is not impeded. In one-stage implantation, one-piece implants are used, and these can be applied in an edentulous mandible for bar-retained prostheses and fitted in a single session.

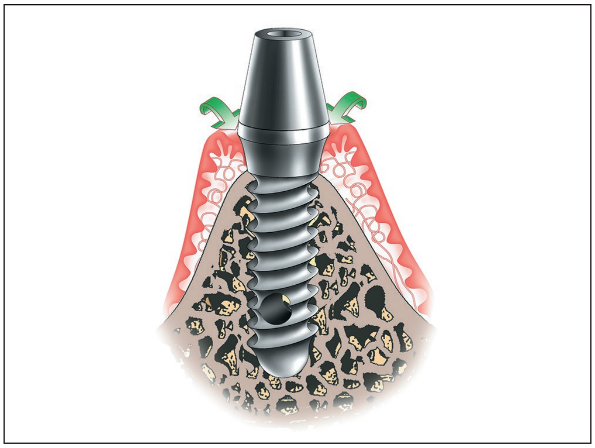


Fig 9-1 Open implants are replacement tissue parts sunk into the body with an implant component permanently protruding through the surface of the body. This provides a constant entry portal to the inside of the body for disease pathogens. Dental root replacement parts for fixation of dentures are open implants. Closed implants are surrounded on all sides by bodily tissues, for example closed magnetic implants, replacement joints, or heart valves. These implants cannot be corroded by external factors and do not offer any entry portals for pathogens.

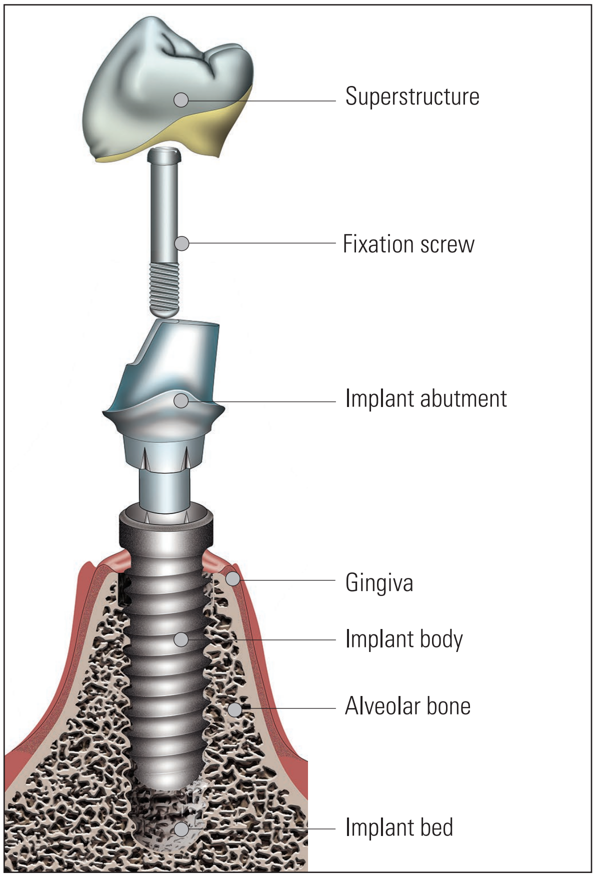


Fig 9-2 An endosseous implant comprises the endostructure (the part sunk into the bone, or implant body) and the exostructure (the part protruding out of the tissue), onto which the mesostructure (the component that connects to the prosthetic replacement) is fixed.

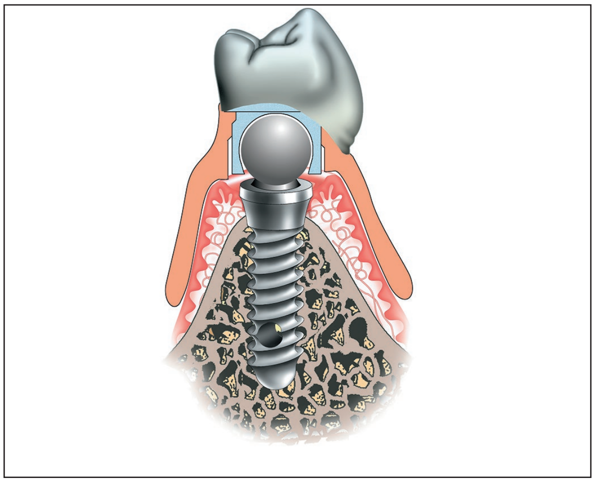


Fig 9-3 The abutment is intended to connect the implant to the superstructure (that is, the tooth replacement). Ball attachments can be used for removable complete dentures, such as those also fitted onto root crowns.

In two-stage implant placement, the implant is covered by sutured mucosa and is not functionally loaded by a tooth replacement throughout an unloaded healing phase (about 3 to 6 months) when direct bony ingrowth (osseointegration) of the implant is possible. In a second procedure, the neck of the implant is exposed and the mesostructure (abutment) is screwed in place. Two-part implants, in which the endostructure (implant body) and exostructure (abutment) are separate (Fig 9-2), are available for this two-stage method. In two-part implants, the abutment can be aligned with the prosthetic replacement (Fig 9-3).

The implant bed is the bony cavity for endosseous implants; in the case of mucosal implants, it is the dimensionally accurate hollow in the mucosa into which the implant is inserted. A cavity congruent with the implant is milled into the bone or punched into the mucosa. Internally cooled implant cutters are available for preparation of the bony implant bed. These are special bone cutters for low-speed milling (approximately 200 rpm). They have a central hole in the cutter shaft for the coolant, which cools the cutter and the preparation field while simultaneously and continuously rinsing out the bone chips.

Immediate implant placement refers to implantations that are performed directly after tooth extraction and before bony consolidation of the socket. The alveolar bone contour remains intact so that rapid functional loading of the alveolar section can take place and the alveolar ridge is retained. Immediate implants can match the dimensions of the natural roots of the teeth being replaced.

Delayed immediate implants are implantations that take place 2 weeks to 9 months after tooth extraction, or at least after the soft tissues have healed, so that the implant can be covered with a mucoperiosteal flap.

Late implant placement takes place after tooth extraction when the alveolar bone is severely atrophied. As a result, in addition to the vertical and transverse recession, the internal bone structure also alters. Late implants are usually smaller than the roots of the teeth being replaced.

Temporary implants are designed for short-term use when immediate dentures need to be anchored or when orthodontic implants (ie, mini-implants or temporary anchorage devices) are being used to stabilize orthodontic appliances.

Indications for Implants

Fixed implant-supported dentures have demonstrated long-term reliability equal to that of conventional fixed prostheses. In the case of removable prosthodontics, implant-supported restorations yield even better results than periodontally supported partial dentures. In any event, when treating edentulous arches, there is no alternative to anchorage with implants. The general indication for implant placement is when a removable denture cannot be integrated (eg, the patient has epilepsy) or when the patient has special occupational requirements or specific pastimes (eg, musicians who play brass or wind instruments, actors, or politicians). Today implant-supported restorations are considered standard treatment because of their long-term functional reliability (Fig 9-4).

Uncontrolled forces may be exerted because dentists do not perceive the intrinsic mobility of the implant or how osseointegration results in cushioning on loading and because periodontal receptors are absent. This must be offset by special shaping of the occlusal relationships.

Single-tooth implants are indicated for closing a dental arch, for example after loss of a single tooth within an intact arch that is free of fillings or caries. A single-tooth implant saves natural dental tissue, for example incisors that would otherwise have to be prepared as abutments. This key argument in favor of implant placement is supported by the fact that a single-tooth implant usually has a better outcome than treatment with an anterior partial denture.

Endosseous dental implants are indicated for small edentulous gaps, shortened dental arches, or reduced residual dentitions with large edentulous gaps and an unfavorable abutment arrangement; only implant support can guarantee the static relationships in these circumstances. Implants are especially indicated for edentulous arches that do not offer adequate retention for a complete denture because of advanced resorptive atrophy of the alveolar ridges or jaw defects.

General contraindications include surgical risks, primarily in a wide variety of cardiovascular diseases and other organic conditions (eg, liver damage). Acute infections, leukemia, diabetes, and impaired immune resistance are also contraindi-

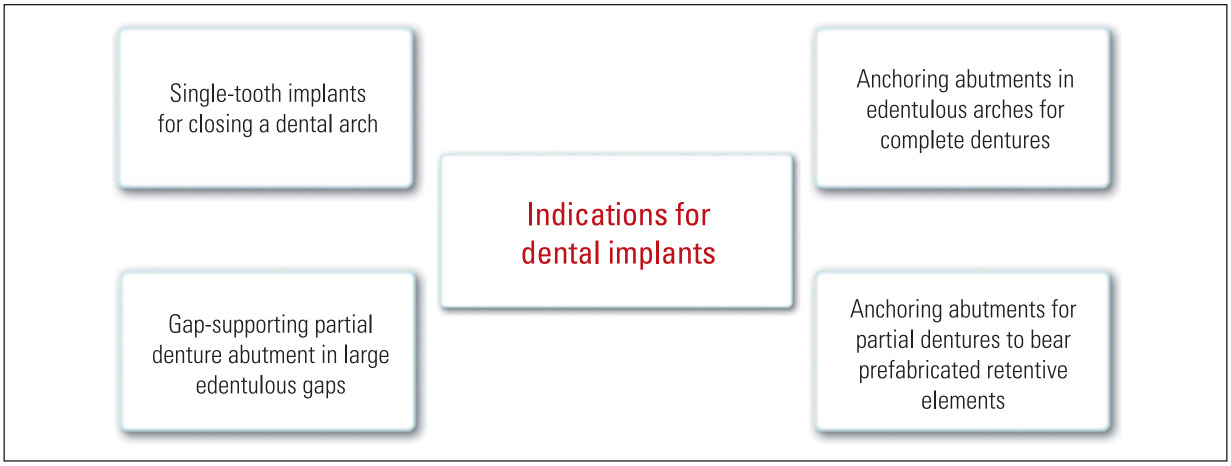


Fig 9-4 Implants that act as a tooth root replacement are suitable for universal use. If there are no specific contraindications, implants may be regarded as the standard treatment. This means it is possible to anchor a denture in the mouth without involving other teeth. Combined forms of anchorage are often used; that is, a removable partial denture may be anchored on implants and natural abutment teeth.

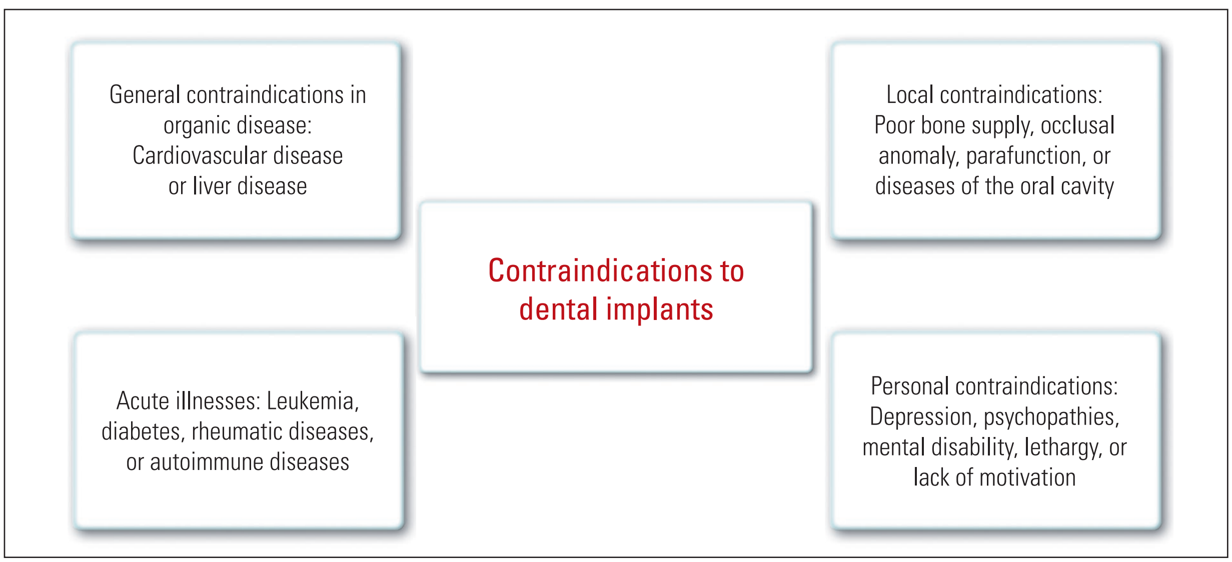


Fig 9-5 Because implant placement requires considerable surgical and operational effort, a general contraindication exists if there are surgical risks that would also make other clinical procedures difficult; chronic or acute illnesses therefore rule out any implant placement. The patient's personal disposition, such as poor motivation and psychopathies, may also prohibit dental implantation.

cations for implant placement. In addition, implant placement is ruled out in patients receiving drug treatment for rheumatic diseases, various skin and autoimmune diseases, AIDS, and other acute infectious diseases (especially in the oral cavity) as well as in patients with depression or women who are pregnant (Fig 9-5).

If bone quality is reduced as a result of bone disease (eg, osteoporosis) or calcium excretion is increased in patients with renal insufficiency, implant placement is equally questionable, just as it is in the case of patients who have severe physical or mental disability or personality-altering psychopathies or who are poorly motivated and

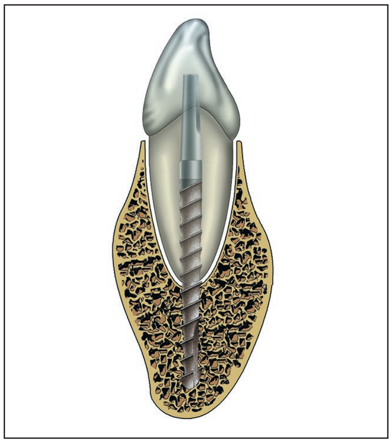


Fig 9-6 A transdental (endodontic) implant is sunk into the bone through the root canal and lengthens the natural root. A distinction is made between apically closed implantation, in which the transfixation pin is placed in the periapical bone, and apically open implantation, which is combined with an apicoectomy.

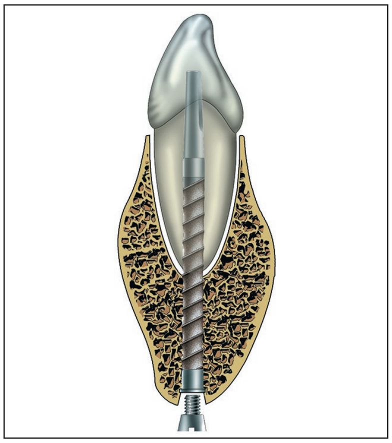


Fig 9-7 A transosseous (transmandibular) implant is placed caudally through the mandibular body and extends into the tooth.

lethargic. A local contraindication exists if the bone supply is too small for an implant bed; if the vertical distances or alveolar ridges are too small or too large; or if there are anomalies of occlusal position, parafunctions, or a residual dentition requiring remedial work.

Inflammatory reactions at the marginal periodontium display patterns and features similar to inflammation in the peri-implant tissue, which means there are no appreciable differences between peri-implantitis and periodontitis despite the different biologic structures involved. Excessive stresses, which have only minimal influence on periodontally damaged teeth, nevertheless have a much greater impact on peri-implant inflammation.

The part enclosed by tissue (ie, mucosa, bone) as far as the gingival collar is called the *endostructure* and comprises the implant apex, implant body, and implant shoulder. This part has to divert the masticatory load into the bone. Compared with the functional root surface of natural teeth, endosseous implants have a smaller retentive surface in the bone. Therefore, endosseous implants are less able to absorb masticatory pressures than natural teeth.

The *exostructure* is the part protruding out of the tegument into the oral cavity, which comprises the neck of the implant and the abutment. This structure is the particular hallmark of an open implant, which pushes through the closed covering of the body and can form an entry portal for pathogens. This structural feature is also a limiting factor in terms of indications.

Implantation Methods

The various methods of implantation are differentiated according to the localization of the dental implants.

Transdental implants are sunk into the bone through the root canal of a tooth to lengthen the natural root (Fig 9-6). In an apically closed implantation, the transfixation pin is moved into the periapical bone, whereas an apically open implantation is combined with an apicoectomy. This transdental fixation system is a combination of conventional root pins and endosseous implants. The physiologic periodontium remains intact and a closed implant results.

Transosseous implants are mandibular implants that run vertically through the entire mandibular body (Fig 9-7).

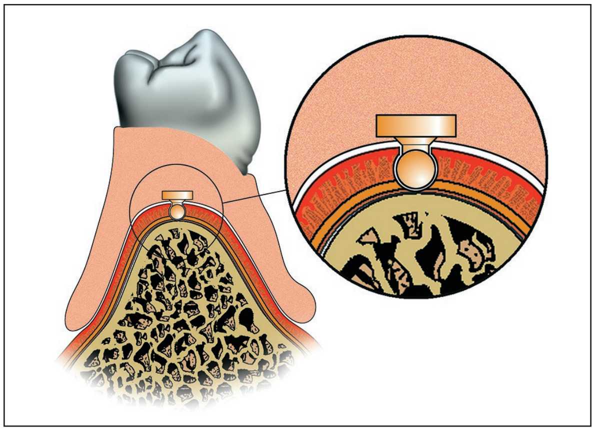


Fig 9-8 An intramucosal implant is the ball attachment of a removable prosthesis that is sunk into the mucosa. The ball attachment is sunk into an artificial cavity in the mucosa of the jaw, which is lined with normal epithelium.

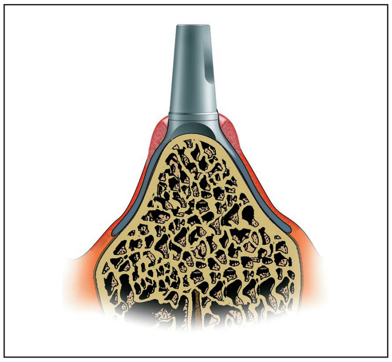


Fig 9-9 A subperiosteal implant is interposed as a metal framework between the bone surface and periosteum. After an impression of the bone surface has been taken, the accurately fitting metal framework is prepared by the model casting technique and placed onto the bare bone surface.

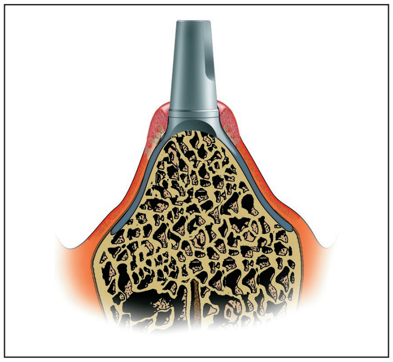


Fig 9-10 An endosseous-subperiosteal implant is sunk into the bone between the bone surface and periosteum; the abutment penetrates the mucosa of the dental arch. It is made by the model casting method. The implant bed is prepared into the bone.

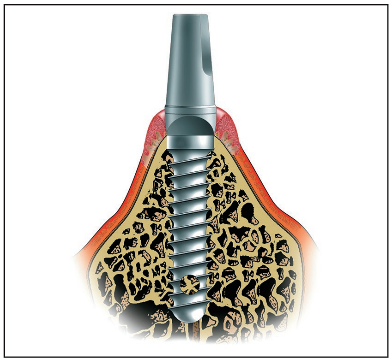


Fig 9-11 An endosseous implant is sunk into the bone and punctures the mucosa of the dental arch. The part enclosed by tissue is the endostructure, and the part protruding into the oral cavity is the exostructure; the mesostructure is the component that connects to the prosthetic replacement.

Intramucosal implants are ball attachments that are sunk into the mucosa and fixed basally to a removable denture (Fig 9-8). The intramucosal ball attachment is sunk into a cavity in the jaw mucosa that is lined with normal epithelium. The button-shaped retentive part sits firmly in the denture base and is removed from the implant bed when the denture is removed.

Subperiosteal implants have a custom model-cast framework that is interposed between bone surface and periosteum (Fig 9-9). To do this, the bone surface is exposed and an impression is taken. The framework is accurately prepared by the model casting technique and placed onto the bone surface so that it can be subsequently re-covered with the periosteum and mucosa. The abutments puncture the mucosa at defined points.

Endosseous-subperiosteal implants are sunk into the bone as well as interposed between the bone surface and the periosteum (Fig 9-10). The abutments break through the mucosa covering of the dental arch. These implants are produced using the model casting method by preparing the implant bed into the bone and taking an impression of the implant bed.

Endosseous implants are root replacement parts that are sunk into the bone and puncture the mucosa of the dental arch (Fig 9-11). Endosseous implants are placed into a form-fitting cavity in the jawbone, which has been prepared with special instruments suited to the form of implant.

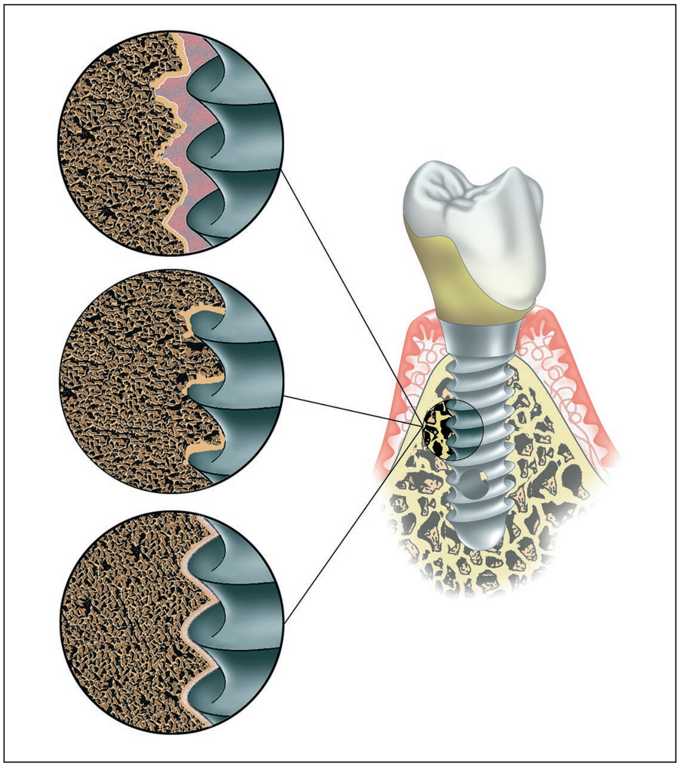


Fig 9-12 *(top)* When connective tissue encapsulation occurs or a capillary gap forms between the bone and the implant during the course of implant healing, this is known as *distance osteogenesis*.

Fig 9-13 *(center)* Contact osteogenesis is complete bony (osseous) containment of an implant without any separating layer of connective tissue.

Fig 9-14 *(bottom)* Ion exchange can occur if there is close chemical ongrowth of bone onto the implant (exchange osteogenesis). During healing, the implant is incorporated into the physiologic metabolism of the growing bone. This functional ankylosis is known as *osseointegration*.

Implant Integration

Bone displays various tissue reactions with respect to the implant material. The tissue reaction of the implant bed can be influenced by micromorphologic and macromorphologic improvements in retention of the implant body, for example special coating techniques, roughening, or screw threads.

During implant healing, connective tissue encapsulation of the implant (distance osteogenesis) may occur, or a capillary gap may form between bone and implant (Fig 9-12). Collagen fibers may also be deposited on the implant surface (contact osteogenesis) (Fig 9-13).

Osseointegration is a direct structural bond with no separating layer of connective tissue between the bone tissue and the implant (Fig 9-14). This bond forms a rigid (ankylotic) connection in which periodontal fibers are absent, and thus the implant has only minimal mobility. Mobility only occurs as a result of the elasticity of the surrounding bone. The bond between implant and bone must ensure the transfer of forces on loading of the implant.

A biologic connection is created between epithelial cells of the mucosa and the implant neck: A junctional epithelium with basal lamina is formed out of glycoproteins (Fig 9-15). This tissue junction has histologic and biochemical characteristics similar to those of the junctional epithelium in natural teeth and carries the epithelial mucosa up to the hard surfaces of the implant. This junctional epithelium has a constant rate of renewal and thus prevents bacterial deposits on its surface. Similarly, neutrophilic granulocytes accumulate in this area, and these are able to resist periodontal or peri-implant infections. In addition, in the tissue area—similar to the situation with natural teeth—a system of circular connective tissue fibers running perpendicular to the implant surface is formed that fixes the mucosa to the implant. It has not yet been proved whether these fibers are anchored firmly to the implant surface.

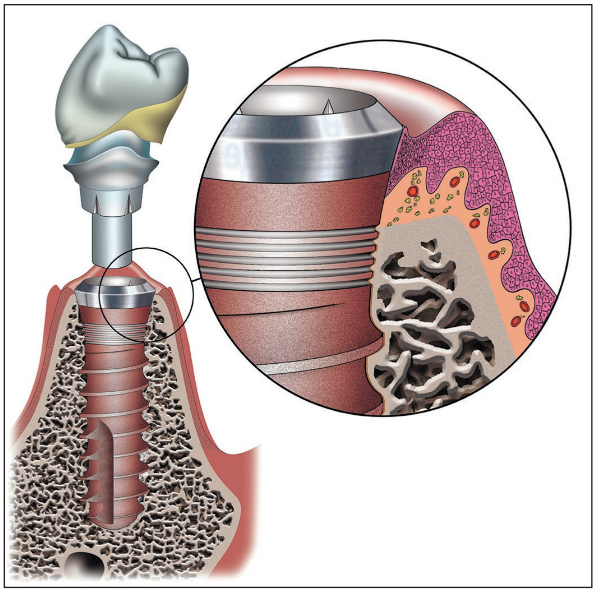


Fig 9-15 An epithelial join between the mucosa and the implant surface is formed on the smooth or polished neck of the implant. Junctional epithelium is formed with a basement membrane that displays similar characteristics to marginal periodontium. A buildup of leukocytes may also be noted in this tissue area. At the crestal transition (passage through the alveolar bone), modern implants have special surface structures that can improve attachment in the hard cortical layer.

After implant healing is completed, the implant has to be subjected to normal loading to ensure physiologic bone maintenance because only loaded bone will stabilize and be stimulated to form new tissue.

Quality of Implant Materials

Implant materials are classified into four groups:

- Autogenous materials (from the same body)
- Homologous materials (from the same species)
- Heterologous materials (from a different species)
- Alloplastic (nonbiologic) materials

Autogenous implants are derived from the same organism, for example extracted teeth or endogenous bone grafts. Homologous implants are tissue parts transferred from other people. Heterologous implants are tissue parts transferred from a different species. Alloplastic materials are metals and their alloys, ceramics, or plastics. The requirements for implant materials are mechanical stability and biocompatibility.

The mechanical properties of implant materials and bone must be approximated to each other so that masticatory forces do not give rise to shearing stresses between bone and implant bond. The aim is to find a material with sufficient strength and a modulus of elasticity matched to that of bone. Metals have sufficient strength, elongation at fracture, and variable elasticity, while ceramic has high fracture toughness.

Implant material is biocompatible if the cells in contact with the implant can participate unimpeded in the natural process of metabolism. Tissue that is in contact with nonbiocompatible materials may display antibody reactions, allergies, encapsulation, and toxic and inflammatory reactions and ultimately die. On the other hand, the implant material may corrode in the body, or it may be leached out, abraded, or resorbed.

In dental implantology, alloplastic materials are used almost exclusively because their availability is virtually unlimited, they are easy to store, and they can be produced to a defined and controllable quality level. However, foreign-body reactions to alloplastic materials may occur. In particular, metallic implants may have complex interactions with the implant bed tissue, resulting in corrosion and development of metallosis in the implant bed tissue. Metallosis can lead to a connective tissue separating layer between bone tissue and metal implant.

Corrosion is damage to metals or alloys caused by chemical or electrochemical reactions. Tissue fluids and saliva, in which ions and salts are dissolved, act as electrolyte solutions in the body that attack the metal. Galvanic processes between the metallic materials of the implant and superstructure, contact and friction corrosion, as well as local elements may give rise to other damage to the implant and the tissue of the implant bed.

The movements of ions in tissue disrupt the natural physiologic processes, can disturb the biologic equilibrium in cell growth, or can trigger allergies. Metal ions also get into the digestive tract via saliva and reach organs of the body where they accumulate beyond the physiological-

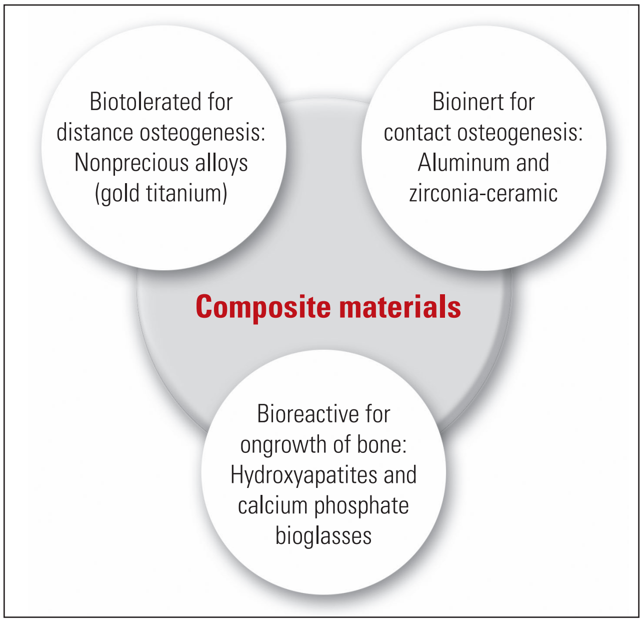


Fig 9-16 Dental implants are almost exclusively made from alloplastic (nonbiologic) materials. Metals have the most favorable physical properties, such as hardness, toughness, fracture strength, and elasticity; among metals, only pure titanium is sufficiently biocompatible. Materials are classified as biotolerated, bioinert, or bioactive, depending on their degree of biocompatibility.

ly tolerated limit. The transport of ions can damage remote organs.

Metals can protect themselves against various forms of corrosion by means of a passivating surface layer. Many metals spontaneously form a passivating protective layer by oxidation; these metals are passivatable. An oxide film is formed over the entire metal surface, which prevents the exchange of charge carriers with other media and protects the metal against further corrosion. This passivation layer can be mechanically damaged but regenerates quickly by renewed passivation.

Some base metals form stable, highly noble surface oxides as a passivation layer even when the oxygen supply is minimal. Titanium and its alloys display particularly rapid growth of a passivation layer; other implant alloys contain passivating additives. Gold and platinum alloys, as precious metals, are corrosion resistant even without a passivating protective layer.

Saliva forms a closed electrical circuit between jawbone and implant, where local galvanic currents transport the corrosion products. The deposition of corrosion products first causes dark discoloration in the implant bed tissue; cell activity is impeded, and aseptic necrosis may ensue. These reactions do not occur with titanium. Ceramics and plastics are corrosion resistant but can be resorbed by bodily fluids.

Implant Material and Tissue Reaction

Dental implants have to fulfill extremely varied requirements because they protrude into the oral cavity and are in contact with various types of tissue, such as jawbone, periodontium, and gingiva. They are made almost exclusively of alloplastic material, such as metals, ceramics, and composites (Fig 9-16). The mechanically stable metallic materials include titanium and titanium alloys. In terms of nonmetallic implant materials, acrylics, aluminum oxide ceramics, biolite carbon, glass-ceramics, calcium phosphate ceramics, and hydroxyapatite ceramics have been tried and, in most cases, rejected.

Composite materials are the coatings applied to implant surfaces, for example titanium plasma, hydroxyapatite, or biolite carbons, to achieve direct ongrowth of bone onto the implant.

Alloplastic implant materials can be classified as biotolerated, bioinert, or bioreactive, depending on their suitability for achieving intensive osseointegration and thus according to their degree of biocompatibility. Biotolerated materials (mostly metals) form a separating layer of connective tissue between the implant and its bony bed, a process known as *distance osteogenesis*. The interlayer of connective tissue weakens the retention of the implant and may arise because of the interaction of bone with toxic metal ions or when the implant is loaded during the healing phase. Bioinert materials (mostly oxide ceramics) hardly release any ions and do not react with the tissue of the implant bed. The bone attaches directly to the implant material, which is known as *contact osteogenesis*. Bone regeneration extends right up to the implant surface. Bioreactive materials (mostly hydroxyapatites, tricalcium phosphate) actively create close chemical ongrowth of bone. Calcium phosphate ions are released from the apatite portion of these materials, and these ions become involved in the physiologic metabolism of the growing bone during healing of the implant. Bone is deposited in the surface pores of the implant without an interlayer of connective tissue. Faster osseointegration may ensue.

Osseointegration refers to the rigid (ankylotic) join between implant and bone, which is evident as a direct transition from bone to implant without an intermediate layer of connective tissue. Ion exchange between implant and bone (exchange osteogenesis) occurs in this functional join; the implant appears to be incorporated into the physiologic metabolism of the growing bone.

The mechanical roughness of the implant surface in its micromorphology is vitally important. This is because the macroscopic mechanical retentions of the bone-to-implant contact ensure primary stability during the healing phase. The biologic reaction of active bone growth results in mechanical fixation in microscopically small undercuts when the bone grows into surface pores.

Surface roughness with a depth of 1.4 µm creates stable bioadhesion of the implant in the implant bed. It is impossible to ascertain exactly what influence the chemical composition of the implant coating has on the stability of the bone-to-implant connection. However, the proven success rate of over 95% of implants without artificial overlying mineral or protein seems to indicate the functionality of a roughened surface without a coating. To achieve this, healing must take place in an absolutely immobile state because this is the only way bone can grow onto the implant surface. If there is any mechanical loading, bone contact is lost and separating layers of connective tissue will form.

As a result of this roughness, the surface is more wettable, and bone contact is markedly improved. The rough surface also prevents the formation of intermediate layers of connective tissue, increases the formation of new bone, and enhances the bioadhesion of the bond between implant and bone.

The elastic behavior of implant and bone determines the functional integration of the implant into its bony surroundings. The greater the congruence of the elasticity moduli, the better the ingrowth of the implant, and the formation of new bone will also be stimulated. The elasticity of titanium can be perfectly adapted to the bony bed.

Titanium as an Implant Material

Titanium is currently the most widely used implant material because of its mechanical and biocompatible properties. The mechanical characteristics of pure titanium, expressed in a 0.2% yield strength and modulus of elasticity, vary widely depending on the admixture of iron and oxygen. Titanium surfaces bind oxygen within fractions of a second and release iron equally well; different strength values arise, depending on the amount of the admixtures. The yield strength and modulus of elasticity also increase as a result of the strain hardening after cold deformation. This effect is given as a grade, whereby the greatest hardening of pure titanium reached upon cold deformation is grade 4.

An increase in the mechanical values is achieved by forming alloys with aluminum and niobium (or vanadium). Both additives partly prevent the transformation from the body-centered high-temperature phase to the hexagonal low-temperature lattice, so that a crystal mixture from both phases exists. This two-phase crystal mixture is known as *(α–β)-titanium* and displays lattice stresses that are reflected in a marked increase in these values. However, biocompatibility seems to suffer in the process.

The excellent biocompatibility of pure titanium is due to its passivatable surface. Pure titanium is an extremely ignoble metal in the electrochemical series and spontaneously forms a passivating ox-

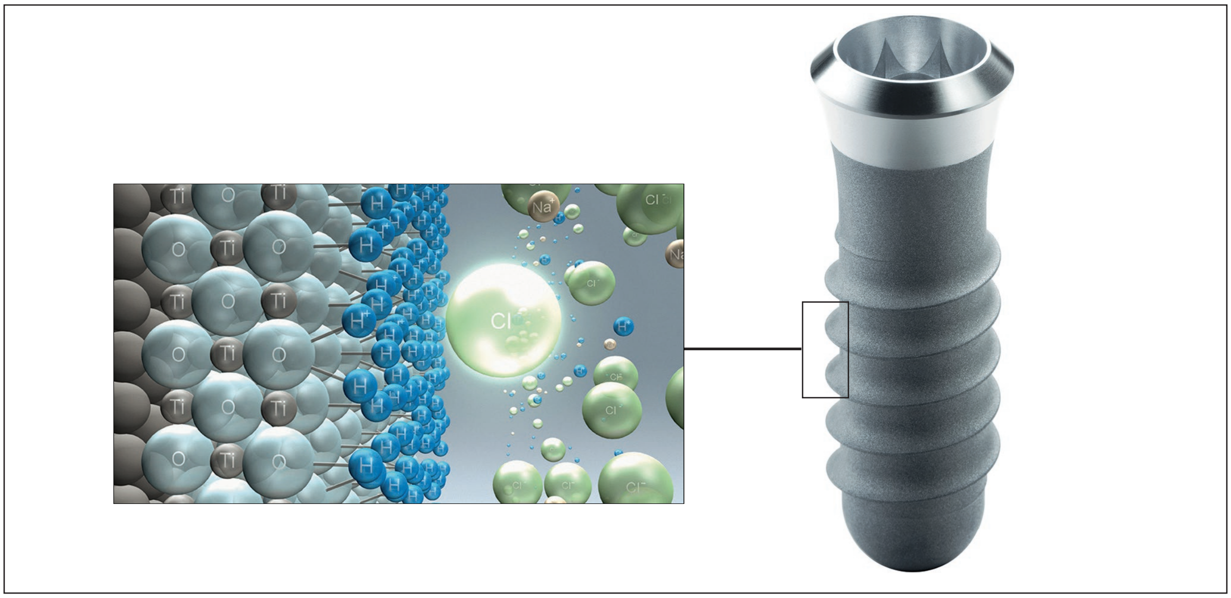


Fig 9-17 Smooth titanium surfaces are hydrophobic (ie, they repel water). Faster osseointegration can be achieved by hydrophilic, osteoinductive properties, as in the case of the SLActive implant surface from Straumann. The surfaces interact with the tissue and accelerate cell activity so that growth-promoting cytokines (bone morphogenetic proteins) are released. In the SLA production process, the implant surfaces are airborne-particle abraded with large-grit particles followed by acid etching with heated hydrochloric and sulfuric acid. The acid etching produces a microroughness of 2 to 4 µm. The surface is subsequently conditioned in nitrogen and stored in an isotonic salt solution. Bone contact with the conditioned implant surface is considerably improved, which shortens the healing process to about 3 to 4 weeks and speeds up osseointegration. Immediately after implant insertion, substantially more bone is formed on the enlarged SLActive surface; in special cases, there is an increase in bony tissue. (Illustration courtesy of Straumann.)

ide on the surface, which displays bioinert behavior in tissue. The passivated titanium surface does not corrode, and only a few titanium ions get into the surrounding bone. Titanium ions do not appear to prevent bone apposition. Titanium with its various compounds is in any case a natural constituent of the body, and as yet reports of allergic reactions to titanium have been extremely rare, with an estimated prevalence of 0.6%. Therefore, titanium should preferably be used non-alloyed because alloy constituents may release ions due to corrosion.

Pure titanium has become almost fully established as an implant material, its excellent biocompatibility and the roughening of the surface being crucial prerequisites to osseointegration. Pure titanium can be planed to a very smooth finish by machining of the surface, leading to good epithelial attachment in the emergence area and facilitating excellent cleaning. However, distance osteogenesis with poor quality of anchorage arises in the implant bed.

Various methods are used to roughen the implant surfaces, such as acid etching, airborne-particle abrasion, anodic oxidation, and application of coatings. In the acid-etch technique, the surface processing is done with various combined acids that roughen the titanium surface in the micrometer range (approximately 1 µm). The osteoblasts are able to embed in this rough surface, resulting in improved bone apposition. Surface machining by airborne-particle abrasion with abrasives, such as aluminum grit size 1.2 to 2.2 µm, produces medium roughness of 1.4-µm depth, which is the most advantageous roughness for contact osteogenesis. As blast particles may remain in the surface depending on the blasting medium, the abraded surfaces are then acid etched to produce an even finer surface relief. A further etching process with isotonic sodium chloride solution alters the wettability so that bone apposition is accelerated (Fig 9-17). If the implant is also treated with ultraviolet C radiation after the combined etching processes, the surface tension is switched

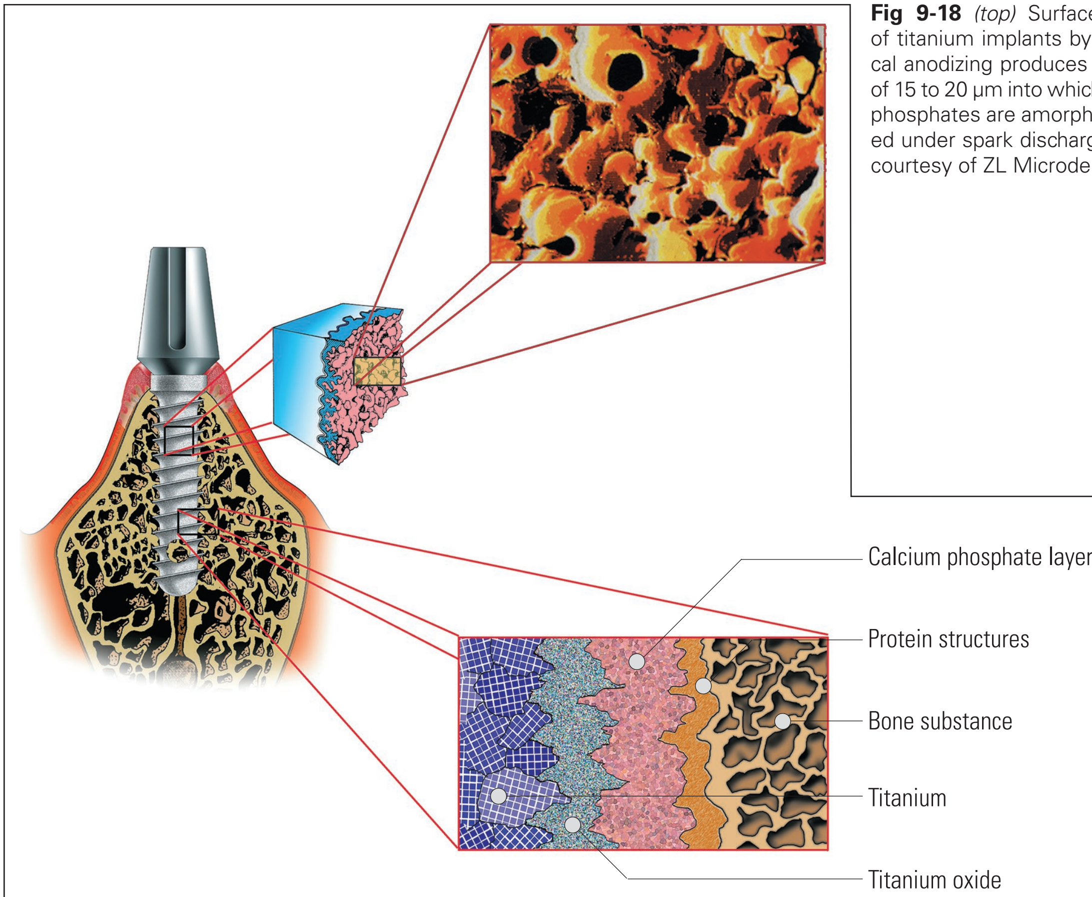


Fig 9-18 *(top)* Surface conditioning of titanium implants by electrochemical anodizing produces an oxide layer of 15 to 20 µm into which 40% calcium phosphates are amorphously integrated under spark discharge. (Illustration courtesy of ZL Microdent.)

Fig 9-19 *(bottom)* The physically measurable surface can be enlarged sixfold by means of plasma coating. The resulting roughness of 1.4-µm depth improves osseointegration of the implant. Given the concentration of calcium phosphates in the implant surface, proteins should be better absorbed and healing of the bone wound promoted. Faster healing of the implant has not been observed with coated implants.

from negative to positive, the osteoblast reaction increases, and more intensive bone-to-implant contact results.

Surface coating by anodic oxidation (anodizing) is performed by means of spark discharge in an aqueous electrolyte where calcium phosphates are amorphously integrated (Fig 9-18). Accelerated bone regeneration and more intensive osseointegration occur at the porous implant surface. Surface coating with hydroxyapatites is done by sintering in an immersion bath. The chemical deposition of nanoparticles is intended to produce fast osseointegration with high bone-to-implant contact.

The implant surface can be conditioned and enlarged sixfold by coating with titanium plasma (Fig 9-19). This method involves welding particles of titanium powder onto the titanium in a layer 30 to 40 µm thick at high temperature; this produces a defined roughness of 1.5 µm.

Zirconia ceramic is a polycrystalline material that exists in three chemical phases with different properties: monoclinic, tetragonal, and cubic. The tetragonal phase, which is suitable as an implant material, is metastable at room temperature and can be destroyed by thermal stress (friction heat during grinding). Zirconia is biocompatible and can be radiographically depicted like metal. It has high strength, is extremely break resistant, can be stained to natural tooth color, and is superior to titanium in terms of esthetics and plaque resistance.

Aluminum oxide ceramics are chemically, thermally, and mechanically highly resistant and differ considerably from bone in terms of elasticity, so shearing forces arise in the bone-to-implant bond during loading. The aluminum oxide surface behaves in a bioinert fashion, which means the bone structure is densely deposited.

Calcium phosphate ceramics are bioactive materials comprising calcium oxide and diphosphorus pentoxide; they are similar to mineral bone. Hydroxyapatite ceramic and tricalcium phosphate ceramic are of clinical relevance.

Forms of Endosseous Implants

Endosseous implants are open implants that protrude out of the body's surface. They are dictated by the anatomical conditions, such as shape and position of the maxillary sinus and the mandibular canal. Following are different types of implants:

- Cylinder implants
- Hollow-cylinder implants
- Screw implants
- Blade implants
- Abutment-and-pin implants
- Needle implants

Cylinder implants (or cylindric implants) are full-body implants whose surfaces are roughened by chemical or mechanical processing or by a plasma coating (Fig 9-20). As a result, the surface is enlarged and bond stability is increased. Some cylinder implants have apical perforations, which fill with bone during the loading-free healing phase to achieve additional stabilization. For cylinder implants, system-specific bone cutters must be used to prepare a form-fit implant bed. The implant can be tapped into the cavity with a seating instrument until it wedges in the cancellous bone in a press fit. Intramobile cylinder implants (eg, IMZ implant system) comprise the implant body and a cushioning component, the intramobile connector.

A hollow-cylinder implant comprises a rotationally symmetric, perforated implant body that has a large implant anchorage area and, because of its small implant volume, requires only minimal loss of bone substance when preparing the implant bed (Fig 9-21). The implant bed is cut with a hollow cutter at low speed, which is intended to produce a form-fit implant bed with uniform pressure distribution to the bony tissue. Various types of hollow-cylinder implants are available (eg, ITI hollow-cylinder implants, Straumann) as single cylinders and double cylinders, which support the abutment on a connecting bar. Hollow cylinders have an implant stiffness that is similar to bone, which reduces the stresses between bone and implant when the bone grows into the perforations.

Screw-type implants have a cylindric or tapered implant body with screw threads (Fig 9-22). The surface of metallic screw implants (mostly titanium) can be coated. Self-tapping threads are distinguished from those that are screwed into precut cavities. The thread flanks are intended to guarantee uniform transfer of force into the bone without stress peaks. Self-tapping threads sit firmly in the loose cancellous bone and are immediately loaded. On precutting of threads, contact surfaces for the implant may break off, but the bone chips are flushed out before the implant is screwed in place, thus guaranteeing better healing. Tapered screw implants have an approximate root shape so that little bone tissue has to be sacrificed for immediate implant placement.

Blade implants are extension implants with greatly expanded, flat, disk-shaped, or even double-blade–shaped implant bodies (Fig 9-23). Extension implants offer large, functionally effective surfaces for bone apposition. The forms of implant commonly used today emerged from extension implants. Blade implants may be indicated where there is an extreme horizontal lack of bone and when a rotationally symmetric implant cannot be inserted. The drawback to blade implants lies in the high bone loss if explantation is required. This is because the implant needs to be widely exposed if it has to be removed.

Abutment-pin implants are endosseous implants that have a pinlike implant shaft and abutment-like wing extensions for antirotation protection (Fig 9-24). The slender aluminum oxide ceramic pins were once used as a late implant for single-tooth restoration in the maxillary and mandibular

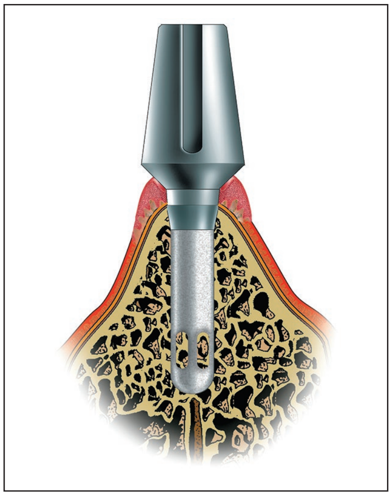


Fig 9-20 Surfaces of whole-cylinder implants may be roughened by chemical or mechanical processing or by plasma coating, which displays bond stability. Some cylinder implants have apical perforations.

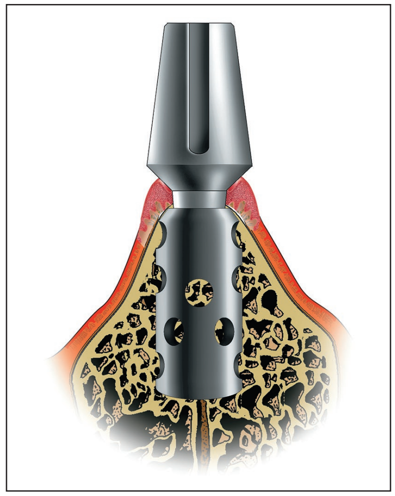


Fig 9-21 Hollow-cylinder implants are perforated tubes with a double bonding surface. Only a little bone tissue is milled out to prepare the implant bed.

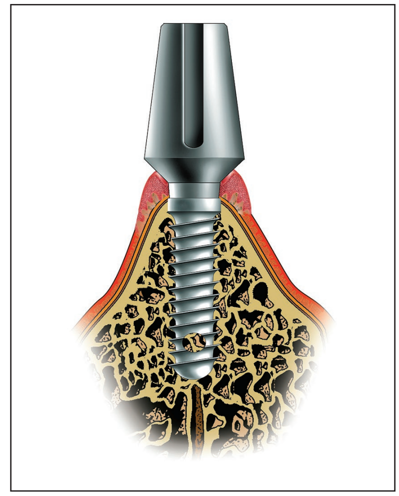


Fig 9-22 Screw-type implants with a cylindric or tapered implant body are created with threads that evenly transfer force via the thread flanks. The surfaces can be coated. Screw implants may have self-tapping threads.

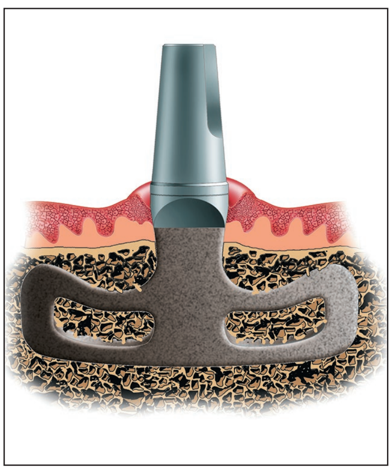


Fig 9-23 Blade implants are extension implants with a double-blade shape and a flat body that provide functionally effective surfaces for bone apposition. They are only indicated where there is an extreme horizontal lack of bone.

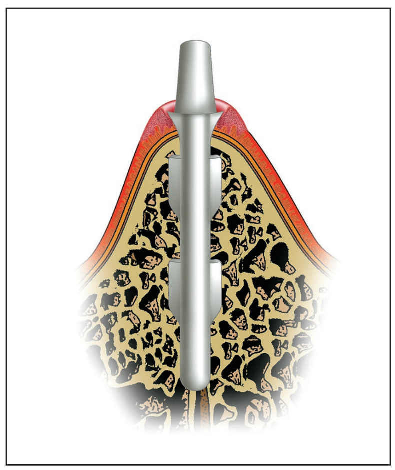


Fig 9-24 Abutment-pin implants, which are no longer used today, were pin-type endosseous implants with abutment-type wing extensions for antirotation protection. They were made from aluminum oxide ceramic and were not very fracture resistant.

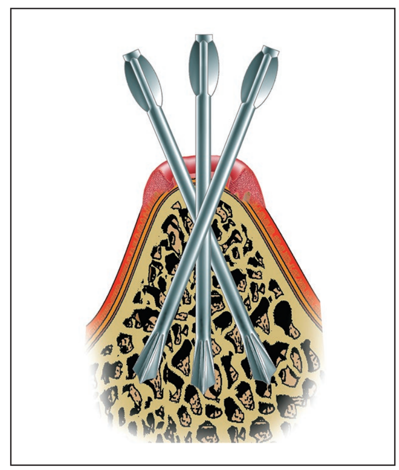


Fig 9-25 Needle implants, which are no longer used today, were made from tantalum with surface-ground points that were driven into the bone with hammer blows. Several needles were always inserted.

anterior region. These delicate tooth root replacements are no longer used because of the risk of fracture.

Needle implants are long, needle-shaped metal pins made of tantalum (Fig 9-25). The surface-ground pointed needles were either self-drilling and driven into the bone with hammer blows or self-tapping and inserted with a contra-angle. Several needles were always inserted, for example three crossing needles or seven to ten needles as a needle path. Needle-shaped implants are no longer used because of the high failure rates.

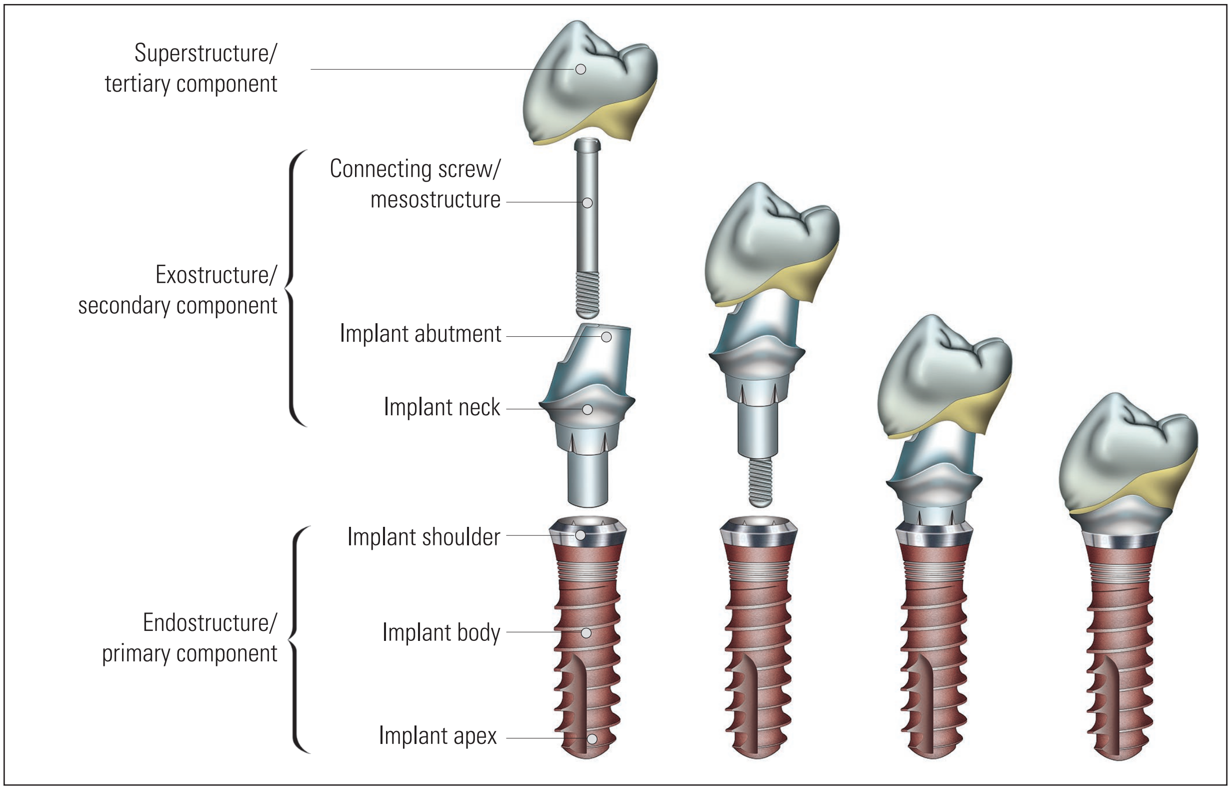


Fig 9-26 Structural components of an implant.

Design of Endosseous (Permucosal) Implants

The parts of an implant are individually functioning or morphologically distinct sections, such as the implant apex, implant body, implant shoulder, implant neck, and abutment (Figs 9-26 and 9-27). The implant body is the part of a root replacement sunk into the bone (endosseous), in which the implant shoulder and implant apex can be differentiated. The two types are hollow-body and full-body implants. Hollow-body implants are perforated, hollow cylinders (ITI hollow-cylinder implants) with an internal and external implant anchoring surface, a smaller implant volume, and a deformation behavior similar to that of bone. Full-body implants are cylindric or tapered and enable osseointegration at the external surface as bone is able to grow into a basal perforation in the implant and stabilizes the implant against torsion.

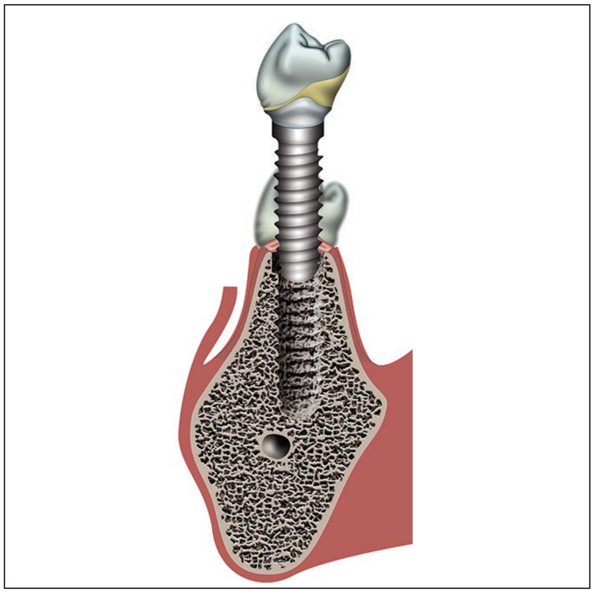


Fig 9-27 The implant bed is the bone cavity for the implant body; it must be rigorously prepared and must not harm internal bone structures, such as the mandibular canal in the mandibular body, as shown here.

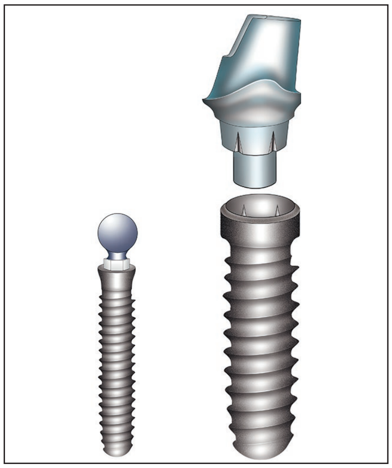


Fig 9-28 A distinction is made between one-piece and two-piece implants. One-piece titanium implants with a very small diameter are usually intended for temporary use as provisional implants. Two-piece implants consist of the implant body and the abutment.

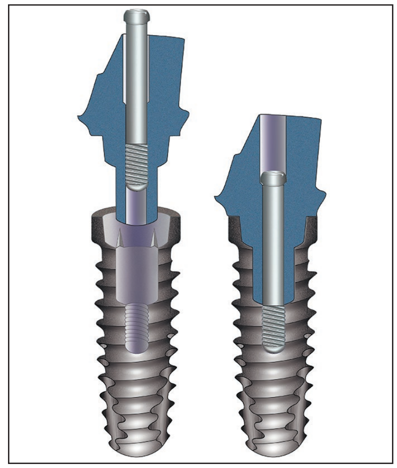


Fig 9-29 The quality of the connection between implant body and abutment affects the security of the abutment against tilting and rotation. A distinction is made between internal and external connections.

The implant apex is the lower (apical) portion of the implant body, by means of which the force directed vertically onto the implant is transferred to the bone. In screw implants, part of the vertical force is directed into the bone via the screw threads.

The implant shoulder forms the transition from implant body to implant neck or to the abutment elements. This protruding initial part of the implant body is sunk in the bone and lies in the area where the compact bone is penetrated. The implant shoulder is narrow, high-gloss polished, and beveled buccally to allow esthetically advantageous shaping of the replacement tooth.

The implant neck lies in the area where the mucosa is penetrated, between the implant body inserted in the jawbone and the abutment. The coronal part of the implant body is sometimes known as the *implant head*. The implant neck is particularly pronounced in one-piece implants and lies slightly supragingivally so that the implant shoulder lies markedly above the alveolar ridge. The implant neck is an inverted cone or is slightly collar-like to protect the peri-implant transition against vertically directed stresses. It is polished to a high gloss to prevent plaque from being deposited. The mucosal collar should attach without irritation to a smooth, rounded implant neck.

A junctional epithelium, an epithelial adhesion, and a fibrous system for attachment of the mucosal collar may be formed. To adapt the height of the implant neck to the mucosal thickness, exchangeable spacer sleeves can be fitted. These spacer sleeves can be replaced by new, high-gloss polished components if they become badly contaminated or damaged.

The implant post, also known as the *abutment*, is the buildup protruding into the oral cavity; it sits on the implant neck and directly receives the superstructure or a special mesostructure. In one-piece implants, the abutment is firmly joined to the implant body, whereas in two-piece implants, the implant body and the abutment are separated and joined together by a separate screw connection (Fig 9-28). The implant body is generally referred to as the *implant* for short.

The connection between implant neck and abutment must ensure anti-rotation protection, freedom from gaps, and adequate mechanical stability (Fig 9-29). Abutments can be cemented into, screwed into or onto, or force fitted onto the implant body, and they are then rigidly joined together.

An intramobile element made of plastic can also be inserted between implant and superstructure (Fig 9-30). This intramobile element is

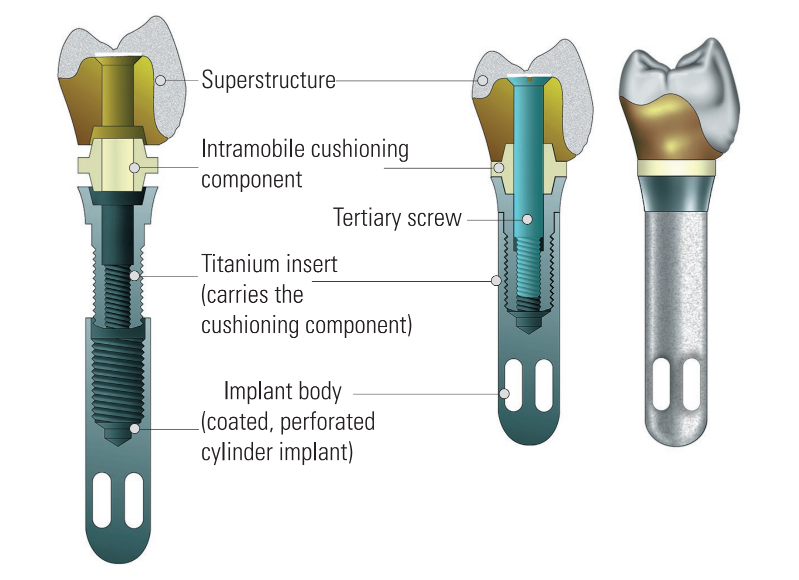


Fig 9-30 Structural components of an implant with an intramobile cushioning component.

flexible and is intended to imitate the resilience of the periodontium when a denture with mixed support (seated on implants and natural teeth) is being fabricated.

The superstructure is the prosthetic replacement, which can be cemented onto the abutment in a removable or fixed fashion, bonded, or screwed in a partly removable way. A ready-made cylinder can be inserted between superstructure and abutment; it can take the form of a prefabricated bondable or screwable titanium or gold cylinder, ceramic coping, or burnout plastic cylinder.

The implant disk in two-piece implants is an abutment in the form of a circular ledge on the implant body that ends with the superstructure and ensures an optimal marginal fit.

Implant-Abutment Connection

In two-piece implants, the form and stability of the connection between implant and abutment needs to be examined in more detail. For prosthodontic use, it is essential to clarify what antirotation protection exists, whether the connection is tapered or parallel, and whether an external or internal connection exists.

Antirotation or anti-tilting protection refers to the connection being secured against torque in the vertical connection axis, which is especially important in single-tooth restorations. Several implants that are rigidly connected (splinted) by a partial denture or denture framework are not subject to rotation. In these circumstances, non-axial forces can tilt the implant-abutment connection, which can lead to loosening of the implant screw. Antirotation protection must exist with internal and external connections and can be created by a suitably angled connection profile (eg, internal or external hex) (Fig 9-31).

Tapered or parallel contact surfaces in the implant-abutment connection affect the reliability of the connection. The inclination of the contact surfaces varies from parallel-walled to conicity and from 1.5 to 11 degrees. Very steep-walled conical connections develop very high surface pressure in the contact area so that permanent conical connections can arise as a result of cold welding.

External and internal implant-abutment connections can loosen or break due to minimal loading movements. Comparatively speaking, internal connections prove more stable than external connections, but a long internal connection will weaken the implant body so that a fracture could occur there. If several implants are inserted to support a long-span partial denture, an external connection

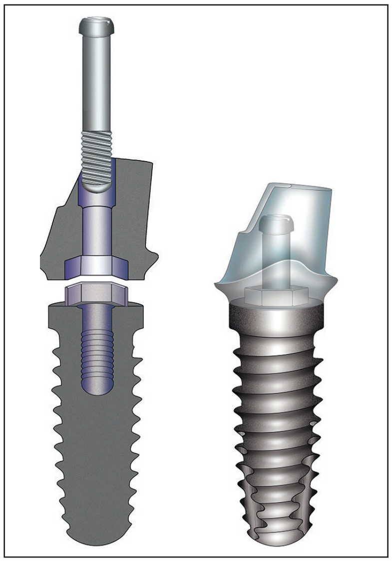


Fig 9-31 The abutment is placed into or onto the connection profile and fixed with a screw. The stability of this connection depends on screw diameter and the anti-tilting protection.

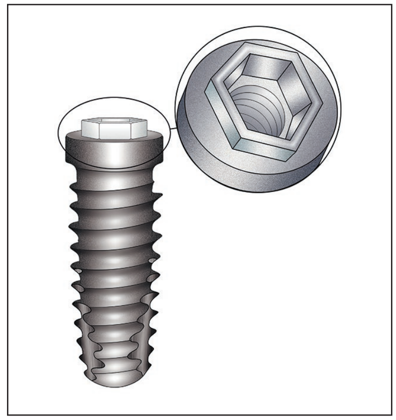


Fig 9-32 An external connection between the implant parts can be rendered rotationally secure by an angled connection profile, for example a hexagonal profile.

in the case of divergent implant axes offers the advantage that the partial denture can be screwed directly in place. With internal connections to nonparallel implant axes, the abutments have to be parallelized for a common path of insertion.

External connections can be shaped in the form of an external hex (Fig 9-32). The implant as a full screw bears a low, parallel-walled external hex ring above the implant shoulder, through which the retention screw is guided. The connection is rotationally stable but might tilt as a result of nonaxial forces, which may loosen the screw mechanism and lead to fracture of the connection (eg, Brånemark implant, ZL Microdent implant).

Implant systems with internal anchorage have one path of insertion, which results from the implant axis. Where there are several implants, the variations in the path of insertion must be balanced by the abutments in order to receive splinted structures. The abutments can either be parallelized or angled toward the implant axis (Fig 9-33).

Internal connections with a parallel-walled tube-in-tube connection are rotationally stable if they have several internal grooves for a form-fit connection (eg, Camlog implant). Internal connections, in which the tapered area is octagonally or hexagonally shaped, are just as rotationally secure as tapered internal connections with an additional hex (eg, Straumann implant). Internal tapered connections without additional antirotation protection allow for 360-degree universal positioning of the abutment. Rotational stability is achieved with a steep tapered connection (1.5-degree taper). This type of connection is suitable for particularly short implant bodies at least 5 mm long (Figs 9-34 and 9-35).

One-piece implants are predominantly zirconia ceramic implants and implants with very small diameters or temporary titanium implants. The implant body and the abutment form a unit and are therefore not submerged during healing. One-piece implants with a very small diameter (1.8 mm) have a spherical abutment for anchoring overdentures. They can be inserted by minimally invasive surgical techniques and can be immediately loaded.

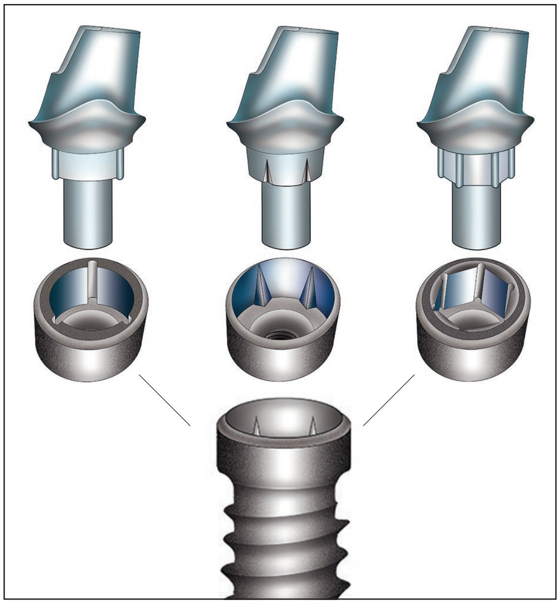


Fig 9-33 An internal connection can be shaped to have parallel walls or to be tapered and rendered rotationally secure by means of various internal grooves. In addition to an internal hex, three to eight grooves can be created. The more grooves, the more ways the abutment can be positioned. Universal positioning options offer a rotationally symmetric connection without additional antirotation protection.

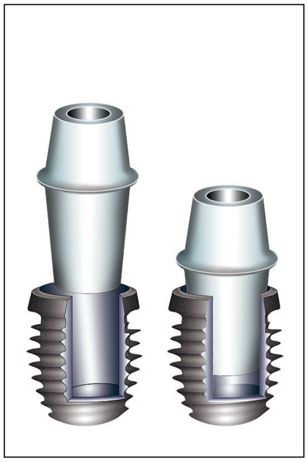


Fig 9-34 In extremely short implants, the internal connection takes up the entire 5-mm-long implant body, while rotational stability arises from a steep-walled (approximately 1.5-degree) tapered connection in which the sides of the cone can fuse.

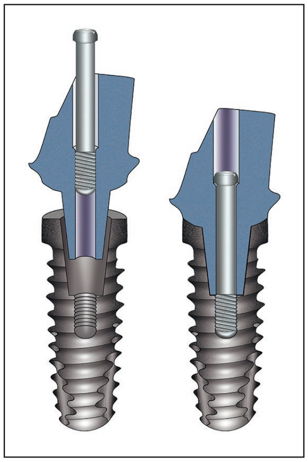


Fig 9-35 The connection profile of an internal cone offers no primary antirotation protection. The two parts of the implant are created by an additional screw connection.

Temporary implants have a diameter around 2 mm and are used during postextraction healing or after placement of final implants; osseointegration is not the goal.

Zirconia ceramic implants come in a variety of forms and can be individualized by preparation. The impression is taken in the same way as for a normal tooth preparation.

Implant-Superstructure Connection

Superstructures can be screwed onto an abutment or a bar or, like conventional restorations, can be cemented onto individual cementation abutments of the implants that have been inserted (Fig 9-36). Single-tooth restorations can also be placed onto ceramic abutments by the acid-etch technique with composites.

Screw fittings can be guided occlusally and transversally and are used for partly removable superstructures. Ease of removability makes repairs and hygiene measures easier and is essential for long-span partly removable partial dentures. Screws are used for fixing onto individual abutments and onto bars. The occlusal or transverse screw fixation of implant-borne superstructures is being used less and less frequently because minor inaccuracies in fabrication cannot be tolerated—especially on long-span partial dentures—and it might not be possible to use a partial denture that fits onto the model (Fig 9-37).

Occlusal screw connections must be covered after insertion and exposed again before undoing the screw connection. They have poor esthetics and in some circumstances may impair masticatory function.

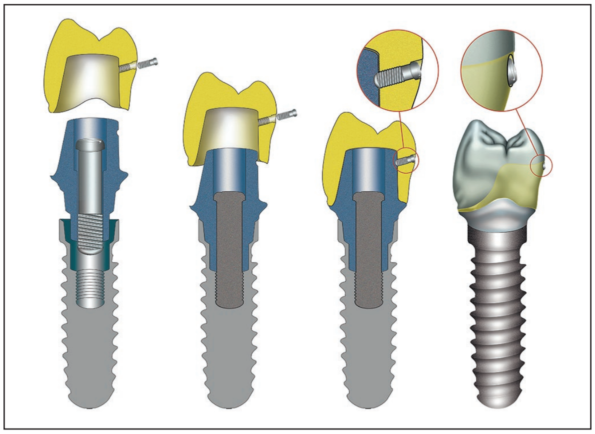


Fig 9-36 Superstructures can be screwed onto the abutment. The screw connection can be attached occlusally or transversally. Transverse screw connections are guided from the mesiolingual direction for esthetic reasons; they allow tension-free seating but are difficult to handle and create gaps that can cause odor problems.

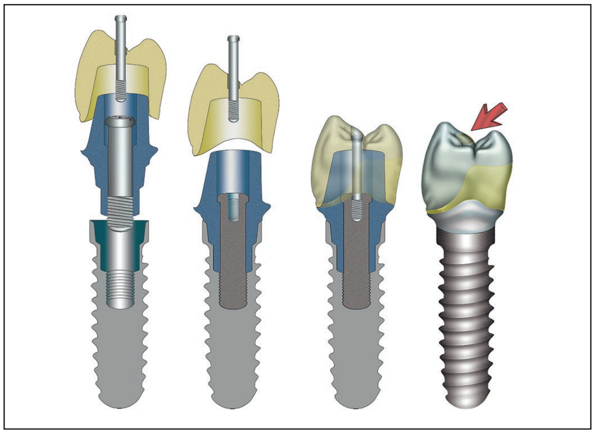


Fig 9-37 Screw connections guided occlusally are functionally critical and will not tolerate fit errors; even minor fabrication errors might make it impossible to insert the screw fitting. The screw hole must be covered occlusally, which may be an esthetic drawback.

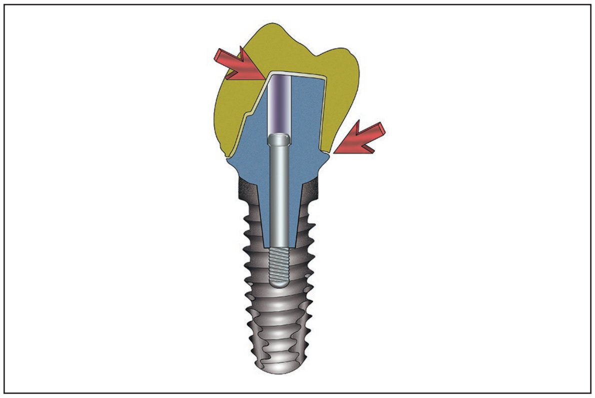


Fig 9-38 Transverse or occlusal screw connections of superstructures are only rarely used because of the described deficiencies (minimal fabrication tolerance, esthetic shortcomings, and difficulty in handling). Cementing the superstructure onto the abutment can compensate for all the disadvantages: Both fit errors and gaps are offset by the cement layer.

Transverse screw connections are not as problematic esthetically and functionally; the tension-free seating is easier to produce, but they do result in large gaps that cause taste and odor problems. They are difficult to handle and require a voluminous, orally prominent construction with an unsightly screw hole.

Cementation is being used more and more often because it can compensate for all the drawbacks of screw connections (Fig 9-38). Cementation has the following advantages:

- Cemented superstructures do not have the same esthetic and functional limitations as occlusal screw connections, and occlusal surfaces do not have to be perforated for a screw.
- A superstructure can be removed again if temporary cements are used.
- The cement layer compensates for inaccuracies of fit caused by fabrication and ensures tension-free seating of a partial denture structure.
- Different implant axes can be better compensated for.
- Cemented, implant-supported single crowns do not differ from natural teeth in terms of wearing comfort, cleanability, and amount of aftercare.
- Use of customized abutments is possible so that the path of insertion, gingival contour, and position of the crown margin can be perfectly shaped.

The disadvantage of definitive cementation is that the superstructure cannot be removed without being destroyed; that is, if the screw connection between implant and abutment breaks, the superstructure has to be replaced. Therefore, a rotationally stable, reliable, and loadable implant-abutment connection is essential.

When prosthetically restoring alveolar ridge defects that cannot be remedied surgically by bone augmentation, a removable construction must be used for optimum oral hygiene. Double crowns or a bar construction can be cemented permanently onto the abutments, while the replacement covering the mucosa and designed as a partly removable restoration can be screwed onto the substructure. A partial denture structure with alveolar ridge replacement made of ceramic can also be permanently cemented in place if cleanability is guaranteed.

Implants can be joined together rigidly by the superstructure or splinted. The implant-borne restoration then distributes all stresses to the splinted implants and reduces the loading. As in conventional prostheses, a distinction is made between primary splinting by fixed structures and secondary splinting by removable structures. The more implants are included in the splinting and the larger the supporting polygon, the smaller the loading on the individual implant.

Concepts of occlusion for implant-supported restorations do not differ from the concepts of conventional prosthetics. Canine guidance or tooth-group guidance can take place as much as with periodontally supported dentures. Unilateral or bilateral balanced occlusion can be constructed in quasi-complete dentures that are anchored with implants, depending on the quality of the denture-bearing mucosa.

Special Forms of Implants

Immediate implants are conical tooth replacement parts that are inserted immediately after extraction of a tooth to shorten the edentulous period. Immediate implant placement takes place right away or a few days after a dental extraction when no bone loss has yet taken place. An approximate form fit between implant and socket can be achieved by root-analog, tapered screw implants. Implant screws with a large-volume screw core can lie fully up against the alveolar bone for an optimal implant-bone connection.

Immediate implant placement can only be performed if the socket or extraction wound is not infected and there are no apical defects. Immediate implant placement is usually necessary if traumatic tooth loss occurs because of an accident or if the tooth can no longer be preserved after a tooth fracture (Figs 9-39 to 9-44).

Delayed implant placement refers to implant insertion that takes place after epithelial wound healing is completed, about 6 to 8 weeks after extraction of the tooth. At that stage the socket is grown through with connective tissue without fully developed new bone.

Interim implants are implants with an ultrasmall diameter (2 mm) with which immediate partial dentures are anchored during the healing phase of the definitive abutments. Complete or partial dentures can be supported on such temporary implants to accomplish the following:

- Protect definitive implants against unwanted stresses during the healing period
- Facilitate guided bone regeneration in preimplant augmentation or sinus elevation procedures
- Allow a temporary immediate restoration before delayed implant placement
- Fix orthodontic appliances (mini-implants)
- Fix the drill template for definitive implant placement

For transitional implants, a pilot hole is placed in the bone with a spiral drill, and the interim implant is screwed in place. These implants are loaded immediately after placement and removed again after the interim denture–wearing period.

Mini-implants

Special endosseous palatal implants or mini bone screws are known as *mini-implants*; they provide positionally stable fixation and can be used for stationary anchorage of orthodontic appliances (Fig 9-45). Orthodontic stresses on anchoring teeth to which the appliances would otherwise be fixed can thereby be avoided. Other anchoring methods, such as headgear or maxillomandibular elastics, are not necessary, which reduces the

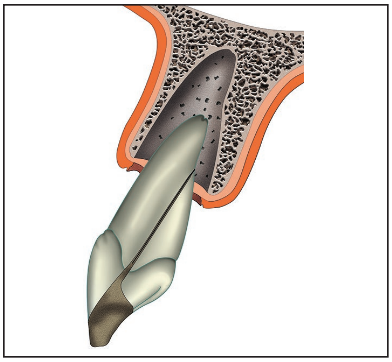


Fig 9-39 After traumatic tooth loss, a replacement tooth root can be inserted into the extraction wound, provided that the socket is preserved and not infected.

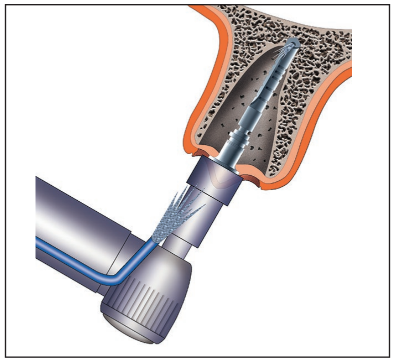


Fig 9-40 The socket is cleaned and deepened to the implant length in the apical area. The pilot hole acts as a guide for the implant cutter.

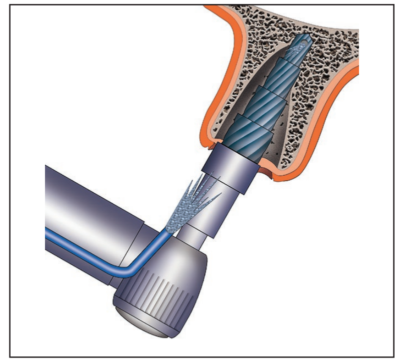


Fig 9-41 The implant bed is prepared with cutters of increasing diameter without damaging the lingual and vestibular walls of the socket.

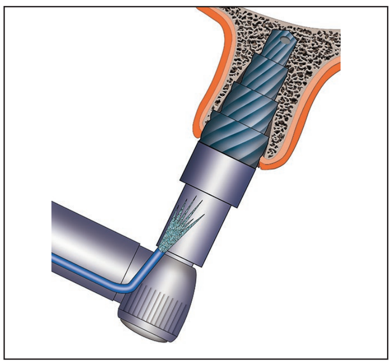


Fig 9-42 The largest implant cutter excavates the implant bed to the diameter of the eventual implant. Cutting is always done under cooling with physiologic saline.

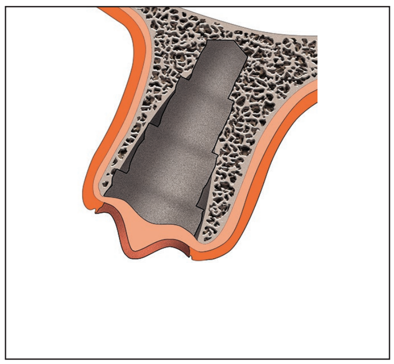


Fig 9-43 The finished implant bed for the root replacement roughly follows the conical shape of the socket or the anatomical shape of the tooth root.

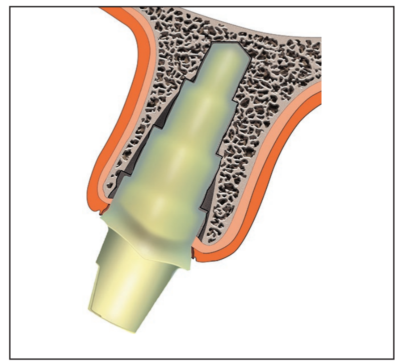


Fig 9-44 The stepped immediate implant has no thread but is tapped into place. Two-piece components may be used where submerged healing of the implant body takes place.

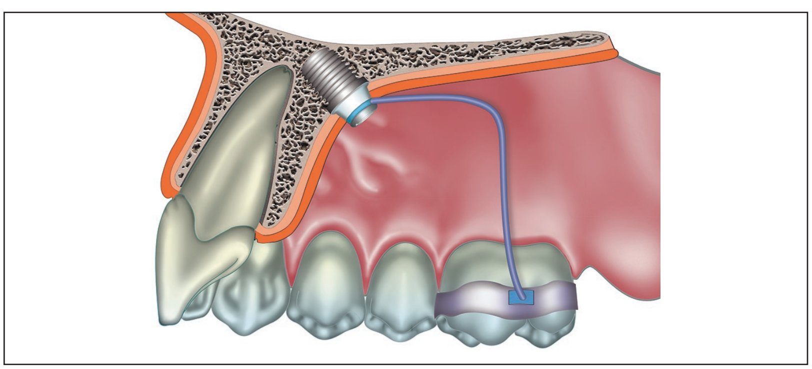


Fig 9-45 Mini-implants create absolute anchorage by which orthodontic tooth movement can be performed in all three spatial dimensions. These are very short palatal implants that have to be removed after the orthodontic measures.

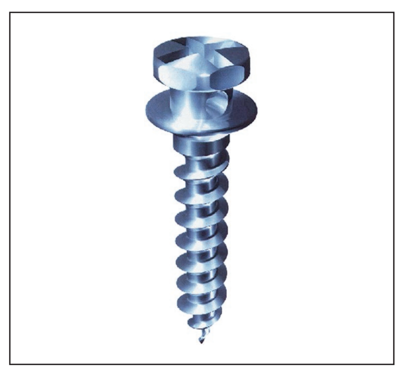


Fig 9-46 Endosseous mini–bone screws with 1.8- to 2.0-mm thread diameter and a 6- to 8-mm thread length can be used for orthodontic anchorage.

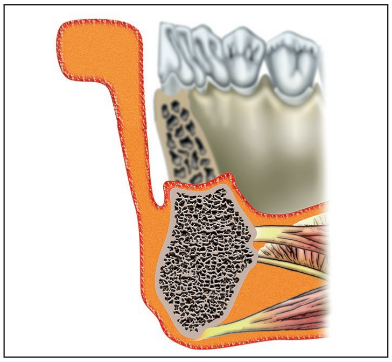


Fig 9-47 Severely atrophied ridge regions are only suitable for implant placement if an adequate bony bed is created by surgical measures.

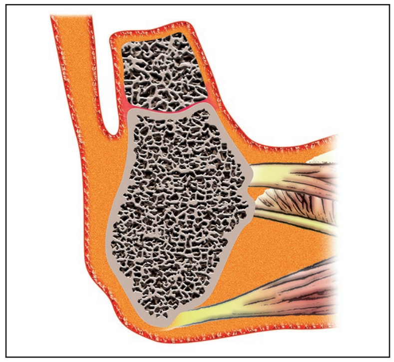


Fig 9-48 *Alveolar ridge augmentation* refers to an augmentation method in which a piece of autogenous bone (from the patient's own body) is fitted onto the ridge. Grafts harvested from jawbone are the most suitable.

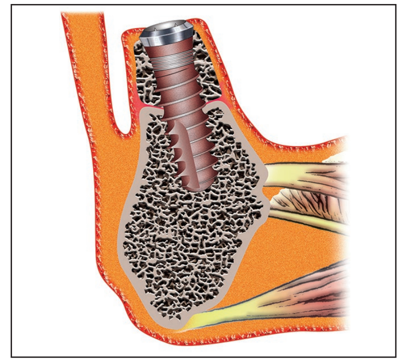


Fig 9-49 The graft can be fixed to the augmentation area with screws. If an implant cavity is created before the bone is harvested, the graft can be fixed with the implant screw.

mechanical complexity of orthodontic appliances. The force exerted is direct; for example, when inclined teeth are to be uprighted or intruded, teeth need to be lifted out.

Anchorage with mini-implants is indicated if there is no possibility of periodontal anchorage, if there are too few teeth, or if extraoral anchorage is rejected in adulthood. The use of mini-implants also makes orthodontic treatment possible in periodontally damaged dentitions. Mini-implants are used in pre-prosthetic measures when abutment teeth need to be parallelized for the planned restorative work. In this situation, the implants can be fitted into the dental arch and later used for prosthodontic purposes.

Special mini-implants are placed outside the dental arch. They are moved palatally as palatal implants because endosseous implants cannot be inserted in the alveolar process or the dental arch before skeletal growth is completed. Healing time is 10 to 12 weeks, before orthodontic forces can be applied. The implants have to be surgically removed after use, which reduces patient acceptance.

Endosseous mini-implants are therefore being used increasingly. With a thread length of 6 to 8 mm, thread diameters of 1.8 to 2.0 mm, and specially prepared screw heads, they are intended for orthodontic anchorage (Fig 9-46). These mini-screws can be inserted and removed in a minimally invasive procedure. They largely protect the anatomical structures (tooth roots, nerve structures) inside and outside the alveolar part of the jawbone and create favorable lever conditions when they can be inserted in the dental arch.

Augmentation Methods in Implantology

If implants of adequate length and diameter cannot be placed in an atrophied jaw, the bony bed can be optimized by extended surgical interventions, creating enough space for implant insertion (Fig 9-47). Various augmentation methods are used for this purpose, such as alveolar ridge augmentation by means of bone grafts, alveolar bone splitting and split osteotomy, elevation of the sinus floor or sinus elevation with bone condensation, and alveolar ridge distraction. As the cancellous bone (spongy-type bone) is permeated by numerous cavities containing bone marrow, there is less apposition contact with the implant; this can be remedied by condensing the bone.

Alveolar ridge augmentation by means of bone grafts or onlay grafts refers to augmentation of the implantation area with bone grafts that are primarily harvested from the retromolar region, the chin area, or the iliac crest (Fig 9-48). The grafts can be fixed onto the atrophied alveolar ridge with screws or plates or with the implant itself (Fig 9-49). For this purpose, an implant cavity can be drilled before the graft is harvested. The eventual screw implant will press the graft onto the area being augmented.

Apart from cases of seriously advanced atrophy of the alveolar process in the maxilla and mandible, this augmentation method can also be used after resection of tumors or for genetic defects (eg, cleft lip and palate). It is important to ensure that there is a direct bone contact surface in the augmented area and an adequate blood supply for the graft tissue.

Alveolar bone splitting (spreading of the alveolar ridge, alveolar extension plasty) is performed in cases with a minimum ridge width of 3 mm (Fig 9-50). An implant bed should be created by driving the alveolar ridge apart horizontally and condensing the cancellous bone in the implant area (Fig 9-51). To do this, the vertical cortical lamella is separated in the mesiodistal direction with a fine diamond disk and moved apart with a chisel-shaped spreader. In the process, the practitioner swivels and turns the spreading instruments carefully to and fro, thereby condensing the cancellous bone. Once the depth of the split is adequate for the implant, the implant can be inserted simultaneously or the cavity can be filled with bone/bone replacement material (Fig 9-52).

In an alveolar split osteotomy, the collapsed alveolar process is separated along the course of the dental arch, and a bone segment joined to the periosteum is moved vestibularly by the width of the alveolar ridge and fixed. This osteoplasty (segmental bone splitting) is intended to create space for the implant. The cortical bone in turn is vertically split, and a right-angled osteotomy (cutting the bone) is performed mesially and distally to the planned implant extending down to the basal bone. The bone lamellae at the base are then surgically fractured with care and moved transversally. The bone lamellae can be stabilized with miniplates. The nourishing periosteum attached to the mobile bone lamellae must be preserved; if not, the bone will be resorbed. The resulting cavity can be filled with bone chips or replacement material.

A cavity can be demarcated from the bone with a membrane that is fixed precisely to the bone. This cavity is filled with autogenous bone (collected drilling chips) or bone replacement material. After 6 months, the membrane can be removed and the bone surface smoothed. Vertical or transverse bone gain of about 3 mm can be achieved.

Sinus elevation makes the maxillary sinus smaller or builds up the sinus floor (augmentation). The lateral bony wall of the maxillary sinus is split (osteotomy) just above the alveolar ridge, the periosteum and sinus membrane (Schneiderian membrane) are raised, the resulting cavity is filled with augmentation material (bone chips and bone substitute), and the cavity is stabilized with a vestibular membrane.

If a facial window is cut into the maxillary sinus, a distance of more than 1 cm from the upper (crestal) alveolar ridge must be maintained so that the alveolar process does not collapse. If the bone height in the implantation area is still 4 mm, implant placement can be performed simultaneously. After the operation, nose blowing is not allowed for 14 days and nasal drops are prescribed; overseas flights and diving are prohibited for 4 weeks because of the pressure increase involved.

In a closed (internal or inner) sinus elevation, the bony bed in the posterior region of the maxilla can be enlarged and condensed by detaching the mucosa from the floor of the maxillary sinus and filling the resulting cavity with bone replacement material (Fig 9-53). The implant can be inserted in the same surgical procedure or implanted at a later date once the bone has regrown. This technique does not require lateral access to the maxillary sinus, which is necessary in a sinus floor elevation procedure.

For vertical augmentation, the mucosa of the maxillary sinus is raised with a bone condenser without tearing. The implant site is fixed with a spherical bur so that a pilot instrument with a small diameter of up to 2 mm can be pushed as far as the sinus floor (Fig 9-54).

Increasing sizes of bone condenser are then driven in carefully so that the bone is condensed in a circular and vertical fashion (Fig 9-55). This instrument, which has the same shape and dimensions as the implant, breaks open the floor of the maxillary sinus (Grünholz fracture) and compresses the bone chips and the bone replacement material introduced at the same time, while lifting the sinus endothelium by about 3 mm (Fig 9-56). No drilling is involved, but the instrument, in increasing diameters, is driven toward the maxillary sinus with hammer blows and carries the bone replacement material at its tip (Fig 9-57).

In the case of bone condensing, the expansion time needed by the bone must be taken into con-

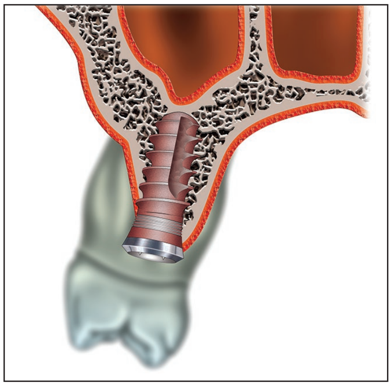


Fig 9-50 If the width of the alveolar ridge is much narrower than the implant diameter, an implant cavity can only be created by spreading the ridge.

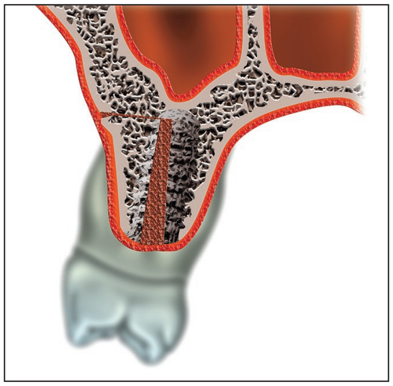


Fig 9-51 In alveolar bone splitting, a vertical lamella of cortical bone is split and pushed apart horizontally, and the cancellous bone in the implant area is condensed.

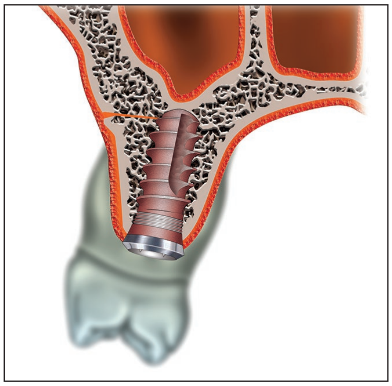


Fig 9-52 If the alveolar ridge is sufficiently spread, the cavity can be filled with bone replacement material, or the implant can be simultaneously inserted.

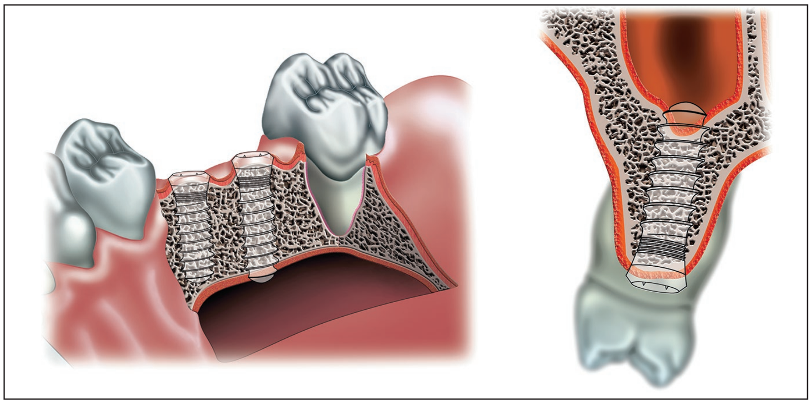


Fig 9-53 A closed sinus elevation can be employed if the alveolar ridge is large enough but the maxillary sinus so extensive that the necessary implant length would extend into the sinus.

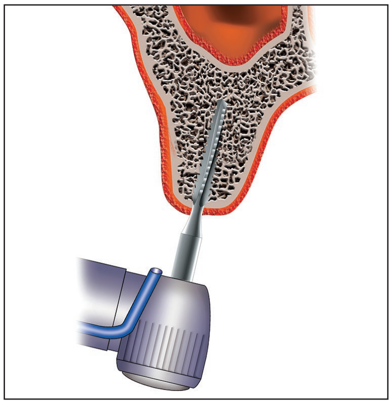


Fig 9-54 A pilot drill is used to create an implant channel 2 mm in diameter as far as the sinus floor.

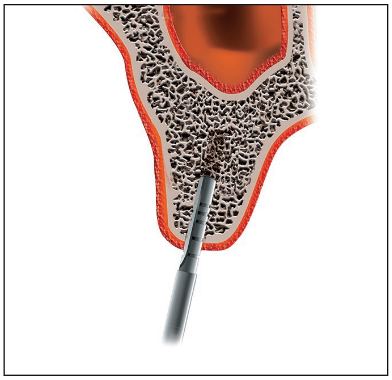


Fig 9-55 A bone condenser is carefully driven into the pilot drill hole, and the sinus floor is elevated without tearing.

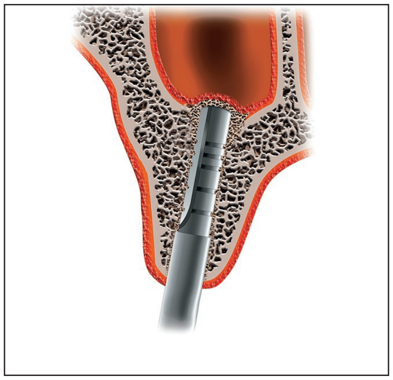


Fig 9-56 The implant bed is widened with a larger-diameter bone condenser, the cancellous bone is condensed, and the sinus floor is elevated by 3 mm.

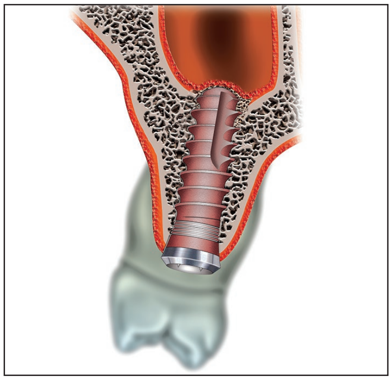


Fig 9-57 An implant with self-tapping threads can be screwed in with a torque-protected ratchet in a single working step.

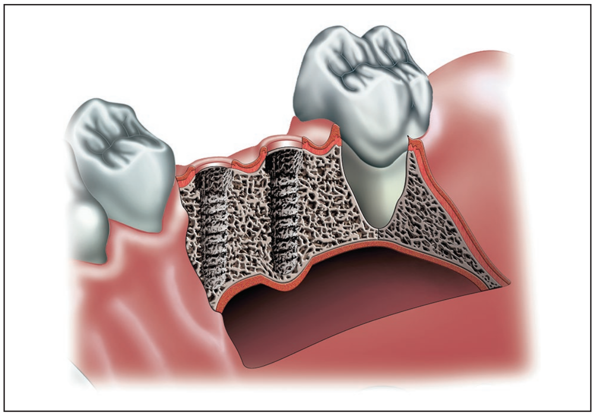


Fig 9-58 A closed sinus elevation can also be performed in a two-stage operation. The implant can be placed after resorption of the replacement bone and regeneration of the implant region. A minimum distance between implant sites is necessary for undisturbed osseointegration.

sideration, and the intraosseous blood vessels must not be constricted. The bone replacement material introduced is compressed into the sinus floor with the cancellous bone until the desired implant length relative to the height of the alveolar ridge is reached. Figures 9-58 to 9-66 illustrate the procedures for sinus elevation.

Vertical alveolar ridge distraction is a method adopted from orthopedics in which a distractor is used to move apart two bone segments separated by osteotomy. The resulting gap is closed by the formation of new bone. Distraction is applied in cases of severe vertical atrophy of the alveolar ridge when an adequate transverse bony base is still present. Compared with other forms of augmentation, distraction involves hardly any bone resorption, no bone graft has to be harvested, and the treatment time is shorter.

For distraction osteotomy, the operating field is exposed by reflecting the mucoperiosteal flap vestibularly. The vertical distractor can be fitted to the bone in the correct position with suitable bending forceps so that a pilot drill can be used to create the holes for screws that will later fix the distractor in place.

Osteotomy of the bone segment to be raised is then performed with fine-cutting osteotomy instruments, for example a diamond cutting disk or jigsaw, and special fine chisels. The distractor in the correct position is then connected to the local bone and mobile bone segment to be lifted, and a distraction gap is left. The operation wound is closed, and the result of the operation is checked by radiograph. The patient can carry out continuous distraction himself or herself with a special screwdriver. Implant placement can take place 12 weeks after the desired distraction height has been reached; at that point the distractor is removed.

Bone substance regenerates very slowly because of its lower metabolic rate. Complete regeneration of bony tissue takes 10 years, compared with 6 months for liver cells and 3 days for intestinal epithelium. Synthetic bone replacement material, such as tricalcium phosphate, is similar to bone and is used as a spacer in the case of bone defects. The use of foreign material delays the regrowth of a person's own bone but can define the direction of growth. Bone replacement materials contain vital protein structures, such as bone morphogenetic proteins, which specifically stimulate osteoblast formation and hence bone growth (therefore, they are osteoinductive) so that a high-quality implant bed can be formed.

Implant positions must be a minimum distance apart to ensure that the bony tissue is properly nourished or to achieve undisturbed osseointegration. The minimum distance between implant abutments at the gingival emergence site is 3 mm; the distance from natural neighboring teeth should be a minimum of 1.5 mm.

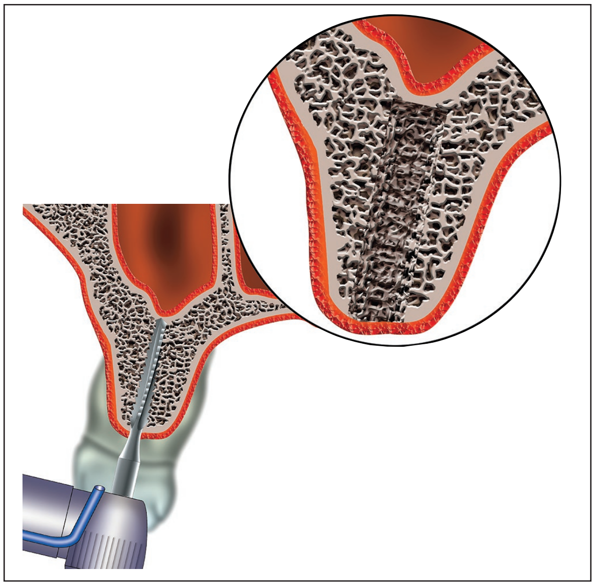


Fig 9-59 In a closed (internal) sinus elevation, an implant channel is milled transcrestally (through the alveolar process) as far as the cortical bone of the maxillary sinus. It can be advanced with conventional bone cutters or by piezoelectric surgery up to about 1 mm before the maxillary sinus.

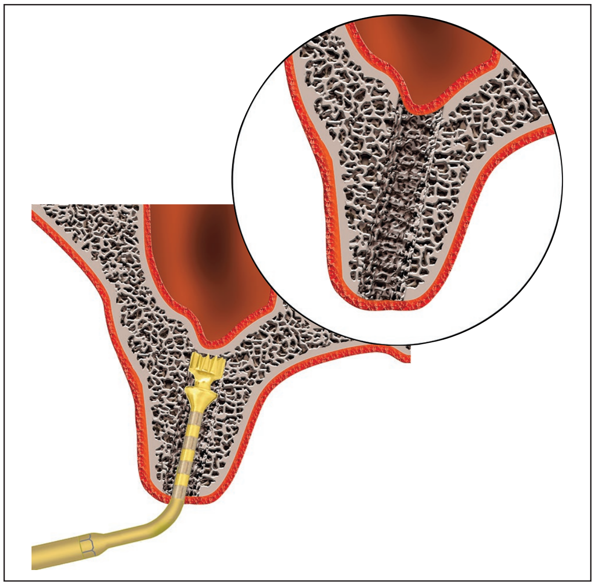


Fig 9-60 The risk of perforating the sinus membrane can be reduced by puncturing the cortical bone with a high-frequency vibrating piezoelectric instrument. The piezoelectric instrument can thus be gently guided against the soft tissue without perforating the sensitive membrane.

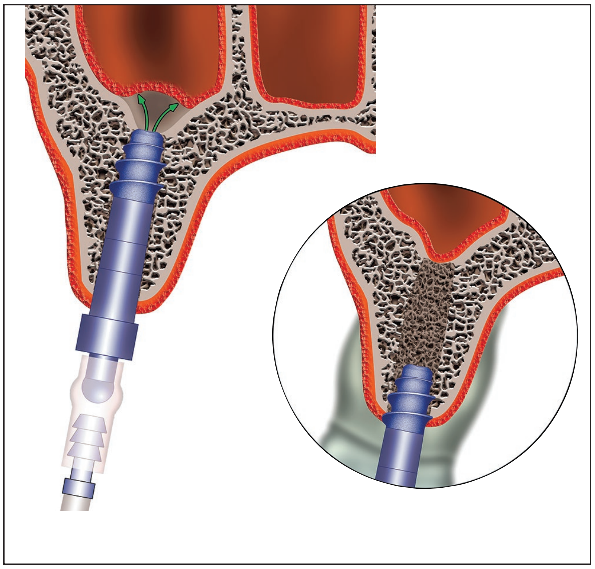


Fig 9-61 This mucous membrane is detached from the floor of the maxillary sinus with physiologic saline that is injected under controlled pressure or a fluid-filled balloon catheter. The quantity of saline or the volume of the balloon will determine the height to which the mucosa is detached.

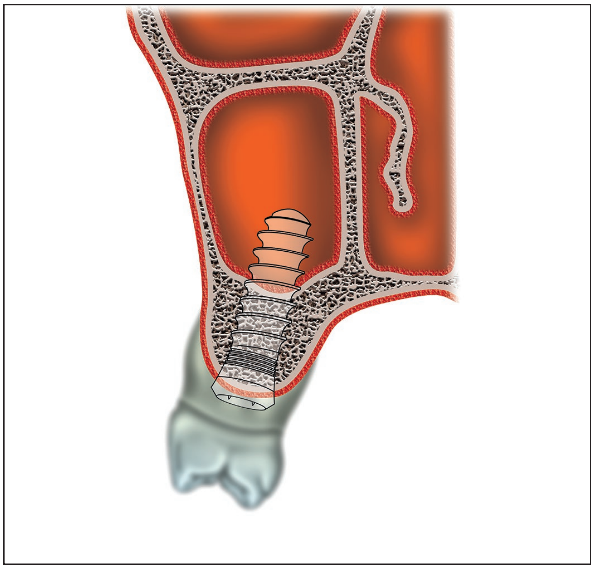


Fig 9-62 Elevating the floor of the maxillary sinus (ie, sinus elevation or sinus floor augmentation), becomes necessary when the bone supply is insufficient for implant placement because the maxillary sinus is too large, ridge absorption is severe, and short implants are not sufficient to bear the superstructure.

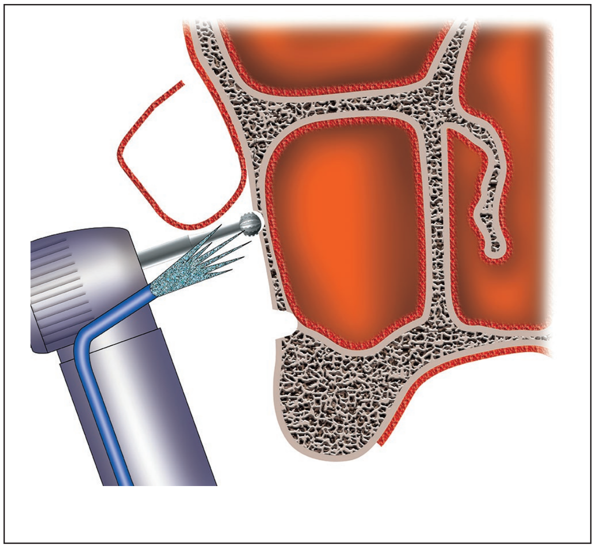


Fig 9-63 For an external or open sinus elevation, the maxillary sinus is opened with a facial window under general anesthesia. During osteotomy of the bony side wall, the mucosa of the maxillary sinus (sinus membrane) must not be damaged.

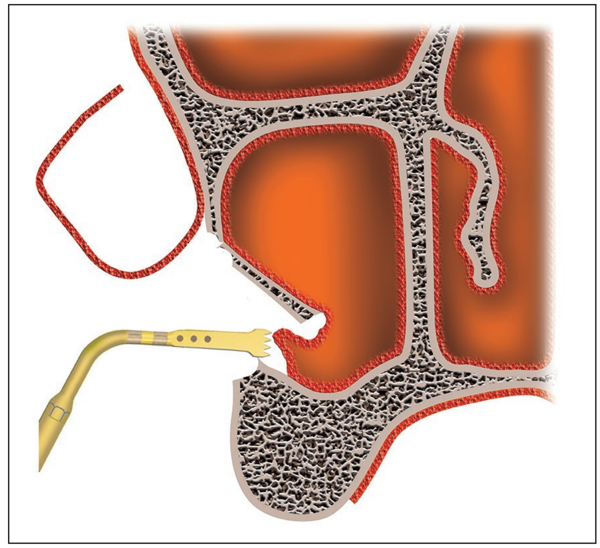


Fig 9-64 To ensure that the sinus membrane is not perforated during elevation of the sinus floor, piezoelectric instruments are used to lift the soft tissue with high-frequency vibrations (up to 36 kHz). The mucosa is detached from the bone margins with small, replaceable, disk-like preparation attachments.

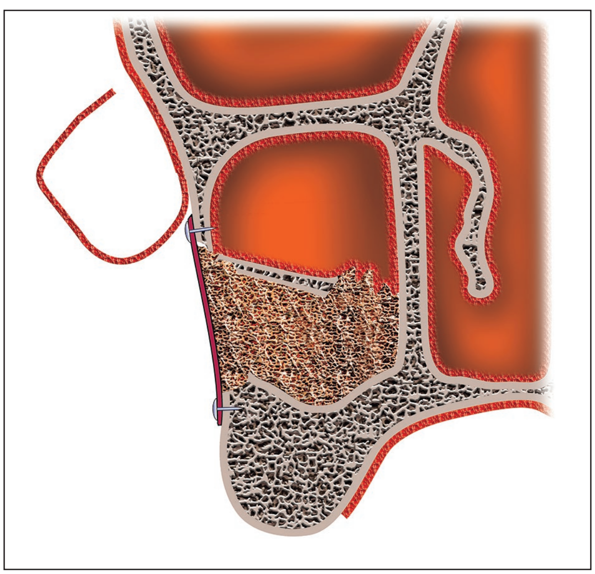


Fig 9-65 The separated bony wall is folded upward and inward, and the periosteum and sinus mucosa are carefully detached and pushed upward. The resulting cavity is filled with bone chips or bone replacement material under direct vision. The operating field is then covered with a membrane.

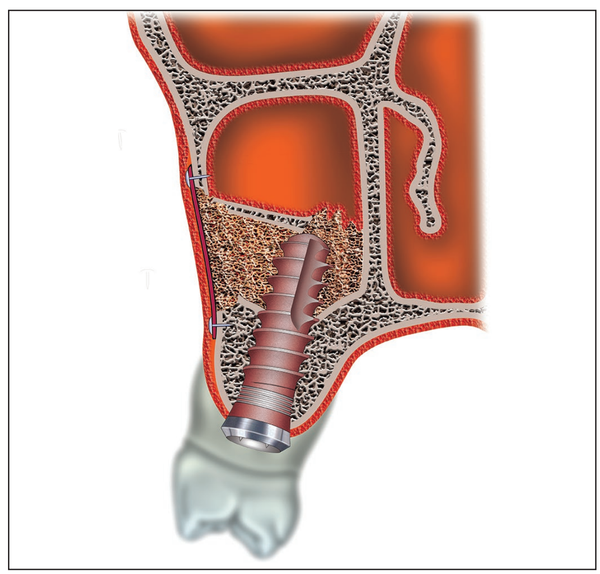


Fig 9-66 If the available alveolar bone is stable enough, an implant can be inserted immediately, an approach that has proved to be osteoinductive. If not, the implant bed can only be prepared and implant placement carried out after an appropriate healing phase (a minimum of 6 months).

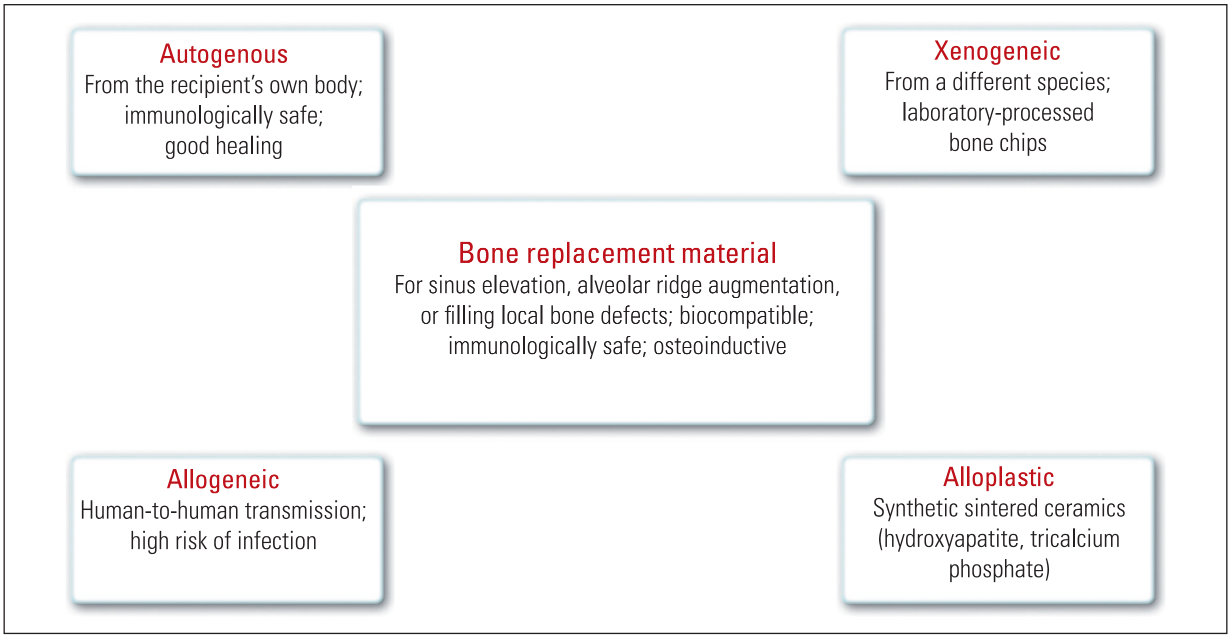


Fig 9-67 Types of bone replacement material.

Bone Replacement Materials

Bone replacement material is used in sinus floor augmentation and alveolar ridge augmentation or is used to fill local bone defects after bone resection. The material must be biocompatible and immunologically safe while having a positive (osteoinductive) effect on bone growth. The following paragraphs describe different types of bone replacement materials (Fig 9-67).

Autogenous bone grafts are pieces of replacement bone from one's own body. They are immunologically safe and heal most effectively when close to the donor site from which they are harvested. As the antigens in autogenous bone are identical to those at the implant site, no rejection reactions will occur. Nevertheless, specifically sensitized lymphocytes can form antibodies to the graft if the autogenous implant is obtained from more distant regions of the body.

Allogeneic bone grafts come from donors who are not genetically identical to the recipients but belong to the same species, for example human-to-human transmission. Because there is a high risk of infection due to the transfer of pathogens from donor to recipient, allogeneic bone replacement materials are not used in implantology today.

Xenogeneic bone grafts (or xenografts) come from a different species (eg, cattle, pig) than the recipient. The replacement material is denatured and used as bone chips after laboratory processing. The replacement material acts as a spacer and is permeated by osteocytes; it resorbs and attaches to the person's own bone. The bovine (ie, relating to cows) hydroxyapatite produced at high temperature forms the densest cell structures.

Alloplastic bone replacement materials are the synthetic sintered ceramics, such as nonresorbable hydroxyapatite, resorbable tricalcium phosphate, and resorbable bioglasses. Mixed products comprising hydroxyapatite and tricalcium phosphate are also available.

Small defects can be filled with bone replacement materials to which autogenous bone chips are added. The best way to make up for large bone defects is with one's own bone because endogenous tissue forms a stable foundation for implants after healing. Narrow, flat, atrophied alveolar ridges, for example, are built up by autogenous bone. The harvested bone blocks are fixed with special screws and heal over several months. During the healing phase, the new bone is covered with a membrane.

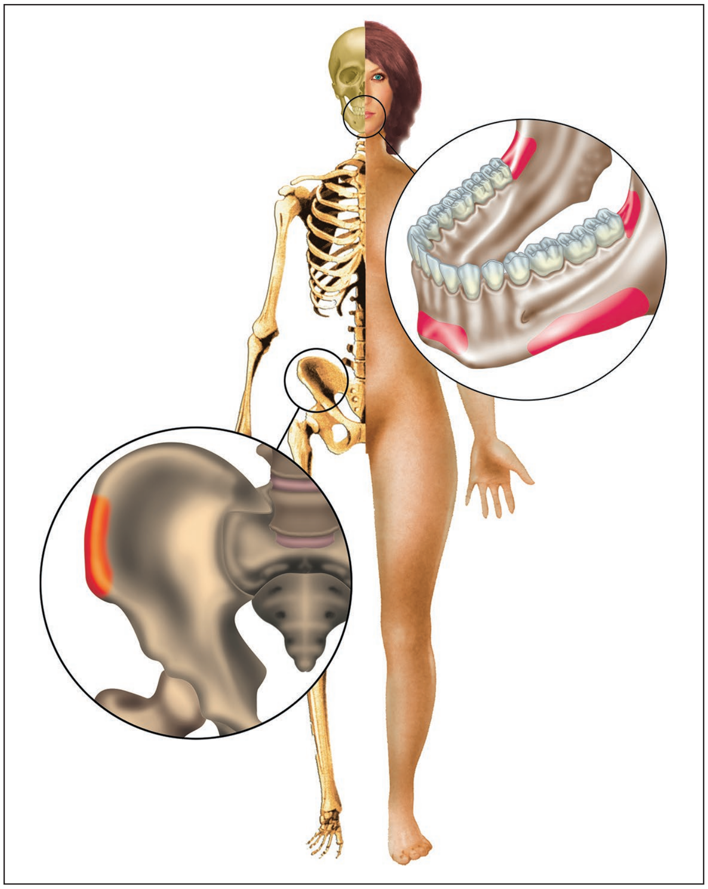


Fig 9-68 The preferred mandibular donor sites for bone grafts are the symphysis or chin region, the edge of the mandible, and the retromolar region. Grafts can also be harvested from the mandibular angle or the tuberosity region of the maxilla. These local donor sites provide bone fragments with the best healing rate because they are coupled to the localized system of messenger proteins and will not resorb. Autogenous bone from remote areas of the body, such as the iliac crest, are not as well suited for this reason.

Bone defects are classified as space-making or volume-making defects or non–space-making defects depending on their dimensions. In non–space-making defects, autogenous bone in the form of block grafts is the augmentation material. The ability of osteoblasts surviving in the autogenous bone to form new bone determines the speed of bone repair. Growth-inducing bone proteins (bone morphogenetic protein), which get into the grafting area with the blood, have the same influence on bone repair.

Local donor sites for dental implant placement are the maxillary tuberosity, oblique line, mandibular angle, retromolar region, and chin area (Fig 9-68). Remote sites are the iliac crest (bone chips), ribs, or tibia. Cancellous bone without compact bone (cancellous graft) is most suitable as graft material because the loose bone structure heals most effectively. Autogenous bone replacement requires a second operation with all the possible complications and wound healing problems.

Healing of a bone replacement fragment starts with initially resorptive processes, followed by repair phases and capillary containment from the surrounding implant bed tissue through to functional integration of the graft, which is promoted by load transfer through implants.

Remote autogenous bone (eg, from the hip) behaves like synthetic material and merely acts as a spacer. It forms the scaffold for the formation of new bone and is initially broken down like synthetic replacement material before the jawbone can build up new bone. This mechanism arises because every type of tissue needs genetic messenger proteins destined for a specific location in the body for its growth; nutrients alone will not result in tissue growth. Grafted bone from a different region of the body is decoupled from the localized system of messenger proteins and is therefore resorbed.

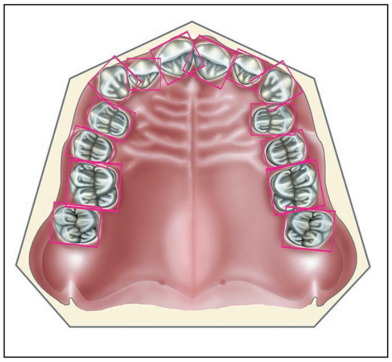


Fig 9-69 The planning of prosthetics or orthodontic projects has always been done with the aid of anatomical casts. For the purpose of treatment planning starting from the end product, an anatomical cast can be sawn into small segments (teeth and jaw sections), which are then placed in a planned position.

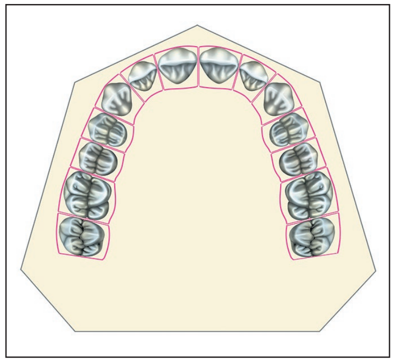


Fig 9-70 In a diagnostic setup, the individual teeth are placed in the normal position in order to show the treatment objective. A setup may also be the working basis for fabricating orthodontic appliances.

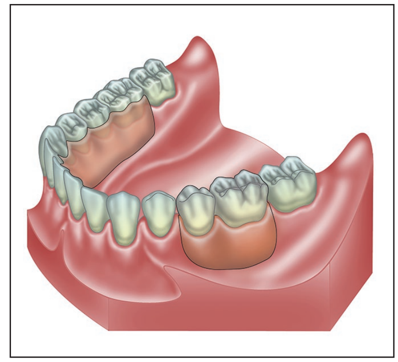


Fig 9-71 The setup of artificial teeth on an anatomical cast is intended to show the position of the teeth that will later be replaced. This setup illustrates the shape and position as well as the occlusal relationships of the planned restorative work, from which the position of an implant can be deduced. A setup can be placed in the patient's mouth as a demonstration model and is synonymous with the term *wax-up*. In order to check all functional situations in a patient's mouth, the setup can be converted into acrylic resin and is then called a *mock-up*.

Treatment Planning

Treatment planning for extensive dental restorative work, especially in implantology, involves analyzing all the treatment measures, identifying their repercussions, and defining the end result of the prosthetic work in relation to the patient's needs and wishes. In other words, planning for an implant-borne denture starts with a precise depiction of the end product, which the dentist uses to discuss the possibilities and limitations of treatment with the patient.

Planning backward from the treatment objective is particularly necessary when preimplant augmentation procedures for building up a sufficient bone mass become necessary to ensure the prosthetically optimal positioning of the implants. *Backward planning* denotes treatment planning starting from the end product, for which a setup, wax-up, and mock-up serve as the basis of the planning (Figs 9-69 and 9-70).

Setup refers to the preparation of a simulation model and has become a keyword in various techniques (Fig 9-71). In orthodontics, a setup model becomes the working basis for producing a positioner. This involves sawing individual teeth or whole jaw sections out of an anatomical cast and moving them to an ideal position. A thermoformed splint is pulled over this ideal position, with which orthodontic tooth movements can be performed.

A setup for diagnostic purposes should represent the ultimate treatment objective and is one of the fundamental working steps in the clinical and laboratory procedures of implant prosthodontics. To achieve this, the artificial teeth are set up in the intended position in wax on a model. Such a setup is also known as a *wax-up*, another keyword. The wax-up, converted into acrylic resin, can be used as a demonstration model and tried in the patient's mouth before any dental intervention has taken place.

Mock-up is the term for such a demonstration model, with which all the functional conditions in the patient's mouth can be checked (Fig 9-72). In addition to a check of esthetic appearance and accessibility to oral hygiene measures, a phonetic check can be carried out to assess the position of

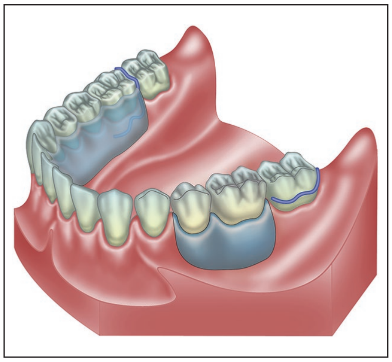


Fig 9-72 A mock-up anchored to the residual dentition with clasps provides a preview of the planned end product and guidance for implant positioning.

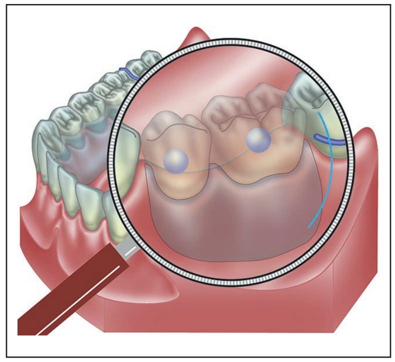


Fig 9-73 The mock-up is converted into a radiographic template by polymerizing geometric reference bodies in place, which are sharply depicted on radiographs and provide an indication of dimensions.

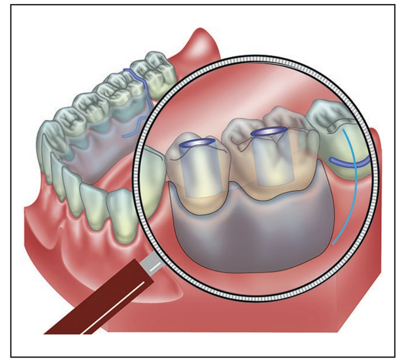


Fig 9-74 The setup/mock-up can be converted into a drill template by introducing drill sleeves in the precise implant position and direction.

the anterior teeth and decide on definitive solutions. For the clinical diagnostic process in implantology, this mock-up can be converted into a radiographic template and then into a drill template (Figs 9-73 and 9-74).

Examination

Implant placement is preceded by a clinical and radiographic examination intended to assess the topographic and anatomical structures (mental foramen, mandibular canal, maxillary sinus) and the bone supply in the implantation area. Radiographs of the implantation area show bone height and soft tissue thickness and make it possible to establish implant positions. The choice and number of suitable implants are based on analysis of the bone and the implant position. The exact clinical and laboratory procedure can be represented by the example of gap closure in the mandibular posterior region.

Anatomical casts that precisely depict all of the anatomical features are placed in an adjustable articulator, and a wax-up is prepared. Prefabricated teeth are set up in exact occlusion, and a silicone key is made. The wax-up is removed, and the set-up teeth are created in transparent acrylic so that a radiographic template results; this can later be reworked into the drill template.

For a radiologic check of the planned implant positions, measuring spheres are polymerized in place at the tooth positions. These are depicted on the radiograph and enable bone height to be calculated. Metal sleeves can also be polymerized at the ideal implant positions and serve as reference positions on the radiograph. If the sleeves sit directly on the mucosa, mucosal thickness can be identified. This measurement determines whether severely resorbed alveolar ridges need to be augmented.

The mucosal thickness over the implantation area can be checked in the mouth with a probe and the relevant thickness transferred to sawn segments of the anatomical cast (Fig 9-75). To this end, the ridge segments at the implantation site are sawn out of the duplicate of the anatomical cast, and the points for measuring the relevant mucosal thickness are marked. Joining the points together shows the available bone supply for implant placement (Figs 9-76 to 9-78).

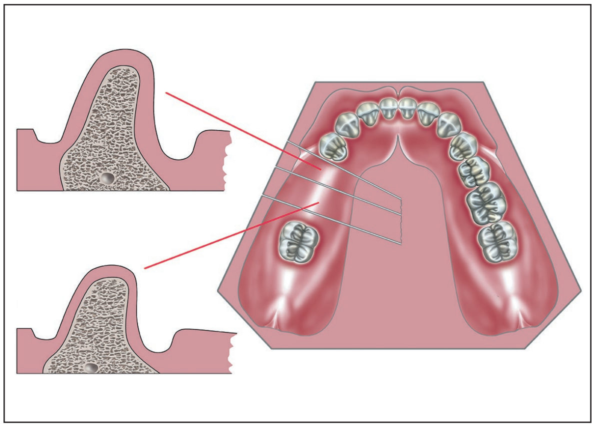


Fig 9-75 If the mucosal thickness has been checked in the mouth with a probe and marked on the model segments, an initial approximation of the bone supply for the implant site can be estimated, and the implant position and direction can also be established.

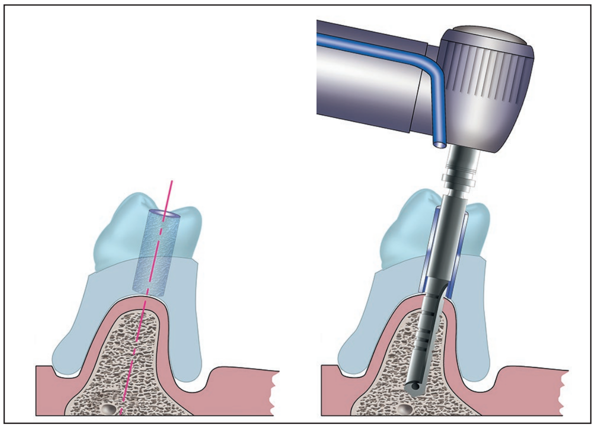


Fig 9-76 If the bony bed has been depicted by marking the mucosal thickness, the implant direction can be transferred to a drill template, and the drill sleeves can be aligned and polymerized in place. The drill sleeves are referenced to the diameter of the system-specific pilot drill and provide instrument guidance during implant placement.

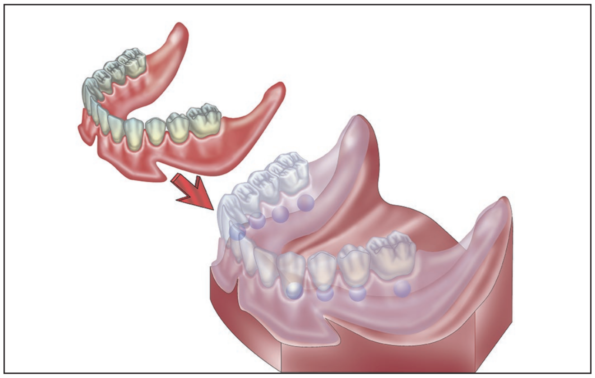


Fig 9-77 A wax-up/setup is converted into a scanning template with geometric reference bodies. The radiopaque scanning template and reference bodies are clearly shown on the radiograph.

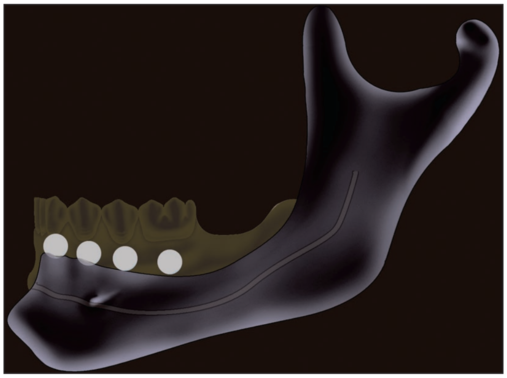


Fig 9-78 The radiograph not only depicts the scanning template but also provides information about bone thickness and the position of the mandibular canal. The reference bodies serve as a comparative dimension for measuring bone supply.

Navigated Implantation

Computer-navigated implantology involves the diagnosis and planning of the operating procedure on a computer. Three-dimensional images of the individual anatomical tooth and jaw relationships also provide information about the quality of the bone, the nerve canal in the mandible, or the dimensions of the maxillary sinuses.

For this purpose, computed tomographs (CT scans) or cone beam volumetric imaging (CBVI scans) of the jaws are required, which are then converted into three-dimensional images by specialized computer programs (Fig 9-79). For the tomographic scans (CT/CBVI) a special x-ray or scanning template with a geometric reference body is required, which can be precisely identified on the radiographic image. For this purpose, a diagnostic setup is converted into a radiopaque (not transparent to x-rays) acrylic template, that is, a scanning template that is sharply depicted on the radiograph. A radiopaque Lego brick or radiopaque spheres, for instance, can be used as geometric reference bodies.

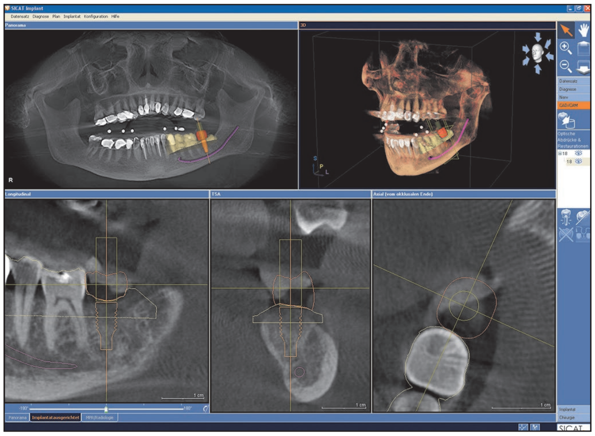


Fig 9-79 Sophisticated computer-aided design/computer-assisted manufacturing (CAD/CAM) systems, such as SICAT three-dimensional software, allow for computer-navigated implantation planning and fabrication of drill templates. The image data from the tomographic recordings (CT/CBVI) are imported via a DICOM (digital imaging and communications in medicine; universal file format for transmitting and storing medical data) import. When the CT surface data are linked to the CBVI volume data, both the gingival contour and gingival thickness—as well as the bony bed with the course of blood vessels, cavities, and nerve paths—can be accurately depicted and converted into a computer-generated design proposal. The system supplier fabricates a drill template based on the data. (Courtesy of Sirona.)

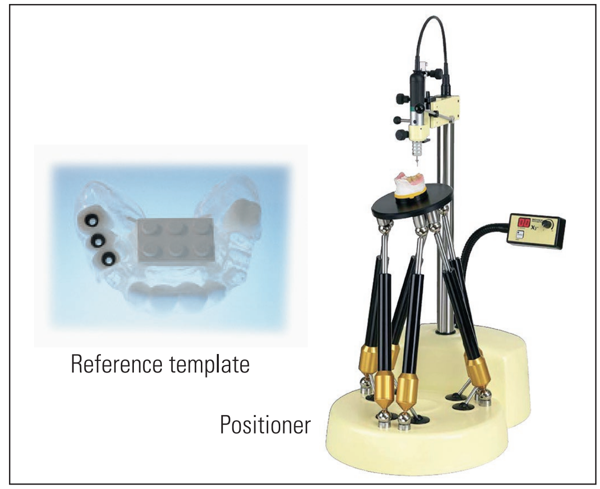


Fig 9-80 Data sets for drill templates can be created on the computer with the CEHA Implant System (C. Hafner/Pforzheim). The CT/CBVI data are generated on the computer and used for the virtual implant positioning. The software for the CEHA Implant System produces drilling instructions for all the implant positions with adjustment instructions for the milling equipment. As a result, the milling spindle can be aligned with point accuracy in the positioner and can be controlled using the software. The reference template for the tomographic images also serves as a reference for merging the data for the drilling instructions. The drill holes for the drill sleeves are placed exactly at the planned position of the eventual implants. After drilling, a sleeve holder is clamped in place and holds the titanium sleeve during polymerization.

By means of the radiographic scan, very detailed information about bone density, the position of the nerve canals, and the maxillary sinuses is obtained. This information facilitates the following:

- Detailed virtual planning of a procedure on the computer
- Very accurate alignment of the implants
- Reduction of the risk of injury to nerve and blood vessel structures
- Less invasive surgical implant insertion

A virtual simulation is created on the screen, showing the optimal length, diameter, inclination, and position for the implant; what drilling direction and drill depth should be selected; and what the eventual superstructure will look like.

The radiopaque scanning template depicts the setup so accurately that precise alignment of the implant relative to the superstructure can be carried out. These data sets can be converted into models of the jaws; they aid in the fabrication of drill templates and can form the basis for computer-aided design of the denture. After virtual implant positioning, the drill templates with the drill sleeves are fabricated by the stereolithography process, or the scanning templates are reworked into drill templates (Fig 9-80). The radiopaque reference bodies enable the scanning template to be aligned in the computer-controlled drill stand so that the drill sleeves can be accurately positioned.

Clinical Implantation

Establishing mucosal thickness or depicting the available bone supply makes it possible to establish the direction of the implant axis. The radiographic template can now be converted into a drill template. The measuring spheres or metal sleeves are removed, and the cavities are closed with acrylic. The pilot drill holes are then placed with a milling machine.

The drill hole is aligned with the middle of the tooth that is being replaced and with the center of the alveolar ridge or the available bone. The central positioning should permit a large enough implant diameter so that an optimum emergence profile can be created for the molars to allow adequate oral hygiene. The emergence profile signifies that the replacement tooth needs to be matched cervically to the implant diameter without creating any niches where contaminants can build up.

The implant axis can be corrected by the axis of the abutment. Most implant systems offer angled abutments that can be prepared at a later stage. When drilling, it is important to ensure adequate distances between implants and to pay attention to the implant axis, which should run in the middle of the available bone. Both parameters can be checked by pilot holes on the sawn model.

Metal sleeves, which are matched precisely to the diameter of the pilot drill or the implant drill, can be polymerized into the correctly positioned drilled shafts. The drill template may be reduced in some circumstances to permit an adequate hole depth for the pilot drill.

It must be possible to fix the drill template precisely to the neighboring teeth, either with clasps or by intraoral containment of the teeth bordering the gap; there must be no shift between the model and the intraoral situation. Finally, the drill template is trimmed vestibularly enough to ensure that a visual field for the implant site is created.

1. Surgical phase (implant insertion)

A system-specific set of instruments, containing everything necessary for the operation, is used for implant insertion. Patients are treated under local anesthesia on an outpatient basis; general anesthesia is rarely indicated. The actual implant insertion involves several steps:

1. The incision clearly exposes the operating field and must later allow for optimum wound closure. The mucosa is first incised with a scalpel, the periosteum of the alveolar ridge is lifted off, and the mucoperiosteal flap is reflected lingually and vestibularly (Fig 9-81).
2. The implant area is smoothed with a large bone cutter, and soft tissue remnants are removed with a bone curette (Fig 9-82). The drill template is then overlaid, and a marking hole is made with a round bur (at 2,000 rpm) (Fig 9-83).
3. Preparation of the implant bed with the aid of the drill template starts with making a pilot hole to assess bone quality and establish the implant axis and length (Fig 9-84). This drilling process must be done with external cooling.
4. Milling out the implant bed is performed with system-specific rotary instruments. The intermittently guided milling processes are constantly cooled with physiologic saline. The bone chips are carried away with the cooling fluid. The implant bed is prepared in several steps with internally cooled hollow drills in increasing diameters (Fig 9-85). The cutters have marking rings to act as depth guides. Drilling or milling is performed at low speeds (approximately 2,000 rpm) to avoid friction heat that would damage tissues (Fig 9-86).
5. Dimensionally accurate widening of the implant bed can be done with conical or cylindric reamers. This working step can be performed with a hand instrument known as a *ratchet*.
6. In the case of screw implants, a thread can be cut into the milled tunnels with a thread cutter and the implant bed flushed out. Thread cutting is performed with a ratchet.
7. Screwing in the screw implant is done at low speed (15 to 20 rpm) without pressure. Cylinder implants are tapped into place (Fig 9-87).
8. A sealing cap is screwed onto the implant (Fig 9-88). The insertion area is covered with the mucoperiosteal flap, and the wound is sutured tension free. A radiographic check is performed once implant insertion is completed (Fig 9-89).

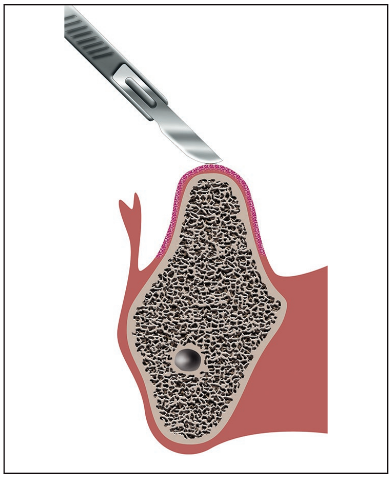


Fig 9-81 The operating field is clearly exposed by incising the mucosa with a scalpel, lifting the periosteum off the alveolar ridge, and reflecting the mucoperiosteal flap.

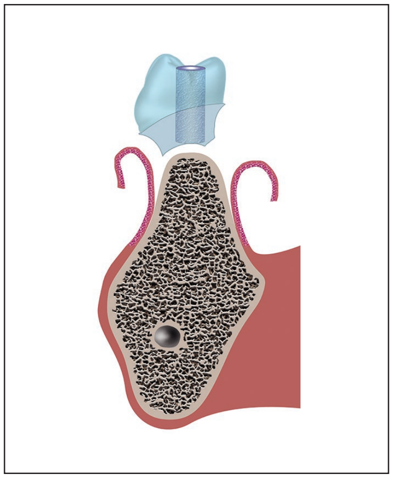


Fig 9-82 The implant area is smoothed with a large bone cutter, and soft tissue remnants are removed with a bone curette. The drill template is then overlaid.

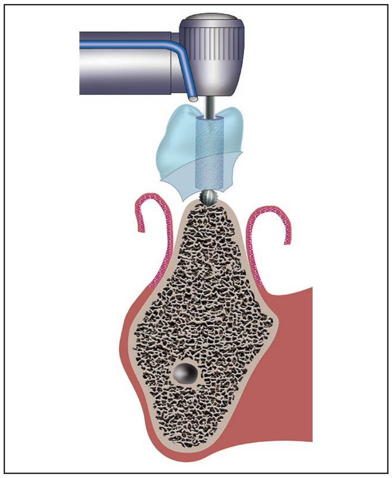


Fig 9-83 A marking hole is first made with a round bur rotating at a maximum of 2,000 rpm. Guidance is provided via the drill template.

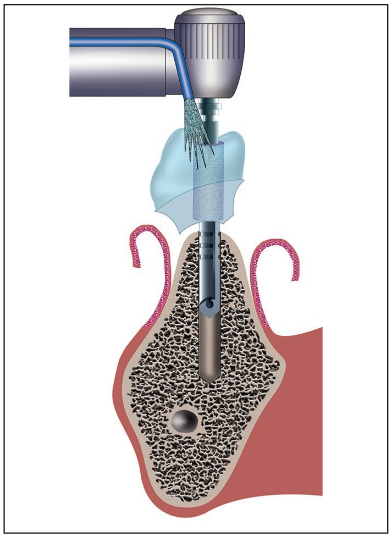


Fig 9-84 Preparation of the implant bed starts with the pilot hole, which is made to assess bone quality and establish the implant axis and length. The drill template is intended to provide reliable guidance and must be firmly fixed for the purpose.

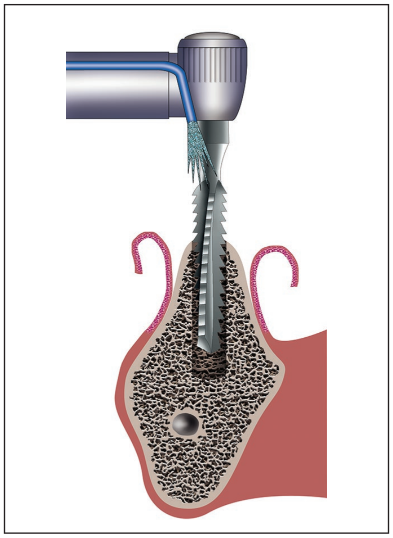


Fig 9-85 The implant bed is prepared with system-specific rotary instruments. The internally cooled hollow drills are intermittently guided and cooled with physiologic saline, which provides the means of removing the bone chips.

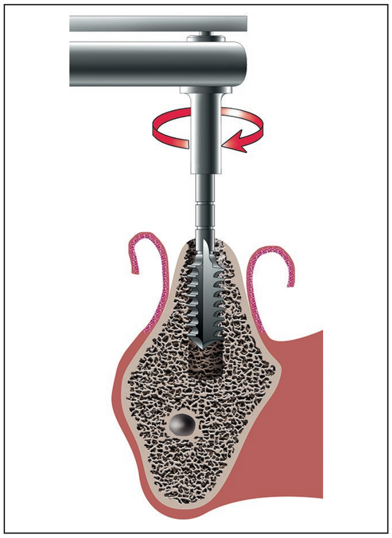


Fig 9-86 Drilling or milling is performed at low speeds (approximately 2,000 rpm) to ensure that no friction heat will damage tissues. In the case of screw implants, the thread is cut into the milled tunnels with a hand instrument and the implant bed is flushed out.

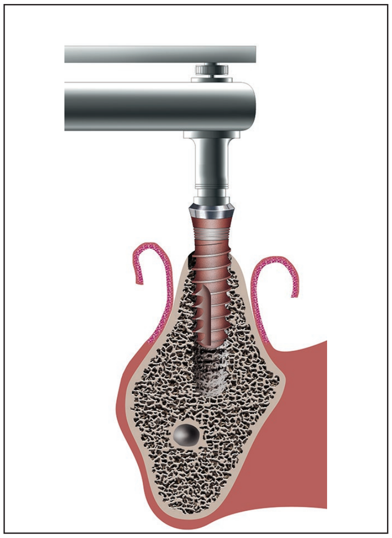


Fig 9-87 A screw implant is screwed in at low speed (15 to 20 rpm) without pressure, usually with a torque-regulated ratchet. Cylinder implants are tapped into place.

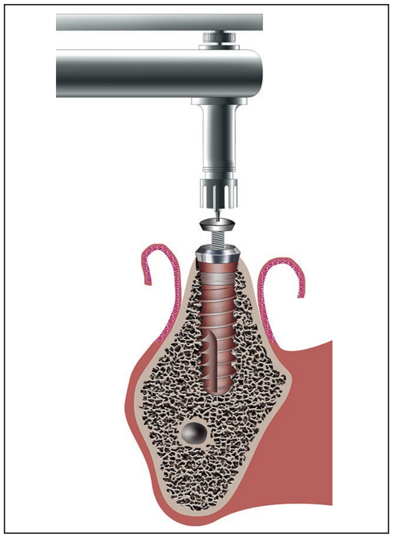


Fig 9-88 A sealing cap is finally screwed on without pressure and without moving the implant.

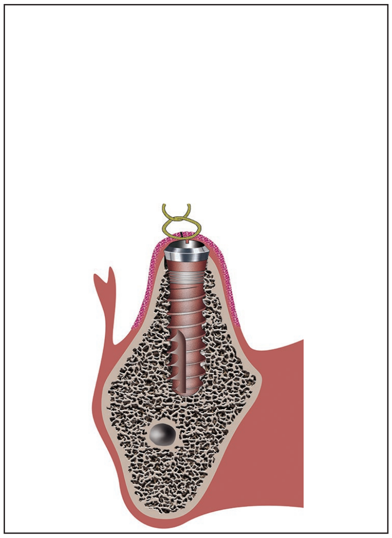


Fig 9-89 The insertion area is covered with the mucoperiosteal flap, and the wound is sutured without tension. Implant insertion is then done under radiographic control.

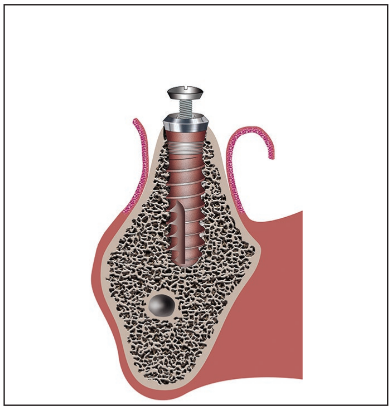


Fig 9-90 After an appropriate healing period of about 6 weeks, a second operation is performed to expose the implant and unscrew the closure screw. The mucosa can be surgically exposed or excised with a mucosal punch.

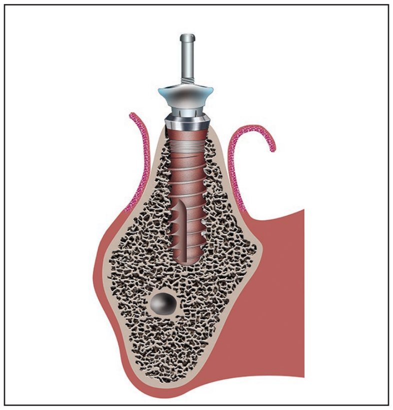


Fig 9-91 A sulcus former (also known as a *gingival margin molder* or *healing abutment*) is inserted, and the mucosa is sutured around this sulcus former to create tight adaptation of the soft tissue.

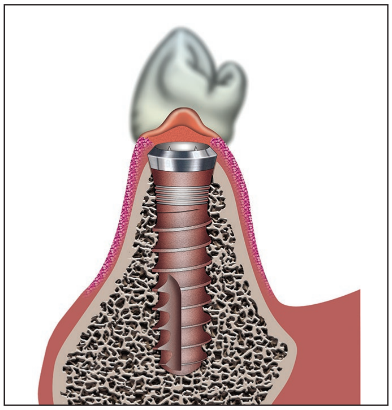


Fig 9-92 After the soft tissue heals, a gingival situation should arise that resembles the course of the gingiva in natural dentitions; an interdental papilla should be formed that is adapted to the emergence profile of the replacement tooth.

2. Surgical phase (implant exposure)

In a second operation, the implant is exposed, the closure screw is removed, and a sulcus former (gingival margin molder, healing abutment) is inserted (Fig 9-90). The mucosa over the closure screw can be surgically exposed or excised with a mucosal punch. The mucosa is sutured around the sulcus former, creating tight adaptation of the soft tissue (Figs 9-91 and 9-92).

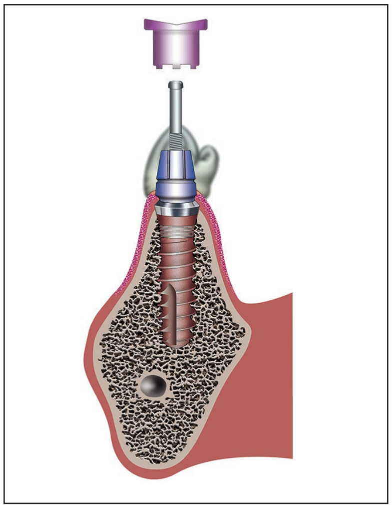


Fig 9-93 An impression abutment is screwed onto the implant for the impression-taking. This abutment is shaped so that an impression can be taken of the gingival situation.

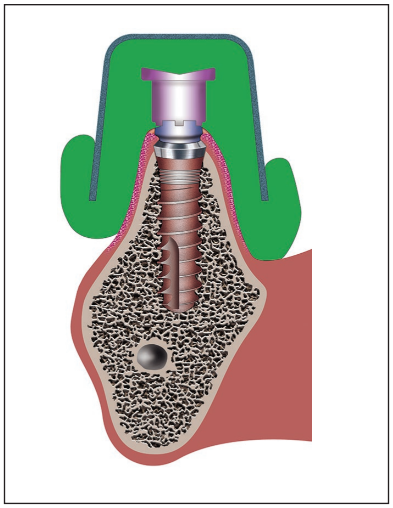


Fig 9-94 An impression coping is placed on the impression abutment. The coping has retention wings so that it sticks immovably in the impression material. An impression is taken with a prefabricated tray.

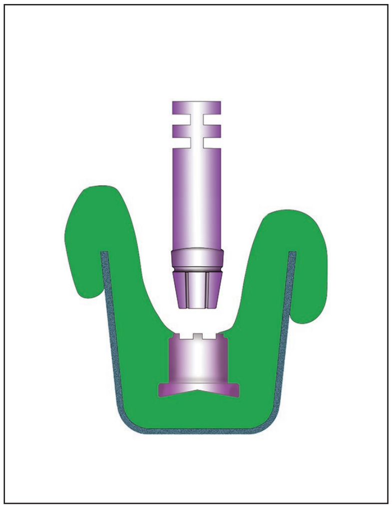


Fig 9-95 The impression abutment is unscrewed from the implant, screwed to a model implant, and repositioned into the impression coping.

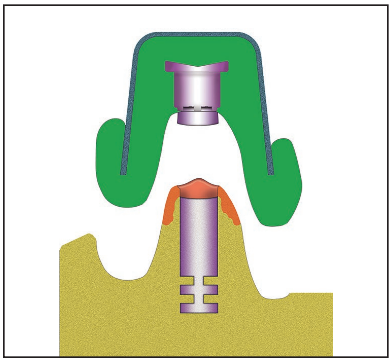


Fig 9-96 First the gingival mask is injected into the impression. Then a one-piece working model is prepared into which the model implant is inserted. The impression abutment is unscrewed so that the precise gingival situation is visible.

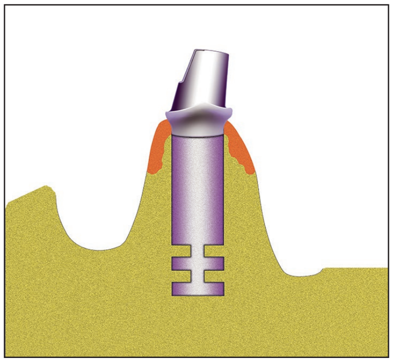


Fig 9-97 A precise model abutment is screwed on and provides the working basis for fabricating the superstructure. This impression technique is suitable for single parallel implants.

3. Clinical phase (impression-taking)

Impression-taking and preparation of the working model are performed with system-specific accessories for impression-taking with closed trays (repositioning technique) and impression-taking with open trays (pickup technique) to achieve precise transfer of the implant position to the working model. In the case of one-piece implants, an impression is taken of the abutment and the gingival situation in the same way as a normal tooth preparation for crown and partial denture.

Taking impressions with closed trays

To take the impression, impression abutments are screwed into the implants (Fig 9-93), and impression copings are fitted. The impression is

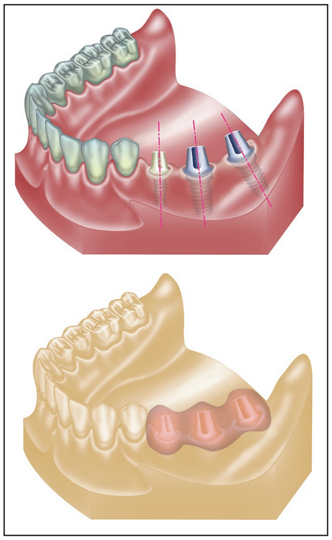


Fig 9-98 If the implant axes are divergent, a custom tray must be used to take an impression. The custom tray should be prepared on an anatomical cast depicting the impression abutments. The impression abutments are generously blocked out.

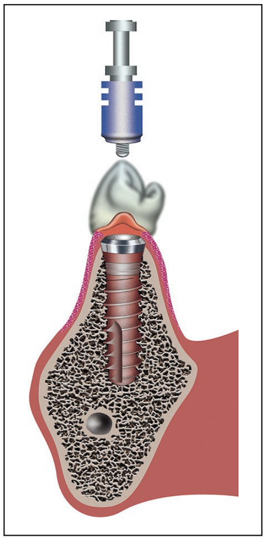


Fig 9-99 An impression abutment is again screwed on, using a special screw system that is provided. Once again the gingival situation is exposed for impression-taking.

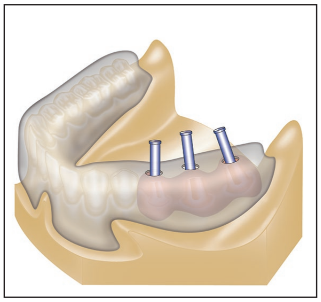


Fig 9-100 The custom tray has large holes through which the screw system with its divergent implant axes protrudes. The impression encompasses the screw system.

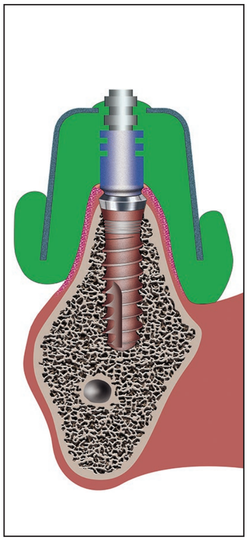


Fig 9-101 A silicone impression is taken of the firmly screwed impression abutments and the screw system, with particular care being taken to depict the gingival situation. Once the impression silicone has set, the screw system is detached and the impression removed. The impression abutment and screw system remain in the impression.

taken with a prefabricated impression tray. The impression coping remains in the impression material after the impression has been taken (Fig 9-94). The impression posts are unscrewed from the implants and screwed to the model implant. To prepare the model, the impression abutments with screwed-on model implants are repositioned in the impression copings in the impression (Fig 9-95). The impression abutments engage in the grooves of the impression coping.

The impression is cast without loosening the impression abutments. It is advisable to prepare a gingival mask that accurately and flexibly depicts the situation of the surrounding gingiva. After the model has set and the impression has been taken off, the impression abutments are unscrewed from the model implants (Fig 9-96). This method is only suitable for roughly parallel implants (Fig 9-97); open trays must be used for divergent implant axes.

Taking impressions with open trays

A custom tray is necessary for the definitive impression of the implant situation where there are divergent implant axes, and this tray must have occlusal openings at the implant positions. The custom tray is fabricated on an anatomical cast that shows the screwed-on impression abutments. The impression abutments must be blocked out with wax for the anatomical impression (Fig 9-98).

For the definitive impression, the impression abutments are screwed onto the implant (Fig 9-99). The screw system protrudes occlusally through the custom tray (Fig 9-100). Once the impression material has set, the screw connection is detached so that the impression can be taken out of the mouth. The retentive impression abutments remain in the impression (Fig 9-101).

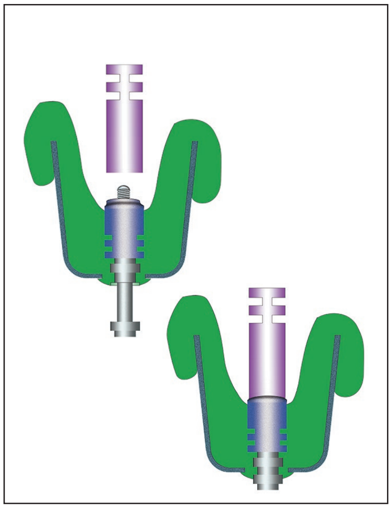


Fig 9-102 The screw system is also designed for the model implant, which is then screwed onto the impression abutment. A gingival mask is again injected and the impression cast.

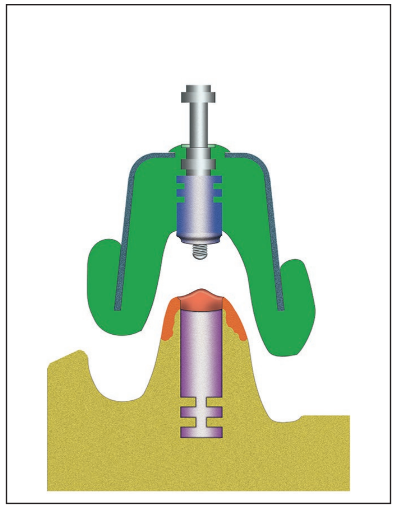


Fig 9-103 After the cast has set, the screw is loosened, and the impression and impression abutment are removed. A sawn model is not produced, but the flexible gingival mask provides guidance for a correct prosthetic emergence profile.

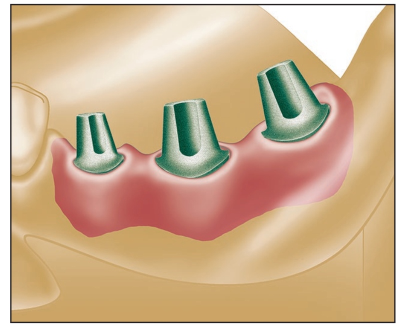


Fig 9-104 The finished one-piece model with gingival mask and the screwed-on laboratory analogs (model implants) form the working basis for the superstructure.

For model fabrication, the model implants are screwed to the impression abutments (Fig 9-102). It is also advisable to prepare a flexible gingival mask because the impression abutments are removed after model fabrication, and abutments are mounted (Figs 9-103 and 9-104). If no gingival mask is prepared, it might not be possible to attach the abutments. Special plaster cutters are then used to expose the shoulders of the laboratory implants in the cervical area of the implant neck to allow interference-free seating of the abutment.

4. Laboratory phase (superstructure)

Most implant systems permit preparation of the abutment. The implant length, implant axis, and gingival contour can be modified with system-specific instrumentation (Figs 9-105 to 9-107). The original wax-up serves as a guide. The silicone key of the wax-up is overlaid so that the axes and lengths of the implants can be adjusted. After modification, the superstructure can be prepared.

The screw head and screw channel of the abutment must first be covered or sealed with a removable material. The abutments are then isolated, and the crown copings are modeled, invested, cast, finished, and veneered in the customary way. When fabricating the veneers, it is important to ensure that the emergence profile allows good oral hygiene. No niches should arise, and cleaning possibilities for interdental brushes must be created.

For insertion, the abutments are detached from the model implant and fitted onto the implant in the mouth with new abutment screws. The crowns are first fixed temporarily. After a follow-up session, the crowns can be definitively inserted.

Implications for dental technology

There are no essential differences between the fabrication of a superstructure (ie, an implant-supported denture) and a restoration with periodontal or mixed support. The difference from fabrication of normal prostheses lies in the fact that system-specific prosthetic accessories for the implants have to be incorporated according to the manufacturer's instructions. The choice of material should be based on the implant materials to avoid a diversity of materials and associated corrosion processes. Abutments can be in-

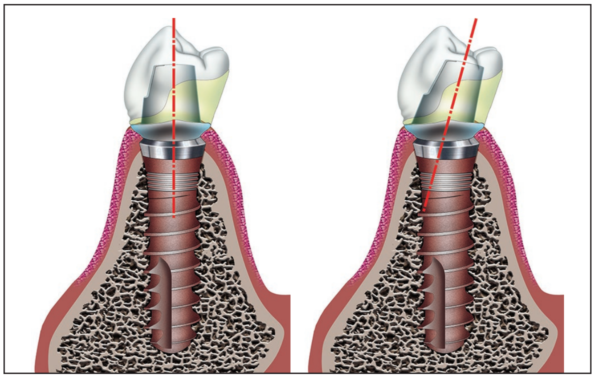


Fig 9-105 The abutments are available in different inclinations of axis so that, in common with the rotationally symmetric connections between implant body and abutment, it is possible to precisely align the inclination of an abutment with the finished crown. If necessary, most abutments can be suitably reground.

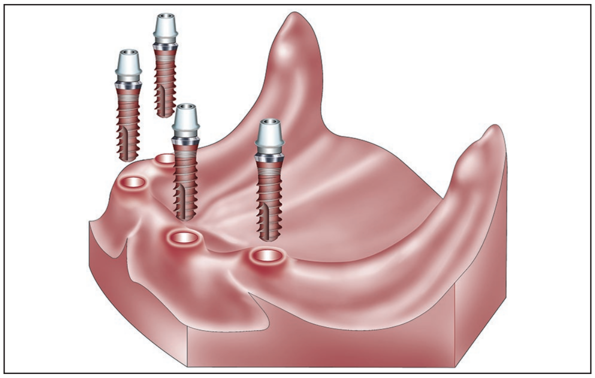


Fig 9-106 Modern implant systems have a difference in diameter between the implant body and the abutment, which is known as *platform switching*. The abutment and implant shoulder do not finish flush; the diameter of the abutment is reduced.

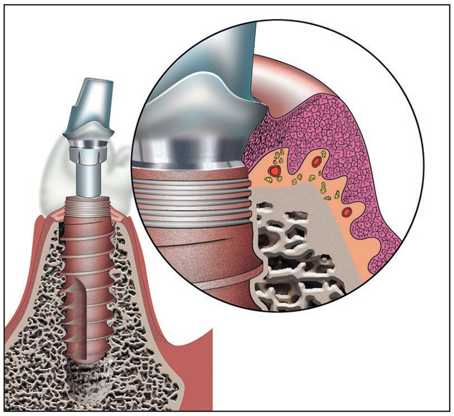


Fig 9-107 By means of platform switching, the potential microgap to the implant shoulder is moved inward, and the distance from the bone is enlarged; this provides microbial protection to the marginal hard and soft tissue. The polished abutment provides the basis for adapting the soft tissue by means of a basement membrane.

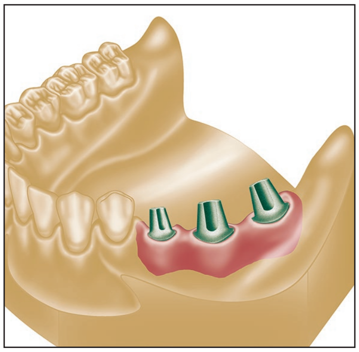


Fig 9-108 The superstructure should be fabricated on a one-piece working model with gingival mask. The superstructure must satisfy periodontal hygiene as well as esthetic and static requirements.

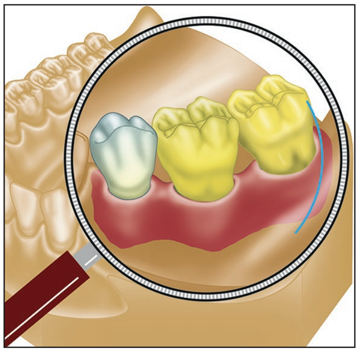


Fig 9-109 The emergence profile concerns the harmonious (ie, the esthetic and periodontally hygienic) transition from the abutment to the contour of the denture. A gingival sulcus and, if possible, an interdental papilla should be created, or an interdental situation should be created that is easy to keep clean.

terpreted as tooth preparations that are covered with single crowns, partial dentures, or partial or complete dentures in the form of overdentures.

The superstructure is prepared on laboratory implants (laboratory analog, manipulation implant) that are inserted into one-piece working models made of artificial stone (Fig 9-108). In the area of the laboratory implants, no sawn sections are created because the gingival region must remain intact for an emergence profile that allows good periodontal hygiene with a harmonious transition from the crown form to the implant neck and to the interdental papilla (Fig 9-109). The superstructure must satisfy the criteria of statics, esthetics, and periodontal hygiene and must permit full masticatory function.

The masticatory forces are transferred directly to the bone via superstructure and implant because the cushioning between implant and bone is absent. The IMZ TwinPlus implant, for example, has an intramobile cushioning component between abutment and superstructure. The implants are more resistant to vertical forces than horizontal forces. Therefore, a primarily vertical direction of force should be ensured.

A single implant can be loaded in a similar way to a single-rooted natural tooth. To absorb horizontal forces, the restoration must be connected to the natural dentition. The following *occlusal criteria* apply to osseointegrated prosthetics:

- Fully bone-anchored prosthetics are produced in physiologic occlusion with disocclusion in the posterior region on eccentric mandibular movements.
- Implant-borne complete dentures display balanced occlusion.
- Anterior partial dentures as far as the canine with mixed support (osseointegrated/periodontal) permit group-guided occlusion.
- Posterior partial dentures with mixed support (osseointegrated/periodontal) are constructed with anterior canine guidance.

An implant-borne complete denture can be retained on several implant abutments. In the mandible, preferably two to four cylinder implants are placed in the section of the alveolar ridge between the two mental foramina. Bar connectors, ball retainer clasps, or conical crowns are suitable as mesostructures. The superstructure is shaped as a purely mucosa-borne prosthesis with extended base, functional margins, and reduction needs. The objective is a statically favorable setup of the dentition with balanced occlusion.

The implant bars should be placed so that they axially load the implant abutments without long lever arms and so that there is a distance of approximately 2.5 mm between the lower edge of the bar and the alveolar process to create favorable hygiene conditions. In the case of ball-head abutments, the resilient secondary anchoring parts are polymerized directly into the denture base. In the case of tapered connections, the implant abutments form the subcrowns on which conical coping finished parts are seated; the conical copings are integrated into a model cast framework.

Preparation of the crown, partial denture, or model cast frameworks is done on impression copings or on system-specific mesostructures (gold or titanium copings). The framework can be bonded, cemented, or cast onto the mesostructures.

If there is a screw connection between mesostructure (occlusally or lingually) and abutment, the screw hole must be kept clear in the framework of the superstructure. The lingual screw hole is oriented mesiolingually so that it is easily accessible.

Fixed crown or partial denture frameworks are cut back at the gingiva and interdentally to create adequate space for oral hygiene and allow self-cleaning. The transitions between implant and superstructure must be smooth and gap free to avoid providing any sites for accretions.

On bar-retained overdentures, the abutments and their gingival borders must be avoided.

Overdentures

Overdentures or hybrid dentures (also known as *overlay dentures*) are removable prostheses that are fixed to and supported by natural tooth remnants and/or implants with concealed anchoring components (Fig 9-110). A quasi-complete denture anchored with resilient telescopic crowns is also classified as a hybrid denture.

Hybrid dentures are indicated in severely reduced partially edentulous dentitions. They are mainly mucosa borne and have base dimensions like complete dentures. The anchorage to root preparations, implants, or resilient double crowns provides horizontal positional stability and a better retentive function than with a denture that is held to the dental arch by adhesion, cohesion, and suction. To a small extent, periodontal support is also achieved, which greatly improves chewing efficiency. Overdentures can be designed as a prospective interim solution for severely damaged residual dentitions, allowing for expansion to a complete denture.

The considerable positional stability of hybrid dentures can greatly reduce the resorptive processes affecting the denture-bearing area. For a mucosa-borne hybrid denture, two anchoring elements per jaw are sufficient to ensure retention of

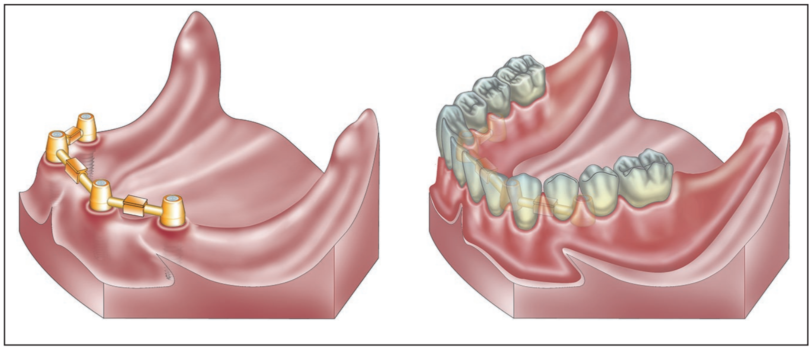


Fig 9-110 Hybrid cover dentures or overdentures are removable prostheses that entirely cover the anchor abutments. Tooth or root preparations as well as implants can serve as anchor abutments. The retentive and supporting elements can be rigid or have several degrees of freedom. Here four implants are placed, which are joined together by bars and form a closed support block. The bar sleeves can be given some resilience clearance to dissipate the masticatory load to the mucosa and relieve the implant bed.

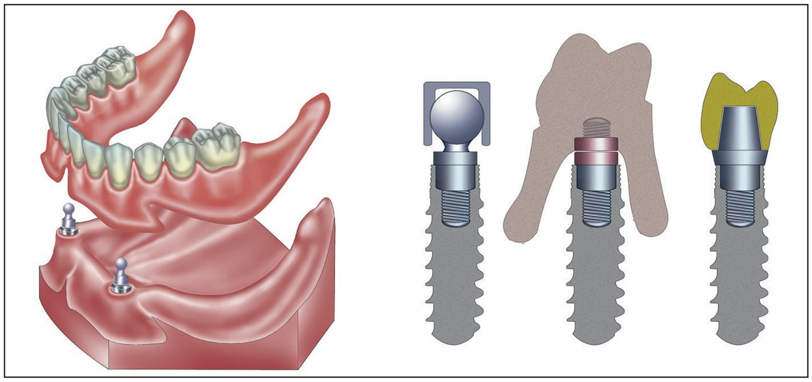


Fig 9-111 Implants can be fitted with different retentive elements for the removable superstructures. In addition to bar attachments, ball clasps can be used according to the stud-attachment system or magnet connectors as well as telescopic parallel or tapered fittings. Bars, stud attachments, and magnets are prefabricated components, but telescopic connections are usually individually fabricated.

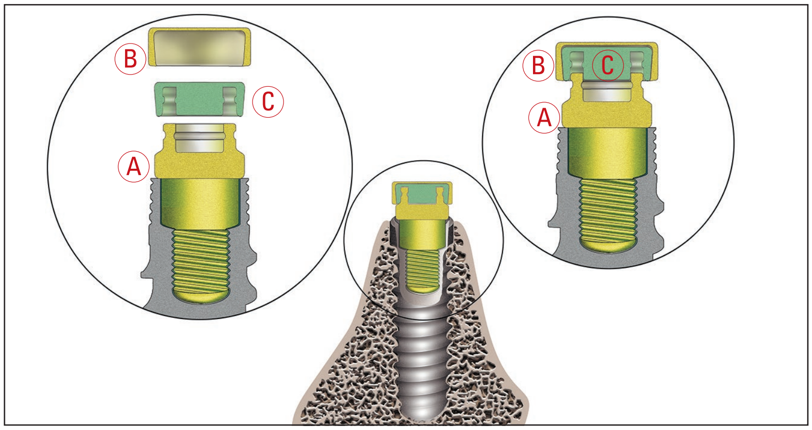


Fig 9-112 The prefabricated connector called a Locator (Zest) is a two-piece flat abutment made of metal. The primary part (A) has a ring-shaped inner and outer groove as well as a central depression. The secondary part (B) bears replaceable retention inserts (C) made of rigid plastic in different color-coded grades of retentive force, which engage on the primary part. The primary part of the Locator is available in various heights for different gingival situations.

the denture. In the maxilla, cumbersome palatal plates can be omitted from the denture base. The overdenture, anchored or supported on implants, does not touch the mucosa and transfers masticatory force via the implants directly into the jawbone. This design is a possible alternative to a fixed partial denture, is better for oral hygiene, and requires the same number of supporting implants as fixed constructions.

Which connecting and anchoring elements are used depends on the number and distribution of the implants and abutment teeth and on the rigidity of the superstructure. If there are few implants or abutments, connectors with several degrees of freedom should be used, such as resilient bars, ball clasps, and magnets (Figs 9-111 and 9-112). If there is a sufficient number of implants and abutment teeth, form-fit and force-fit rigid anchoring and supporting elements are possible; these distribute forces better because of their primary and secondary splinting effects.

Ball clasps can be used as abutments for implants and to anchor root crowns. The integration of stud-attachment secondary parts into the denture base is technically the same with root crown anchors and implant anchors, for which only one working model with model implants is necessary. In order to take an impression of the implant anchors, impression copings are placed on the implant, and the model implants are integrated into the impression. A working model with these model implants can then be produced. Later, stud-attachment matrices can be incorporated into the record base so that interocclusal registration can be performed with support on the implants.

Bar attachments are used for implant-borne overdentures with four or more implants. They are parallel bars that take on not only a retentive but also a supporting function. Bars with a round or oval profile are used when there are two implants in the region of the mandibular canines for a mucosa-supported denture, which is able to rotate around an axis of rotation of the resilient bar.

Telescopic double crowns provide easy-to-handle denture anchorage, especially for elderly patients. In purely implant-borne constructions, at least four implants are required, and if they are given resilience clearance, the denture is mucosa and implant supported. If conical telescopes are used, the secondarily splinted implants take on the full supporting function.

Tapered or parallel-walled primary parts can be individually modeled and cast or milled out of system-specific abutments relative to one path of insertion. These abutments are made of gold, ceramic, or titanium. The telescopic secondary parts are fabricated by conventional dental technology methods and integrated into a model cast framework.

In the case of implant-retained overdentures, magnets are preferably fitted onto two implants in the mandible. As magnets are liable to corrosion in the oral environment, the magnets are encased in a dense titanium housing (eg, Steco-System Technik). The magnets are worked like stud attachments from the dental technology point of view.

Therapeutic Concepts Based on Indication Classes

Dental implant placement presupposes a need for prosthodontic treatment, and this is based on a systematic diagnosis, starting with the history taking, followed by clinical, functional, and radiologic examination, and continuing through to the development of an overall therapeutic approach. A need for prosthodontic treatment exists when very severe changes in the orofacial system have occurred or are to be expected as a result of tooth loss. The implant-borne or implant-retained denture has the same functions as conventional dentures, namely biomechanical, therapeutic, prophylactic, and regulating functions. As well as the lasting functionality and expansion option afforded by the prosthetic solution, it is also expected that the use of dental implants will ensure a fixed denture that protects the available hard dental tissue or removable dentures that can be stabilized and securely anchored.

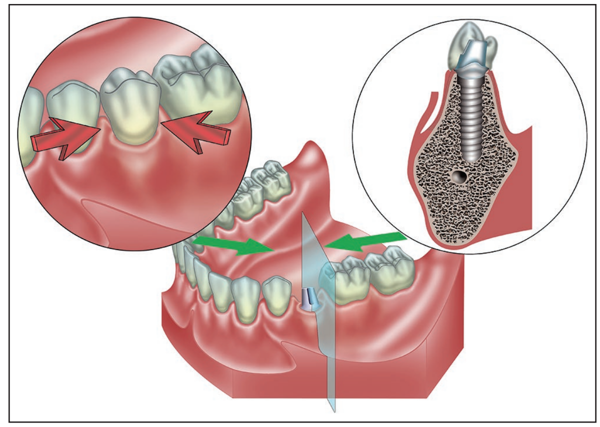
The need for prosthetic treatment can be identified and assessed based on indication classes. Accordingly, six prosthetically determinate indication classes are distinguished (A to F).

Single-tooth replacement (class A)

A single-tooth implant is indicated for loss of an anterior or posterior tooth when the adjacent teeth are caries free and not worth undergoing coronal restoration, provided jaw growth is completed and the alveolar process is intact (Fig 9-113). This also applies to several adjoining spaces that are to be treated by single-tooth implants. In the maxilla, up to four anterior teeth can be replaced with single-tooth implants; in the mandible, only two implants can be placed anteriorly because of the spatial conditions. A single implant is placed for each missing tooth. Implant size is determined by the amount of available bone, the size of the gap, and the size of the tooth being replaced.

The minimum distance from an implant to adjacent teeth is 1.5 mm, and where there are several missing teeth, the distance between implants is 3 mm; given a standard implant diameter of about

Fig 9-113 A class A single-tooth replacement is indicated if the adjacent teeth are not to undergo coronal restoration because they are free of caries and undamaged. For esthetic reasons, the abutments should be adapted to the soft tissue contour so that the course of the crown margin runs in the subgingival area. The abutment should be inclined so as to approach the inclination of the axis of the tooth that is being replaced.



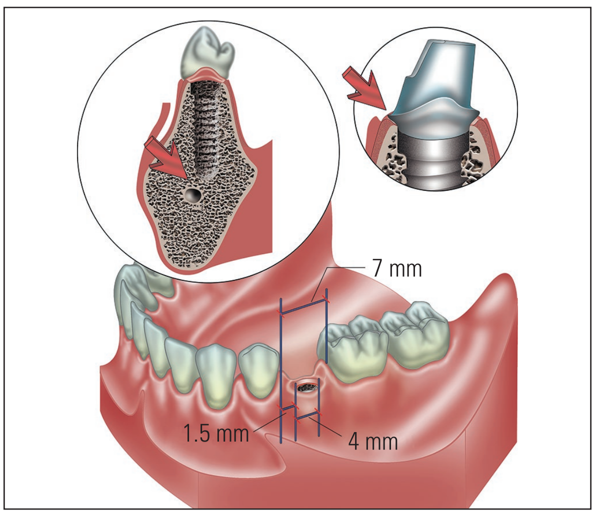


Fig 9-114 Given a standard implant diameter of 4 mm, the edentulous space must be at least 7 mm wide so that a distance of at least 1.5 mm from the neighboring teeth can be maintained. This is the only way to ensure that the hard and soft tissues can be nourished and an interdental papilla can be formed.

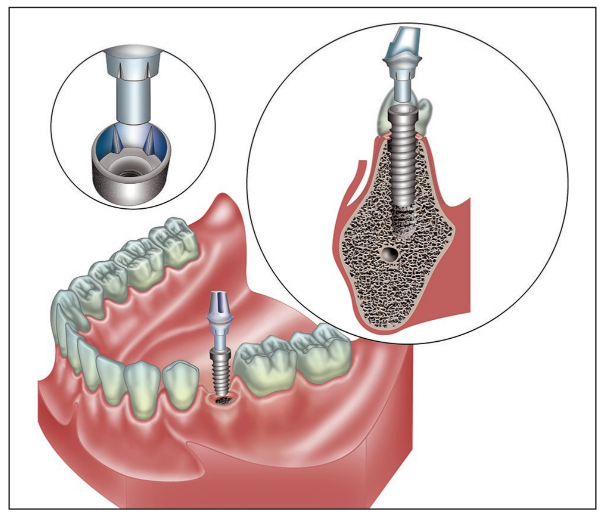


Fig 9-115 For single-tooth implants, antirotation protection between the implant body and the abutment is essential. Implant length and inclination of axis must be selected so that nerve and vessel channels and cavities are not injured.

4 mm, a gap must have a minimum mesiodistal width of 7 mm (Fig 9-114).

Abutments for single-tooth implants must have antirotation protection (Fig 9-115); they should be individualized and adapted to the course of the soft tissue so that the crown margin can be laid into the subgingival area. Metallic or zirconia ceramic abutments are available.

Restoration of free-end gaps (class B)

In this case, a distinction is made between unilateral (class B I) and bilateral (class B II) free-end situations as well as between purely implant-borne and tooth/implant-supported dentures. Free-end gaps can be restored with fixed or removable

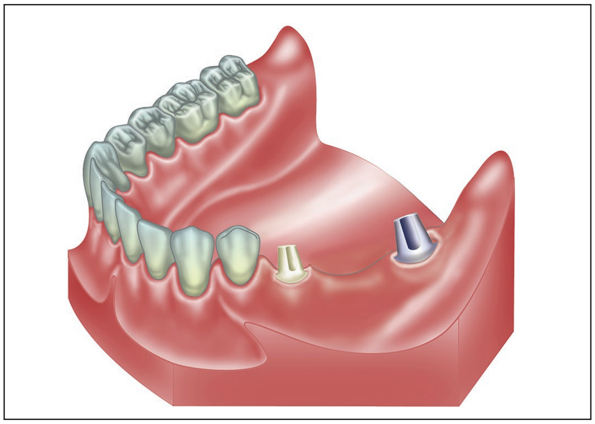


Fig 9-116 When determining the number of implants, the principle is that an implant may only bear a maximum of one premolar's width of additional load as well as the single-tooth load. If the free-end gap is to be closed by the second premolar distal, two implants are sufficient.

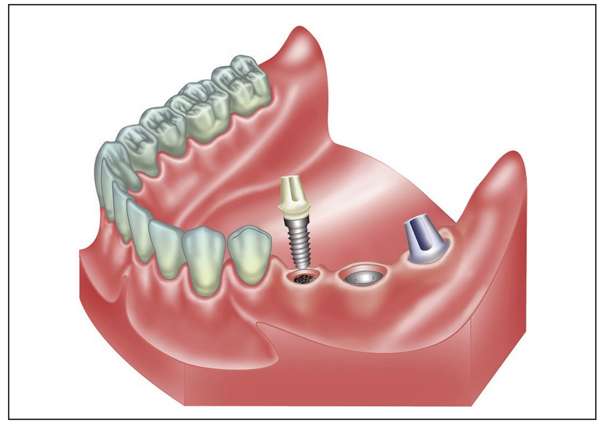


Fig 9-117 Provided the spatial conditions and the size of the bony bed permit, three implants can be placed for a posterior free-end gap for three replacement teeth.

partial dentures, which are supported solely on implants or via mixed support on teeth, mucosa, and implants. If the residual dentition is caries free, the use of implants avoids or reduces preparation of the teeth for a fixed restoration.

To determine the number of implants, guide values can be set that relate to the size of the free-end gap and the implant loading. According to these values, an implant should not bear more than one premolar's width of additional load as well as the single-tooth load (Fig 9-116). Accordingly, the following rules apply if any teeth are missing:

- If the second and third molars are missing, implant placement is not indicated.
- If all of the molars are missing, one or two implants are required.
- If the second premolar and all molars are missing, two or three implants are required (Figs 9-117 to 9-119).
- If the premolars and molars are all missing, three implants are required.

In the case of fixed dentures for free-end gaps, a distinction can be made between a purely implant-borne restoration and hybrid partial dentures (mixed support on implants and teeth). Because teeth are mobile within the width of the periodontal space, it was previously believed that mixed support on teeth and implants necessitated a compensatory element. However, long-term studies demonstrate comparable retentive strength for healthy periodontium and implants; that is, the survival rate of purely implant-supported partial dentures is roughly as high as for mixed support on implants and healthy abutment periodontium.

A fixed denture for free-end gaps can be created in the form of an extension partial denture; that is, free-end pontics can be fitted. This results in the same static conditions as with cantilever partial dentures that have purely periodontal support. The longer the free-end pontic, the greater the lever effects or torques acting on the partial denture: On free-end loading, the end abutment is pressed into its bony or periodontal bed, while the anterior abutment is lifted out. Therefore, a free-end pontic should not exceed one premolar's width.

The implants are placed so that they stand centrally under a replacement tooth in order to create a cleanable and esthetically satisfactory cervical situation (Figs 9-120 and 9-121). The implants should also stand on the midline of the alveolar ridge—not too far orally because they would crowd the tongue and not too far vestibularly because they would jeopardize esthetics.

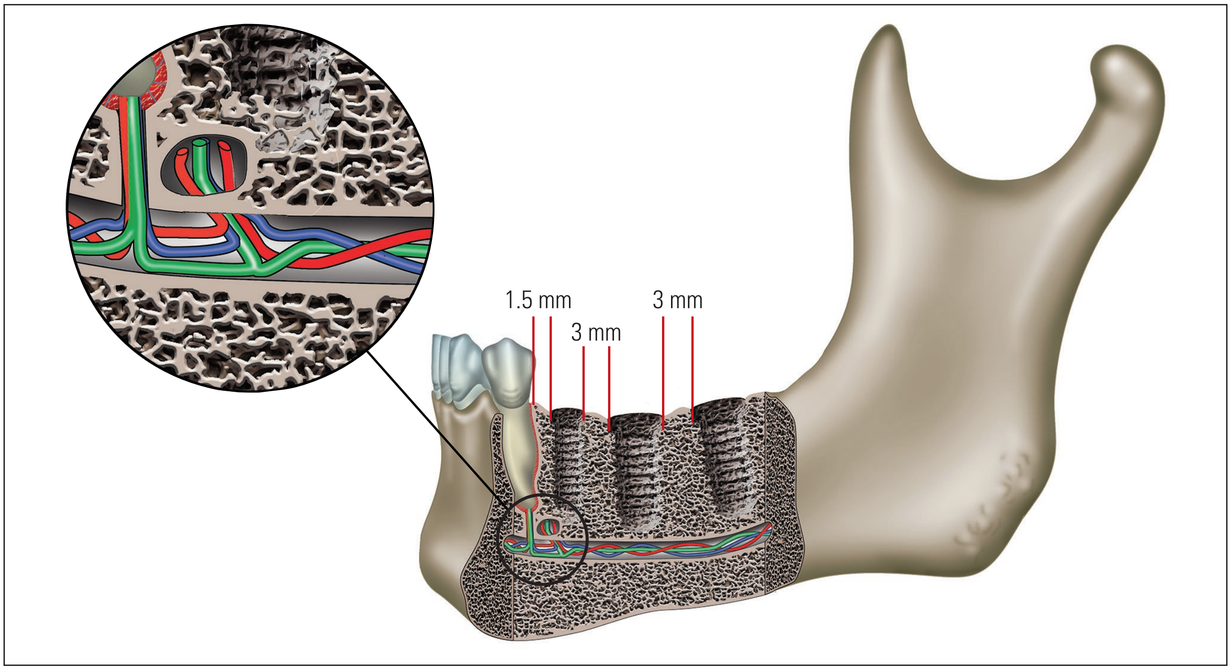
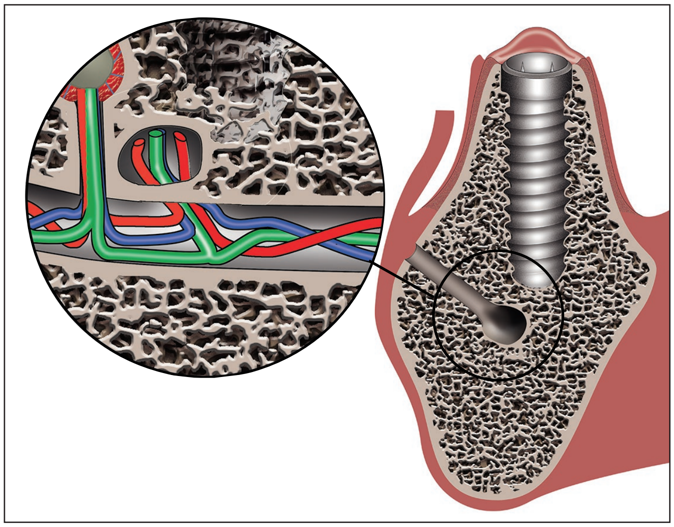


Fig 9-118 In the mandible, the length and inclination of the implants is determined by the mandibular canal and the mental foramen. Minimum distances must be maintained between the implants and from the residual teeth, just like the minimum distance from the nerve and vessel channels. The position and shape of the channels are recorded by CT and can be viewed on a monitor. This aids implant planning and the construction or fabrication of precise drill templates.

Fig 9-119 The spatial course of the nerves and vessels in the mandible can be depicted in a two-dimensional radiograph. A normal radiograph here would show the implant in the nerve and vessel pathway to the mental foramen. Safe implant positioning can only be achieved with computer-navigated implant planning.



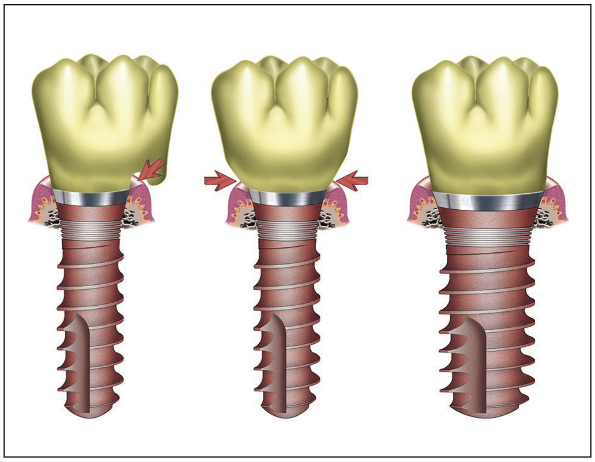


Fig 9-120 If the area of the alveolar ridge is already severely shrunken and the replacement crowns have to be lengthened cervically, the tooth contour and the abutment should be matched to each other. The implant body should be positioned centrally under the replacement tooth. To ensure that the dental crown does not have an extreme taper at the neck, a larger implant diameter must be chosen to achieve a favorable emergence profile.

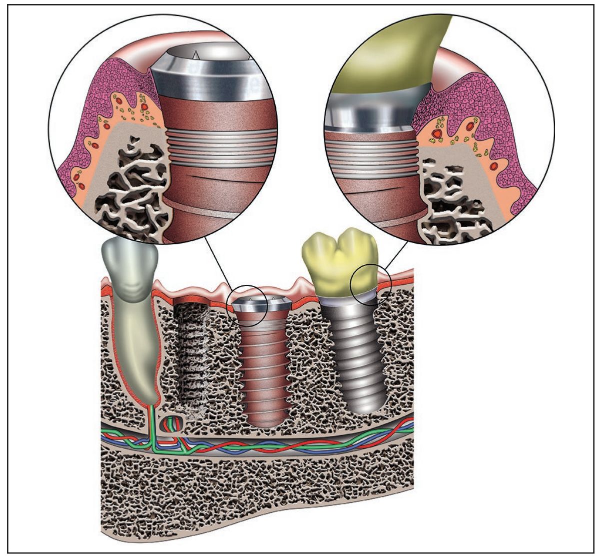


Fig 9-121 For good periodontal hygiene, it is important to ensure that the implant body lies subgingivally in the bone. The soft tissue should attach to the abutment and be congruent with the crown margin. The marginal gap between the abutment and the implant should lie away from the bony bed.

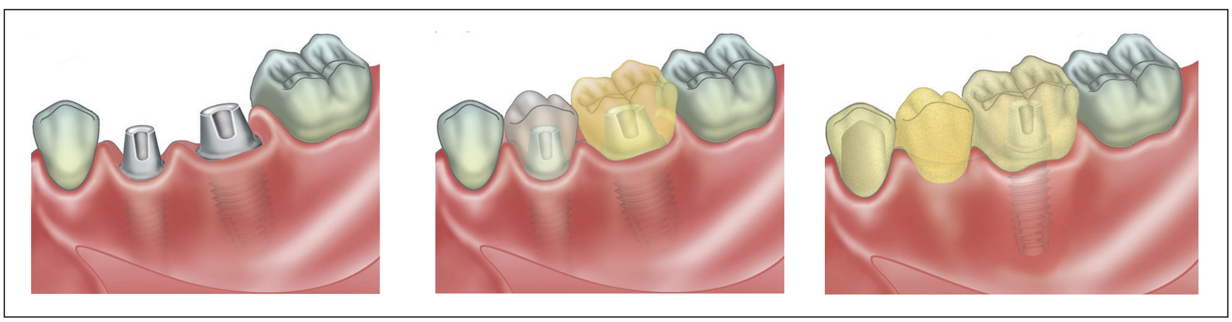


Fig 9-122 Closing edentulous gaps can be done with single-tooth implants or partial dentures, which can be purely implant borne or have mixed (osseous/periodontal) support. Fixed or removable dentures can be implemented. In severely reduced residual dentitions, hybrid dentures can be fabricated where the anchorage provided by the remaining teeth is supplemented by gap-supporting implants.

Restoration of edentulous gaps (class C)

The treatment of interdental edentulous gaps is not problematic. Both purely implant-borne and mixed-support dentures are possible. If two or more adjoining teeth are lost, single-tooth implants can be placed or implant-supported partial dentures constructed (Fig 9-122). Fixed partial dentures in large edentulous gaps can be supported with one or two implants at statically favorable positions. As previously mentioned, hybrid (combined) partial dentures presuppose intact periodontium of the abutment teeth and do not call for implants with cushioning elements.

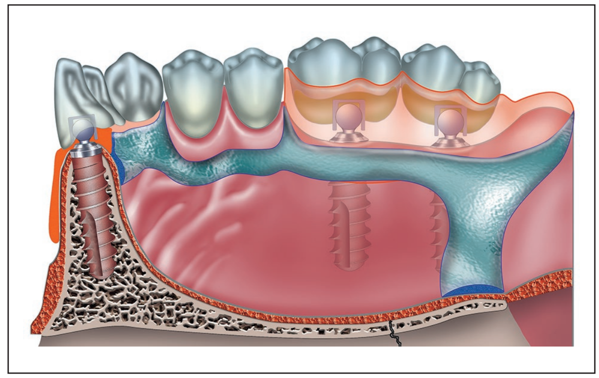


Fig 9-123 A severely reduced partially edentulous dentition can be remedied with a removable denture supported solely on implants if the remaining teeth can no longer be used as anchoring abutments.

Restoration of severely reduced residual dentitions (class D)

Based on the Kennedy classification, severely reduced residual dentitions are those with two or three teeth remaining. The static relationships of this residual dentition are extremely unfavorable. In terms of prosthetic restoration, purely implant-borne restorations (partial dentures) and mixed-support partial dentures or removable hybrid dentures may, in principle, be considered. Whereas at least eight abutments in a statically favorable position are necessary for a fixed restoration in the maxilla, only six abutments are needed for the mandible. In this situation, one abutment corresponds to one tooth or implant. In the case of removable prosthetics, six abutments (maxilla) and four abutments (mandible) are sufficient in statically favorable positions (Fig 9-123). A statically favorable position exists if a minimum of two abutments are available in each quadrant.

Removable partial dentures are generally used to restore severely reduced residual dentitions. They are anchored to the remaining teeth via clasping or hybrid prosthetic retentive elements, such as double crowns, attachments, or studs. The static relationships in the case of partial dentures show the correlation between the number of anchoring abutments and the life span of the restoration. Just a small number of implants at statically favorable positions can greatly increase wearing comfort, security of retention, and the life span of a partial denture. If the residual dentition is distributed in a statically favorable way, the number of necessary implants is reduced; a statically unfavorable residual dentition increases the number of required implants. Retention can be achieved with telescopic components, such as double crowns, attachments, or, in the case of implant abutments, ball retainer clasps. Fixed constructions can work as combined partial dentures, depending on the abutment distribution, where the remaining free-end situations can be restored with extension partial dentures.

Restoration of edentulous arches (class E)

The maxilla and mandible have differing bone quality and denture-bearing areas of different sizes, which is why they need to be viewed separately. Restoration of the edentulous maxilla (class E I) can be achieved with removable or fixed replacements. At least six implant abutments are necessary for removable constructions. The implants should be primarily or secondarily splinted in order to distribute transverse loads to a resistance block. For secondary splinting, double crowns are appropriate; primary splinting is achieved via bar attachments. Splinting structures call for framework reinforcement in removable dentures.

If a fixed partial denture is to be fabricated for an edentulous maxilla, at least eight implants should be planned for support. Even given minimal atrophy of the maxilla, it may be practical to design a partly removable partial denture, especially if mucosal parts need to be replaced for esthetic reasons and for unimpeded phonetics. If the maxilla is so severely atrophied that hard and soft tissues

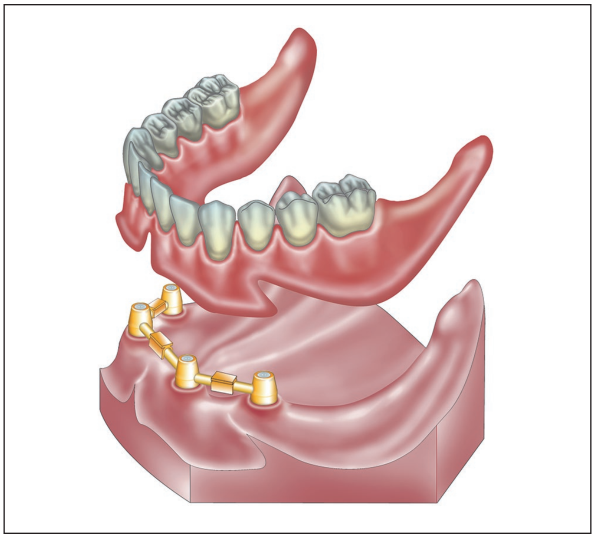


Fig 9-124 An edentulous mandible can be restored with an overdenture that is supported on four bar-connected implants. The dentition is not entirely replaced; usually the second molars are omitted to reduce tipping stresses.

have to be prosthetically replaced, removable overdentures should always be preferred to fixed partial dentures in terms of hygiene, phonetics, and esthetics.

Restoration of an edentulous mandible (class E II) can be achieved with overdentures (Fig 9-124) or with removable or fixed partial dentures. The classic case is the minimal implantology solution with two implants in the position of the canines. The implants can be primarily or secondarily splinted and crucially serve to anchor a mucosa-borne prosthesis. Because such a denture will sink distally on masticatory loading, the denture must not be secured via rigid anchoring elements but rather with ball-head connections, a resilient bar, or a resilient bar attachment.

If a removable implant-borne construction is envisaged, four to six implants are necessary; the distal extension should be kept short and should end at the first molar. The implants should be placed in the region of the mandibular lateral incisors and the first premolars. Six implants in statically favorable positions on a slightly atrophied jaw can also receive a purely implant-borne extension partial denture. In the case of severe atrophy, a removable overdenture is preferable because of esthetics and functional hygiene problems.

Restoration of defects (class F)

Implants are also used in defect prosthodontics. Here a distinction is made between intraoral and extraoral defect restoration. Intraoral defect restoration becomes necessary after trauma-related, tumor-induced, or congenital (inborn) defects and can be achieved with fixed or removable solutions. Extraoral defect restoration serves to anchor epitheses, which are usually designed to be removable via studs, bars, or magnets.

Design Guidelines for Superstructures

Implant-supported dentures should be fabricated just like removable or fixed prosthodontics. The demands in terms of function, phonetics, and esthetics are the same as those that apply to conventional dentures. Special requirements should be laid down with regard to the accuracy of fit of the superstructure on the abutments (tension-free seating), the bonding system between veneer material and framework, the accessibility of the denture to hygiene measures, occlusal abrasion resistance, and stability under permanent loading.

Careful implant planning with diagnostic wax-up and radiodiagnostics becomes necessary because the implant position and implant diameter can influence the positioning of the replacement teeth, esthetic impression, and functioning of the superstructure. Both implant position and implant axis should be established during this diagnostic planning process. If there is a major discrepancy between implant position and replacement tooth, a removable overdenture can be used to conceal the implant and support the lips or cheeks.

Angled or customized abutments cannot correct an incorrect implant position: however, angled abutments compensate for an adverse implant axis, thereby improving spatial relationships with respect to the replacement teeth and also ensuring the bonding of several implants and natural abutment teeth.

The dimensions of frameworks for the superstructure are designed to ensure adequate stability in order to tolerate permanent loading and facilitate esthetic veneering or tooth fixation without having to overcontour the veneer. Generally speaking, both the materials (nonprecious or precious metal alloys) and the dimensional measurements for the fixed or removable periodontally supported denture can be carried over to the design of superstructures. Bonding technologies, such as cementing attachment parts to an individually cast framework, can also be adopted.

One-piece casting for fabricating frameworks offers adequate processing safety and physical material qualities. Computer-aided design/computer-assisted manufacturing (CAD/CAM) techniques, in which metal frameworks are milled out of a single piece, provide better accuracy of fit than cast frameworks but require high metal consumption. As of 2012, additive methods, in which the framework material is applied step by step, are not yet sufficiently developed for metallic and ceramic materials.

Severe ridge resorption in the area of the missing teeth makes it necessary to replace gingiva and bone tissue. A decision needs to be made as to whether a fixed partial denture or a removable (over)denture should be fabricated. The accessibility of a removable prosthesis to hygiene measures may have to be set against the needs of the patient, especially when a short upper lip would make the marginal contour of a fixed partial denture visible relative to the ridge contour. The esthetic requirements can be fulfilled more effectively by a hybrid prosthesis that reproduces the gingival contour by means of a denture base.

Whether primary or secondary splinting is chosen is a design decision, because removable partial dentures or hybrid prostheses can splint the implants together. Primary splinting can be planned that involves bars on which the restoration rests, or secondary splinting can be achieved via a rigid denture or partial denture framework. Secondary splinting can only be implemented with rigid anchoring components, namely with double crowns or telescopic parallel fittings; stud attachments or magnetic connections do not offer rigid splinting. Fixed superstructures that are rigidly cemented or screwed onto the implants always provide a primary splinting function. If no splinting is to be carried out, one implant must be inserted for each tooth being replaced.

Mixed-support removable hybrid dentures rest on implants and the mucosa. An overdenture supported on at least four implants can be combined with resilient anchoring components, enabling the denture to move against the mucosa. An overdenture anchored with two implants can be retained via a resilient bar or studs or magnets, between which one axis of rotation runs; the denture rotates around this axis against the mucosa.

Summary

Figure 9-125 outlines the clinical and laboratory procedures for dental implant placement.

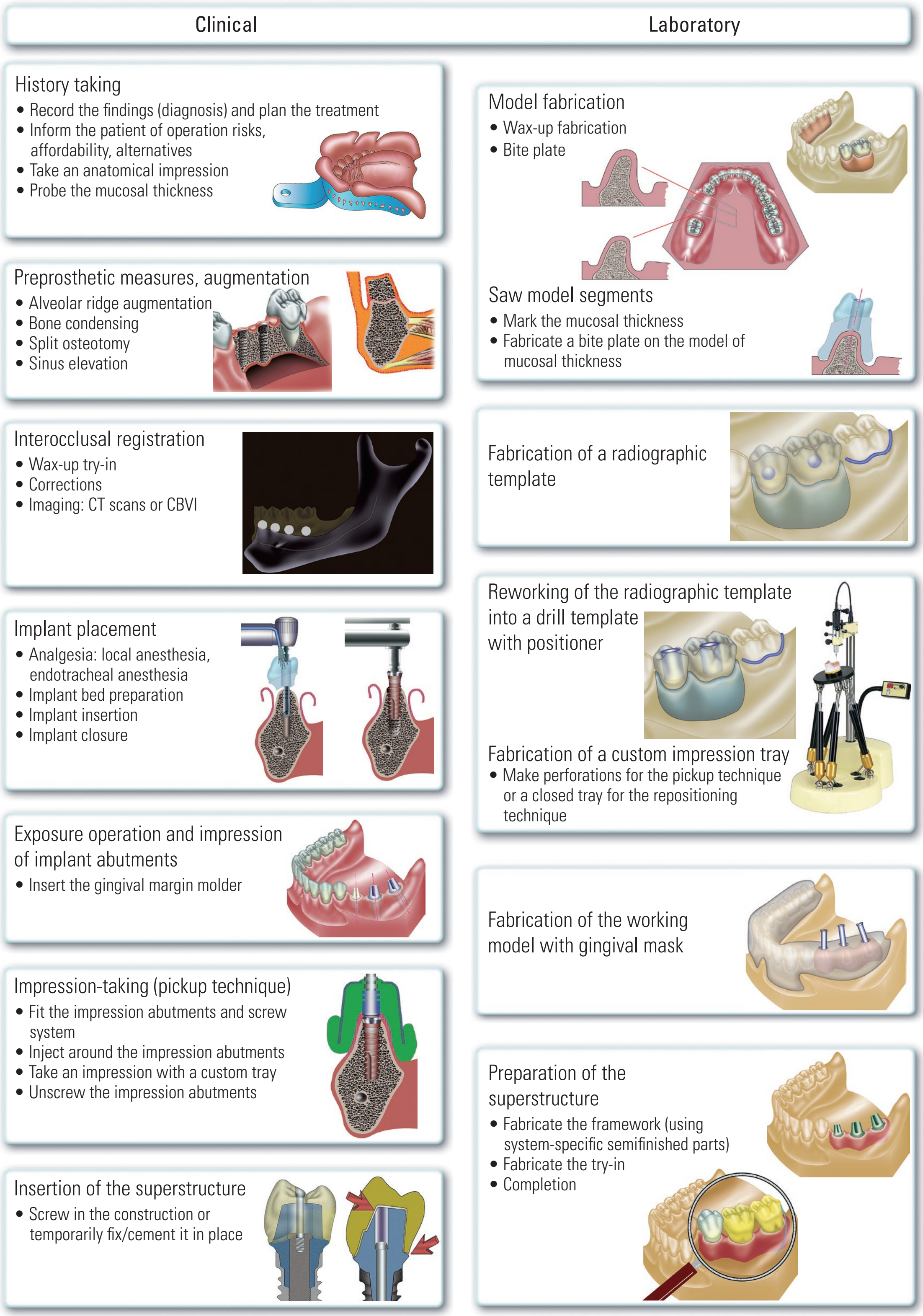


Fig 9-125 Procedures for dental implant placement.

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