Microsurgery in Endodontics

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Syngcuk Kim, DDS, PhD, MD(Hon)
Samuel Kratchman, DMD

Associate Editors:

Bekir Karabucak, DMD, MS
Meetu Kohli, DMD
Frank Setzer, DMD, MS, PhD

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*This book is dedicated to our **"PENN ENDO FAMILY"**; those who were educated at Penn. Without their dedication and practice in their schools and offices this field would not be what it is today!*

Contents

Contributors

Fouad Al-Maki, DDS
Endodontic Resident
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

SeungHo Baek, DDS, MSD, PhD
Professor/Chairman Emeritus
Department of Conservative Dentistry
School of Dentistry
Seoul National University, South Korea

Georges Bandelac, DDS, MS
Diplomat American Board Periodontology

Ian Chen, DDS, MS
Lecturer School of Dentistry
National Yang-Ming University
Adjunct Clinical Instructor
Department of Dentistry
National Taiwan University Hospital
Private Practice: Taipei, Taiwan

Ingrida Dapkute, DMD, MS
Private Practice: Landsdale, PA

Spyros Floratos, DMD
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Athens, Greece

Garrett Guess, DDS
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Diplomate American Board of Endodontics
Private Practice: San Diego, California

Aleksander Iofin, DMD
Clinical Assistant Professor of Endodontics
Department of Endodontics
College of Dental Medicine
Columbia University
Adjunct Clinical Assistant Professor of Endodontics
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: New York, NY

Bekir Karabucak, DMD, MS
Chair and Associate Professor of Endodontics
Director, Postdoctoral Endodontics Program
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

Raed Kasem, DDS, MS
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Clearwater, Trinity, Tampa, FL

Euiseong Kim, DDS, MSD, PhD
Professor and Chairman
Vice Dean for Graduate Affairs
Director, Oral Science Research Institute
Department of Conservative Dentistry
College of Dentistry
Yonsei University, Korea

Syngcuk Kim, DDS, PhD, MD(Hon)
Louis I. Grossman Professor and Chairman
Department of Endodontics
Associate Dean of Global Affairs
Associate Dean for Advanced Dental Education
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

Meetu Kohli, DMD
Clinical Associate Professor of Endodontics
Director Continuing Education and International Program
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

Samuel Kratchman, DMD
Clinical Associate Professor of Endodontics
Director of Microsurgery
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Exton, West Chester, Paoli, PA

David Li, DMD
Clinical Instructor
Section of Endodontics
University of California, Los Angeles
Private Practice limited to Endodontics
Greater Los Angeles area, CA

Francesco Maggiore, DDS
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Aschaffenburg, Germany

Paula Mendez-Montalvo, DDS
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Houston, TX

Siva Rethnam-Haug, BDS, Dr Odont
Associate Professor and Clinical Director
Section for Endodontics
Department of Clinical Dentistry
Faculty of Medicine and Dentistry
University of Bergen, Norway

Chafic Safi, DMD, MSc, FRCD(c)
Adjunct Assistant Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA
Private Practice: Montreal, QC, Canada

Frank Setzer, DMD, MS, PhD
Assistant Professor of Endodontics
Director, Predoctoral Endodontics
Endodontic Clinic Director
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

Sujung Shin DDS, MS, PhD
Associate Professor
Department of Conservative Dentistry
College of Dentistry
Yonsei University, South Korea

Jorge Vera, DDS
Department of Endodontics
University of Tlaxcala
Tlaxcala, Mexico
Private Practice: Puebla, Mexico

Preface

In January 1992, when I came to the Department of Endodontics at the University of Pennsylvania as a new chairman, there were two goals: incorporation of the microscope in endodontic treatment and development of microsurgery in endodontics. Twenty-five years later we can say we have accomplished our goals.

Apical surgery or endodontic microsurgery is no longer the domain of oral surgeons. New microsurgical techniques and instruments have been developed along with new concepts, based on scientific and clinical research results by endodontists. We now believe endodontic microsurgery is *our* domain.

The differences between traditional endodontic surgery and microendodontic surgery are vast and profound. The surgical concept, instruments, and materials are all different and there is little similarity between the old and the new techniques. The only similarity is the purpose – to save teeth. The old, traditional way of using a low-speed microhandpiece with a round bur to prepare the root end and fill with amalgam are long gone. We now use ultrasonic tips for root end preparations under the microscope and Bioceramic materials for root end fillings. These new advancements have been unequivocally proven by basic and clinical research. The main purpose of this book is to introduce these advancements in endodontic microsurgery.

Endodontic surgery, while generally recognized as an important treatment modality within the endodontic specialty, is not sufficiently taught in the endodontic postgraduate programs, nor covered adequately in textbooks. In fact, most undergraduate dental students in this country do not receive endodontic surgery experience (such as chair-side assisting) or even an introduction during their dental school years. This is because endodontic surgery (apicoectomy) was taught by oral surgeons, who gave little importance to this procedure. In this age of implants, where extraction and implant placement are so prevalent, apical surgery receives even less attention from oral surgeons. Many dentists simply do not know what it is; not to mention its benefits. However, patients make the difference. They are the ones who want to save their natural teeth. Thus microsurgery in endodontics is here to save the natural dentition.

The current book, *Microsurgery in Endodontics*, is an accumulation of experiences and knowledge of many endodontists gained by practicing microsurgery over the past two decades. As we wrote the chapters, however, the techniques and technology kept evolving and we kept rewriting the chapters to incorporate the newest technologies, such as CBCT integration for treatment planning microsurgery.

In writing this book we followed the way we teach at our institution, the University of Pennsylvania, and the way we practice in our private practices: New York, Philadelphia, and around the world. We made an effort to organize the materials so that the needs in a real clinical situation took precedence over other considerations.

We sincerely hope that our readers benefit from this collection of our experiences. I wish to express my special thanks to Mrs Janice Kelly in the Department of Endodontics at Penn, to Mrs Sophie O'Rourke and Ms Mary Marmol in my office in NYC for over two decades of devotion and hard work, and to Ms Jee Hee Hong for her dedicated support.

Syngcuk Kim, DDS, PhD, MD(Hon)
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

When Dr Kim asked me to co-author this textbook on microsurgery approximately 5 years ago, I was honored and excited. I had no idea what was in store for us, especially trying to coordinate so many additional authors, from around the US and globally. I am proud of the result, because it represents what we have been teaching our residents and colleagues for many years, and in fact this book belongs to our entire department at Penn. I need to thank all the authors as well as my residents over the past 25 years at the University of Pennsylvania. Without them this textbook would never have happened, and I must admit that I have learned as much over the years from my students as hopefully I have been able to teach them.

Dr Kim has been my mentor, colleague, father figure, and confidante for the past 25 years. He has pushed me to always strive for greater things and to never be satisfied with the status quo. I thank Dr Kim for where my career has taken me and for his guidance throughout the process. I also wish to thank my wife, Amy, and my two children, Devon and Zac, for "putting up" with me over these past 5 years and for sacrificing quality "faja" time when there were deadlines to be met for the textbook.

On a sad and tragic note, my dedicated assistant for the past 22 years, Kimberly McDowell, passed away on April 9, 2017, after a 10 month battle with colon cancer. She was only 47 years old. Every single surgery I did for the past 22 years was with Kimberly, and without her assistance, the cases I have presented in this textbook would not have been possible.

Samuel Kratchman, DMD
Department of Endodontics
School of Dental Medicine
University of Pennsylvania
Philadelphia, PA, USA

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1

The Dental Operating Microscope

Frank Setzer

KEY CONCEPTS

- Parts and functions of the dental operating microscope.
- Advancements in dental microscopy.
- Applications of the dental operating microscope in endodontic microsurgery.
- Individual adaptation of the dental operating microscope (parfocaling).

Endodontic therapy is performed in a naturally dark and confined working space. Operating microscopes were introduced into Endodontics in the early 1990s, and then into endodontic specialty programs in the United States. Since then, operating microscopes have become widely accepted by endodontists and are also increasingly being used by other specialists. The American Association of Endodontists made teaching the operating microscope a required standard for postgraduate endodontic education in 1998. The standard now requires the instruction in using magnification devices "beyond the scope of head worn magnification devices", at an in-depth level, which is the highest of the levels of knowledge described by CODA.

Higher magnification was demonstrated to significantly increase the successful outcome of endodontic surgery. Both the operating microscope and endoscope provide appropriate magnification and illumination that is required to perform surgical and non-surgical endodontic procedures with high success rates. Moreover, from an ergonomic perspective, a microscope can allow the clinician to maintain an upright position, which can help avoid long-term back and neck problems that may range from general discomfort to disability (see Chapter 22).

1.1 Benefits of the Operating Microscope

Loupes and microscopes offer different ranges of magnification (Figure 1.1). An increase in magnification decreases the focal depth. Wearing loupes, especially at magnifications higher than ×4, requires the practitioner to stay in a narrow range from the object to stay in focus. In contrast, even at high magnifications, a microscope remains stable and the practitioner can work in an upright and ergonomically non-stressful position. Moreover, microscope use reduces strain on eye muscles, fatigue, and soreness compared to loupes. Through a microscope the light reaching the left and right eyes appears to be essentially parallel, achieving the effect of far distance observation (Figure 1.2) and avoiding short accommodation stress as with the naked eye. Binoculars of loupes and thus the viewing direction are convergent, resulting in similar eye strain. In addition, microscopes provide imaging virtually free of shadows, allowing excellent image quality for clinical operations and documentation.

1.2 Key Features of Operating Microscopes

Basic components of an operating microscope are binoculars, microscope body with magnification and fine focus adjustments, and a light source (Figure 1.3). Depending on usage and preferences of the practitioner, a microscope can be further configured to individual specifications. For non-surgical and surgical endodontics, different magnification ranges are required (Table 1.1). In addition, surgical procedures will require more angulations to view resected root

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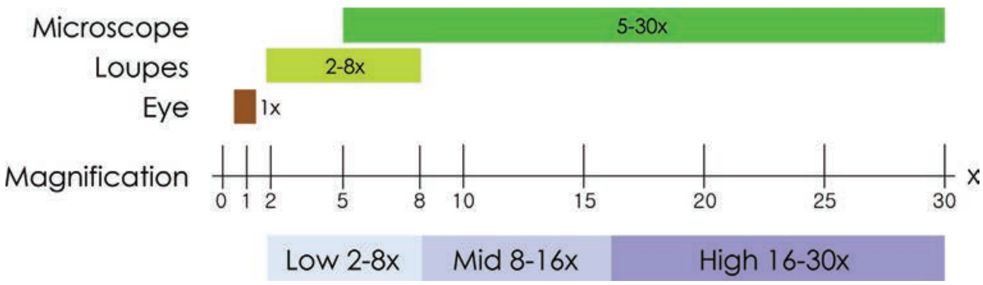


Figure 1.1 Comparison of magnification ranges: loupes versus microscopes.

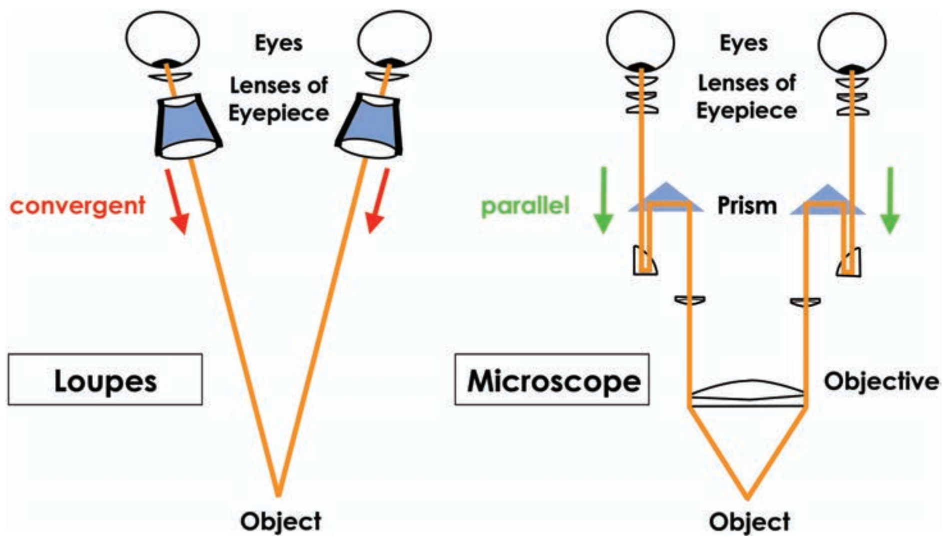


Figure 1.2 Comparison of ocular angles and viewing directions of loupes and microscope.

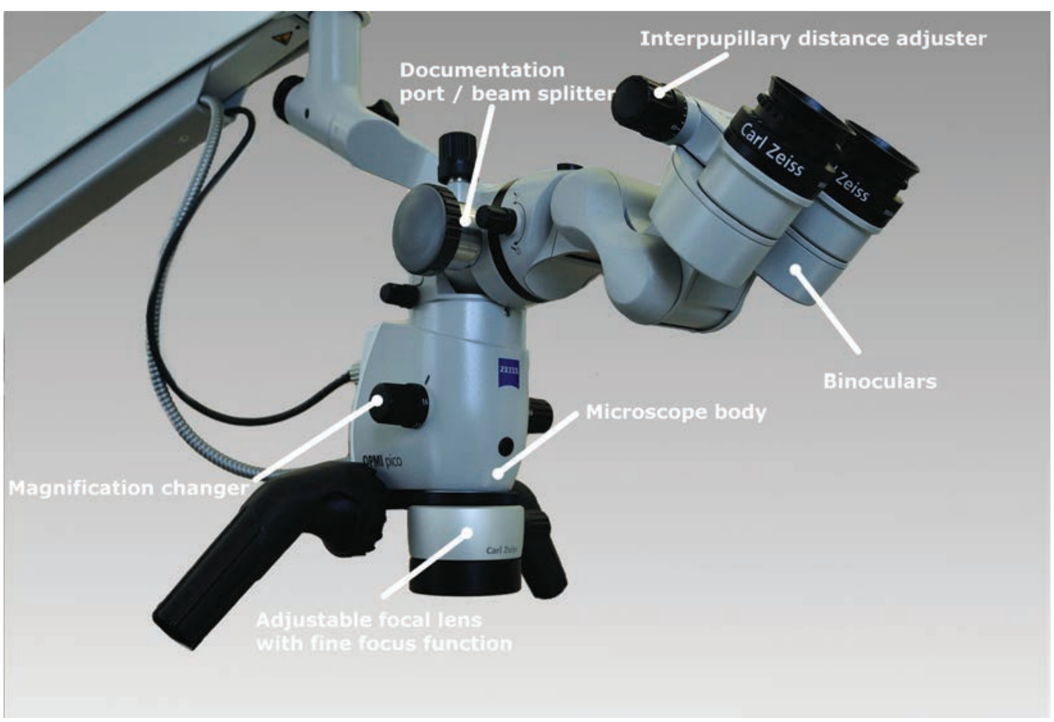


Figure 1.3 Key microscope features (Penn Dental Endodontic Clinic).

Table 1.1 Recommended magnification ranges for different stages of non-surgical and surgical endodontic treatment.

Non-surgical Endodontics	Surgical Endodontics
Low Magnification ~ ×5–8×	
–	Orientation Inspection of surgical site Initial osteotomy Ultrasonic tip alignment Suturing (6.0+) Suture removal
Mid Magnification ~ ×8–×16	
Access Orifice identification Fracture identification Obturation	Hemostasis Tissue removal Root tip identification Root tip resection Root surface inspection Root end preparation Root end filling Root amputation
High Magnification ~ ×16–×30	
Orifice identification Fracture identification Calcified canal location Identification of fine anatomical details Documentation	Root surface inspection Root end preparation inspection Root end filling inspection Identification of fine anatomical details Documentation

surfaces and other anatomical details. At a minimum, a microscope being used for surgical endodontics should be equipped with 180°-tiltable binoculars to address the angulation requirements and an eyepiece with a reticle. A reticle is a set of fine lines that provide proper centering on the object in focus and allows for individual calibration (parfocaling) of the microscope, most commonly in the shape of cross-hairs or concentric rings.

1.3 Customizing a Microscope

Microscopes are available as floor-standing, wall- or ceiling-mounted units, depending on personal preferences and possible locations in the operatory. Modern microscope innovations allow for upgrades or modifications of standard microscopes. For example, in the past, a microscope was delivered with a fixed focal distance, typically 200 mm, 250 mm, or 300 mm, depending on the height of the practitioner and his or her most comfortable and appropriate working position. However, top of the line microscopes today include a variable focal distance that can be adjusted to practitioner and patient, often in conjunction with electrical zoom and fine focus options that allow smooth and step-less adjustments of both magnification and focus. Recently, mechanical focal distance adjusters were introduced to upgrade microscopes with a fixed focal distance (Figure 1.4).

Optional ergonomic upgrades allow a left/right swivel of the main body of the microscope. This will allow the practitioner to tilt the microscope in a vertical angulation without changing the horizontal level of the eyepieces. In particular, for endodontic surgery, this is a valuable feature to observe root tips and resected root surfaces in the posterior arches. Other major potential upgrades include extendable (foldable) binoculars for better visualization and ergonomics (Figure 1.3), magnetic arrest functions (clutch) for increased stability, as well as different light sources and documentation options, which are described in greater detail in Figure 1.5).

1.3.1 Light Source

Halogen lighting was the first dental microscope light source introduced. It is still available for standard applications and basic microscopes and displays a yellowish hue. Xenon and the more recent LED light

Figure 1.4 Variable focal distance adjuster (ZEISS Varioskop®; Penn Dental Endodontic Clinic).

sources were developed to deploy better illumination to the operating field. All three light sources differ from each other in light intensity, peak wavelengths, color temperature, heat emission, and lifetime.

Xenon light sources appear almost as natural as daylight while providing the highest light intensity. This ensures the best illumination for fine anatomical details and allows shorter documentation exposure times, which will provide sharper images.

LED light sources are similar to xenon in color temperature and appear close to natural daylight. In comparison to xenon and halogen the heat emission from LED radiates from the back of the light source, resulting in a greatly reduced temperature surrounding the microscope. Table 1.2 provides an overview of the light spectra, appearance, color temperatures, intensities, and average lifetimes of the three light sources. Most microscopes provide additional orange

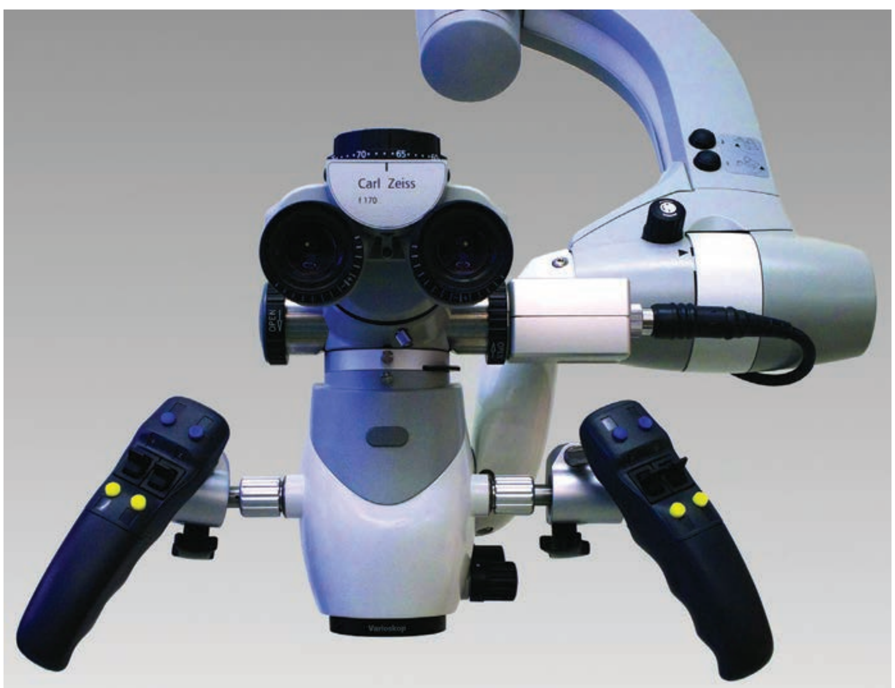


Figure 1.5 Top of the line microscope with electrical zoom, fine focus, and magnetic arrest functions, 3-chip HD video camera (TRIO 610) attached to right documentation port (ZEISS PROergo; Penn Dental Endodontic Clinic, Surgical Suite).

Table 1.2 Comparison of microscope light sources.

	Xenon	LED	Halogen
Light spectrum range and peak(s)	Homogenous spectrum from 400 to 700 nm	Green part of emission spectrum under represented Peaks: 450 nm and 550 nm	Peak: 600–700 nm
Appearance	Like daylight	Comparable to xenon	Yellowish hue
Color temperature	5500 K	5700 K	3300 K
Intensity at 250 mm focal distance	200 000 lux	85 000 lux	85 000 lux
Average lifetime	500 h	70 000 h	50 h

and green filters for restorative work or surgical procedures with increased blood flow. Recent developments include depolarization and daylight UV filters, as well as fluorescence for caries detection.

1.3.2 Documentation

Good documentation is necessary for legal purposes, referral reports, publications, and/or presentations. Still photography can be provided by using a digital SLR camera connected to the beam splitter of the microscope. However, new generation digital mirrorless cameras have demonstrated advantages compared to DSLRs. A beam splitter will divert approximately 20% of the available light intensity to still photography or a video camera. Various options are available for the acquisition of the images, both commercially or customized. For video documentation, options include internal or external cameras of different quality and resolutions. Simpler systems include integrated one-chip cameras that provide simple live streaming and/or recording capabilities. Other modern one-chip options include microchips that allow smart recording to an external, shared network, as well as direct recording to local mass storage devices. Video options are available that record a continuous loop of 30 seconds, providing the option of actually starting a recording in the immediate past, enabling incidences to be documented even after they took place. Current commercial recording qualities range from HD-ready 720p to full HD 1080p resolutions. Full HD 1080p recording combined with three chip cameras are available for the highest quality documentation for publication and presentation purposes.

The latest technology leap included chair-side three-dimensional observation, for both practitioner and co-observers. This technology has so far largely been used for conference settings, using either a shutter or polarized glasses technique, to live-stream surgical procedures. First generation consumer products have been made available recently.

1.3.3 Individual Microscope Adjustment (Parfocaling)

Microscopes are designed to be adjusted to different eye sights to guarantee perfect vision and to avoid fatigue. It is important to understand that depending on the fatigue state of the eyes, e.g., after an entire day of work, parfocaling may lead to slightly different results than when the eyes are rested. It may be necessary to readjust over the course of an intense work period.

First, the practitioner must determine the dominant or leading eye, which predominately adjusts the vision. Several techniques exist, two examples of which are given below.

1. Superimposition technique. The practitioner chooses a distant object, e.g., a street sign. Simultaneously, a near object, e.g., a pencil held with an extended arm, is superimposed over this distant object. Then one eye is closed, with the other one kept open. If the non-dominant eye is closed and the dominant eye is open, the near object will stay centered on the distant object, but it will move sideways if the non-dominant eye is open and the dominant eye is closed.
2. Paper technique. Focusing on a hole in a sheet of paper with both eyes open and then very slowly moving it towards the eyes will result with the hole ending at the dominant eye.

If glasses are worn, the eyecups must be screwed in completely. If an operator wears corrective glasses during the procedures, the parfocaling process must be carried out with the glasses. The eyepiece with the reticle has to be set to the dominant side. Both diopter settings should be moved to the extreme positive setting (Figure 1.6). The microscope should be set to the lowest magnification. This will ease the parfocaling

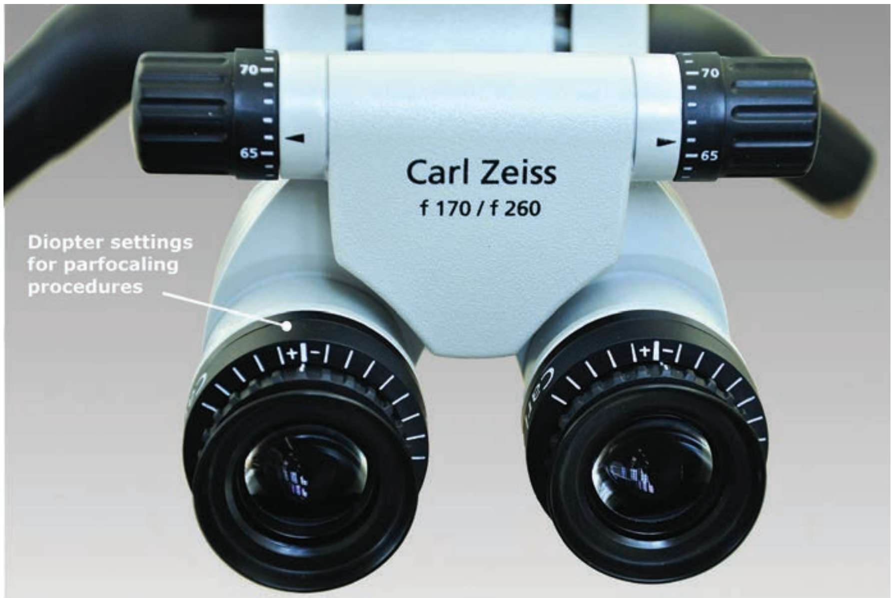


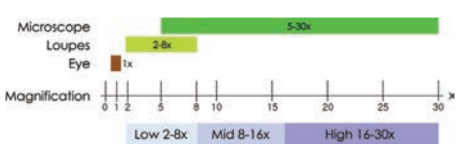
Figure 1.6 Binoculars with diopters for parfocaling procedure (Penn Dental Endodontic Clinic).

procedure for inexperienced practitioners. Individuals with advanced microscope training may adjust the diopter settings at the highest magnification levels.

Starting with the dominant eye, the practitioner needs to find the diopter setting where the reticle is clearly focused. During this procedure, the non-dominant eye remains closed. Next, a flat, non-reflecting object, e.g., a business card, is placed under the microscope. Without changing the diopter setting or any of the focusing knobs or buttons, the microscope should be placed at the appropriate (vertical) focal distance to see a focused image only through the dominant eyepiece. The magnification is then changed to the highest setting. To adjust for changes in focal distance, minor adjustments with the fine focus function can be made. Neither the vertical distance nor the diopter settings are changed at this stage. The microscope is now calibrated to the dominant eye throughout the entire magnification range.

The non-dominant side will then be adjusted to the dominant side. Looking through the non-dominant

Table 1.3 Quick-step guide to parfocaling a microscope.

Step	Magnification Setting	Technique
Determine dominant eye	–	Use near object over distant object superimposition technique.
Adjust dominant eye	–	Place eyepiece with reticule into binoculars on dominant eye side.
	–	Adjust diopter settings on eyepiece until all reticle lines are clearly focused.
	Low	Focus on object through the microscope after initial adjustment of focal distance.
	High	Use fine tuning to perfect focus.
Adjust non-dominant eye	High	Adjust diopter settings on eyepiece until object is focused.
	Variable	Adjust interpupillary distance settings until a single image is clearly visible.

eyepiece only, the diopter settings are turned slowly while looking at the object under the microscope. When the object is focused, the non-dominant side is calibrated. No changes to the dominant side must be made.

Last is the interpupillary distance. The adjustment knob for the interpupillary distance is set to the lowest setting and then slowly turned until one perfectly clear single picture with three-dimensional qualities is visible through the microscope. Table 1.3 is a quick guide of the individual parfocaling steps. Please note that most individual's dominant eye is the right eye and that therefore video outputs are frequently attached to the right eyepiece. This means that the video feed then matches exactly the right eyepiece and provides a two-dimensional monitor image from the dominant eye.

Suggested Readings

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2

Microsurgical Instruments

SeungHo Baek and Syngcuk Kim

KEY CONCEPTS

- Some microsurgical instruments are miniaturized versions of standard surgical instruments, but many more were designed exclusively for microsurgery.
- A 15C blade works well for most tasks, but a microblade is useful when the interproximal spaces are very tight.
- Micromirrors are key instruments in endodontic surgery for inspection of resected surfaces.
- KimTrac retractors, which have a thinner blade than conventional retractors and a wider plastic wing for retracting the gingiva and lips, were specifically designed for endodontic microsurgery.
- A 45 degree surgical handpiece with a Lindemann bone cutting bur is the instrument of choice for osteotomies.
- KiS tips (Obtura/Spartan Co.) and JEtips (B/L Biotech Co.) are a specially designed as microsurgical ultrasonic tips for microsurgery.
- Use of the Stropko Irrigator insures drying of retroprepared cavities.
- MTA block, which is made by cutting grooves into a plastic block, is most often used for the delivery of MTA and Bioceramic putty.
- Micropluggers with a 0.25 mm, 0.50 mm, and 0.75 mm diameter tip and different angles are necessary for root end filling procedures.
- 5-0 or 6-0 monofilament sutures have replaced braided 4-0 silk sutures as the suture material of choice.

The operating microscope has been used in medicine for more than half of a century. Several dentists tried to use the operating microscope around 1960, around the same time it was being used in neurosurgery and ophthalmological surgery. It was not used in endodontic surgery until the late 1980s. However, with hardly any microinstruments being available, endodontic surgery under high magnification was nearly impossible. Traditional surgical instruments are simply too large for working at magnifications of ×10 to ×25. Some microsurgical instruments are miniaturized versions of traditional surgical instruments, but many more are specifically designed for the precision needs of endodontic microsurgery, including ultrasonic tips, the Stropko irrigator/drier, and an array of pluggers, carriers for root end filling material, and micromirrors.

Two main microsurgical instrument kits from Obtura/Spartan and B&L Biotech are shown in Figure 2.1.

2.1 Examination Instruments

The examination instruments include the dental mirror, periodontal probe, endodontic explorer, and microexplorer. The dental mirror, periodontal probe, and endodontic explorer are standard instruments in endodontic practice. Only the microexplorer is specifically designed for microsurgery. It has a 2-mm tip bent at 90 degrees on one end and 130 degrees on the other. The short tip makes it particularly easy to maneuver inside the small boney crypt. This instrument is extremely useful for locating an area of leakage on the resected root surface and for distinguishing a fracture line or canal from an insignificant craze line. A tip of a microexplorer points to the unfilled canal space on a resected root surface and is shown in Figure 2.2.

2.2 Incision and Elevation Instrument

Instruments used for incision and elevation include a 15C blade and handle and soft tissue periosteal

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Figure 2.1 Endodontic microsurgical instrument setup: (a) KiS set from Obtura/Spartan (Fenton, MO) (Image courtesy of Obtura Spartan, Algonquin, IL © 2017); (b) Jet Microsurgical kit from B&L Biotech Co. (Fairfax, VA). The KiS set has titanium handles while the Jet set are grouped as follows: silver color (examination instruments); yellow (elevation instruments); blue (curettage instruments); green (retrofilling carrier and plugging instruments). (Courtesy of B&L BioTech.)

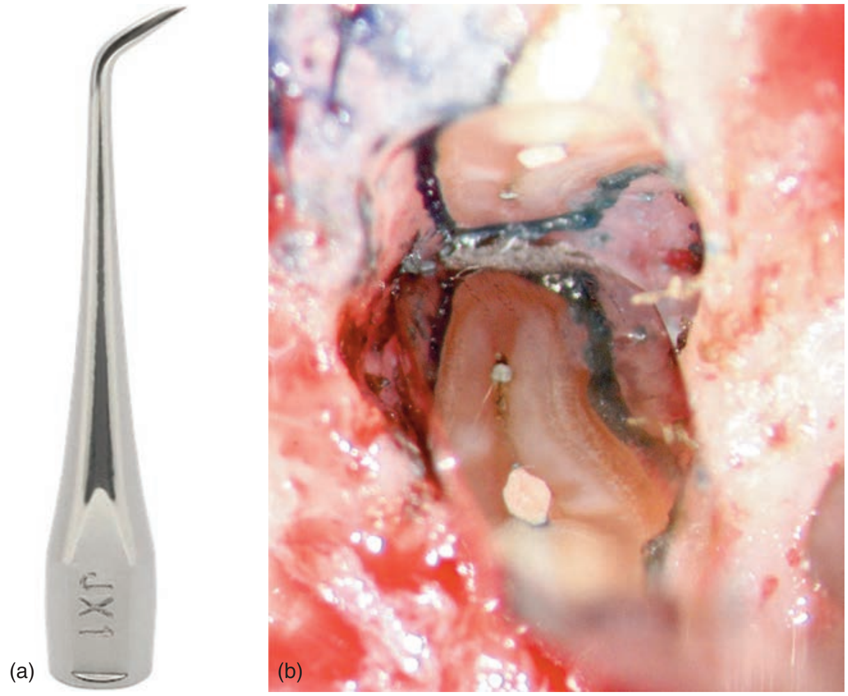


Figure 2.2 The tip of the microexplorer examination instruments, which can be used to search for a leak in a root end filling or to distinguish a canal or craze line from a microfracture line, and to point to the origin of a leak for explanation and documentation purposes (×16).

elevators. The ideal scalpel blade for microsurgery is a 15C blade, which is small enough to manage the interproximal papilla but large enough to make a vertical releasing incision in one stroke (Figure 2.3). Microblades are useful only when the interproximal spaces are tight. The soft tissue elevators are designed to elevate the gingiva and tissue from the underlying cortical bone with minimal trauma to the tissue. As shown in Figure 2.4, one end of the instrument has a thin, sharp, triangular beak and the other end has a sharp, rounded beak that varies in size. Unlike the periosteal elevators used in periodontics, this new design incorporates thin edges and points that allow the soft tissue to be elevated from the bone cleanly and completely.

Figure 2.3 15C blade and microblade.

2.3 Tissue Retraction Instruments

The new retractors developed for microsurgery eliminate many deficiencies of previous traditional retractors, which are basically unfit to microsurgery.

KimTrac retractors (B&L Biotech) have more variable widths than other conventional retractors (from 8 mm to 14 mm compared with conventional 10 mm) (Figure 2.5). KimTrac P1 and P2 retractors have wings to separate the elevated soft tissue from the area of surgery and an additional plastic protector for soft tissue elevation (Figure 2.6). KimTrac can be used with and without a plastic protector. However, the plastic protector is advantageous as it ensures easy flap retraction with highly improved visibility and accessibility to the operating field (Figure 2.7). Unlike other products with blunt ends, the KimTrac is able to

Figure 2.4 Elevation instruments. Enlarged view of the tips of soft tissue elevators.

Figure 2.6 KimTrac-M5 retractor with a plastic protector.

Figure 2.5 Tissue retraction instruments (KimTrac) with various mouth widths and shapes from 8 to 14 mm. These retractors have the thinnest serrated blade available.

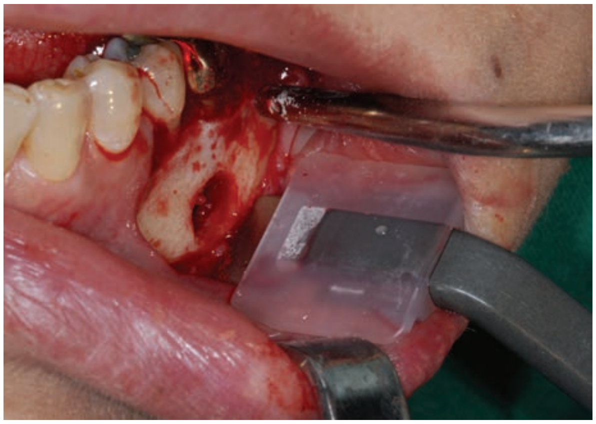


Figure 2.7 The plastic protector could retract and protect the flapped gingival tissue and lower lip.

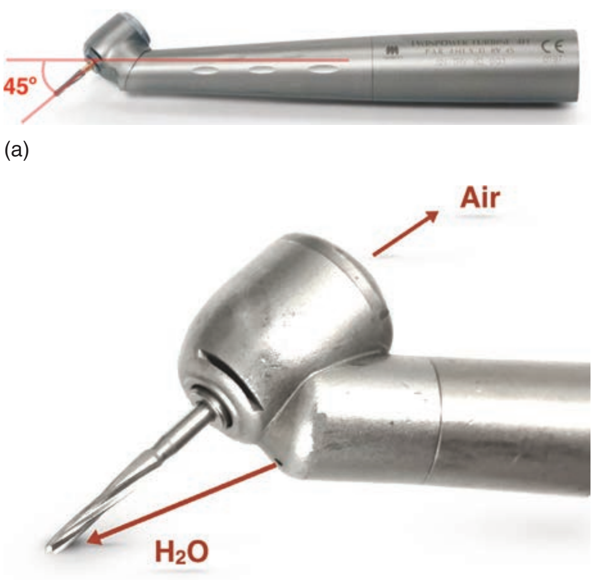
anchor against the cortical boney plate precisely and stably, regardless of whether the shapes are plain or protrusive, due to its serrated end.

Comparison of the thickness of blades of retractors shows that the KimTrac retractor is one-third the thickness of other retractors, making them an ideal retractor using the bone grooving technique on mandibular posterior surgery (Figure 2.8).

The Kim/Pecora (KP 1, 2, and 3) retractors (Obtura/Spartan) also have wider tips than conventional retractors (15 mm compared with 10 mm) and are 0.5 mm thinner (Figure 2.9). Their serrated ends anchor the retractors securely on to the bone. The KP 4 retractor is a small, all-purpose retractor with the same features as the others but has the standard 10-mm width. The KP retractor tips are modeled to

Figure 2.9 Kim/Pecora (KP) retractors. Left to right, KP 1, KP 2, KP 3, and KP 4 retractors.

Figure 2.8 Enlarged views of serrated blade widths. Middle (B) is the KimTrac blade and A and C are KP retractor blades. The KimTrac blade width is one-third that of the KP retractor.



(a)

(b)

Figure 2.10 A 45 degree surgical handpiece (a) is designed to irrigate the surgical site while ejecting air from the back of the handpiece, eliminating water splatter and air emphysema (b).

the concavities and convexities of the cortical boney plate.

Using an endodontic retractor on a convex or flat bone surface is difficult. The contact with the bone is limited to a very small area; in contrast, the KP 1, KP 2, and KimTrac M5 retractors fit the convex contour of the bone. The full contact of the retractor tip on the bone provides a secure, stable hold, eliminating sudden or creeping slippage that results in traumatized tissue, swelling, and painful healing. It also eliminates interference and interruption during the surgery and assistant fatigue. Many retractors are available on the dental market, but only the KimTrac retractors and Kim/Pecora retractors are designed especially for endodontic microsurgery.

2.4 Osteotomy Instruments

A 45 degree surgical handpiece with a Lindemann bur is the instrument of choice for this procedure (Brasseler NSK and Morita) (Figure 2.10a). It is designed to direct water on to the cutting surface by channeling it along the surface of the bur while the air is ejected through the back of the handpiece (Figure 2.10b). This reduces the chance of emphysema and pyemia and creates less splatter than a conventional handpiece. The handpiece's 45 degree angled head makes it easier to work in and visualize difficult to reach areas.

The Lindemann bone cutting bur is used for osteotomies and has fewer flutes than conventional burs, resulting in less clogging and frictional heat and more efficient cutting.

2.5 Curettage Instruments

Complete curettage of granulation tissues from an osteotomy site is probably the hardest part of the surgery.

Curettage instruments (Figure 2.11) include periodontal curettes, surgical curettes, and mini-endodontic curettes. Curettage generally is not a microsurgical procedure and any periodontal curette can be used for that purpose (Figures 2.12, 2.13, 2.14, and 2.15).

Figure 2.11 Curettage instruments.

Figure 2.12 Enlarged view of the specially designed minicurettes and mini-molt curettes.

2.6 Inspection Instruments

Micromirrors are available in many different shapes, but the ones shown in Figure 2.16 have proved to be the most useful.

An important feature of the mirror neck is flexibility. A necessity of this is demonstrated in Figure 2.17a, b, and c, which shows a rectangular micromirror positioned at a 45 degree angle to the resected root in order to reflect the entire root surface. Without the ability to bend the micromirror neck to accommodate the angle, the resected root surface could not be viewed clearly or completely. It has shown rectangular mirrors with 2 mm, 3 mm, and 4 mm widths on a flexible stainless handle are the micromirrors of choice. A round mirror has limited usage on a round resected

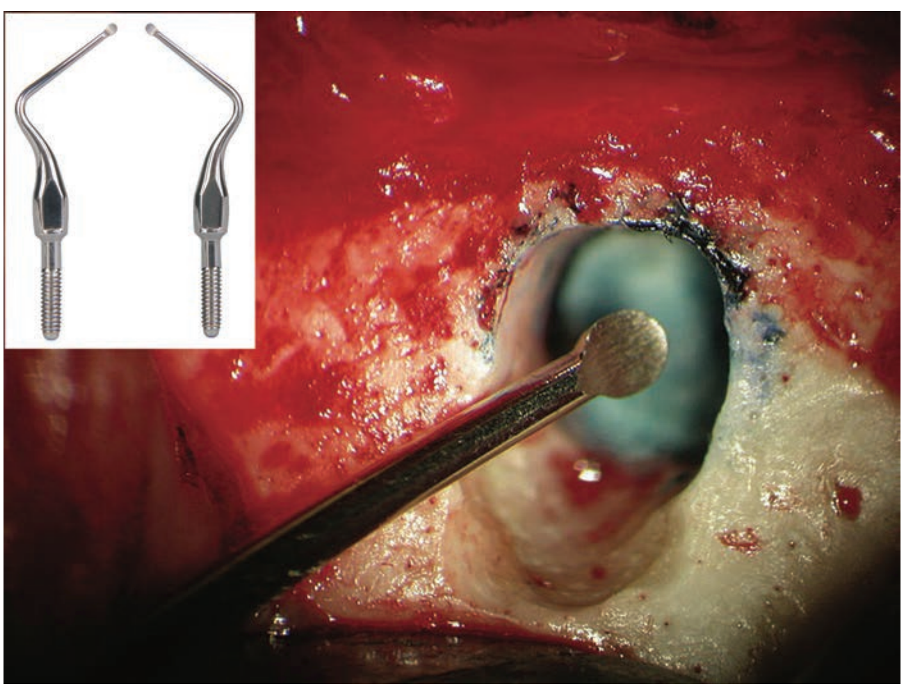


Figure 2.13 Small round curette in action.

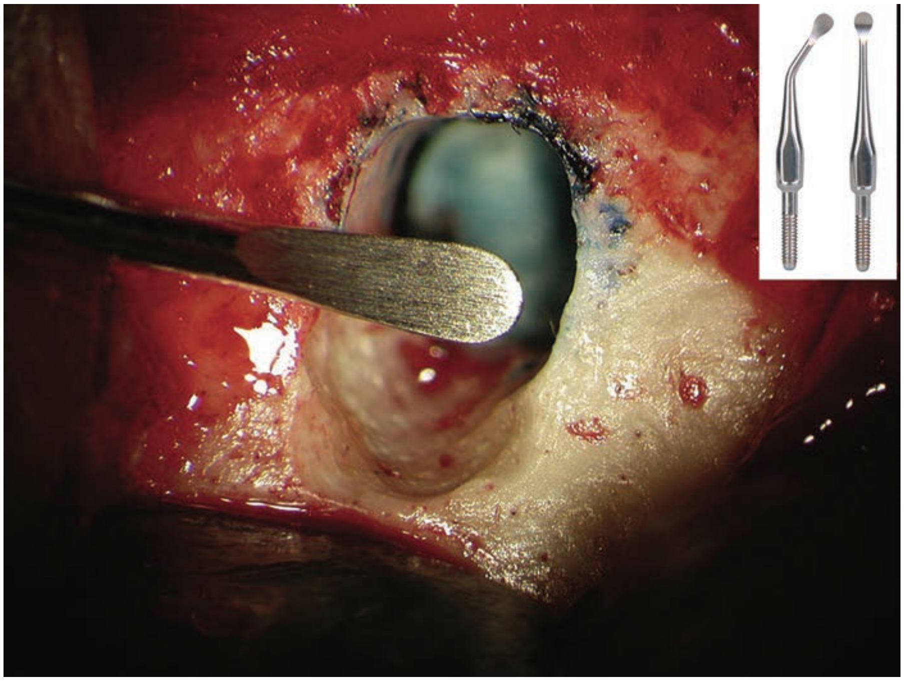


Figure 2.14 Larger elongated curette in action.

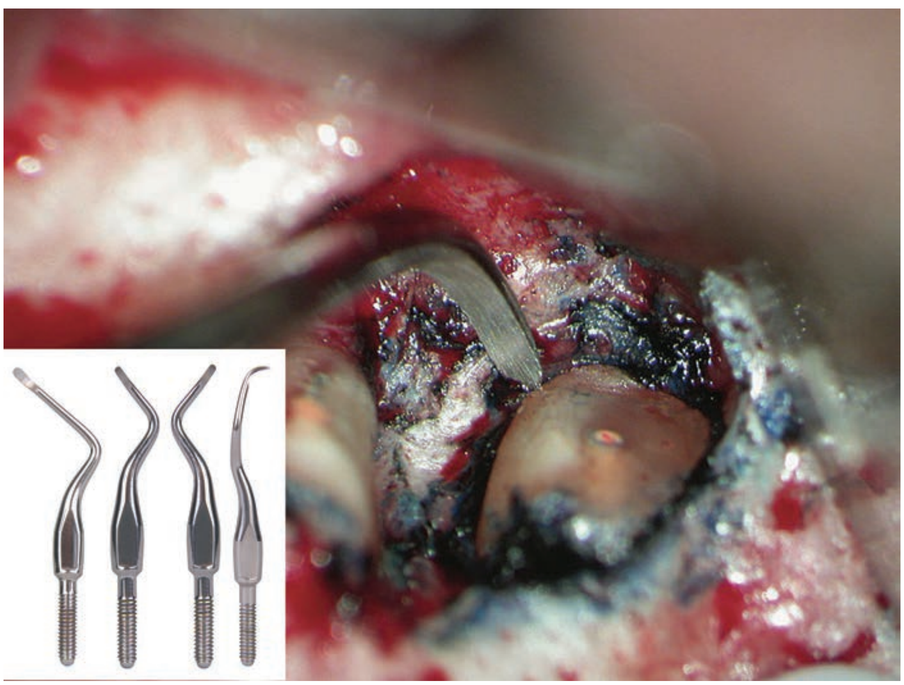


Figure 2.15 Sharp periodontal curette in action.

Figure 2.16 Size comparison of the modified rectangular micromirrors with a regular dental mirror.

root surface, e.g., central incisors. A size comparison of the micromirrors with a normal mouth mirror is shown in Figure 2.16.

2.7 Ultrasonic Units and Tips for Root End Preparation

In the past, root end Class I cavity preparations or slot-type cavity preparations were prepared by a miniature contra-angle handpiece with small burs or a straight slow speed handpiece. Using this type of method, coaxial root end preparation along the root canal was not possible. Furthermore, it caused frequent perforation in the lingual side of the root.

One of the most significant advancements in endodontic microsurgery is the piezoelectric ultrasonic instrument for root end preparation.

ULTRASONIC UNITS: Ultrasonic units create vibrations in the range of 30 to 40 kHz by exciting quartz or ceramic piezoelectric crystals in the handpiece. The energy created is carried to the ultrasonic tip, producing forward and backward vibrations in a single plane. Continuous irrigation along the cutting tip cools the surface and maximizes debridement and cleaning. The three most widely used ultrasonic units are the EMS, the Spartan (Spartan/Obtura), and the P-5 (Acteon). As shown here it is strongly advised to have a unit that has both Piezotome for Groove preparation and ultrasonic root end preparation. Currently, Acteon P-5 has both capabilities.

ULTRASONIC TIPS: The first ultrasonic tips for endodontic surgery were stainless steel Carr Tips (CT 1–5) in 1990. In 1999 Spartan/Obtura introduced KiS (Kim Surgical) tips (Figure 2.18). The KiS ultrasonic tips have a better cutting ability and a more efficient irrigation port. They are coated with zirconium nitride and have an irrigation port near the tip rather than along the shaft. The enlarged view of a KiS tip, which has a 3-mm cutting tip, is shown in Figure 2.19. These advanced tips cut faster and smoother and cause fewer microfractures because of the improved positioning of the irrigation port. The KiS 1 tip, which has an 80 degree angle and is 0.24 mm in diameter, is designed for the mandibular anterior teeth and premolars. The KiS 2 tip has a wider diameter tip and is designed for wider teeth (e.g., maxillary anteriors). The KiS 3 tip is designed for posterior teeth. It has a double bend and a 75 degree angled tip for use in the maxillary left side or the mandibular right side. The KiS 4 tip is similar to the KiS 3 except that the tip angle is 110 degrees, to reach the lingual apex of molar roots. The KiS 5 tip is the counterpart of the KiS 3 for the maxillary right side and the mandibular left side. The KiS 6 tip is the counterpart of the KiS 4 tip (Figure 2.18).

Recently Jet Tips were introduced (Figure 2.20). A special feature of this tip is microprojection of the cutting surface (Figure 2.21), allowing quick and complete removal of gutta percha from the canal. They have bendable ultrasonic tips (B&L Biotech) (Figure 2.22), which the operator can bend in any direction for better access. JETips are available with 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm tips that allow for bending with a tip bending jig that will provide a customized tip angle to meet all microsurgical needs.

STROPKO IRRIGATOR/DRIER (Figure 2.23): This simple but useful device fits on a standard air/water syringe and uses blunt 0.5-mm diameter microtips

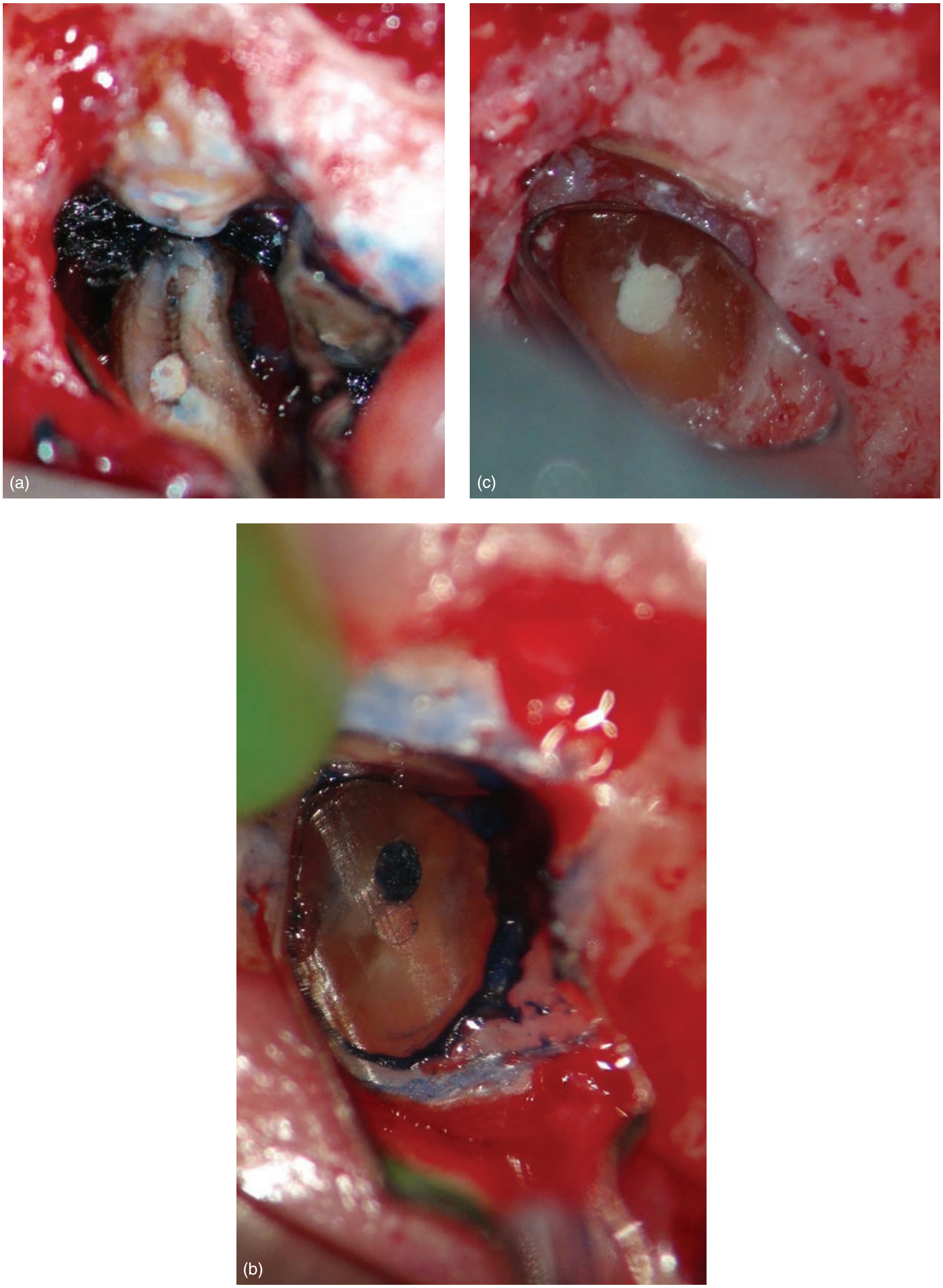


Figure 2.17 Micromirror reflecting the entire surface of the resected root of teeth. (Courtesy of Dr. Kanayo Kon.)

Figure 2.18 KiS tips 1, 2 for anterior teeth and KiS 3, 4, 5, and 6 for posterior teeth (Image courtesy of Obtura Spartan, Algonquin, IL © 2017).

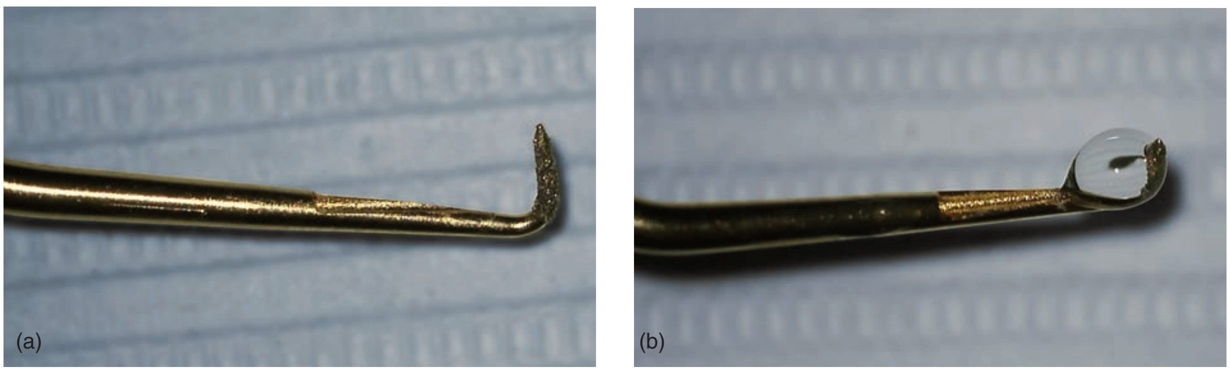


Figure 2.19 KiS 1 tip is 3 mm long and has an 80 degree angle. (a) The tip is coated with zirconium nitride. (b) Water from the irrigation port, bathing the tip.

Figure 2.20 Set of JETips: JETip 1B, JETip 1L, JETip 1R, and JETip 1S (Courtesy of B&L BioTech).

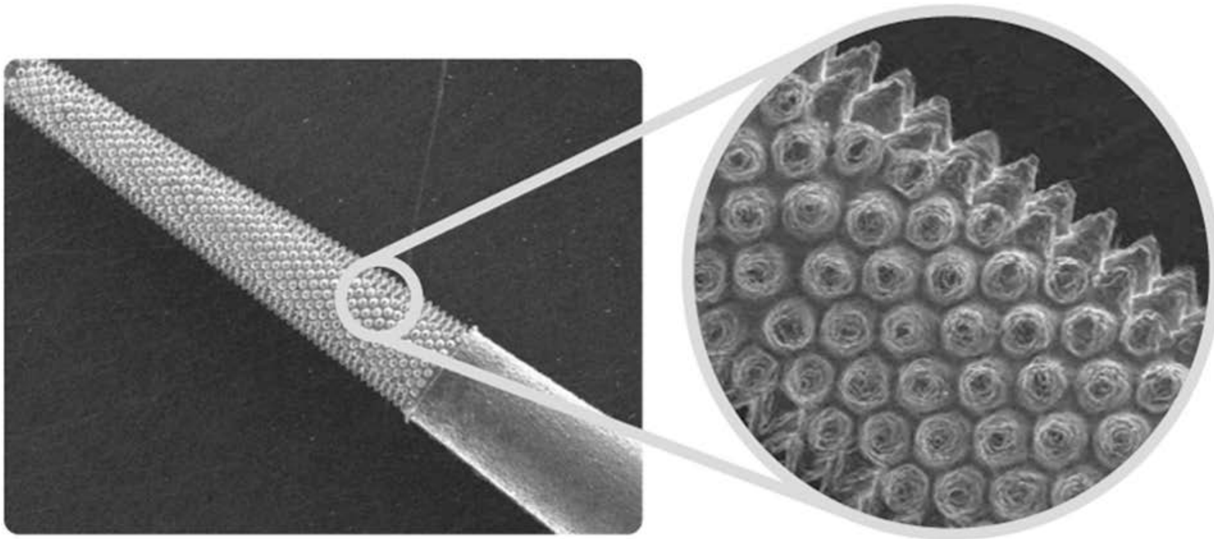


Figure 2.21 JETip with metal microprojection (enlarged view).

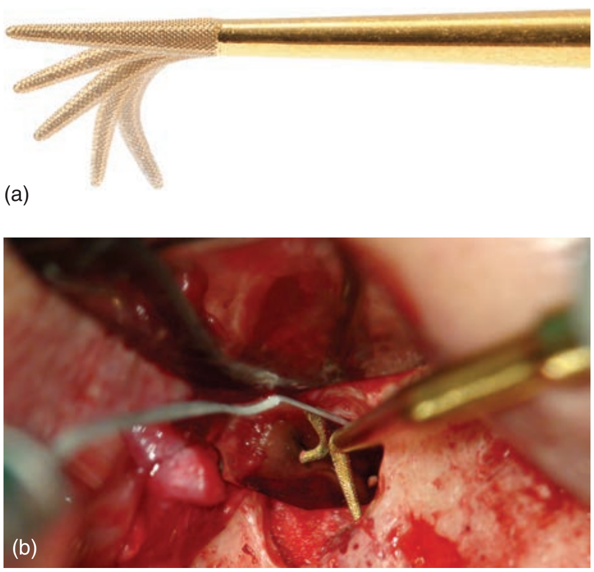


Figure 2.22 (a) JETips for bending that provides a customized tip angle; (b) retropreparation with a JETip.

Figure 2.23 Stropko irrigator/drier.

(Ultradent Co.). It is easy to use and highly effective for irrigating and drying retropreparations and resected root surfaces. It supplants the use of paper points to dry the preparation, which provides no certainty that the preparation is completely dry.

2.8 Microplugger Instruments

After placement of MTA or Bioceramic putty into the root end preparation using the Lee carver, the filling materials need to be gently condensed to fill the whole root end preparation length of 3 mm or a longer length. This procedure is done using micropluggers, one a thin 2-mm diameter (Figure 2.24) and another a thick 4-mm diameter (Fig 2.25), depending on the size of root end preparation.

2.9 Suturing Instruments

The Laschal microscissors, or any small-beaked scissors, and the Castroviejo needle holder are used to manage 5-0 or 6-0 synthetic sutures (Figure 2.26). We recommend these two instruments because standard large-beaked scissors do not cut well enough and are too large in a microsurgical environment. Other needle holders are also too large for microsurgery. The smaller, more delicate Castroviejo needle holder may require some adjustment at first but will reward the surgeon with greater ease in delicate and difficult suturing. Before the advent of microsurgery, 4-0 silk sutures were the standard for endodontic surgery, but

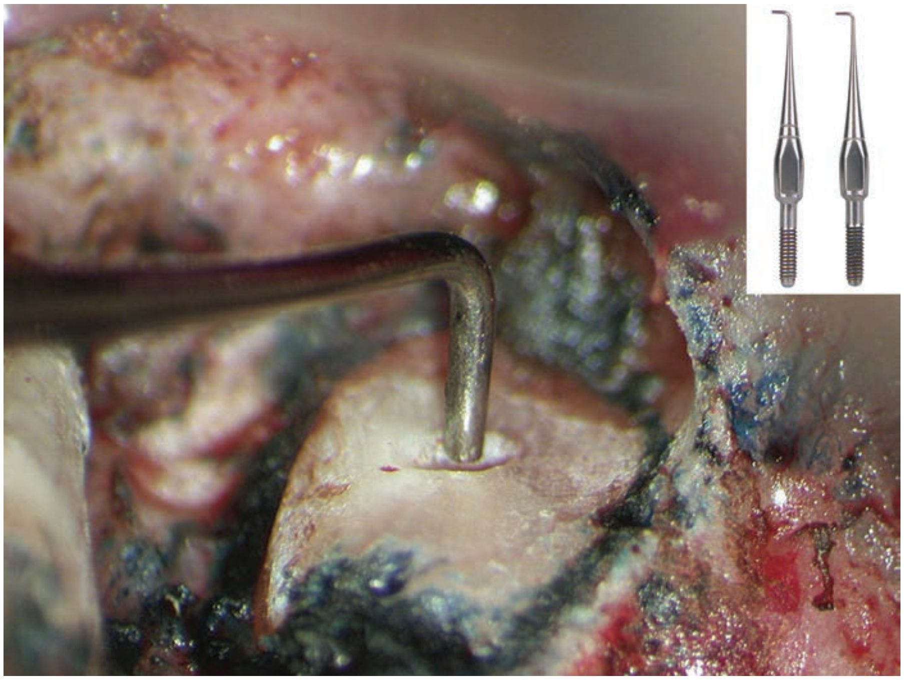


Figure 2.24 Small diameter (2 mm) microplugger in action.

Figure 2.25 Larger diameter (5 mm) microplugger in action.

Figure 2.26 (a) Castroviejo needle holder; (b) Laschal microscissors for microsuturing (Mt Kisko, New York).

they are no longer recommended. Because silk sutures are braided and thick, plaque, food debris, and bacteria readily accumulate on them, resulting in secondary inflammation at the suture site.

To prevent this inflammation and associated delayed healing, 5-0 and 6-0 monofilament sutures of nylon or polypropylene are now used. Suture needles with a triangular cross-section for easy penetration of the tissue and 1/2 and 3/8 curvatures are recommended.

2.10 Miscellaneous Instruments

A number of miscellaneous instruments are used in endodontic microsurgery. A large ball burnisher (Figure 2.27) and a bone file are used to smooth the bone and root surface and to mold bone augmenting material to the boney contours. A small rongeur is used to remove granulation tissue. The beaks of these rongeurs are miniaturized to fit into the hard to reach areas deep inside the boney crypt.

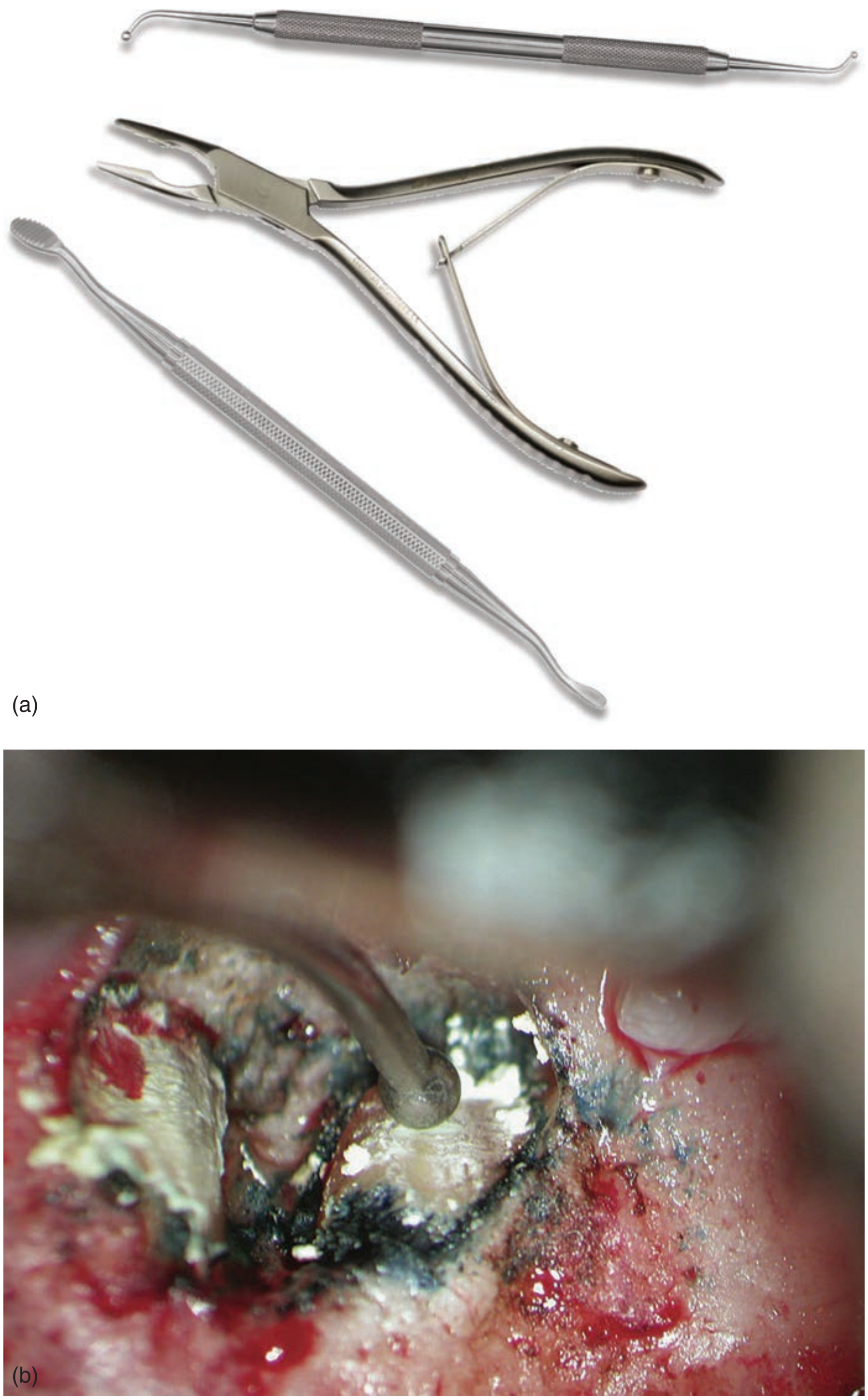


Figure 2.27 (a) Large ball burnisher for condensation of large areas of root end fill; minirongeur for removing granulation tissue from the bone crypt; bone file to smooth the bone and root surface. (b) Large ball burnisher in action.

3

Medication-Related Osteonecrosis of the Jaw and Endodontic Microsurgery

Chafic Safi and Bekir Karabucak

KEY CONCEPTS

- Antiresorptive and antiangiogenic drugs are used to manage, prevent, and treat bone disease and cancer-related conditions.
- Despite their therapeutic effect, these drugs could induce medication-related osteonecrosis of the jaw (MRONJ).
- MRONJ is a serious condition where parts of the maxillary or mandibular bone get exposed with subsequent necrosis, infection, and even sequestration, leading to significant morbidity.
- Dental procedures such as endodontic microsurgery represent a major risk factor for MRONJ in patients being treated with antiresorptives and/or antiangiogenics.
- Strategies for management of at-risk patients are essential in order to prevent MRONJ.

It has been well recognized that bisphosphonates, a class of antiresorptive drugs, are associated with bisphosphonate-related osteonecrosis of the jaw (BRONJ). Recently, newly developed antiresorptive drugs (Prolia: Amgen, Thousand Oaks, CA) and antiangiogenic drugs (Avastin: Genentech, San Francisco, CA) have been associated with growing numbers of jaw osteonecrosis (Table 3.1). In response, the American Association of Oral and Maxillofacial Surgeons implemented a change in nomenclature from BRONJ to medication-related osteonecrosis of the jaw (MRONJ).

Bisphosphonates and other antiresorptives are commonly used in the management and treatment of bone disease (Paget's disease, osteoporosis) as well as the prevention and treatment of cancer-related lytic lesions. They inhibit osteoclast function, maturation, and survival.

Antiangiogenic drugs slow down the formation of new blood vessels, thus limiting tumors, nutrient sources, and metastatic routes. They act as an antibody against vascular endothelial growth factor (VEGF) causing regression of tumor vasculature, and delay of disease progression.

Patients suffering from MRONJ exhibit exposed bone in the maxillofacial area that does not heal

Table 3.1 Examples of commercially available antiresorptive and antiangiogenic drugs.

Generic Name	Commercial Names	Administration Routes	Common Uses
Alendronate*	Fosamax	Oral	Osteoporosis
Ibandronate*	Boniva	Oral, IV	Osteoporosis
Pamidronate*	Aredia	Oral, IV	Cancer
Zolendronate*	Zometa Reclast	IV	Cancer Osteoporosis
Denosumab*	Prolia Xgeva	Subcutaneous	Osteoporosis
Bevacizumab*	Avastin	IV	Cancer

*Indicates bisphosphonate antiresorptive drugs.

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

Figure 3.1 Patient suffering from MRONJ exhibits exposed bone in the maxillofacial area that does not heal regardless of treatment. (Courtesy of Dr Jose F. Lazaro.)

regardless of treatment (Figure 3.1). The exposed bone undergoes avascular necrosis and, in some cases, can get infected. Depending on the extent of the disease, the exposed area can extend beyond the alveolar bone, resulting in pathologic fractures and oral/nasal communication (Figure 3.2). MRONJ is not to be confused with other similar clinical conditions such as sarcomas or osteomyelitis. A diagnosis of MRONJ can be made when the following three conditions are present:

1. Current or previous treatment with antiresorptive or antiangiogenic drugs.
2. Exposed bone or bone that can be probed through an intraoral or extraoral fistula in the maxillofacial region that has persisted for longer than 8 weeks (Figure 3.3).
3. No history of radiation therapy to the jaws.

There are several risk factors for developing MRONJ while undergoing treatment with antiresorptive or antiangiogenic agents. These risk factors can be divided into three groups (Table 3.2):

1. Medication-related factors.
2. Local factors.
3. Demographic and systemic factors.

Overall, the risk for MRONJ is significantly low. Still, it is important to establish a strategy to be able to offer safe treatment, especially when it comes to endodontic microsurgery. A clear strategy starts with prevention of MRONJ by undergoing an early dental consultation when the use of antiresorptive or antiangiogenic therapy is being considered. Endodontic treatment planning for those patients comprises identifying and addressing (non-surgically and/or surgically) acute infection sites or potential infection sites. Furthermore, antiresorptive or antiangiogenic therapy should be delayed until the extraction/surgical site has mucosalized (14 to 21 days). Therefore, if systemic conditions permit and with the agreement of the prescriber, initiation of antiresorptive and antiangiogenic therapy should be delayed until dental health is optimized.

Once a patient is on antiresorptive or antiangiogenic therapy, the dental and endodontic treatment plan may change (Table 3.3).

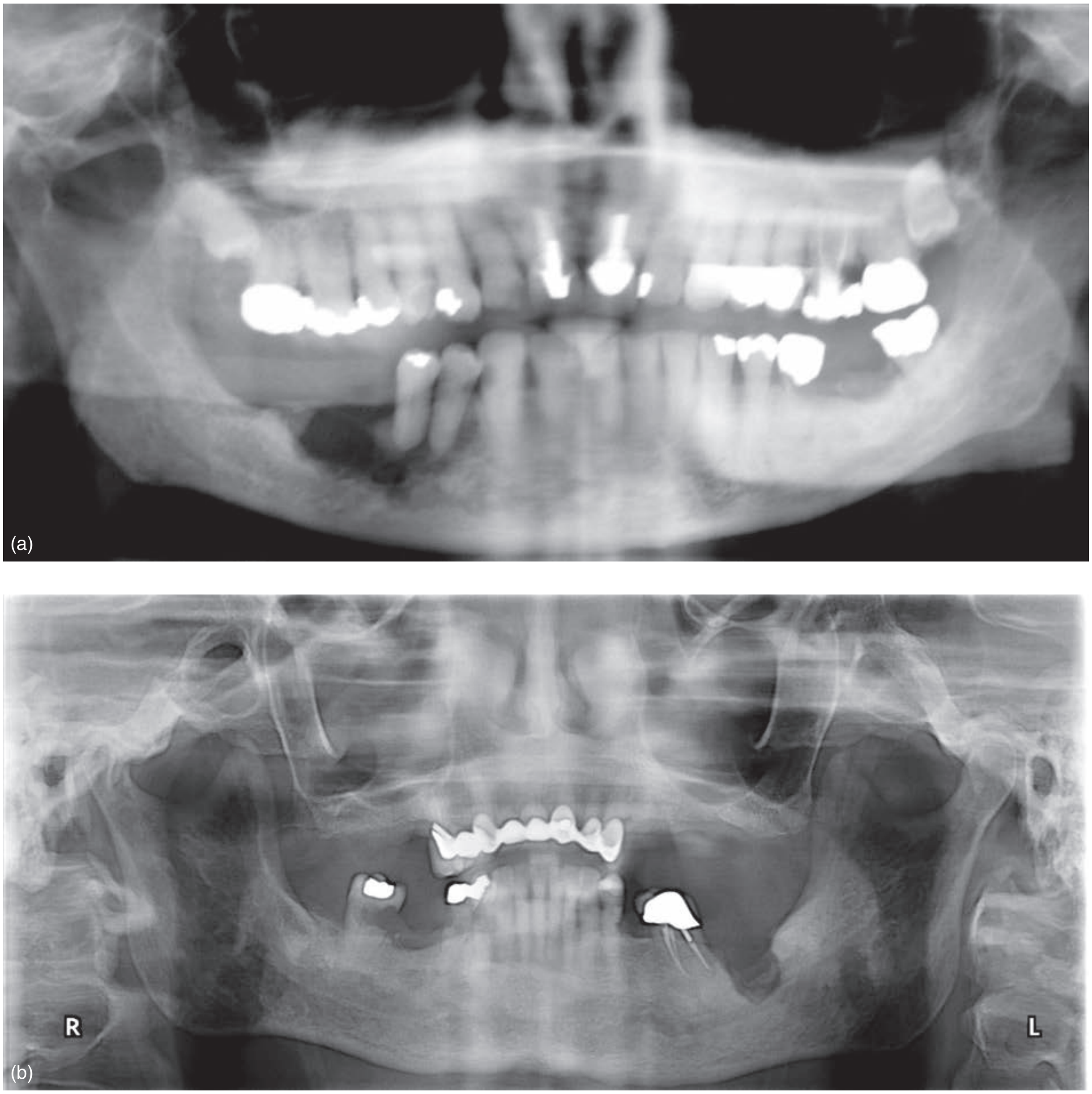


Figure 3.2 Panoramic radiographs of patients suffering from MRONJ exhibit the extent of the disease. The exposed area can extend beyond the alveolar bone and render the jaws fragile and prone to pathologic fractures. (Courtesy of Dr Jose F. Lazaro.)

Figure 3.3 The bone can be probed through an intraoral or extraoral fistula in the maxillofacial region. (Courtesy of Dr Jose F. Lazaro.)

Table 3.2 Common risk factors associated with the development of MRONJ.

Risk Factor	Implication
Therapeutic indication*	Cancer > osteoporosis IV > oral
Duration of therapy*	Longer duration = higher risk
Dentoalveolar surgery+	Endodontic surgery = high risk
Anatomical+	Mandible > maxilla
Concomitant oral disease+	Periodontal disease = high risk Periapical pathology = high risk
Concomitant systemic disease^	Obesity, rheumatoid arthritis, diabetes = high risk Corticosteroids = high risk
Age^	Older patients = high risk

*Indicates medication-related factors.
+Indicates local factors.
^Indicates demographic and systemic factors.

Table 3.3 Endodontic treatment plan recommendations for patients undergoing antiresorptive or antiangiogenic therapy.

Drug Type and Route of Administration	Implications
IV Bisphosphonates IV Antiangiogenics	Surgery *not recommended* Non-surgical treatment with crown resection for non-restorable teeth
Oral or subcutaneous antiresorptives for less than 4 years No other medication/condition	No alteration in treatment plan necessary
Oral bisphosphonate for less than 4 years with concomitant corticosteroid or antiangiogenic drug	Drug holiday for 2 months presurgery* Monitor osseous and mucosal healing
Oral or subcutaneous antiresorptives for more than 4 years with or without concomitant medication	Drug holiday for 2 months presurgery* Monitor osseous and mucosal healing

*Means systemic conditions permitting. Decision must be made with the treating physician.

Suggested Readings

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4

Indications and Contraindications

Bekir Karabucak and Garrett Guess

KEY CONCEPTS

- Endodontic microsurgery offers a predictable single visit treatment option with less restorative risk compared to non-surgical retreatment procedures.
- Radiographs as well as CBCT imaging are important tools to determine if surgical intervention is the best option.
- Careful assessment of the surrounding periodontal tissues is critical when treatment planning microsurgery, as is a careful review of the patient's dental and medical history.
- The quality of the previous endodontic treatment and the conditions under which it was performed are helpful to determine whether non-surgical or surgical retreatment is indicated.

4.1 Introduction

Endodontic microsurgery is not only a predictable method to explore the cause of non-healing in root canal treated teeth, but is also a means to effectively eliminate persistent apical pathology. When a previously treated tooth has persistent symptoms and the patient wants to save their tooth, retreatment of the root canal should be considered with two potential routes of access: non-surgically by accessing through the crown or surgically by directly accessing the root apices and periapical pathology. Both procedures are effective and supporting research shows that these procedures will result in the healing of apical periodontitis in over 80% of the cases treated. The decision to retreat a case surgically or non-surgically can be a challenge, and even sometimes both procedures are required to eliminate apical periodontitis with the most predictability.

4.2 Surgical Success Dependent on Ability to Perform Ideal Protocols

Microsurgery is an effective treatment option when the ideal treatment can be performed which includes:

- Sufficient access to the entire pathologic area with good visualization.
- Proper resection amount and bevel.
- Ultrasonic preparation of all portals of exit.
- Placement of a proper root end filling material.
- Reapproximation of the surgical site with primary closure.

4.3 Etiology Assessment through Examination and Treatment

Determining the etiology for persisting pathology is essential when choosing endodontic microsurgery as a treatment option: if the etiology is endodontic in nature, the prognosis for endodontic microsurgery is favorable. The following conditions may be present that may not respond well to microsurgical treatment and have a questionable prognosis:

- Lateral radiolucency with no apical radiolucency indicative of a strip perforation or vertical fracture (Figure 4.1).
- Primary periodontal lesions (Figure 4.2).
- Combined periodontal and endodontic lesions (Figure 4.3).
- Root resorption affecting the middle or coronal thirds of the roots (Figure 4.4).

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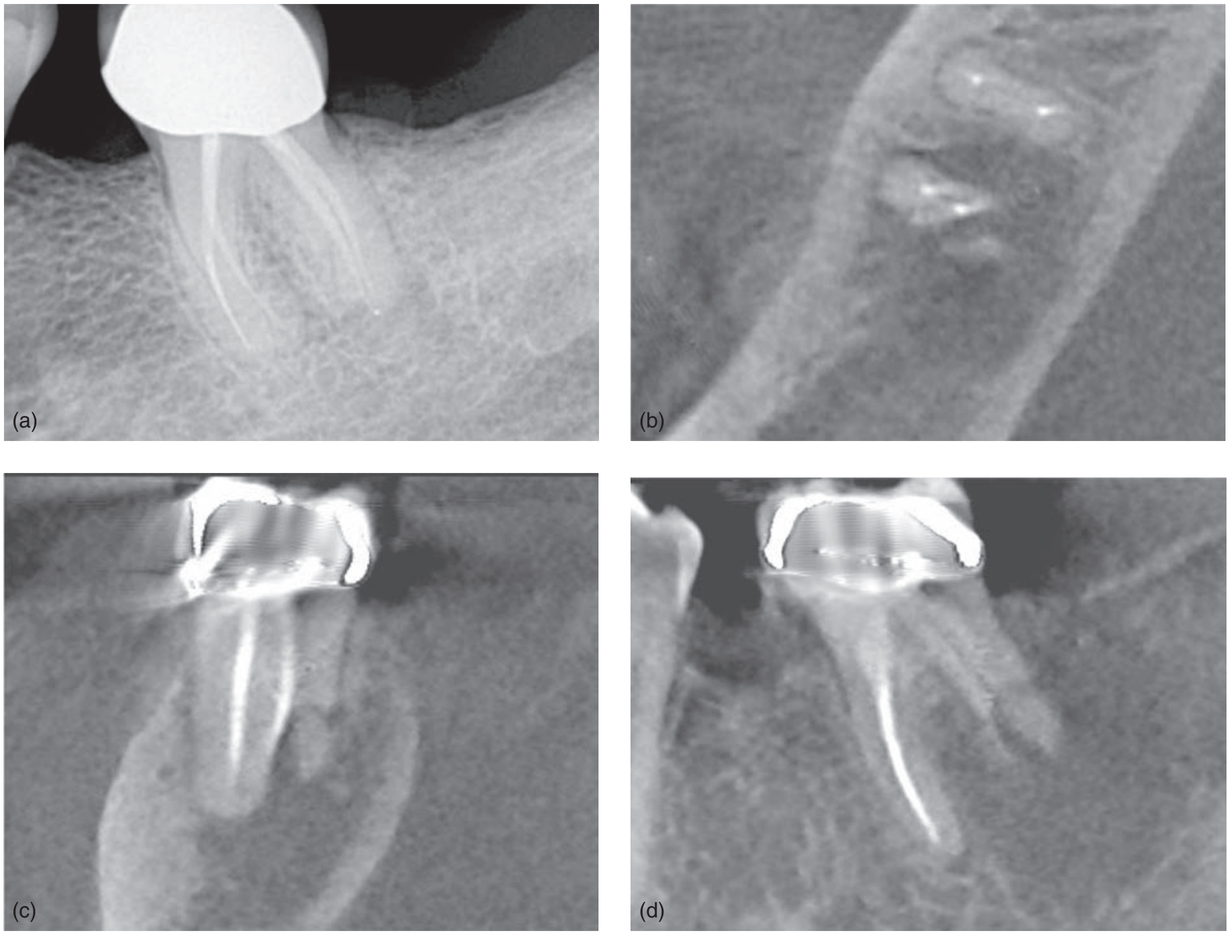


Figure 4.1 Previously treated mandibular molar with a separated file. (a) Periapical radiograph; (b), (c), and (d) axial and coronal views. A distal root fracture was identified on CBCT images that the periodical preop radiograph did not show. Therefore, extraction was opted.

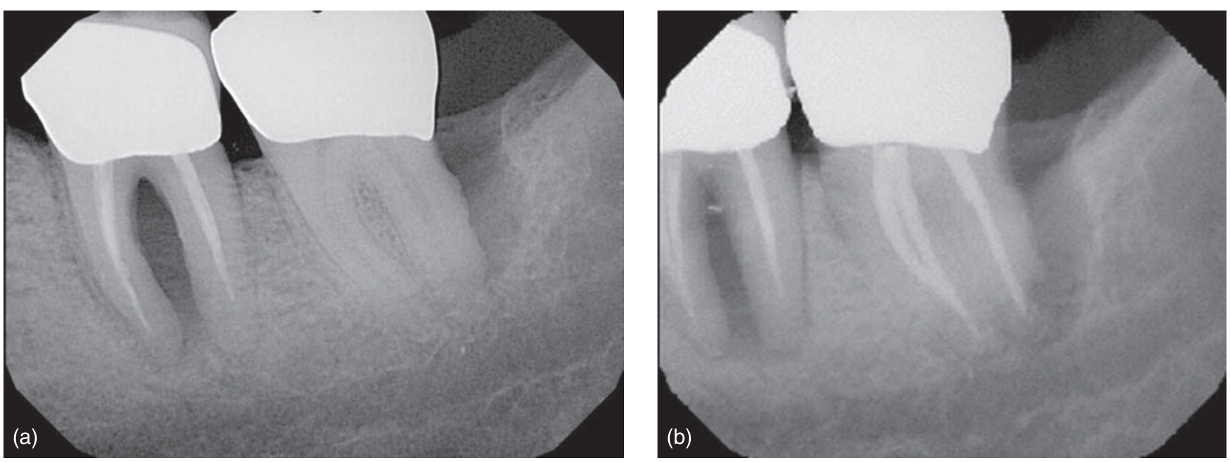


Figure 4.2 Mandibular second molar with combined periodontal and endodontic lesions. Diagnosic tests showed pulp necrosis. (a) Radiograph showing extent of distal bone loss. (b) After endodontic treatment, bony defect and periodontal probing did not improve, indicating that the defect was primarily due to periodontal disease.

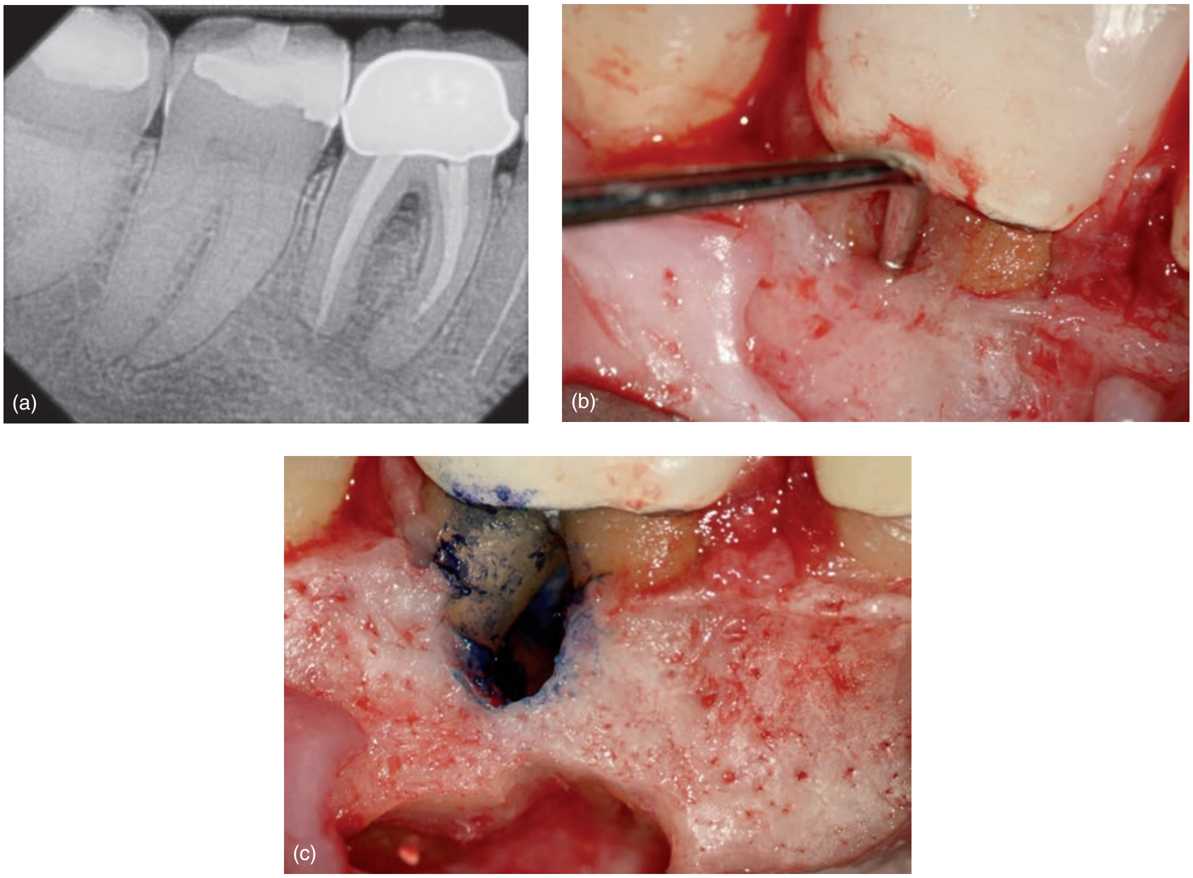


Figure 4.3 Previously treated mandibular first molar with apical periodontitis with furcation involvement. Presurgical probing was within normal limits. (a) Periapical radiograph showing underfilled mesial canals and periapical radiolucency. (b) Intraoral picture showing periodontal involvement and periodontal probing detected after the flap was raised. (c) Osteotomy after root end resection and after cleaning of granulation tissue.

4.4 Periodontal Considerations and Surgery

Endodontic microsurgery is extremely effective in the management of endodontic pathology, but alone does not enhance the tooth's periodontal status and sometimes negatively affects it. Any tooth requires a stable periodontal status to be retained, so it is important to assess the periodontal condition of a tooth that is going to undergo endodontic microsurgery. The following periodontal factors help assess the appropriateness of choosing surgery:

- Effect of adequate resection on a tooth's crown to root ratio (Figure 4.5).
- A tooth's stability in the presence of inadequate periodontal support coupled with traumatic occlusion.
- Buccal plate bone loss and the risk of a severe perio defect post-treatment (Figure 4.6).

4.5 Influential Patient Factors

Treating the whole patient is important when it comes to determining if a surgical or non-surgical approach is best. Endodontic microsurgery requires significant accuracy at high magnification in order to visualize, access, prepare, and fill very small and difficult to reach areas with no margin for error. The following patient-based factors affect the feasibility of performing successful endodontic microsurgery:

- Adequate surgical access through patient positioning.
- Proper maintenance of the patient's position with minimal movement during the entire surgical treatment visit.
- Ability to sit for an extended treatment visit that must be completed from start to finish without the potential to be stopped part of the way through.
- Stated reactions to epinephrine, essential for adequate hemostasis.
- Essential medications that affect bleeding and inhibit effective surgical site hemostasis.

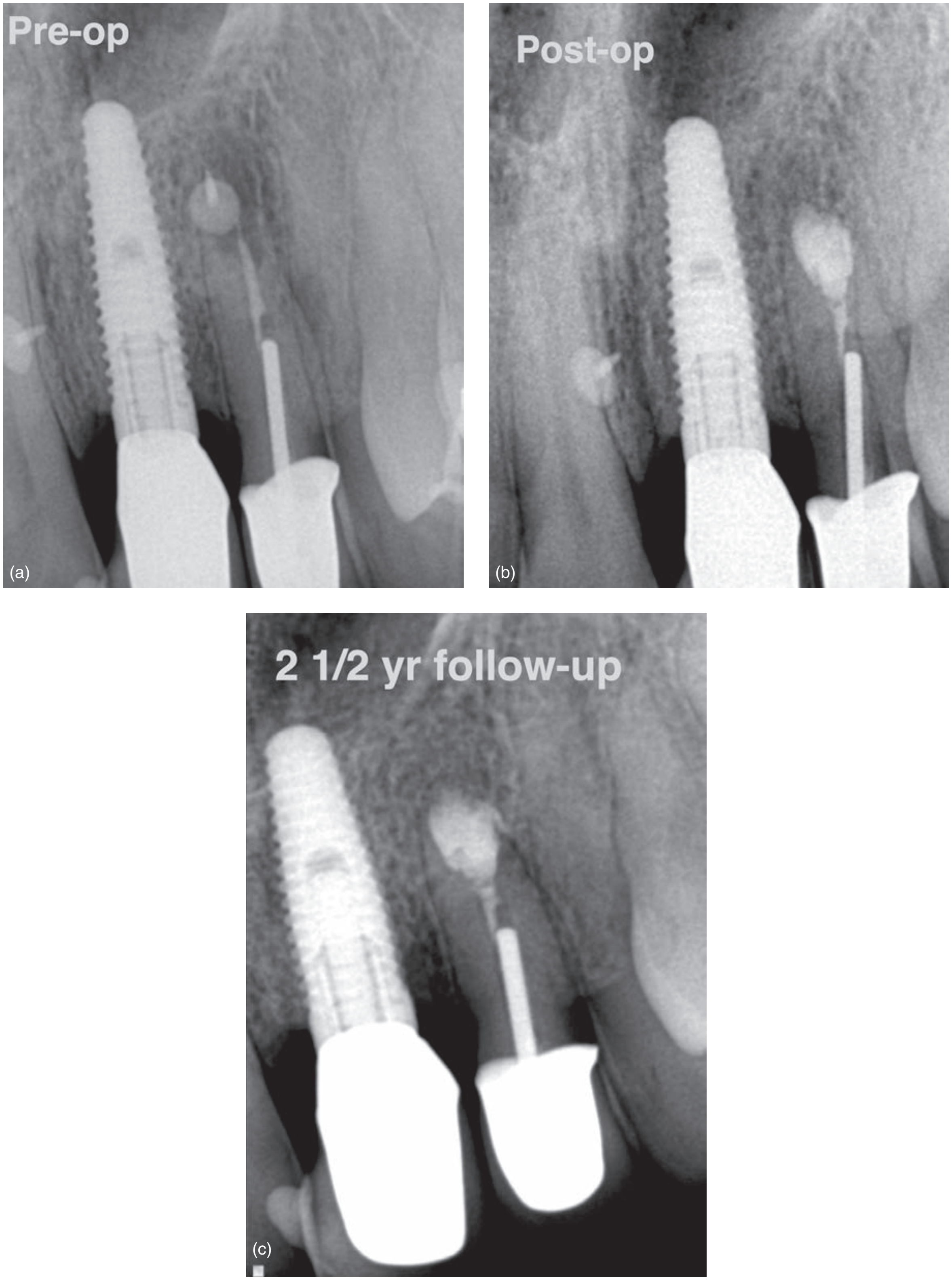
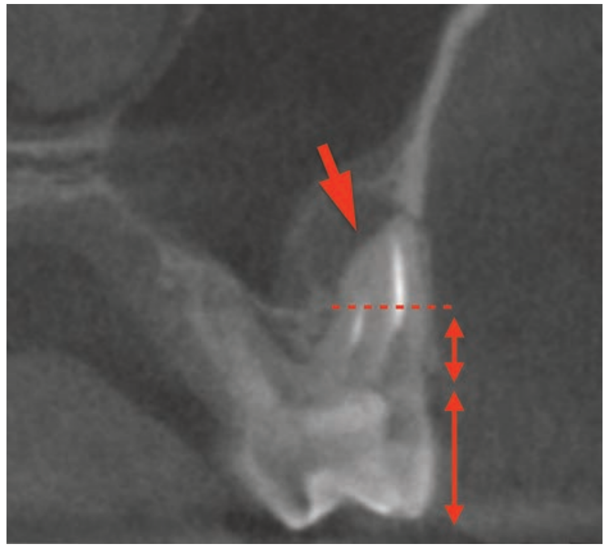


Figure 4.4 Apex of maxillary lateral incisor was resorbed due to misplaced bone tack used to stabilize the bone grafting membrane. (a) Preoperative radiograph showing apical periodontitis and a resorptive defect. (b) Bone tack was removed and root end surgery was performed. Root end and reporptive defect was filled with Bioceramic root repair material. (c) Two and a half year follow-up radiograph showing complete bone healing.

Figure 4.5 Coronal view of a maxillary molar showing apical periodontitis around the MB root. MB2 canal exits palatally at the mid-root area. More than 3 mm of root resection would be necessary to the exposed MB2 canal during surgical retreatment, but more than 3 mm of root resection would compromise the crown–root ratio. Therefore, non-surgical retreatment should be considered.



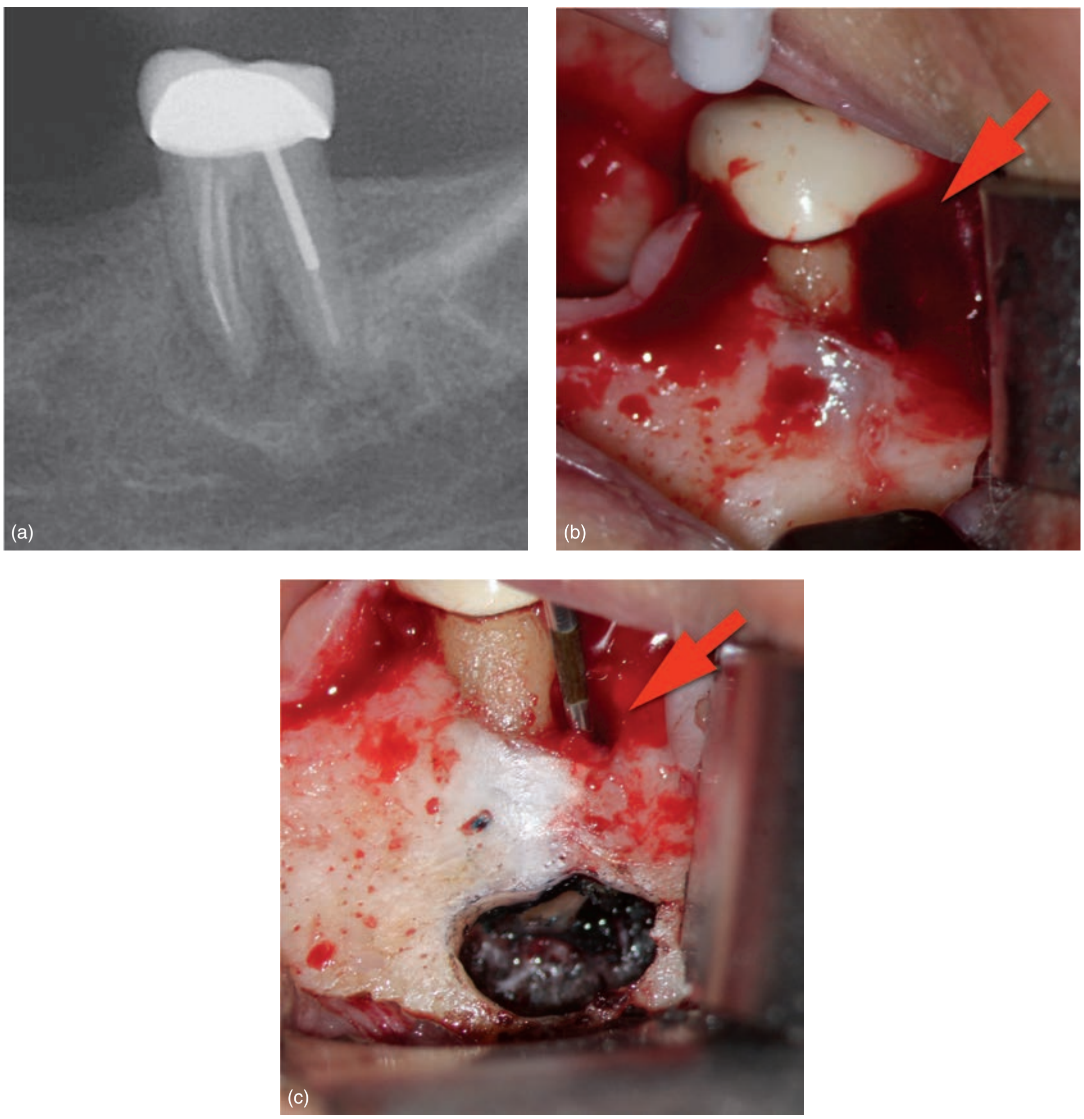


Figure 4.6 (a) Mandibular molar with deep periodontal probing around the distal root. (b) Bony defect showing advanced periodontal involvement. Prognosis is guarded due to furcation bone loss.

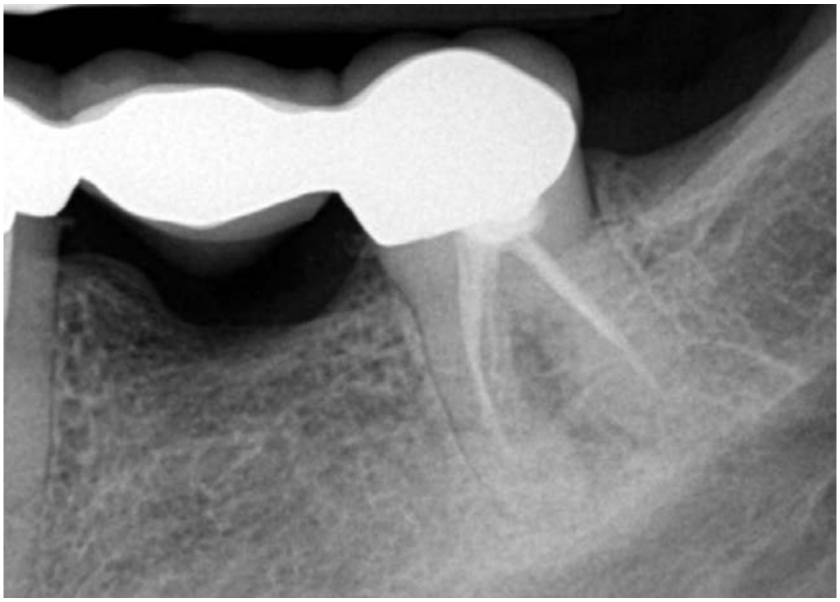


Figure 4.7 Poor quality prior endodontics that can be improved upon utilizing current techniques and technologies.

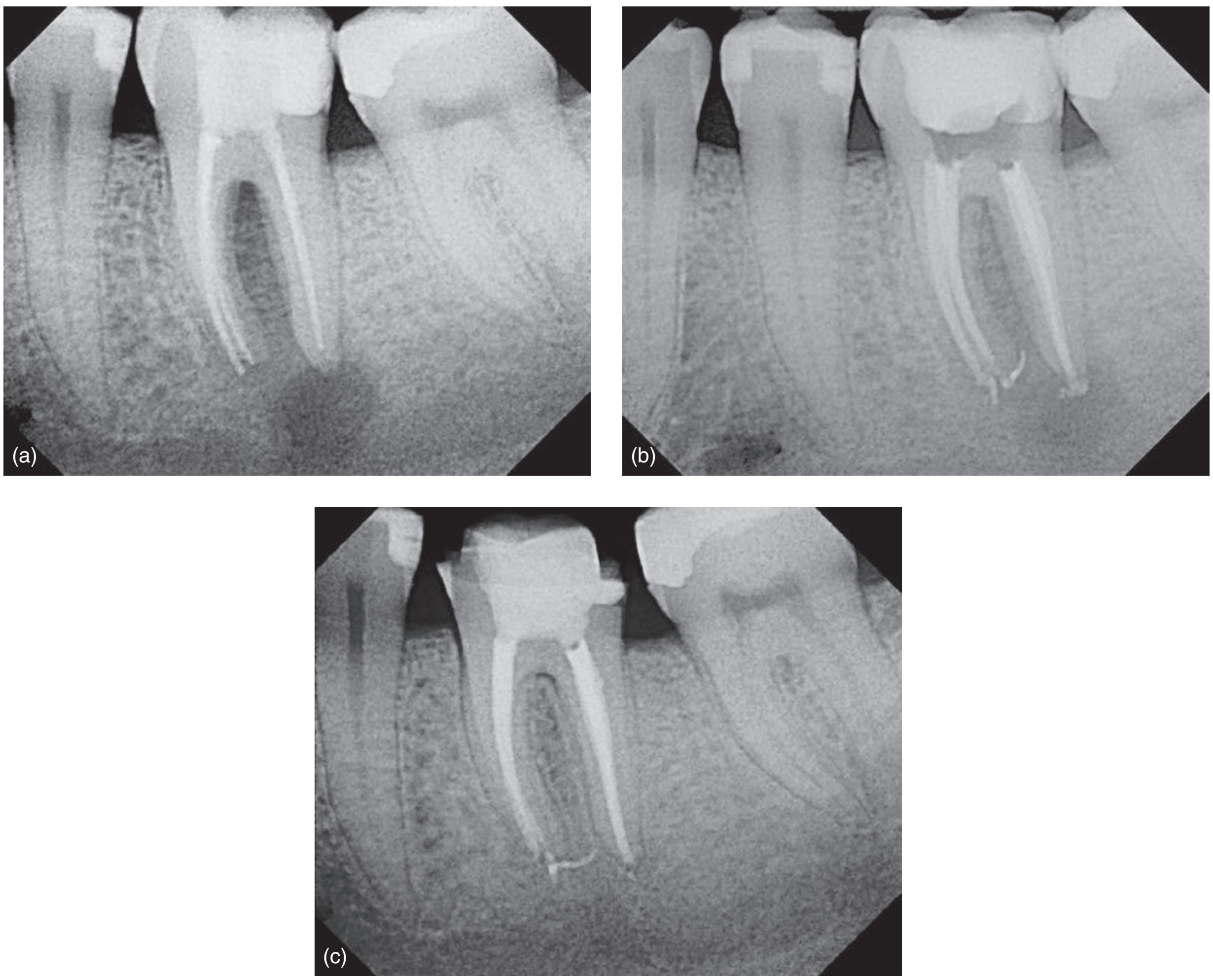


Figure 4.8 Poor quality and inadequate restoration may cause coronal leakage. Non-surgical retreatment with a new coronal restoration should be performed to treat apical periodontitis. (a) Periapical radiograph showing apical radiolucency and inadequate coronal seal. (b) Postoperative radiograph. (c) Six month follow-up radiograph showing complete resolution of apical radiolucency.

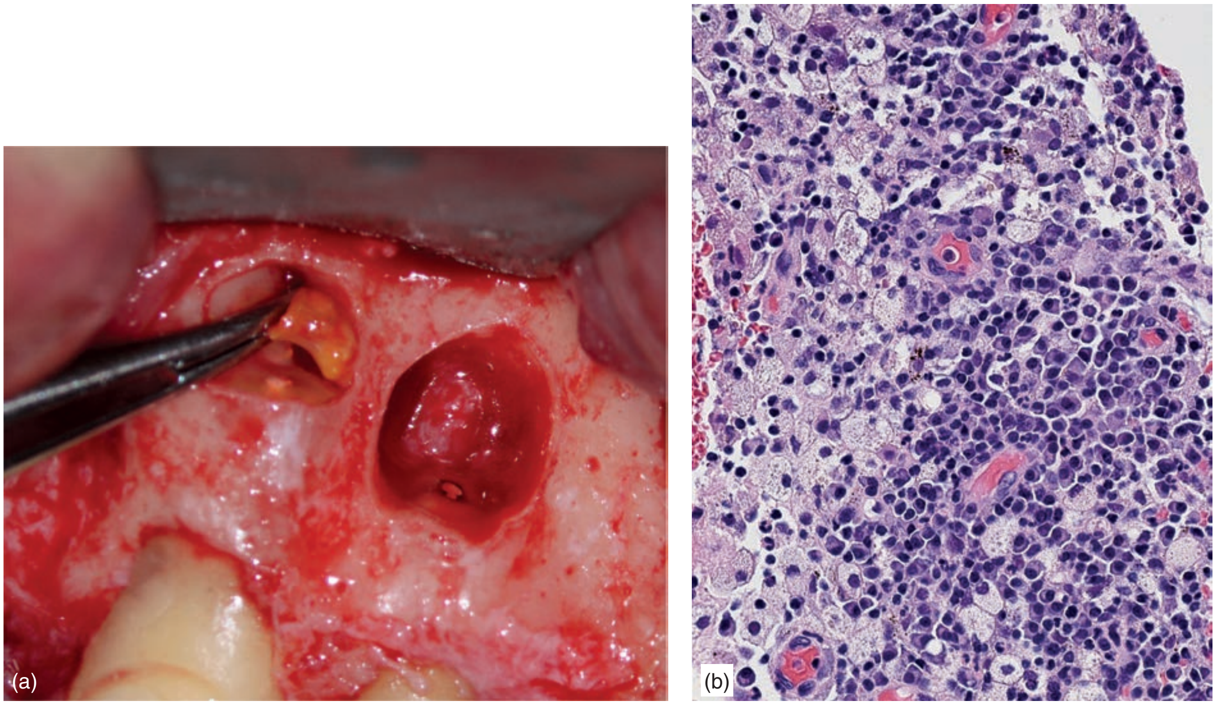


Figure 4.9 Persistent infections outside the root may not be healed by non-surgical retreatment. Periradicular lesion should be surgically removed and should be submitted for pathological evaluation. (a) Intraoral picture showing osteotomy site and tissue removal for biopsy. (b) Biopsy report confirming actinomycosis.

4.6 Condition of Previous Endodontic Treatment

The pretreatment status of the tooth from an endodontic standpoint influences the decision to treat surgically or non-surgically based on the following factors:

- Poor quality prior endodontics that can be improved upon utilizing current techniques and technologies (Figure 4.7).
- Poor quality or inadequate restoration resulting in contamination of the root canal system (Figure 4.8).
- Persistence of infection outside the roots inaccessible to non-surgical treatment (Figure 4.9).
- Complications from unsuccessful initial treatment like naturally or iatrogenically blocked or transported canals (Figure 4.10).

Endodontic microsurgery is an option for almost every tooth in the arch, with the exception of most maxillary and mandibular second and third molars. In general, the risks associated with the procedure are minimal to the tooth as well as the patient, and the costs can be less due to the lack of restorative

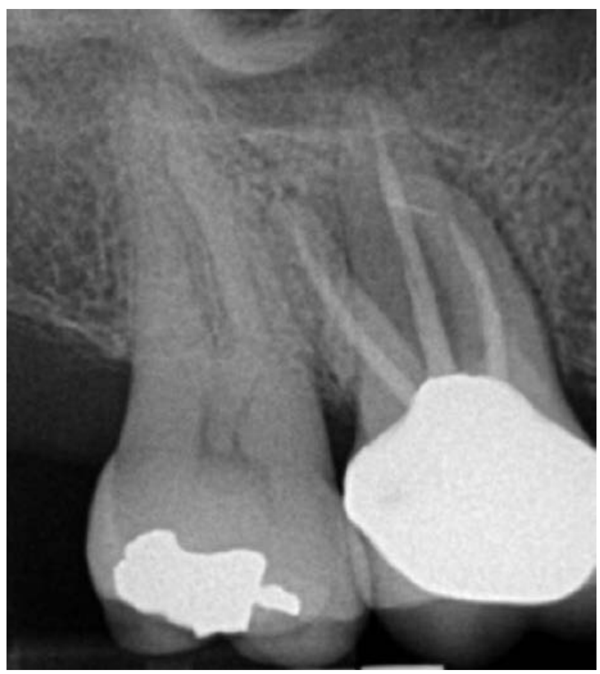


Figure 4.10 Previously treated maxillary first molar. Periapical radiograph showing separated instrument within the curved apical area of the MB canal. Surgical retreatment should be opted to preserve tooth structure and prevent any possible procedural errors during removal of the separated instrument.

follow-up necessary. While in theory non-surgical endodontic retreatment is preferred in all cases in order to retreat the entire canal space, it is not always possible or practical, and not without risks. This is why the indications for endodontic microsurgery are so broad. When the treatment objectives can be satisfied to maximize success and the periodontal and restorative statuses are stable, endodontic microsurgery represents one of the most predictable means to eliminate apical periodontitis, in light of the anatomic challenges that teeth have, which make non-surgical therapy ineffective.

Every day clinicians encounter different cases requiring endodontic retreatment and are required to recommend and provide the best treatment option with the best outcome. Even though the treatment decision is based on the best scientific evidence available, the clinician's previous experiences, training, and skills may affect the treatment decisions. Modern endodontic treatment offers non-surgical and surgical approaches with high success rates. It is the clinician's responsibility to weigh the benefits of different treatment modalities and to offer these to their patients in order to achieve the best outcome.

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5

Anesthesia and Hemostasis

Siva Rethnam-Haug, Aleksander Iofin, and Syngcuk Kim

KEY CONCEPTS

- Profound anesthesia and effective hemostasis are prerequisites for microsurgery.
- Lidocaine 2% with 1:50 000 epinephrine is the anesthetic of choice.
- Both buccal and lingual and palatal injections are required to achieve profound anesthesia and effective hemostasis.
- Epinephrine pellets alone or in conjunction with a ferric sulfate-soaked cotton pellet are effective topical hemostats during surgery.
- True epinephrine allergy is extremely rare.
- Medical history is essential, especially for those taking blood thinners and aspirin every day.

Consulting a physician is necessary if a patient needs to stop a medication prior to surgery.

5.1 Armamentarium

- Mandibular surgery: 27 gauge needles (1 inch and $1^5/_8$ inch)
- Maxillary surgery: 30 gauge needles (1 inch)
- 2% Lidocaine with 1:50 000 epinephrine anesthetic solution
- Micro forceps
- Epinephrine pellets (Racellets)
- Ferric sulfate solution (Cutrol or Stasis)
- DentalVibe device (DentalVibe Inc.)

Adequate hemostasis is essential for microsurgery. In the past, achieving effective hemostasis was a challenge. Many endodontic surgeons performed surgery in a pool of blood, guessing at anatomic landmarks and structures. In order for endodontic microsurgery to be successful, the surgeon needs to examine the root surface at high magnification with the microscope. It is practically impossible to do that without effective hemostasis.

The anesthetic solution of choice for endodontic surgery is Lidocaine 2% HCl with 1:50 000 epinephrine. This high concentration of epinephrine is preferred for surgery because it produces effective, lasting vasoconstriction via activation of the α-adrenergic receptors in the smooth muscle of the arterioles. This prevents the anesthetic from being washed out prematurely by the microcirculation.

5.1.1 Epinephrine

Epinephrine binds α-1, α-2, β-1, and β-2 adrenergic receptors. It can cause either vasoconstriction or vasodilation, depending on the receptors it binds; α-1, α-2, and β-1 are responsible for vasoconstriction, while β-2 receptors trigger vasodilation. Epinephrine causes predominantly vasoconstriction in oral tissues by stimulating the membrane-bound α-receptors on vascular smooth muscle.

A source of enduring controversy in dentistry is the potential of epinephrine for causing systemic effects when used in relatively small amounts for local anesthesia. It has been shown that epinephrine given submucosally elicits little or no response from the cardiovascular system. However, when an identical dose is injected directly into the bloodstream, heart rate, stroke volume, and therefore cardiac output increase. To avoid such an occurrence, an aspirating syringe should be used at all times to ensure that epinephrine is not injected into the bloodstream accidentally. Virtually all adverse effects associated with epinephrine are dose and route dependent. A high dose injected into the bloodstream can be fatal. The current recommended maximum dosages of epinephrine in local anesthetics are shown in Table 5.1.

A dry field is a requirement for a successful apical microsurgery. The vasoconstriction effect of 1:100 000 epinephrine does not provide a sufficient level of

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

Table 5.1 Epinephrine dosages for local anesthesia.

Epinephrine Maximum Dosages				
mg/ml	parts/thousand	mg	ml	#cartridges
0.02	1:50 000	0.2	10	$5\frac{1}{2}$
0.01	1:100 000	0.2	20	11
0.005	1:200 000	0.2	40	22

hemostasis, meaning the surgeon must stop the procedure repeatedly to control bleeding. This is both frustrating and time consuming. Buckley and coworkers provided strong evidence of the need for higher concentration in a clinical study of 10 patients who required bilateral posterior quadrant periodontal surgery. Almost twice as much blood loss occurred when patients were anesthetized with 1:100 000 epinephrine as compared to 1:50 000 epinephrine. These investigators further observed that the reduced blood loss with 1:50 000 epinephrine kept the surgical site drier, reducing the operating time. Postoperative hemostasis was also better.

In our study using a clinic population, no correlation was found between the administration of 1:50 000 epinephrine and the blood pressure and pulse readings during periapical surgery. Most patients had transitory, statistically insignificant increases in pulse rate 2 minutes after the injection. The rate returned to normal within minutes.

5.2 Presurgical Phase

5.2.1 Administration of Local Anesthetic

Any endodontic procedure requires adequate local anesthesia, but with endodontic surgery hemostasis becomes equally important. When properly used, local anesthetics are successful at achieving both objectives. Preparing the patient for anesthesia is important and can significantly reduce the patient's anxiety.

The first step is to reassure the patient that everything will be done to keep him/her as comfortable as possible. Next, a topical anesthetic, Lidocaine ointment USP, 5%, is applied for a minimum of 1 to 2 minutes. It has been shown that an inadequately anesthetized patient produces considerably more endogenous catecholamine in response to discomfort than is contained in the anesthetic solution, and inadequate hemostasis leads to a prolonged, difficult to control procedure.

Unless severe, a cardiovascular disorder does not automatically contraindicate the use of anesthetics containing epinephrine. Consultation with a physician should clarify this issue and alleviate any concerns the patient might have. Some patients may state that they are "allergic to novocaine or epinephrine" or that they had heart palpitations after a procedure in which an epinephrine-containing anesthetic was used. Although the patient's concern should be acknowledged, it is strongly recommended that the surgery be done only if anesthetics containing a vasoconstrictor can be used. The patient should be informed of the reason for this choice.

5.2.2 Injection Techniques

The only way to establish hemostasis is to deliver the vasoconstrictor directly to the surgical site, although an inferior alveolar nerve block has been shown to reduce blood flow to the lingual infiltration to enhance the vasoconstrictive effect at the surgical site. Whatever the injection technique used for anesthesia, infiltration into the surgical site is always required for hemostasis.

Adequate hemostasis can be achieved by a vasoconstrictor containing anesthetic (e.g., 2% lidocaine solution with 1:50 000 epinephrine) being injected into the submucosal tissues at the surgical site at least 20–30 minutes before the incision is made. Injecting into soft or osseous tissues after the incision has been made is useless because powerful vasodilating neuropeptides at the incision site override any vasoconstrictor effect.

The infiltration sites for the anesthesia are in the loose connective tissue of the alveolar mucosa near the root apices. Injection into the deeper supraperiosteal tissues over the basal bone, rather than the alveolar bone, may not provide hemostatic control in the surgical site, but may instead deposit anesthetic into the skeletal muscle. Because skeletal muscle has a predominance of β-2 receptors, injection of epinephrine in such sites produces vasodilation rather than vasoconstriction and therefore should be avoided. If the anesthetic is injected into the muscle, not only is hemostasis inadequate but a more rapid uptake of the anesthetic and vasoconstrictor occurs, increasing the potential for substantial bleeding.

Anesthesia should be distributed throughout the entire surgical field by depositing into numerous infiltration sites. Injection has to be slow and controlled. Rapid injection produces localized pooling of solution, resulting in delayed and limited diffusion into adjacent tissues, minimal surface contact with microvascular and neural channels, and less than optimal hemostasis. The initial incision should be delayed

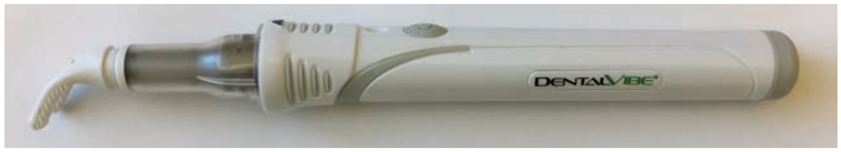

Figure 5.1 DentalVibe device (DentalVibe Inc., Boca Raton, Fl.).

for at least 15 minutes following the injection, until the soft tissues throughout the surgical site have blanched.

5.2.3 Topical Anesthesia

Most topical anesthetics on the market are 20% Benzocaine. Although they often come in great flavors, they are not very effective at anesthetizing the soft tissue. 5% Lidocaine ointment or EMLA paste (2.5% each of lidocaine and prilocaine) are much more potent. They are applied to the injection site on a cotton swab for 1–2 minutes.

For a palatal injection, topical anesthetic should be covered with gauze or, alternatively, an epinephrine patch can be applied.

5.2.4 Additional Techniques

There are several new devices available that attempt to take away the discomfort of an injection, especially the palatal injection. The DentalVibe injection comfort system (Figure 5.1) is a hand-held device the size of an electric toothbrush that produces oscillations to mask the pain from injection. Most of the discomfort of the injection comes from the tissue expanding as the anesthetic solution is being injected, rather than the needle itself. Since the palatal mucosa is very thick and there is little space between the mucosa and the palatal bone, palatal injections are perhaps the most painful that we administer. The DentalVibe can be helpful at significantly reducing the discomfort and anxiety associated with dental anesthesia (Figure 5.2).

The STA single tooth anesthesia system (Figure 5.3) relies on computer-controlled local anesthesia delivery and can also be helpful at minimizing the discomfort of an injection.

If the patient is highly anxious, the surgeon may consider using nitrous oxide in conjunction with a local anesthetic. This assures greater patient comfort and cooperation.

5.2.5 Maxillary Anesthesia

Local infiltration in the mucobuccal fold over the apex of the root and in the adjacent mesial and distal areas is the most effective anesthesia for maxillary teeth. For surgery on anterior teeth, a supplemental nerve block

Figure 5.2 Use of DentalVibe in palatal infiltration.

can be given near the incisive foramen to block the nasopalatine nerve. (Figure 5.4). The best technique for this painful injection is to wait for the buccal infiltration to take effect and then to inject directly into the papilla between the two central incisors, advancing from the buccal to the palatal tissue. After 1 or 2 minutes, the incisive foramen infiltration should be much more comfortable for the patient. For surgery in the posterior quadrant, the anesthetic is injected near the greater palatine foramen to block the greater palatine nerve (Figure 5.5). If the patient has a large swelling in the cuspid and premolar region, an inferior-orbital block injection can be effective for attaining complete and profound anesthesia in this area.

After application of the topical anesthetic, a full carpule (1.8 ml) is injected into the apical area of the tooth and half a carpule (0.9 ml) is injected into the adjacent apical areas. About half a carpule (0.9 ml) is injected into the palate. The injections should be administered slowly.

An aspirating syringe with a 30 gauge, short 1-inch needle is used to prevent the anesthetic solution from being injected into a blood vessel. The high concentration of vasoconstrictor in the anesthetic solution given in stages provides not only profound anesthesia but also effective hemostasis.

Figure 5.3 STA single tooth anesthesia system (Milestone Scientific, Livingston, NJ).

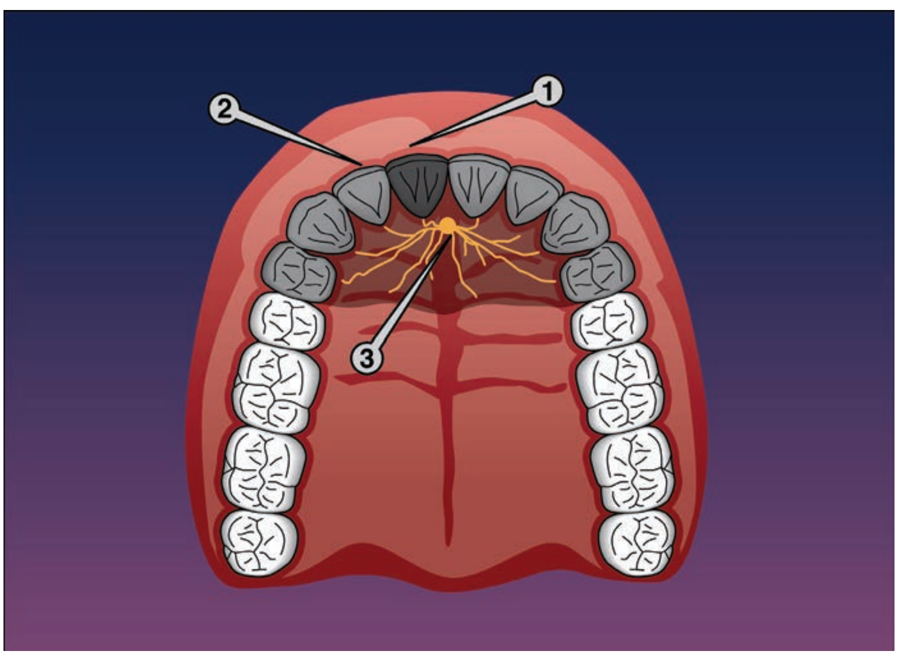

Figure 5.4 Maxillary anterior injection. Anesthetized area and teeth are shown in gray.

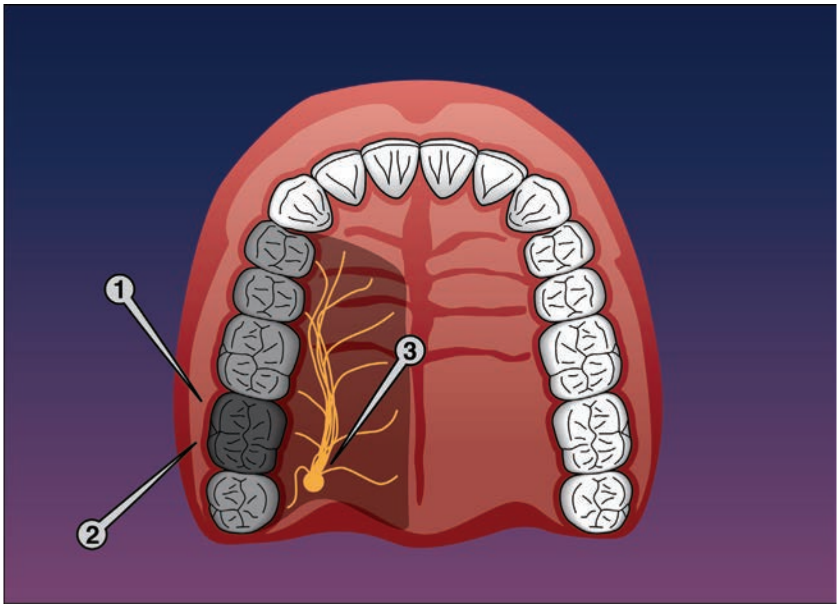

Figure 5.5 Maxillary posterior area injection. Anesthetized area and teeth are shown in gray.

After waiting 20–30 minutes, some patients will express concern as to whether the anesthesia has dissipated. Therefore, a supplemental injection of half a carpule can be administered in order to reassure the patient.

5.2.6 Mandibular Anesthesia

In mandibular surgery, the most effective method is the mandibular and buccal nerve block with a supplemental infiltration in the mucobuccal fold and lingual mucosa (Figures 5.6 and 5.7).

One carpule of 2% Lidocaine HCl (Xylocaine) solution with 1:50 000 epinephrine is administered with a 27 gauge, long $1^5/_8$ inch needle in an aspirating syringe. Studies show no difference in success of mandibular blocks between various types of local anesthetics. Following the mandibular block, another carpule is injected into the mucobuccal fold, buccal and lingual to the tooth. After 10 minutes, another infiltration injection of half a carpule is made.

5.2.7 Bilateral Mandibular Surgery

When operating on both sides of the mandible, for example, on multiple anterior teeth, it is not advisable to administer a bilateral mandibular block in order to prevent postoperative complications due to the

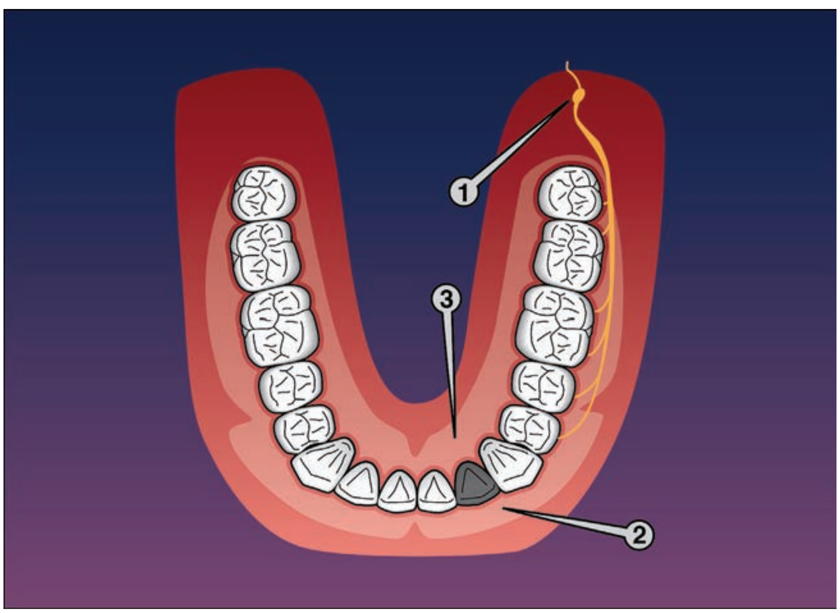

Figure 5.6 Mandibular anterior area injection. Anesthetized area and teeth are shown in gray.

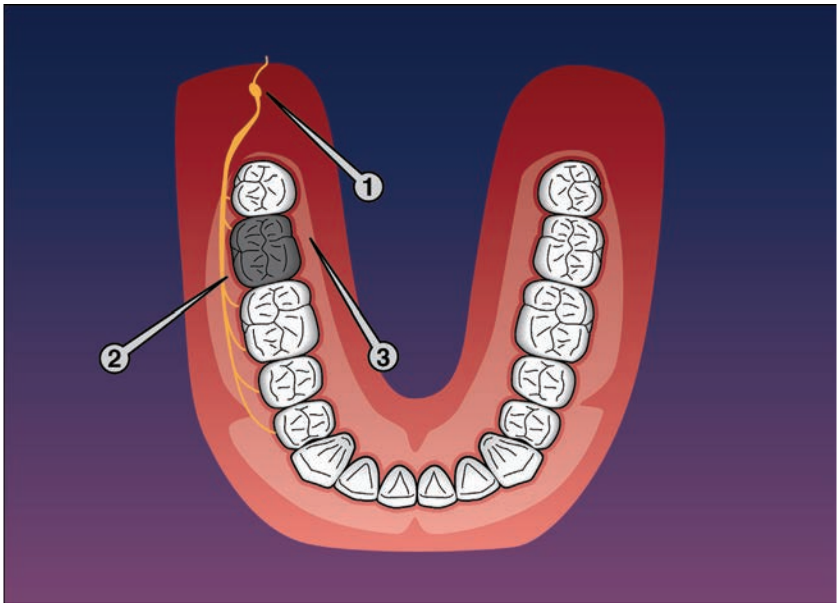

Figure 5.7 Mandibular posterior area injection. Anesthetized area and teeth are shown in gray.

complete loss of sensation in the mandible. A mental nerve block can be used as an alternative on either one or both sides. A successful mental block requires clear visualization of the mental foramen on either a periapical or panoramic radiograph, or CBCT. Once the location is known, the mental foramen can often be palpated with a finger while the cheek is retracted. After the topical anesthetic is applied, the 30 gauge 1 inch needle is bent almost 90 degrees, and the needle is slowly inserted towards the mental foramen coming from the distal towards the mesial aspect of the foramen. Keeping the finger over the foramen while advancing the needle serves as a helpful guide. The anesthetic should be deposited in the vicinity of the foramen. Care should be taken not to enter the foramen to prevent traumatizing the mental nerve.

5.3 Surgical Phase

One of the most common mistakes in endodontic surgery is starting too soon after the anesthetic is administered. It is essential for the surgeon to wait 20–30 minutes before starting the procedure. This waiting time is essential for the anesthetic to filter into the medullary space of the jaw to constrict vessels located within the space, establishing hemostasis.

Bleeding turns any surgical procedure into a challenge. Effective hemostasis is critically important during endodontic microsurgery in order for the surgeon to identify anatomical landmarks. The priority, therefore, is to effectively manage bleeding in the osteotomy site and inside the boney crypt. The next challenge is to control minor local bleeding. If bleeding persists, topical hemostats should be considered.

5.3.1 Topical Hemostatic Agents

Many types of hemostatic agents are available. Those listed in Table 5.2 are broadly classified by their mode of action.

Of all the hemostatic agents above, the two most highly recommended are epinephrine pellets and ferric sulfate.

Table 5.2 Topical hemostatic agents.

Mechanical Agents
Bone Wax™ (Ethicon, Somerville, NJ)
Calcium sulfate
Chemical Agents
Epinephrine
Ferric sulfate
Biological Agents
Thrombin USP™ (Thrombostat, Thrombogen)
Absorbable Hemostatic Agents
Intrinsic action
Gelfoam™ (Upjohn Co., Kalamazoo, MI)
Absorbable collagen
Microfibrillar Collagen Hemostats
Extrinsic action
Surgicel™ (Johnson & Johnson, New Brunswick, NJ)
Mechanical action
Calcium Sulfate Surgiplast™ (ClassImplant, Rome, Italy)

Figure 5.8 Racellet epinephrine containing pellet (Pascal International, Bellevue, WA).

5.3.1.1 Epinephrine Pellets

Racellets are cotton pellets containing racemic epinephrine (Figure 5.8). The amount of epinephrine in each pellet varies according to the number on the box. For example, Racellet #3 pellets contain an average of 0.55 mg racemic epinephrine and Racellet #2 pellets contain 0.2 mg. It has been shown that Racellet #2 did not change the patient's pulse rate when pressed into the bone cavity for 4 minutes. This result is plausible because topically applied epinephrine causes immediate local vasoconstriction with only minimal absorption into the systemic circulation.

A racellet pellet is placed in the bone cavity and packed solidly against the osteotomy wall. In quick succession, several more pellets are packed one by one over the first pellet, filling the entire boney crypt (Figure 5.9). Pressure is applied to these pellets for 1–2 minutes using a blunt instrument.

This is also a good opportunity to let the patient, your assistant, and yourself rest. Remove the retractors, massage the patient's cheek, and have the patient readjust their neck position. This will also allow the flap to rehydrate.

When the retractors are repositioned, all but one of the epinephrine pellets is removed (Figure 5.10). This technique is successful in stopping even the most persistent bleeding. In order to avoid reopening of the ruptured vessels care should be taken to leave the epinephrine pellet inside the osteotomy. The combination of epinephrine and pressure has a synergistic effect, resulting in profound vasoconstriction in the boney crypt. The epinephrine pellet must be removed before the final irrigation and closure of the surgical site.

5.3.1.2 Ferric Sulfate

Another chemical agent used in hemostasis is ferric sulfate (FS). Ferric sulfate is a hemostatic agent that has long been used in restorative dentistry. Unlike other hemostatic agents, FS effects hemostasis through a chemical reaction with blood. Although its mechanism is still unclear, agglutination of blood proteins results from the reaction of blood with both ferric and sulfate ions and the acidic pH (0.21) of the solution. The agglutinated proteins form plugs that

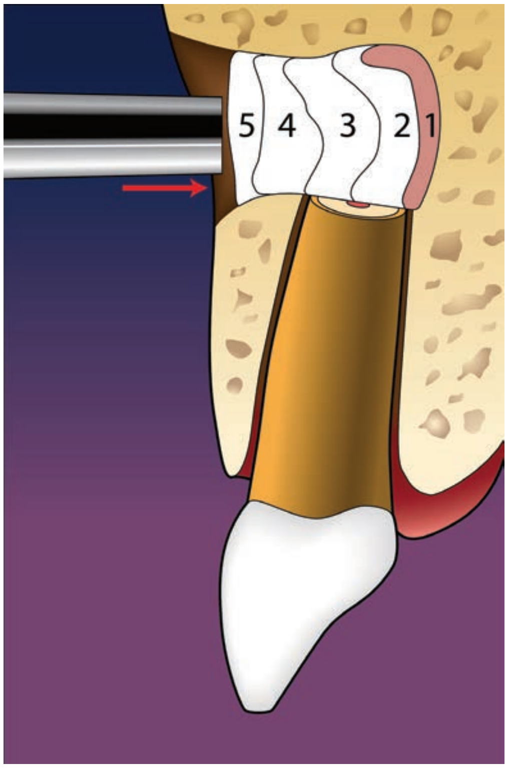

Figure 5.9 Several hemostatic Racellets packed in the osteotomy site and pressure applied for about 2–3 min.

Figure 5.10 Hemostatic pellets removed one by one from the osteotomy site; last one left in for continuous hemostasis.

occlude the capillary orifices. Ferric sulfate is an excellent surface hemostatic agent on the buccal plate for small and slow bleeders. It is easily applied and easily removed by irrigation. The pale yellow FS fluid turns into a dark brown or greenish brown coagulum immediately upon contact with blood and epinephrine. The color differences are useful for identification of the source of any persistent bleeders. Many FS solutions are available, including Cutrol (50% FS), Monsel Sol (70% FS), and Stasis (21% FS).

FS is known to be cytotoxic and to cause tissue necrosis, but systemic absorption of ferric sulfate is unlikely since the coagulum isolates it from the vascular bed. FS has also been found to damage bone and to delay healing when used in large amounts and when left in situ. However, when the FS coagulum is completely removed and the surgical site is thoroughly irrigated with saline before closure, no adverse reactions occur. FS is used for small bleeders within or around the osteotomy site (Figure 5.11). Complete hemostasis is absolutely critical during retrofilling. Brushing FS on to the buccal surface around the boney crypt just before the retrofilling material is placed will ensure hemostasis.

5.4 Summary of Hemostatic Techniques in Endodontic Microsurgery

The first and most important step in achieving good hemostasis is obtaining effective local anesthesia. If the anesthesia is profound, achieving hemostasis during the surgery is a simple task.

The recommended steps are:

1. Administer the local anesthetic, using 2% lidocaine with 1:50 000 epinephrine.
2. Remove all granulation tissue as quickly and aggressively as possible with frequent irrigation of the osteotomy site.
3. Use epinephrine pellets for additional hemostatic control in the osteotomy.
4. Apply ferric sulfate if bleeding continues after the epinephrine pellet technique.

5.5 Postsurgical Phase

Hemostasis has to be maintained even after the surgery. Once the flap has been sutured, a moist sterile gauze is placed over the sutures to control postoperative oozing of blood from the surgical site and to help stabilize the flap. The gauze should be kept in the mucobuccal fold for at least 30 minutes, and an ice pack should be applied to the cheek *frequently*. The patient must be forewarned of a possible rebound

Figure 5.11 Ferric sulfate used for hemostasis on persistent small bleeders during the surgery: (a) 21% ferric sulfate (GingiPak, Camarillo, CA); (b) ferric sulfate being applied with a small cotton pellet.

hemorrhage from the surgical site even hours after the operation. If this occurs, the patient should place a wet tea bag on the surgical site and gently apply an ice pack to the affected cheek. The tannic acid in the tea is an astringent. Combined with gentle pressure and peripheral vasoconstriction by the ice pack, it should stop the bleeding.

When treating aged (50–70 years) white skinned females especially, they must be warned of possible discoloration of the ipsilateral side of the surgical site postoperatively. This postop phenomenon is called Ecchymosis and will disappear in 2–3 weeks and there are no complications associated with this discoloration (Figure 5.12).

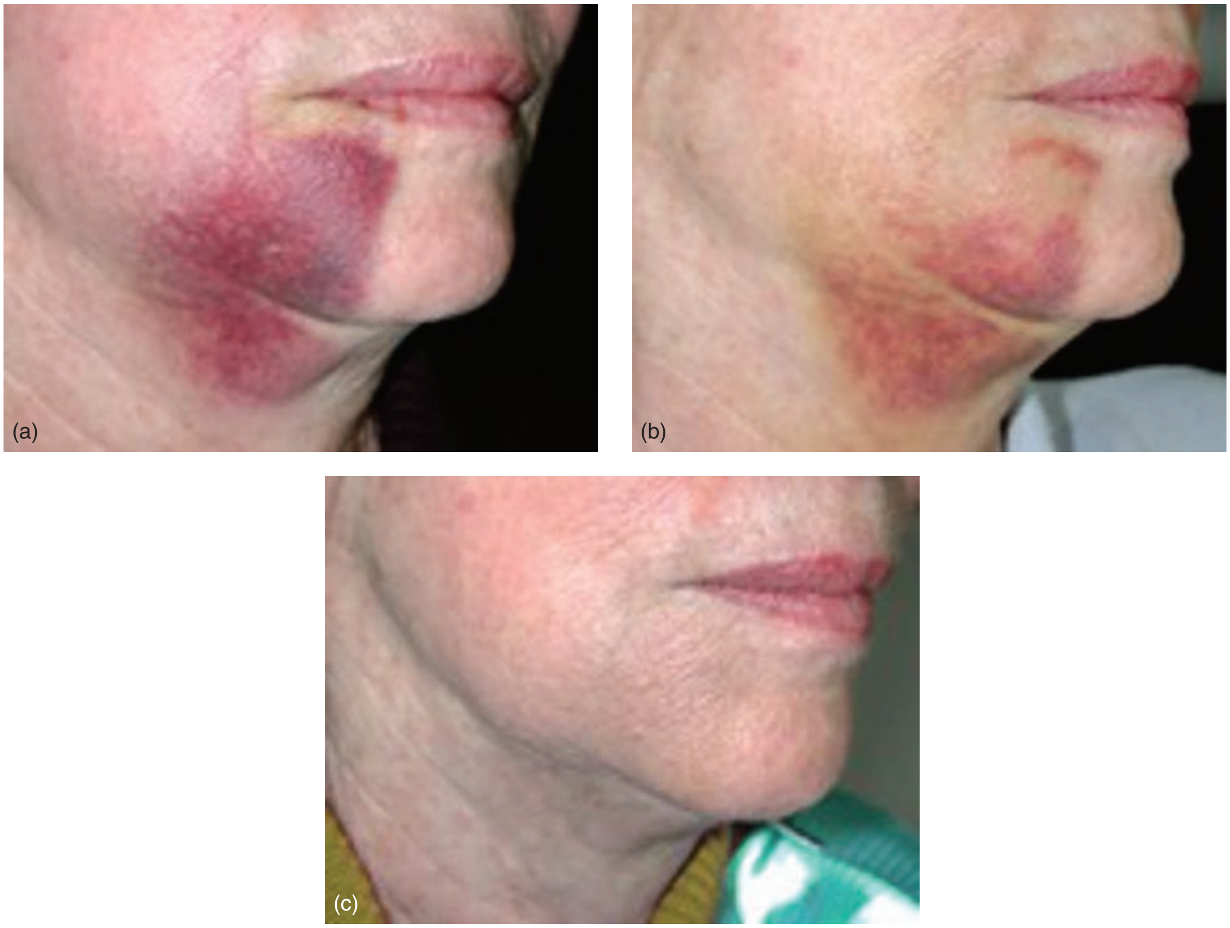

Figure 5.12 Ecchymosis: (a) 4 days after surgery; (b) 1 week after surgery; (c) 3 weeks after surgery.

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6

Flap Design in Endodontic Microsurgery

Francesco Maggiore and Frank Setzer

KEY CONCEPTS

- Two major categories of flap design are an esthetic-oriented submarginal incision and a functional-oriented sulcular incision.
- The triangular or rectangular flap outline depends on the length of the roots, the proximity of anatomical structures, and the convenience to reach the apical area of the treated teeth.
- The vertical incision in the alveolar mucosa should be performed parallel to the orientation of the periostal vessels and placed in the concavity between two root eminences, thus maintaining an adequate blood supply and preventing potential risk of soft tissue necrosis.
- The scalloped submarginal incision should be carried out in the middle of the attached gingiva following the coronal margin of the teeth.

6.1 Armamentarium

- Surgical blades 15C, BB369
- Scalpel handle
- Tissue forceps

A proper flap design and soft tissue management are important to perform endodontic microsurgery appropriately. The primary purposes of the flap design and elevation are to provide adequate surgical access to the underlining bone and root structure and to promote a scar-free soft tissue healing. This procedure should prevent any damage to adjacent anatomical entities. Esthetics and function are two major concepts in dentistry and they also guide the flap design and the soft tissue management in surgical endodontics. In surgical endodontics two major categories of flaps exist:

1. An esthetic-oriented flap to be performed in the anterior region of the mouth that consists of a horizontal submarginal incision together with one or two vertical releasing incisions.
2. A functional-oriented flap to be performed in the posterior region of the mouth, or where otherwise indicated, that consists of a horizontal sulcular incision together with one or two vertical releasing incisions.

Surgery on anterior teeth, due to the position of the roots and root apices, relies on a direct straightforward access to the apical lesion. Furthermore, the esthetics of the soft tissue becomes a priority. In the molar region, esthetics of the soft tissue play a secondary role, with the focus being on a convenient and adequate surgical access to the root apices that allows for a faster and complication-free endodontic surgery.

6.1.1 Flap Outline

There are four major flap designs in endodontic microsurgery (Figure 6.1):

1. Submarginal rectangular flap.
2. Submarginal triangular flap.
3. Sulcular rectangular flap.
4. Sulcular triangular flap.

The flap outline, whether rectangular or triangular, mainly depends on the length of the roots, the proximity of anatomical structures, and the convenience to reach the apical area of the treated tooth or teeth. The rectangular flap consists of two vertical releasing incisions, which are generally placed one tooth mesial and distal to the treated tooth. The rectangular flap is generally used when one or more teeth in the anterior

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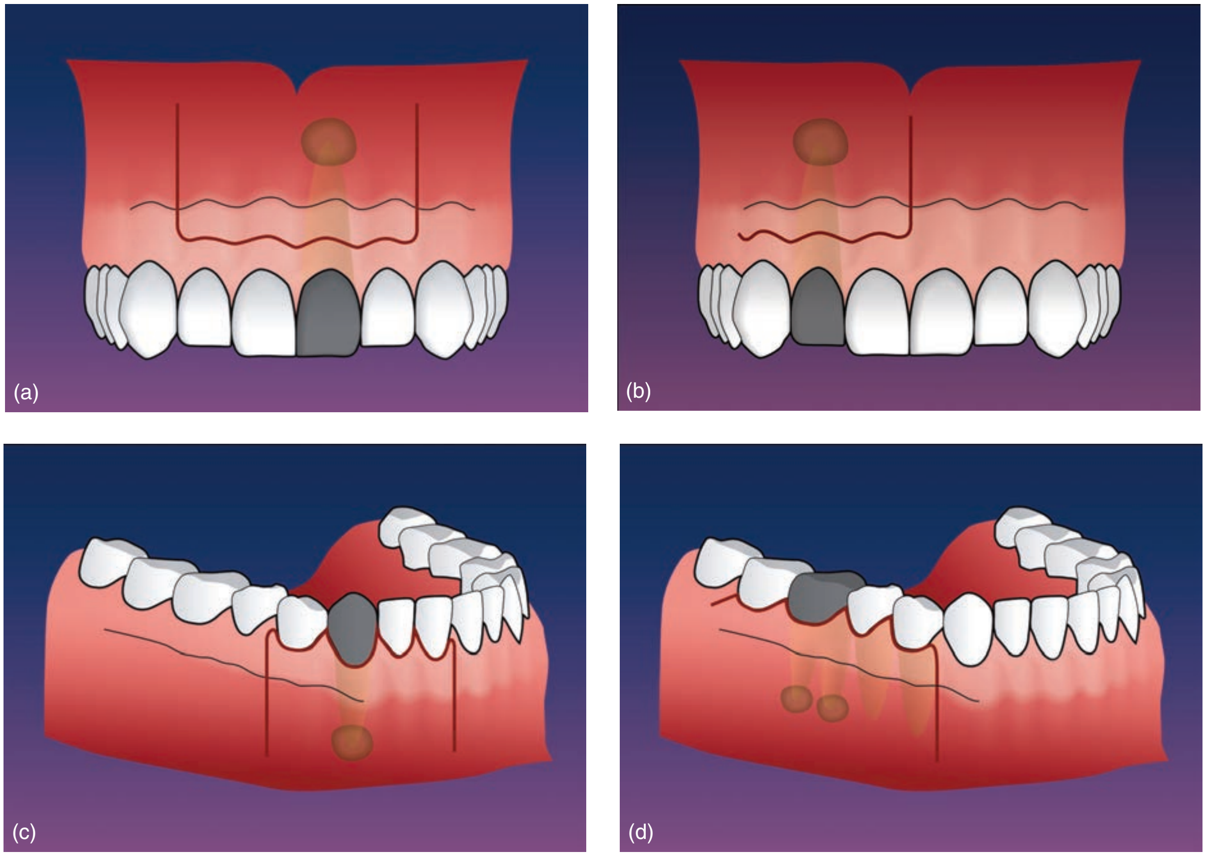

Figure 6.1 Current flap designs in endodontic microsurgery: (a) submarginal rectangular flap; (b) submarginal triangular flap; (c) sulcular rectangular flap; (d) sulcular triangular flap.

region are being treated or when there is a very long root such as an upper canine (Figure 6.1).

The rectangular submarginal type of flap is generally indicated when esthetic concerns play a primary role, such as in the presence of crown-supported anterior teeth (Figure 6.2). The horizontal submarginal incision is performed within the attached gingiva (Figure 6.3). In order to evaluate the attached gingiva correctly, it is advisable to perform periodontal probing

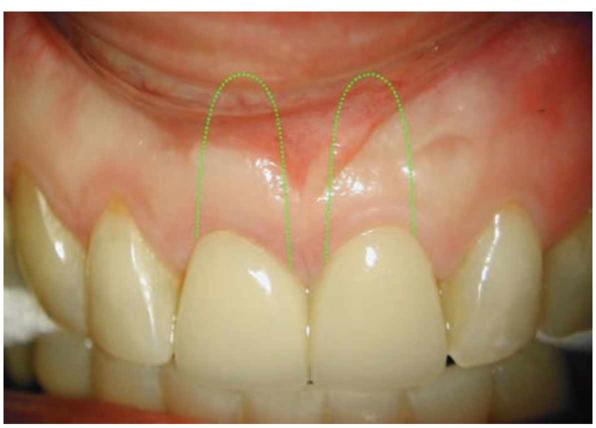

Figure 6.2 The presence of full ceramic crowns on two anterior teeth indicates the need for a submarginal rectangular flap.

Figure 6.3 The horizontal submarginal incision is carried out within the attached gingiva (red line indicates the incision; gray line represents the mucogingival border). The vertical releases are aligned parallel and must never be wider at the base to avoid scarring and allow proper blood supply for all surrounding soft tissues.

of the involved teeth after local anesthesia. When the soft tissues are properly anesthetized the depth of the gingival sulcus and the dimensions of the attached gingiva can be evaluated more accurately.

The triangular submarginal flap design is indicated when treating crown-supported anterior teeth with short roots. A triangular flap is used when the apical region of the treated tooth can be conveniently reached by incising with only one vertical cut. When the intrasulcular flap is properly incised and repositioned, its healing relies on primary intention, even in the presence of crown-supported teeth (Figure 6.4).

A rectangular sulcular incision is generally indicated when the teeth are not covered by crowns, or when it is necessary to completely expose the buccal aspect of the root to check for potential vertical fracture or perforation (Figure 6.1c). The cut is done by inserting the blade into the gingival sulcus, severing the fibers of the periodontal ligament all the way to the crestal bone. The blade fully dissects the papillae and the cut should extend lingually to the mid-col area of the interdental space.

A triangular sulcular flap is very often indicated when the teeth are not covered by crowns and is

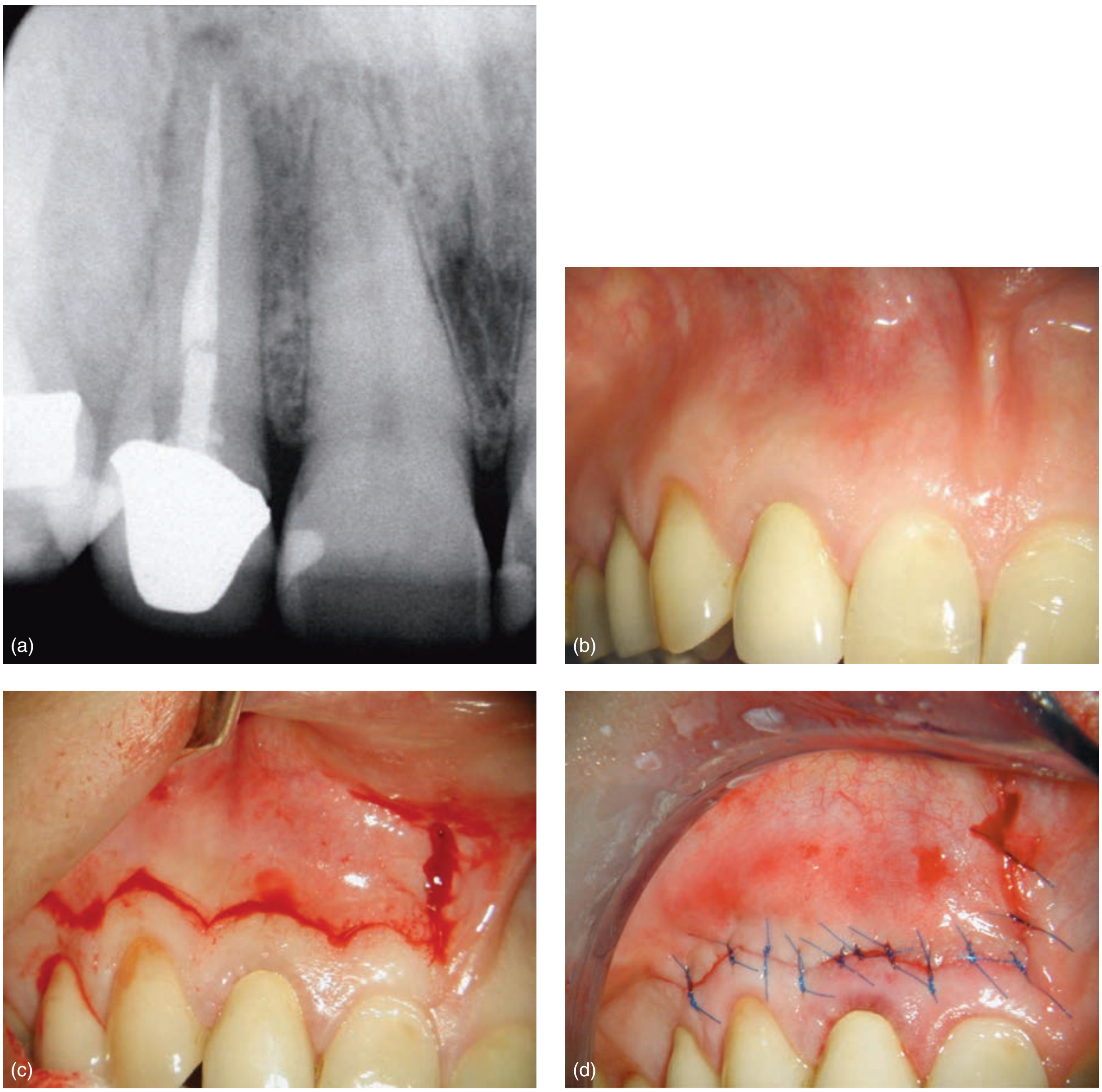

Figure 6.4 Sequence of soft tissue healing after a submarginal triangular flap for microsurgery on a right maxillary lateral incisor: (a) preoperative radiograph; (b) preoperative clinical situation; (c) incision; (d) sutures.

Figure 6.4 (*Continued*) (e) Suture removal 3 days postoperatively; (f) 2 week follow-up; (g) 8 week follow-up.

generally used in the posterior region (Figure 6.1d). When treating mandibular molars and bicuspids, the vertical incision has to be placed one or more teeth mesial to the mental foramen and according to the length and direction of the roots and periosteal blood vessels (Figure 6.5). When the sulcular flap is properly incised and repositioned, its healing relies on primary intention (Figure 6.6).

Particular attention has to be given to the esthetic situation in patients with a high smile line and a thin-scalloped versus a thick-flat periodontal biotype.

6.1.2 Papilla Management

It is critical to properly manage the papillae when they are included in the incision. For a sulcular flap design, the vertical incision should join the horizontal incision lateral to the papilla at a 90 degree angle (Figure 6.7). This kind of junction between the vertical and the horizontal incisions ensures adequate blood supply to both the released and the attached tissues and thus prevents recession of the papilla.

When the papillae are fully elevated a sulcular incision should be placed as far lingually as possible with careful dissection and elevation using dedicated instruments. This will prevent scarring within the

Figure 6.5 Sulcular triangular flap in preparation for surgery on a first mandibular molar.

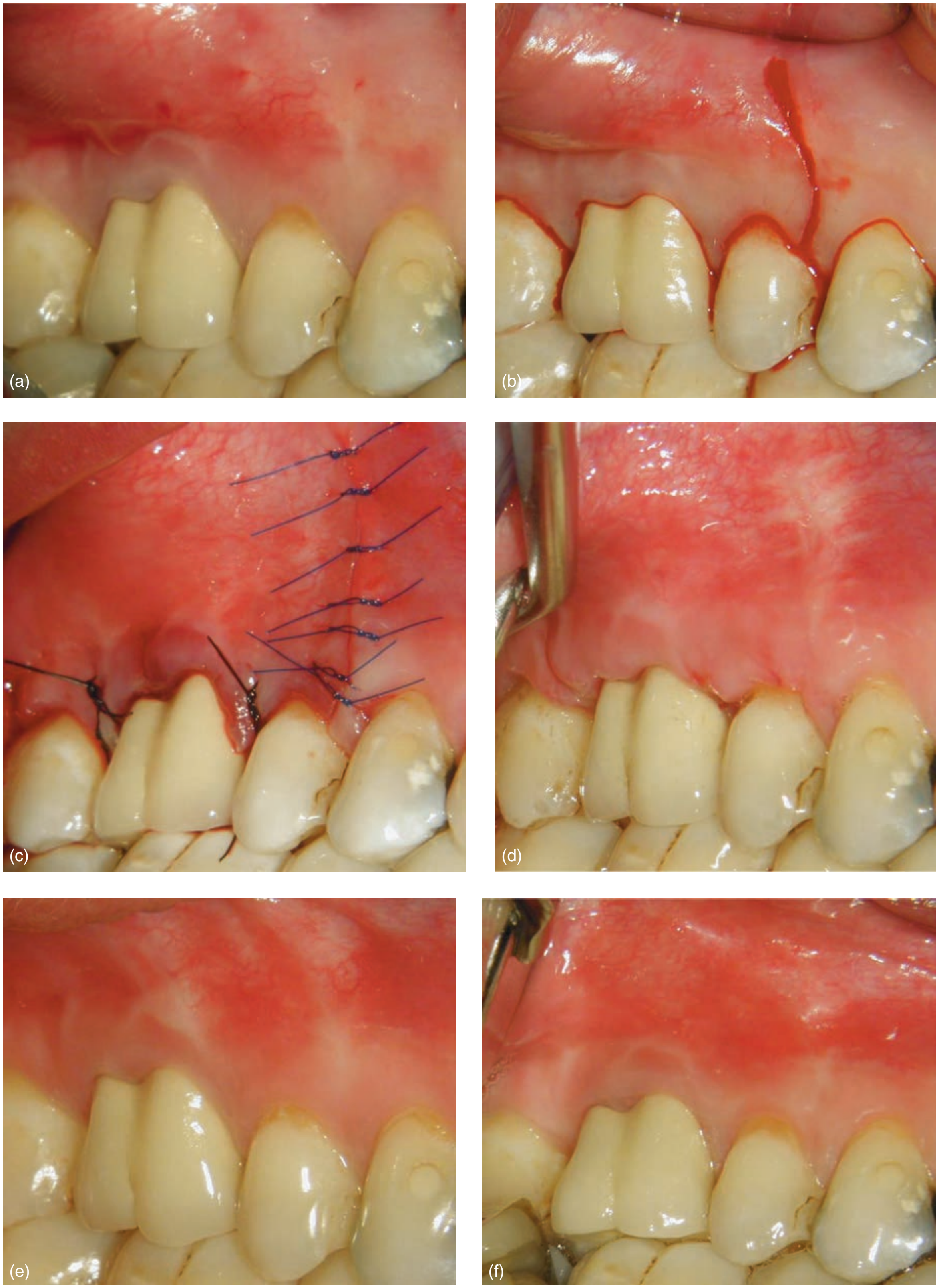

Figure 6.6 Sequence of soft tissue healing after a sulcular incision for microsurgery on a maxillary first molar: (a) preoperative clinical situation; (b) incision; (c) sutures; (d) suture removal 3 days postoperatively; (e) 8 week follow-up; (f) 1 year follow-up; note that no clinical signs of gingival recession are present.

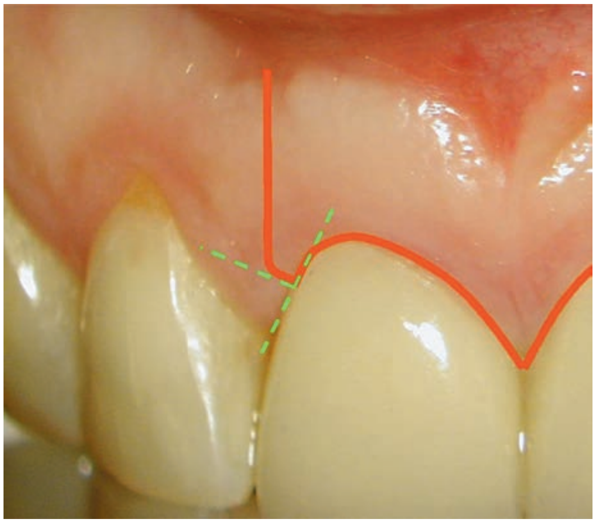

Figure 6.7 For a sulcular incision, the vertical incision joins the horizontal incision lateral to the papilla base at a 90 degree angle.

papilla, a phenomenon known as double papilla formation.

Healing of a fully elevated papilla is usually complication free, and reconstitution of the interdental soft tissues are expected. Papilla recession may occur when the tissue is poorly keratinized, in the presence of a very thin papilla, or when the soft tissues are not carefully managed.

6.1.3 Incision

For an appropriate flap outline any incision must be performed by cutting entirely through attached gingiva, mucosa and periosteum towards the bone. Ideally, this should be achieved in one single stroke. The first 2 mm of the blade provide the actual cutting action and have direct bone contact.

Sulcular and vertical incisions are generally performed using a 15C Bard-Parker blade (Figure 6.8). Submarginal incisions and incisions at the level of the papilla are carried out using either a 15C Bard-Parker blade or a BB369 microblade, depending on the width and size of the papilla (Figure 6.9). A microblade has the advantage of minimizing trauma, especially in the presence of thin or poorly keratinized tissues, which is particularly common in a thin-scalloped periodontal biotype (Figure 6.10). The use of a microblade in combination with proper repositioning and wound closure results in scar-free healing. This is particularly important with surgery on the anterior teeth or when esthetics plays a primary role, as outlined above.

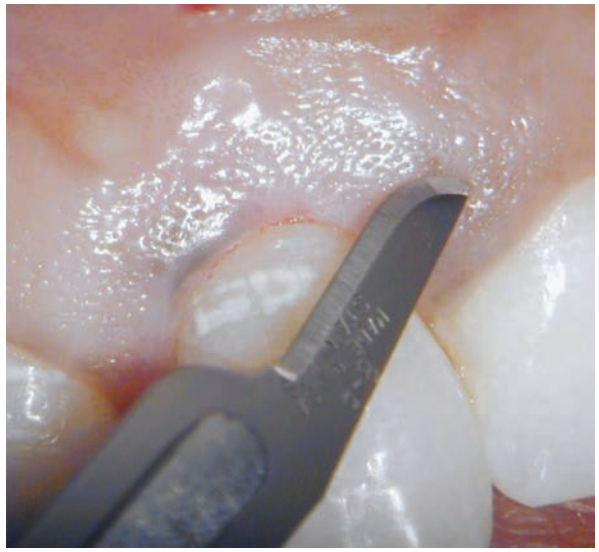

Figure 6.8 15C Bard-Parker blade.

6.1.4 Flap Elevation

Proper management of the soft tissue involves accurate elevation and careful retraction. Once the soft tissue has been incised, the elevation of the flap is carried out by using dedicated instruments that separate the submucosa from the periosteum.

The elevation of the soft tissue progresses horizontally from mesial to distal, in a slow, wiggling, and

Figure 6.9 Microblade indicated in the esthetic zone or in the presence of poorly keratinized tissue.

Figure 6.10 Incision of thin or poorly keratinized tissue using a microblade.

pushing motion, following the contour of the underlying cortical plate. Great care needs to be taken to place the concave part of the instrument facing the bone and the convex part of the instrument facing the submucosa (Figure 6.11).

Particular attention must be given during elevation of the papilla. It is advisable to use small and sharp tissue elevators. Small elevators may enter laterally of the papilla and allow for a lingual progression following the incision with the scalpel. Once a papilla is fully elevated the instrument progresses apically and distally.

6.1.5 Flap Retraction

The retraction of an elevated flap is performed by the surgeon as well as by the assistant. Gentle retraction minimizes the postoperative edema, promotes a complication-free sequela, and contributes to an esthetic healing. In situations with a close proximity to the mental nerve, careful handling of the retractors also minimizes pressure trauma to the nerve tissues that may result in temporary paresthesia as well as edema of the surrounding soft tissues.

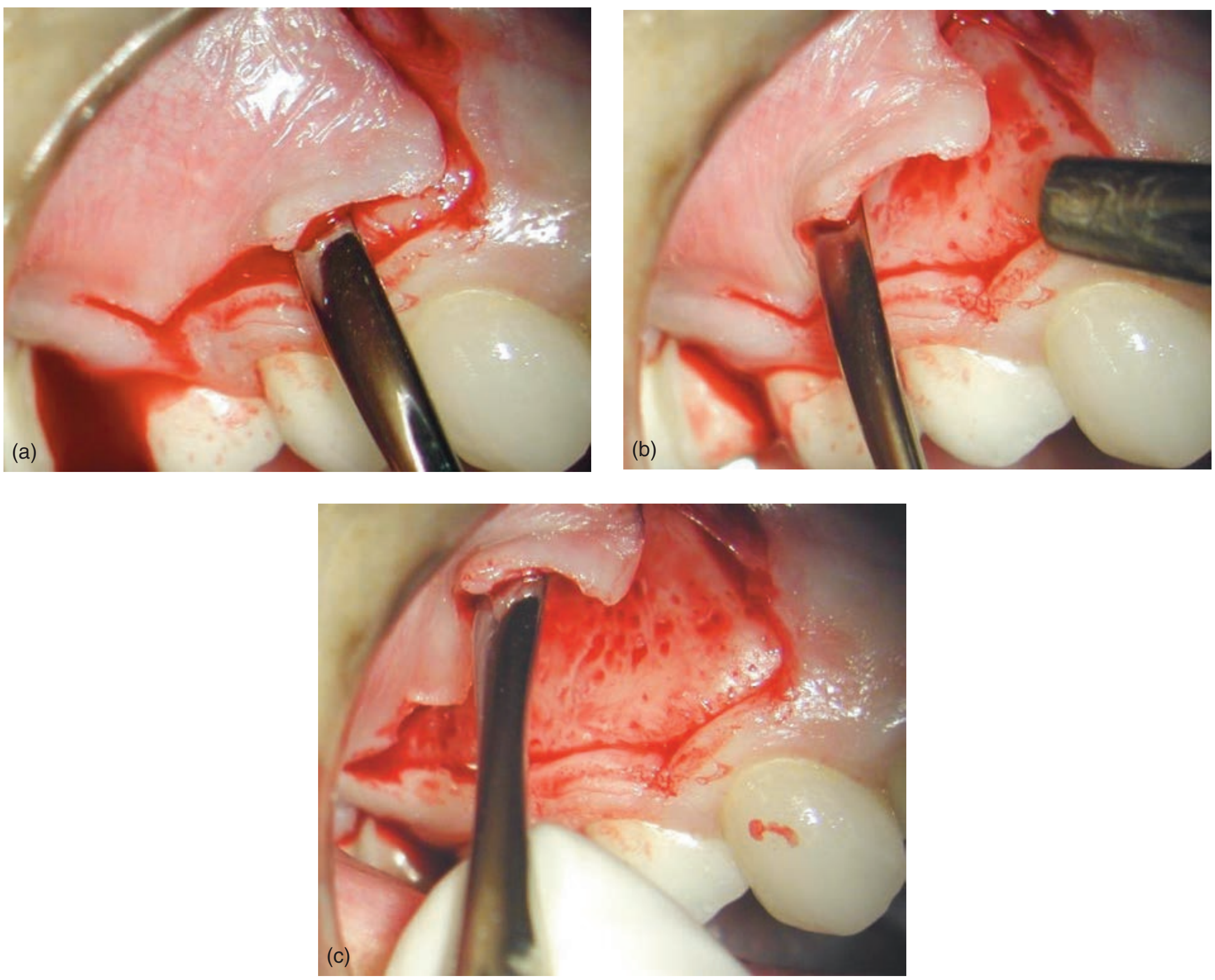

Figure 6.11 Sequence of soft tissue elevation.

Retractors should allow for a good alignment with the anatomical outline of the bony tissues. Anatomical retractors are also characterized by a thin serrated working edge, which is designed according to the contours of the bone, including any eminences and concavities. Proper resting of the instruments on sound bone reduces operator and assistant fatigue and allows for a more efficient and safer procedure.

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7

Osteotomy

Francesco Maggiore and Syngcuk Kim

KEY CONCEPTS

- An osteotomy should be just large enough to accommodate the ultrasonic tip, but no larger than 4 mm in diameter.
- The use of CBCT is an important aid for determining the location and size of the osteotomy.
- An osteotomy should be prepared at the lowest magnification (e.g., ×4).

7.1 Armamentarium

- CBCT
- Lindemann bur
- A 45 degree surgical handpiece
- Micromirrors
- Microexplorers
- Surgical curettes
- Methylene blue dye

7.2 Osteotomy

An osteotomy, which entails the removal of the cortical plate to expose the root end, must be approached deliberately and carefully, so that the osteotomy is made exactly at the apices.

The first step is to take radiographs perpendicular to the roots from two different angles with which to ascertain the length of the roots, the curvature of the roots, the position of the apices in relation to the cusp tips, and the number of roots. Finally, the proximity of the apices to apices of adjacent teeth, the proximity of the mental foramen, the mandibular nerve, and sinus space can be ascertained. However, we are now relying on the CBCT (Figure 7.1). Once the flap has been raised, the mental image of the radiographs should be superimposed on to the cortical plate.

Once the surgeon is sure of the exact location of the apex, the cortical bone is removed slowly and carefully with copious water spray under low magnification. The Lindemann bone cutter and a 45 degree surgical handpiece are best suited for creating an osteotomy (Figure 7.2). The bone cutter bur is specially designed to remove the bone while minimizing the frictional heat. It has fewer flutes than conventional burs, which results in less clogging and more efficient cutting. The advantage of the 45 degree surgical handpiece is that water is directed along the bur shaft, while air is ejected out from the back of the handpiece This creates less splatter than conventional handpieces and decreases the chance of emphysema. The 45 degree angle gives the operator better direct visibility.

7.2.1 Distinction between Bone and Root Tip

The purpose of using the microscope for making the osteotomy is to clearly distinguish the root tip from the surrounding bone. The root has a darker, yellowish color, and is hard, whereas the bone is white, soft, and bleeds when scraped with a probe. When the root tip cannot be distinguished from its surroundings, the osteotomy site is stained with methylene blue, which preferentially stains the periodontal ligament (see Chapter 10). The absence of a distinct PDL stain at medium magnification (×10 to ×12) indicates that the root tip is very small in relation to the osteotomy. The surgeon must be very observant for even the smallest irregularity in the bone, which is usually the root tip. The advantage of using the microscope for this procedure is the minimal removal of healthy bone structure. This more conservative osteotomy generally results in faster healing and, as a result, greater patient comfort. Stages of creating an osteotomy under the microscope are shown in Figure 7.3. The main reason for using the microscope at this stage is to identify the root tip and thus to minimize the unnecessary removal of cortical bone. This procedure perfectly illustrates the

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Figure 7.1 Use of CBCT: (a) a sagittal view from a CBCT image of tooth #19 measuring the distance from the mental foramen; (b) a coronal view from a CBCT image of tooth #19 measuring the distance from buccal plate to the lingual surface of the root; (c) an axial view from a CBCT image of tooth #19 measuring the distance from the buccal plate to the lingual surface of both mesial and distal roots.

main principle of microsurgery: the complete removal of pathology with minimum removal of or damage to healthy tissue structures.

7.2.2 Clinical Situations for Endodontic Microsurgery

The three most common clinical situations for endodontic microsurgery are the following:

1. An intact cortical plate with a very small or no periapical lesion.
2. An intact cortical plate with a distinct periapical lesion.
3. A fenestration through the cortical plate leading to the apex.

The first two cases fall into Classifications A, B, and C of apical surgery, while the third case reflects Classifications D, E, and F (see Chapter 1).

Figure 7.2 A 45 degree surgical handpiece (Brasseler, USA) with a Lindemann bone cutter bur.

7.3 Intact Cortical Plate without a Radiographic Periapical Lesion

Surgery is generally not performed if a periapical lesion does not appear on the radiograph or CBCT. An exception is a patient with undiminished discomfort after endodontic treatment or a tooth with procedural errors that cannot be corrected without surgery. In most cases, persistent discomfort, sensitivity to percussion, and palpation are equally important indicators for periapical pathology. The use of CBCT is necessary for discovering such lesions.

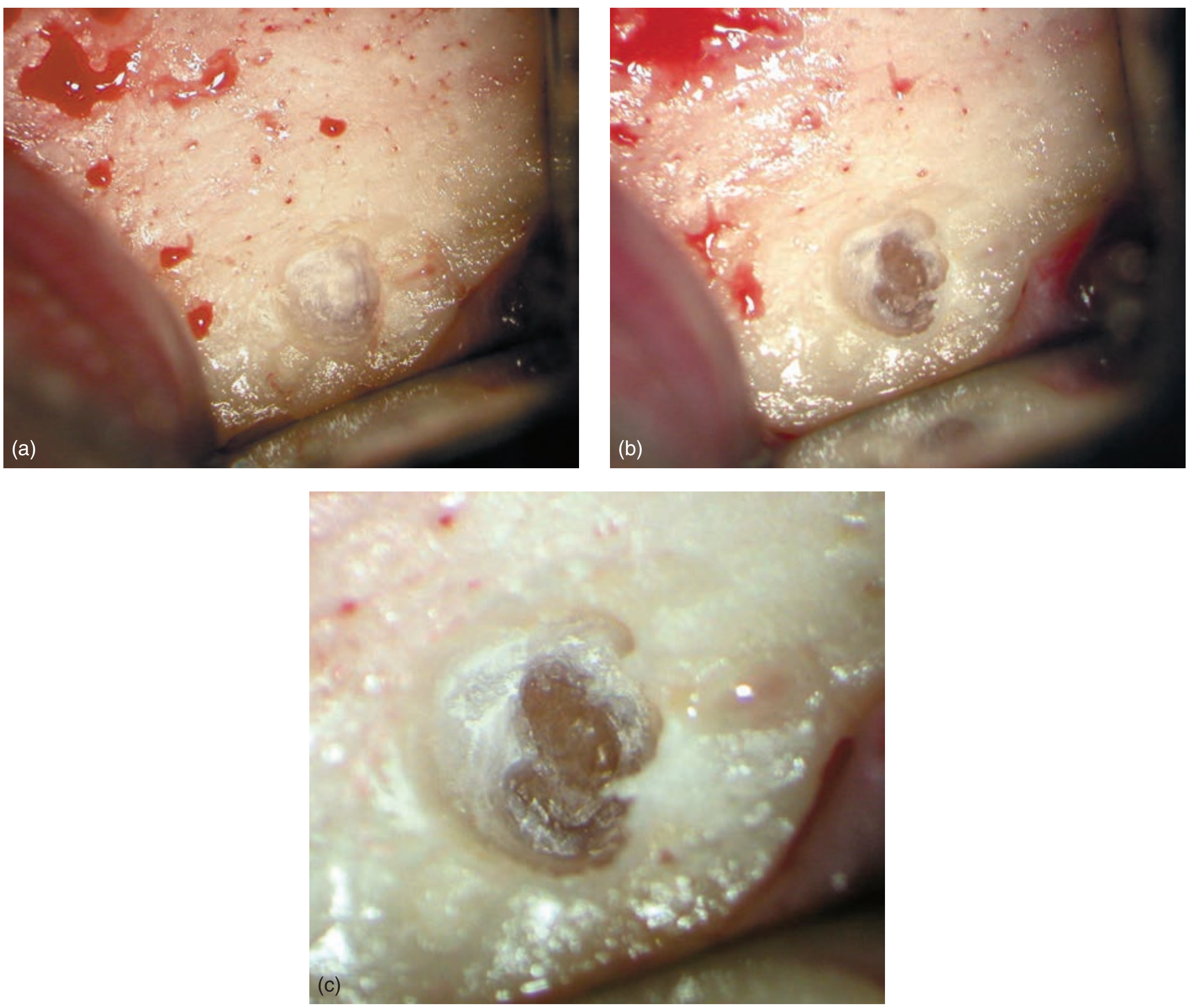

Figure 7.3 Osteotomy: (a) a small initial osteotomy and root tip are hardly visible at ×2; (b) the root has a darker, yellowish color, and is hard, whereas the bone is white; (c) root tip is clearly visible.

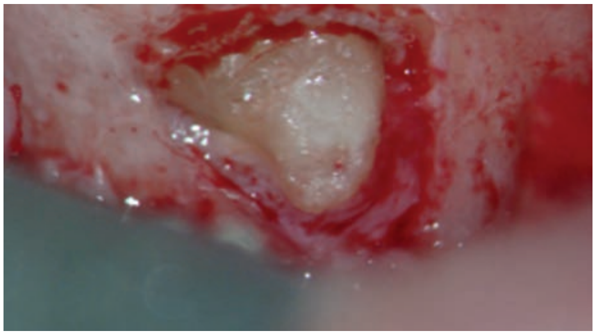

Figure 7.4 Apical fenestration. The root tip is sticking out of the cortical bone.

From a surgical standpoint, the mandibular molar region is the most challenging because the surgeon must be certain of the exact location of the apex. A good analogy is a diver descending to a target through muddy waters. It is not uncommon for an osteotomy to become excessively large because of difficulty in identifying the root apex. As described in the previous section, using the CBCT, multiple angled radiographs and a radiopaque marker along with methylene blue staining are essential aids for accurately determining the position of the apices and for making a conservative osteotomy. The root length and position of the root tip in relation to the cusp tip and to the adjacent roots should be ascertained by CBCT before making the osteotomy (Figure 7.1).

7.4 Intact Cortical Plate with a Periapical Lesion

The intact cortical plate with a periapical lesion is the most common situation in surgical endodontics. In many cases, a probe will penetrate through the thinned cortical bone to the lesion. This thin cortical plate is removed with a minirongeur or curettes. Subsequently, the boundary of the lesion is defined with a 45 degree surgical handpiece and copious water coolant, and the soft tissue removed. Occasionally, the cortical plate overlaying the lesion is thick and appears to be intact. Puncturing the bone with a Lindemann in a 45 degree surgical handpiece will provide an important landmark from which the osteotomy can be carefully enlarged. The size of the lesion is always larger than it appears on the radiograph. This phenomenon is a result of the fact that the lesion begins in the medullary bone and progresses to the cortical bone, where the damage is therefore smaller.

7.5 Fenestration through the Cortical Plate Leading to the Apex

If the fistula exists directly over the affected root, the procedure is a simple one. The osteotomy can be performed quickly and precisely by following the fistula tract and extending the osteotomy to expose the lesion and provide access for the retropreparation (Figure 7.4). However, in many situations fistulas do

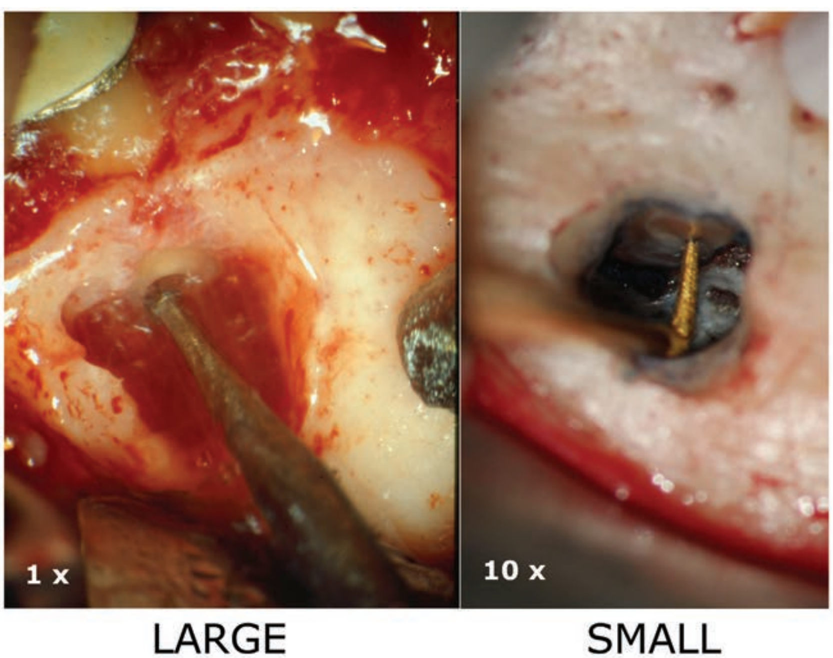

Figure 7.5 Comparison of osteotomies made with standard surgical instruments (left, ×1) and microsurgical instrument (right, ×10). The new techniques result in a significantly smaller osteotomy.

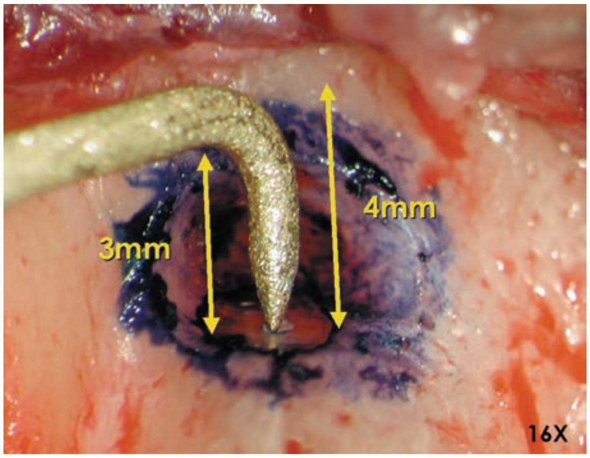

Figure 7.6 The ideal osteotomy is no larger than 4 mm in diameter to accommodate the 3-mm long ultrasonic tip in the bone crypt. The osteotomy is small but large enough to accommodate the ultrasonic tip.

not exit at the locus of the pathology but near an adjacent tooth. In this case, to avoid excess removal of healthy bone, careful measurements using CBCT are necessary to prepare the osteotomy directly over the root.

7.5.1 Optimal Osteotomy Size

The size of an osteotomy depends primarily on the size of the instruments. Traditional endodontic surgery uses relatively large instruments. Consequently, the size of the osteotomy will be large – approximately 10 mm in diameter to allow the surgeon to view and treat the apices with a conventional mirror and a microhandpiece (Figure 7.5). The removal of so much healthy buccal plate has a cost: healing is always slower and often painful, and incomplete healing often causes postoperative complications.

The microscope has also changed perceptions. Since even a small osteotomy looks large at higher magnifications (×8 to ×16), there is a tendency to want to make the osteotomy even smaller. With the availability of microsurgical instruments, the size criteria for an osteotomy is just large enough to manipulate ultrasonic tips freely within the boney crypt. Since the length of an ultrasonic tip is 3 mm, the ideal diameter of an osteotomy is about 4 mm, leaving just enough space to manipulate the ultrasonic tip and microinstruments within its confines (Figure 7.6).

7.5.2 Key Hole Osteotomy Modification

In some cases, a retrograde deeper than 3 mm into the canal is indicated, especially when performing apical surgeries on anterior teeth. Retrograde ultrasonic tips that can be as long as 9 mm may be used for such preparations (Figure 7.7). Such tips will not fit in the 4 mm osteotomy suggested by the authors. A key hole modification to the osteotomy by creating a narrow vertical extension of the osteotomy in an apical direction will create enough space to fit the tip with minimum osseous tissue removal (Figure 7.8).

7.5.3 Bone Window Technique

In cases where there is no detectable buccal cortical plate fenestration, or where a thick cortical plate is expected, e.g., mandibular second molars, the authors suggest a new technique, which aims at preserving the buccal cortical plate and promotes faster healing. A piezo surgery device is used (W&H Piezomed,

Figure 7.7 Ultrasonic tips of varying lengths: 3 mm, 6 mm, and 9 mm.

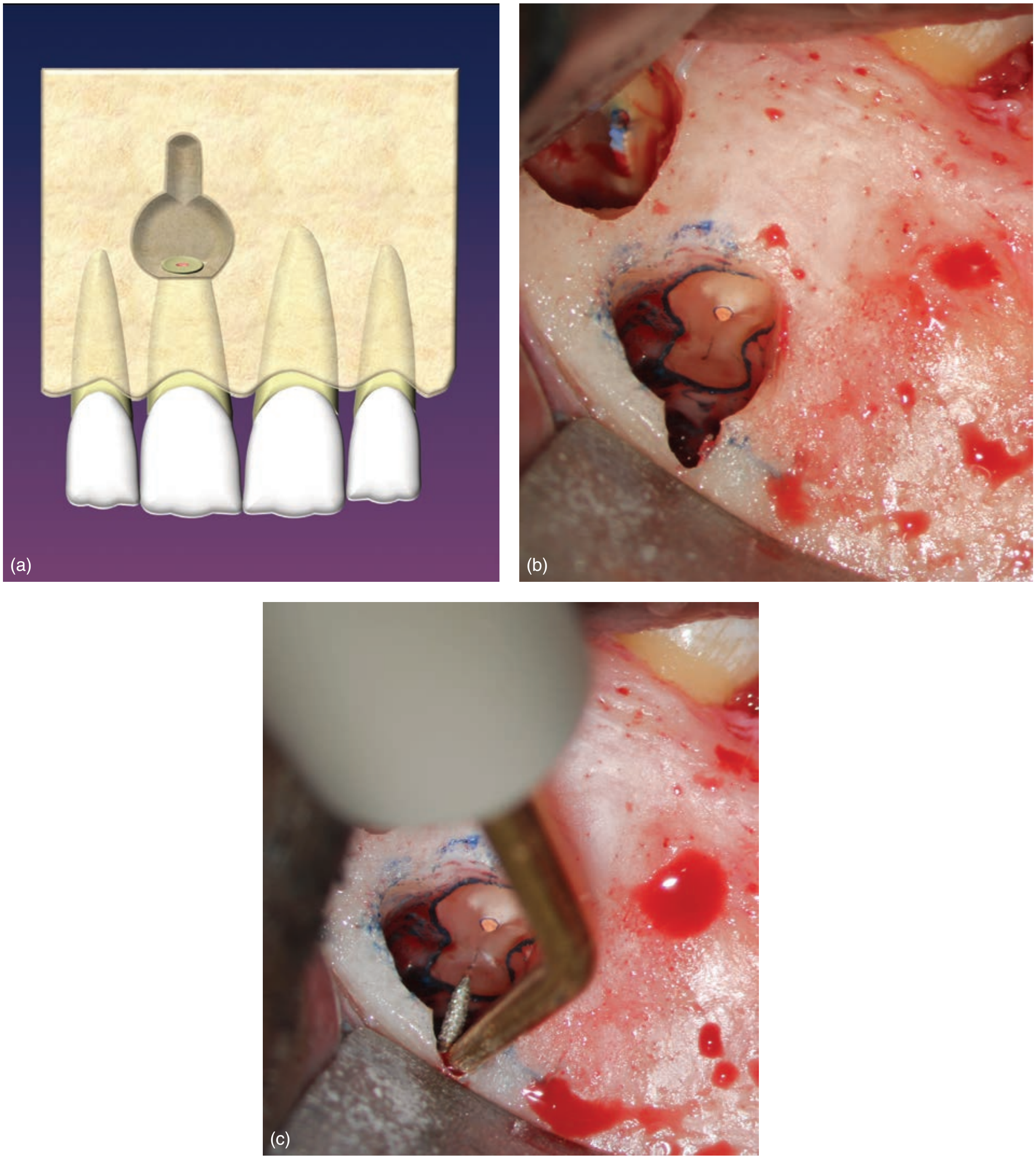

Figure 7.8 (a) Schematic drawing that illustrates the key hole osteotomy modification to accommodate the longer tip without enlarging osteotomy size. (b) Key hole modification on an osteotomy for the mesial root tooth #30. The key hole modification will allow the ultrasonic tip to approach the roots without excessively sacrificing any extra bone structure. (Figure 7.8b and c are courtesy of Dr Kaname Yokota.)

Austria), which resects osseous tissues with high precision while the surrounding soft tissue remains uninjured. Newly designed longer fine-toothed saw tips of 10 mm are used to create a rectangular-shaped bone window to uncover the area of the lesion and the apices of the roots (Figure 7.9). The buccal window walls should be cut in a way that they converge from the exterior surface toward the interior surface, creating a resting seat that prevents the plate from sinking internally when repositioned. Two small round holes

Figure 7.9 W&H Piezome instruments. Fine-toothed saw for fine cuts with 8 mm and 10 mm depth, with little bone loss when harvesting bone blocks.

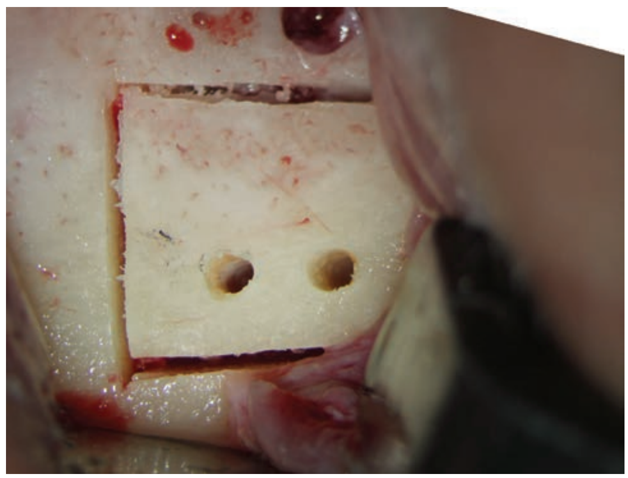

Figure 7.10 A rectangular window is cut in the buccal cortical plate using Piezomed instruments. Two holes were made to facilitate blood circulation during healing.

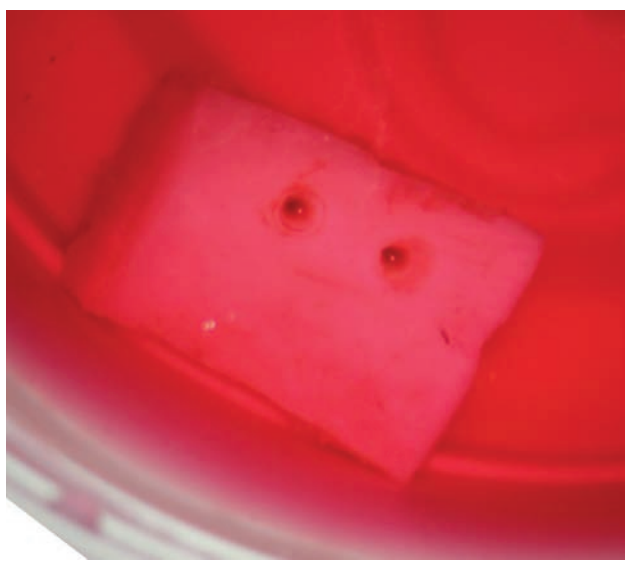

Figure 7.11 The removed bone window is stored in HBSS solution until the end of the procedure.

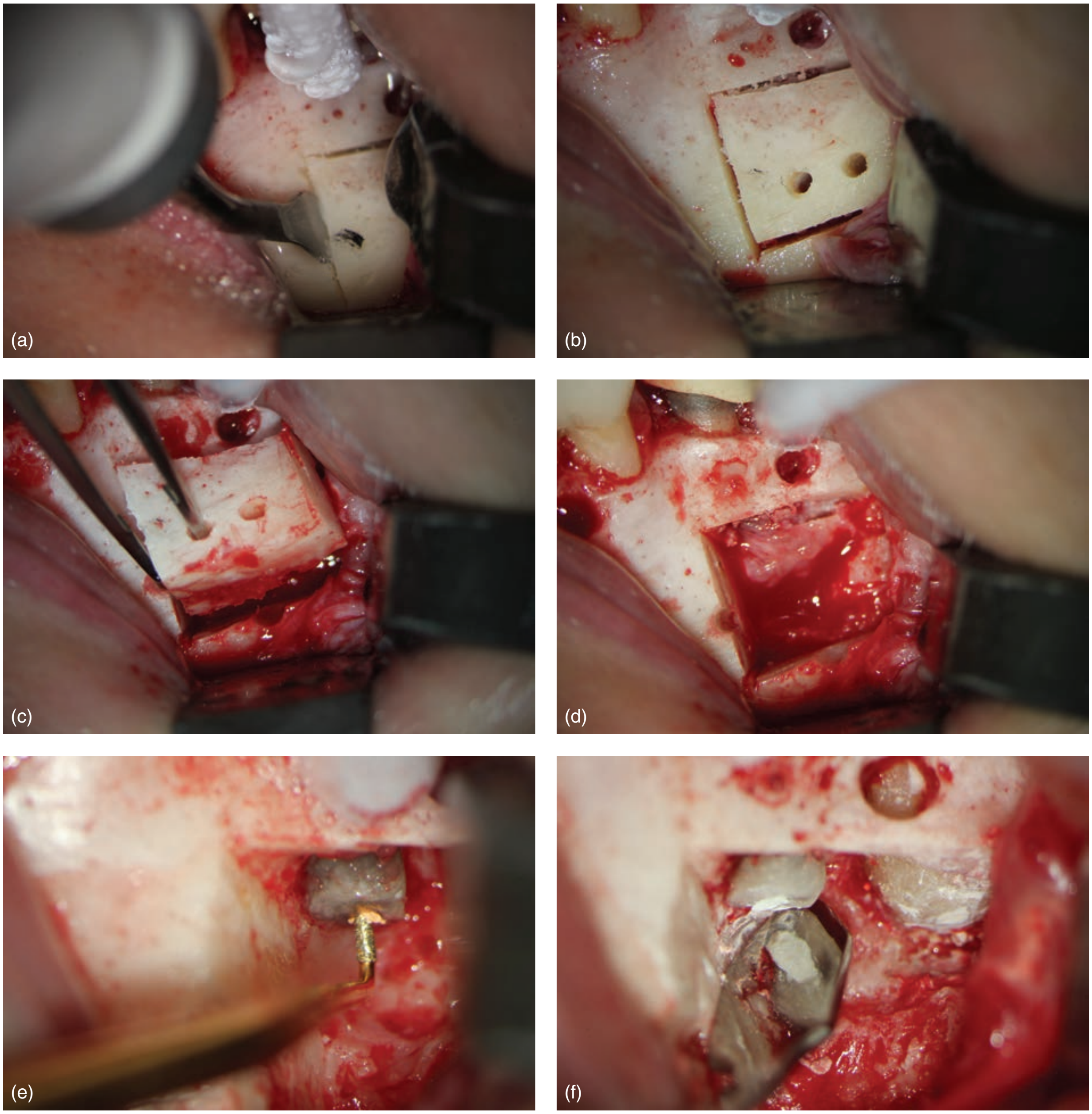

Figure 7.12 Step by step bone window procedure: (a) bone saw preparing window; (b) bone window completed; (c) bone window being removed; (d) granulation tissue exposed; (e) ultrasonic preparation of resected root tip; (f) Bioceramic root end filling.

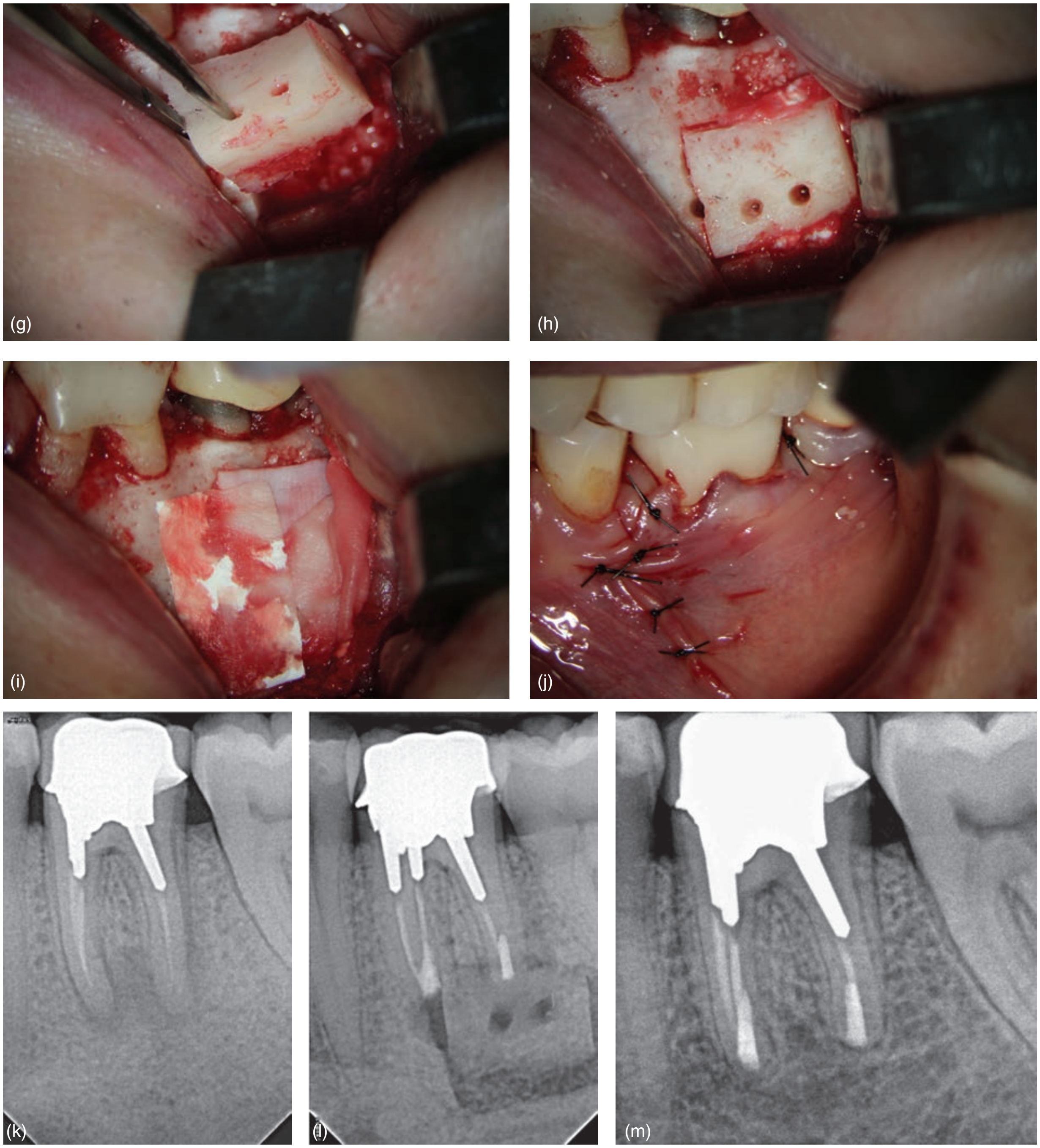

Figure 7.12 (*Continued*) (g) Bone window being replaced; (h) bone window replaced wedging in collagen membrane; (i) two collagen membranes placed over the bone window; (j) sutures placed; (k) pre operative radiograph; (l) post operative radiograph; (m) three year recall radiograh.

are created in the plate before removing it. These holes will later help with maintaining good circulation of the surgical site (Figure 7.10).

The bone window piece is placed in the Hanks balanced salt solution (HBSS) (Lonza Walkersville Inc., Maryland) until the end of the surgical procedure (Figure 7.11). When the apical procedure is completed, the buccal bone plate is repositioned, stabilized using a membrane, and covered with a resorbable membrane before repositioning the flap. Caution is given to the patient not to press the bone window during the healing period (Figure 7.12).

8

Root End Resection

Spyros Floratos, Fouad Al-Malki, and Syngcuk Kim

KEY CONCEPTS

- A root resection of 3 mm from the apex is indicated and should be made perpendicular to the long axis of the root.
- Root resection should be done at a midrange magnification (e.g., ×10).
- The bevel angle of root resection should be shallow, from 0 to 10 degrees.
- Apical curettage addresses only the symptoms of pathology, not the cause.

8.1 Armamentarium

- 45 degree surgical handpiece: NSK (Brasseler, USA) and Morita
- Lindemann burs
- Microexcavators
- Methylene blue dye

8.2 Root End Resection

Once the granulation tissue is removed to the extent where the root apex is clearly identified (Figure 8.1), 3 mm of the root tip is resected perpendicular to the long axis of the root. To perform this effectively, a Lindemann bur should be used in a 45 degree angled handpiece (TwinPower Turbine 45 (Morita, Japan), N45S (Brasseler, USA) or similarly angled handpiece using copious water spray. As a practical rule, 3 mm of root resection equals approximately twice the width of a Lindemann bur (Figure 8.2).

After resecting the root end, complete removal of all granulation tissue is facilitated, as there is often remaining granulation tissue behind the root tip.

Endodontic literature over the last two decades supports several reasons for resection of the apical part of the root during periapical surgery:

- Removal of pathologic processes.
- Removal of anatomic variations (apical deltas, accessory canals, apical ramifications, severe curves).
- Removal of iatrogenic mishaps (ledges, blockages, perforations, strip perforations, separated instruments).
- Enhanced removal of the granulation tissue.
- Access to the canal system when the coronal access is blocked or when coronal access with non-surgical

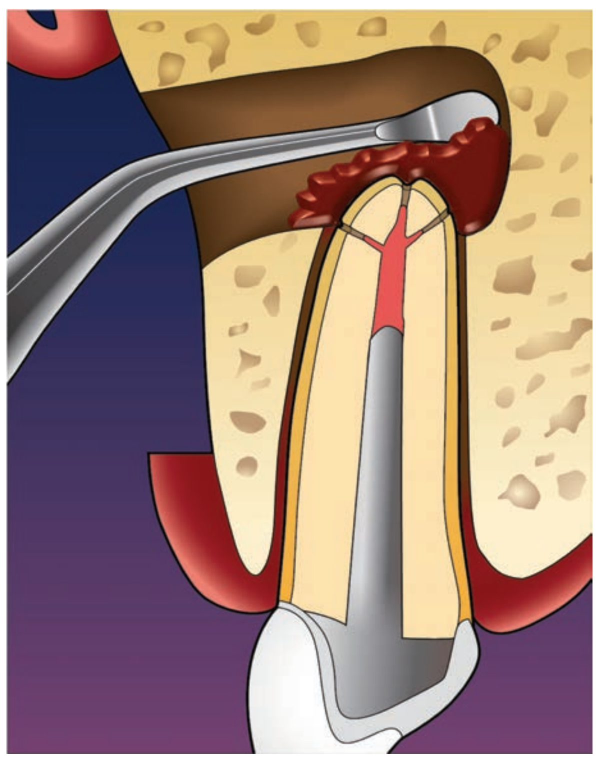

Figure 8.1 Granulation tissue is removed to the extent where the root apex is clearly identified.

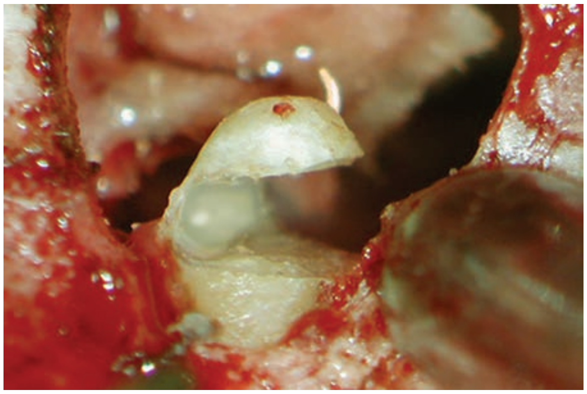

Figure 8.2 3 mm of the root end of tooth #6 is resected (magnification ×10). (Courtesy of Dr Francesco Maggiore.)

retreatment is determined to be impractical, time consuming, and too invasive.

- Creation of an apical seal.
- Evaluation of the apical seal.
- Reduction of fenestrated root apices. This mainly occurs in maxillary premolars and maxillary first molars but can occur anywhere in the dentition. It is associated with symptoms of tenderness on palpation at the site of the fenestration. In such cases, fenestrated apices are resected to the level of the bone, so that the whole root circumference is encased by bone. This will result in the roots being completely covered by bone after healing, which most often leads to elimination of preoperative symptoms.
- Evaluation for complete or incomplete vertical root fractures. The presence of a fracture can explain cases where the root canal obturation is judged satisfactory radiographically but there is persistence of clinical symptoms. Root end resection, staining with a dye such as methylene blue (Vista Dental, Racine, WI, USA), and inspection will expose these fractures that are otherwise not detected on the preoperative radiograph (see the section on inspection in Chapter 9).

There was no consensus concerning the amount of root that should be resected. An anatomical study of the root apex conducted at the University of Pennsylvania revealed that at least 3 mm of the root end must be removed to reduce 98% of the apical ramifications and 93% of the lateral canals (Figure 8.3).

The 3-mm rule of root resection does not apply to certain situations where a number of variables must be evaluated. The proximity of the root tip to the mandibular canal, the mental nerve, or the sinus membrane, for example, may necessitate a more coronal root resection to avoid interfering with those anatomical entities.

Roots that are inclined lingually may require more than 3 mm of root end resection in order to visualize all anatomical structures. The same principle applies for roots that present with a cortical bone fenestration, mainly maxillary premolars and molars. Other factors such as the shape of the root, presence of multiple accessory canals at the level of resection, thickness of dentinal walls, presence and location of a perforation, ledge or separated instrument, the apical extent of a post, or any hard setting material may dictate the level of root resection (Figure 8.4).

The level of crestal bone and the presence of periodontal defects should also be considered before deciding on the level of root resection. Finally, the elimination of an incomplete vertical fracture line may also require cutting more than 3 mm of root (see management of vertical root fractures in the section on inspection in Chapter 9).

In order to verify a complete resection of the root tip, the root surface has to be stained with methylene

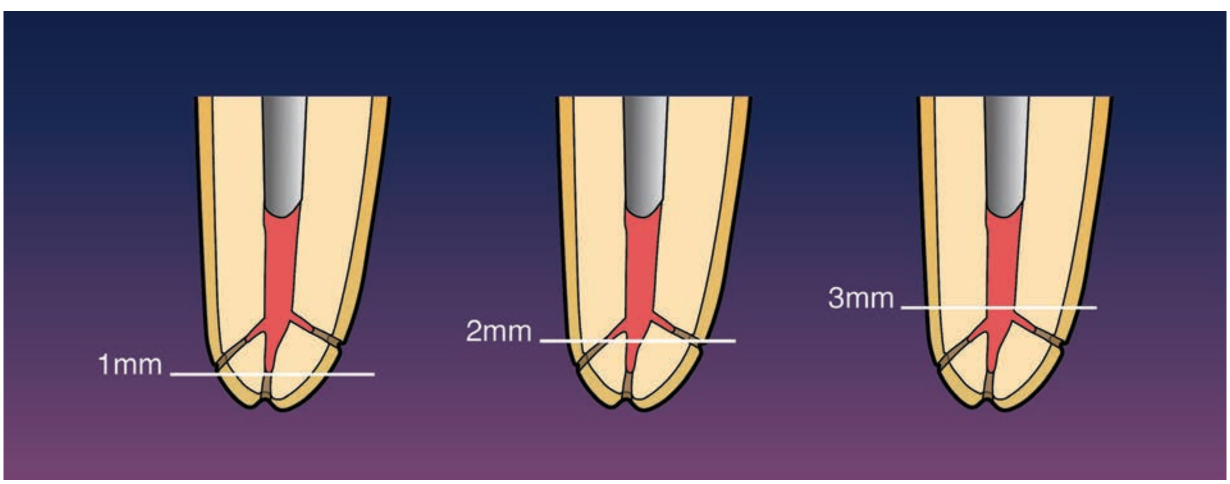

Figure 8.3 Removal or the apical 3 mm end of the root eliminates 98% of the apical ramifications and 93% of the lateral canals.

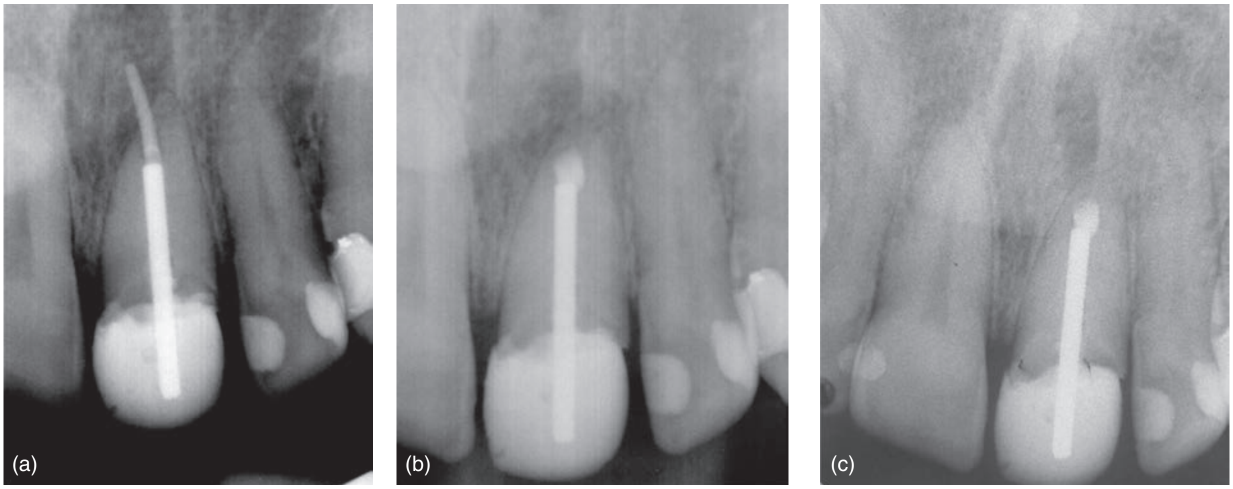

Figure 8.4 Central incisior with extruded gutta percha. (a) Preoperative radiograph of tooth #9 with guttapercha overfilling. A 3 mm root end resection would be at the level of the post. Therefore, 1.5 mm of the root tip is resected. (b) Postoperative radiograph showing MTA root end filling. (c) Radiograph taken 6 months after treatment, revealing complete bone healing.

blue and inspected under a medium magnification (×10 to ×12) for the presence of the periodontal ligament (PDL) (see the section on methylene blue staining which is mostly addressed in Chapter 9). When a complete root end resection has been done, the PDL appears as an uninterrupted circular line around the root surface (Figure 8.5).

A partially disrupted line indicates that only part of the root has been resected (Figure 8.6).

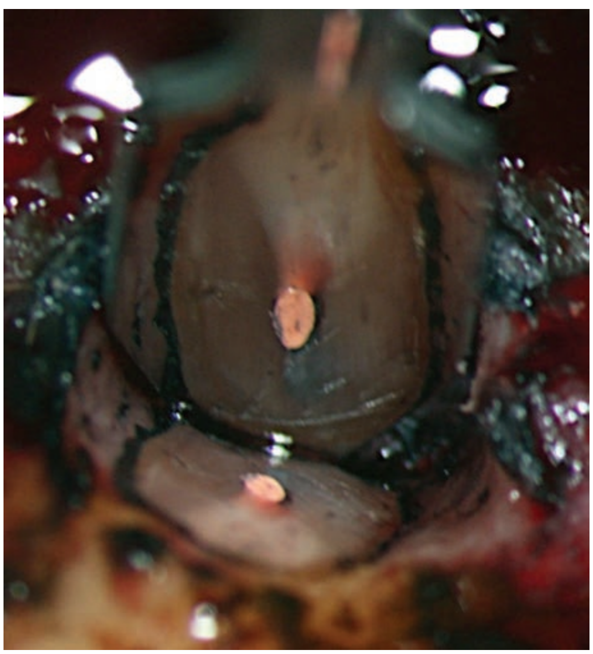

Figure 8.5 Periapical surgery on tooth #7. After methylene blue staining, the PDL appears as an uninterrupted circular line around the root surface (magnification ×16).

In this case, resection must extend deeper lingually and probably more coronally. Incomplete root resection is one of the most common reasons for failure of a surgery. CBCT would best display the depth and thickness of a root end at the 3 mm level.

8.3 Root End Resection: Steep Bevel versus Shallow Bevel

With a traditional surgical technique, it was recommended that the angle of root end resection should be 45 degrees to 60 degrees from the long axis of the root facing toward the buccal or facial aspect of the root. The single purpose for this steep bevel was to provide enhanced direct visibility to the cut root surface and allow the surgeon to perform a root end preparation with a bur in a high or slow speed, angled handpiece. However, there is no biological justification for creating a steep bevel on the resected root end. The steeper the bevel, the more potential for one of the following complications to occur:

- Damage to or unnecessary removal of buccal supporting bone. A common reason for failure of surgery was a large osteotomy and an acute bevel angle with resultant endodontic-periodontal communication. With the use of modern microsurgical instruments and the surgical operating microscope, this need for an excessive removal of healthy bone is no longer justified.
- Incomplete root resection (Figure 8.7). This can lead to missing the main canals entirely or missing any lateral canals or ramifications. This can

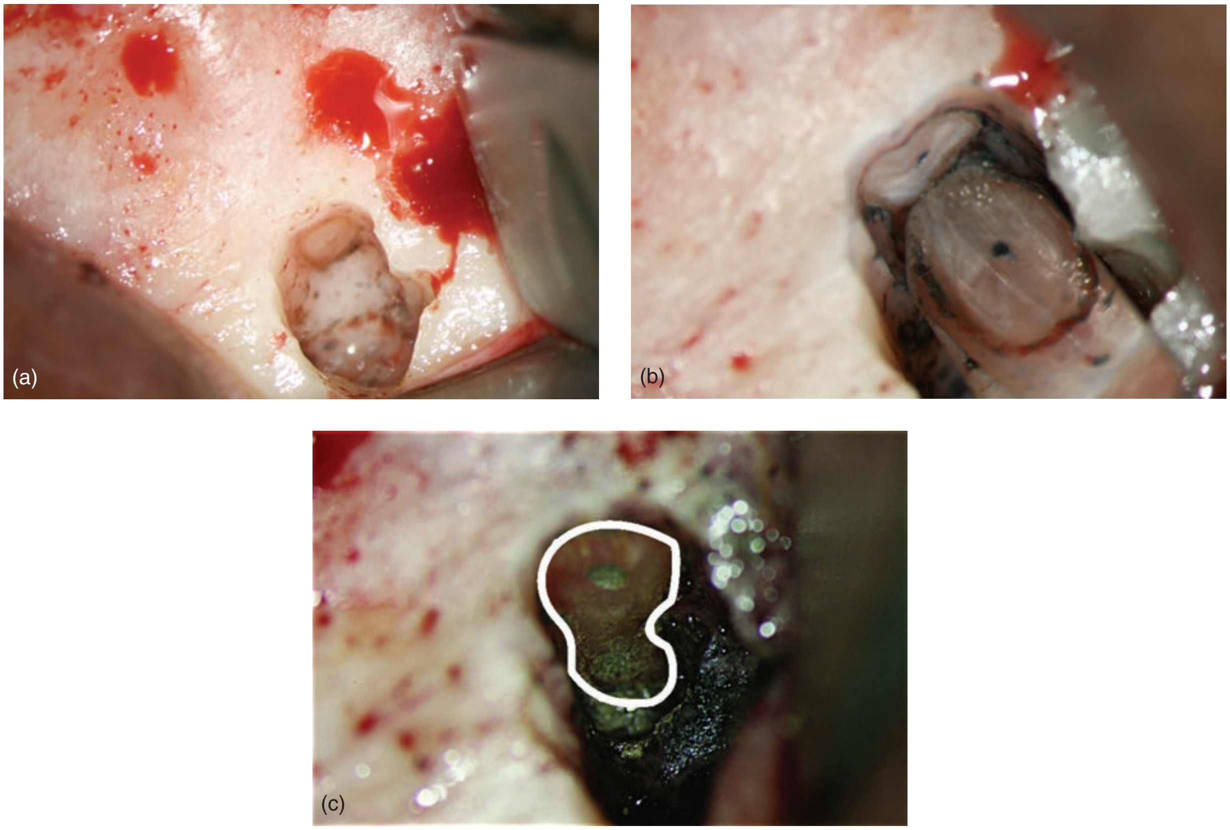

Figure 8.6 Periapical surgery on tooth #19. (a) Partial root resection of the mesial root (magnification ×8). (b) The resected root surface is stained with methylene blue and inspected. The outline of the periodontal ligament (PDL) is disrupted on the lingual aspect of the root. Also, only the buccal canal is stained. Further resection in a lingual direction is needed (magnification ×16). (c) Direct view of the root end filling shows the complete circumference of the root (magnification ×16).

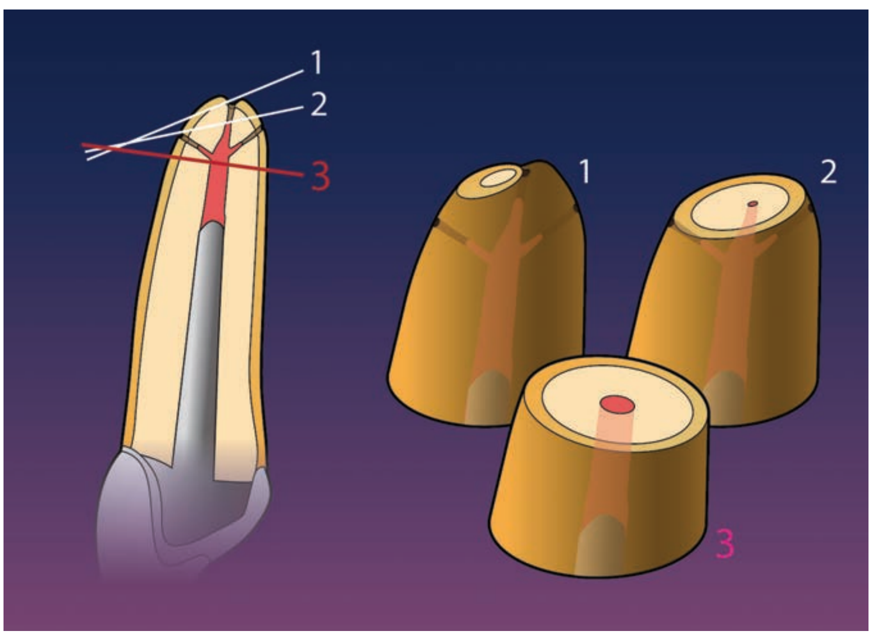

Figure 8.7 Incomplete root resection seen at 1 and 2.

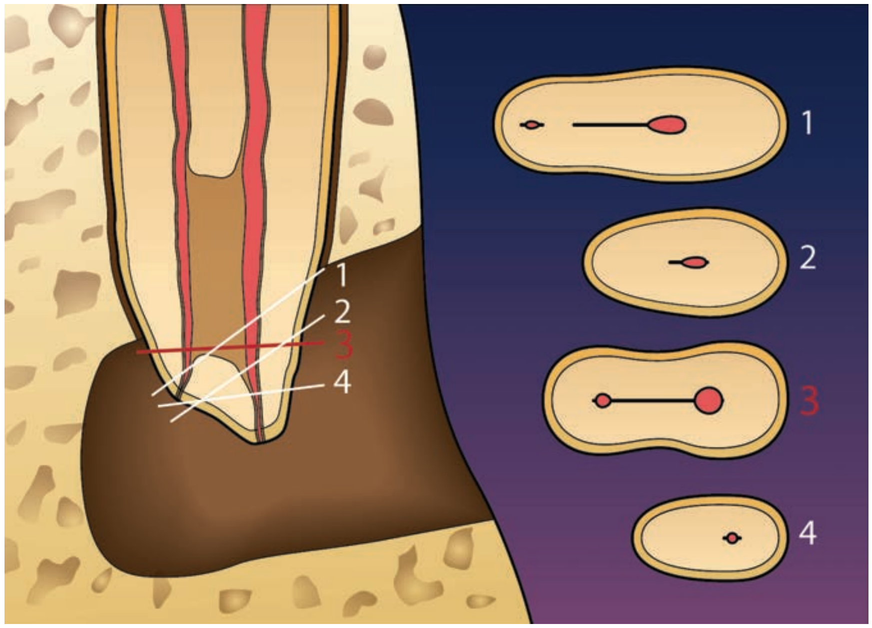

Figure 8.8 Usually a 45 degree angle bevel on a broad or oval-shaped root may reveal the buccal canal (see cut level 1) whereas the lingual canal or accessory canals emerging from the main canals to a lingual direction may be missed. Ideal cut without bevel (see cut level 3, red color).

occur particularly on roots that extend rather deep lingually, such as the roots of a mandibular molar.

- Root canal anatomy missed on the lingual/palatal aspect of the root. Usually a 45 degree angle bevel on a broad or oval-shaped root may reveal the buccal canal whereas the lingual canal or accessory canals emerging from the main canals to a lingual direction may be missed (Figure 8.8).
- Operator's spatial disorientation regarding the true long axis of the canal system can be a result of the long bevel. This increases the risk of perforations of the lingual or palatal dentinal walls during root end preparation (see the section on root end preparation in Chapter 10).
- More exposed dentinal tubules on the cut root surface can be associated with an increased risk of bacterial microleakage postoperatively (Figure 8.9).

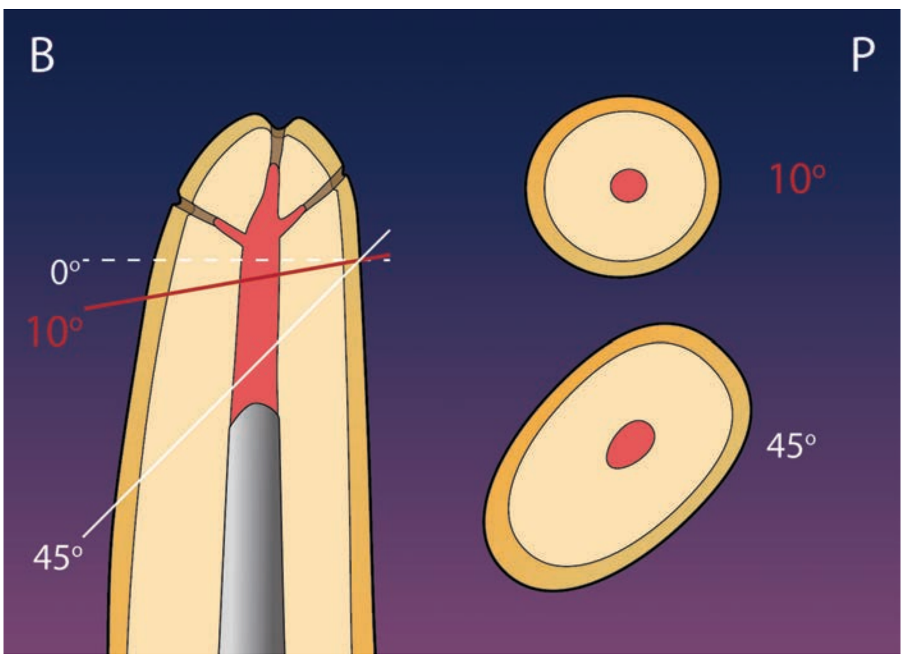

Figure 8.9 A 45 degree angle bevel is associated with more exposed dentinal tubules on the cut root surface, which can be associated with an increased risk of bacterial microleakage postoperatively.

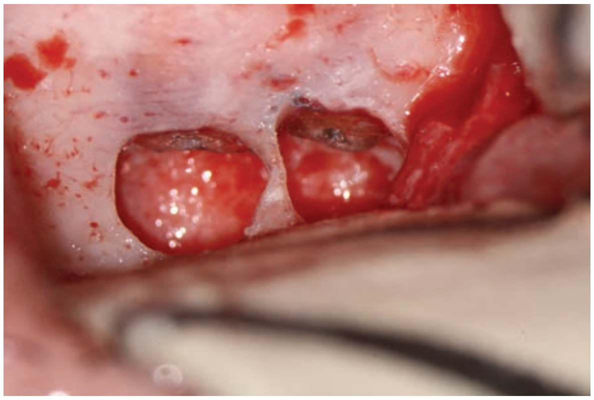

Figure 8.10 Periradicular surgery on tooth #30. The angle of root end resection of the mesial root is 5 degrees to facilitate the direct view of the resected surface under the microscope and the distal root is 0 degrees, perpendicular to the long axis of the tooth.

On the contrary, microsurgery suggests a 0° bevel, perpendicular to the long axis of the tooth (Figure 8.10).

A 0 degree bevel fulfills the following requirements:

- Preservation of root length.
- Less chance of missing lingual anatomy and multiple accessory canals.
- Complete root end resection.
- Less exposed dentinal tubules.
- Dentinal tubules are more perpendicularly oriented to the long axis of the tooth and therefore a short bevel will expose fewer tubules.
- Easier to perform a root end preparation coaxially with the root. The root end preparation should be kept within the long axis of the root to avoid risk of a perforation. The longer the bevel, the more difficult it is to orient and perform a preparation coaxially with the tooth (see the section on root end preparation in Chapter 10).

It was reported that non-surgical retreatment followed by root end resection without root end filling is an acceptable alternative treatment option. The validity of this statement must be put into question. Removal of the diseased periapical tissues by periradicular curettage eliminates only the effect of the leakage, not the cause. Thus, elimination of the periradicular lesion alone will likely result in the recurrence of the lesion. Initially, there may be a cessation of symptoms and a radiographic improvement, but this is only temporary.

After performing a small sized osteotomy, complete root end resection, and removal of all granulation tissue, hemostasis must be re-established. Bleeding occurs despite the vasoconstrictive effect of the anesthetic agent. It is imperative that the operator maintains complete control of the surgical environment. For this reason, each step should be executed to completeness before proceeding to the next one.

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9

Inspection of the Resected Root Surface: Importance of Isthmus

Spyros Floratos, Jorge Vera, Fouad Al-Malki, and Syngcuk Kim

KEY CONCEPTS

- Inspection of the resected root surface is a key step of microsurgery: an important step missing from older surgical techniques.
- During inspection the resected root surface is dried with Stropko irrigator and stained with methylene blue to delineate all anatomical and pathological entities.
- Anatomical entities include isthmus, fins, and lateral and accessory canals.
- Pathological details include microfractures, perforations, microgaps in the root canal filling, and leaky previous root end fillings.
- After staining with methylene blue, inspection must be performed at high magnification (×16 to ×25).
- More isthmuses are found in the mesial roots of mandibular molars and the mesiobuccal roots of maxillary molars.
- Untreated isthmuses frequently cause treatments to fail; therefore, they must be identified, cleaned, shaped, and filled as carefully as the root canals.

9.1 Armamentarium

- Micromirrors: round and rectangular
- Microexplorers
- Stropko irrigator/drier
- Methylene blue dye

Once adequate hemostasis is achieved, the resected surface is ready for close inspection at a high magnification under the microscope.

Inspection under high magnification is the key step of microsurgery that is missing from traditional surgical techniques. It involves the proper identification of anatomical details, aberrations and iatrogenic errors and is critical for the success of surgery. In other words, a careful inspection will identify the possible reason or reasons for failure of the non-surgical treatment. Inspection utilizes the high magnification and illumination that the operating microscope offers. In traditional surgical techniques, root resection is performed without magnification. As a result, inspection of all anatomical details of the cut root surface is impossible. In microsurgery an adequate inspection cannot be done with unaided vision or even loupes. Magnification of the microscope should be set at the range of ×16 to ×25 – higher than the rest of the surgical steps.

During inspection, the resected root end is rinsed and dried with a Stropko irrigator (Vista Dental, Racine, WI, USA) (Figure 9.1).

The dried surface is then stained with methylene blue, which is applied to the root surface with a microapplicator tip (Figure 9.2).

9.1.1 Methylene Blue Staining (MBS)

MBS only discolors organic substances. It rapidly delineates the PDL with a deep blue color but also stains isthmuses, accessory canals, hairline, or complete fracture lines (*not* craze lines) and reveals microgaps in the filling, transportation, areas of microleakage, microfractures, poor adaptation of root end filling materials, as well as any kind of disruption in the integrity of dentin. In this way, the surgeon's ability to see these entities is enhanced. To clearly define all aforementioned anatomical structures during inspection, methylene blue must be used as follows:

- The surface must be dry before application of the MBS.
- MBS is applied with a microapplicator tip saturating the surface and the PDL and leaving it undisturbed for 10–15 s.

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

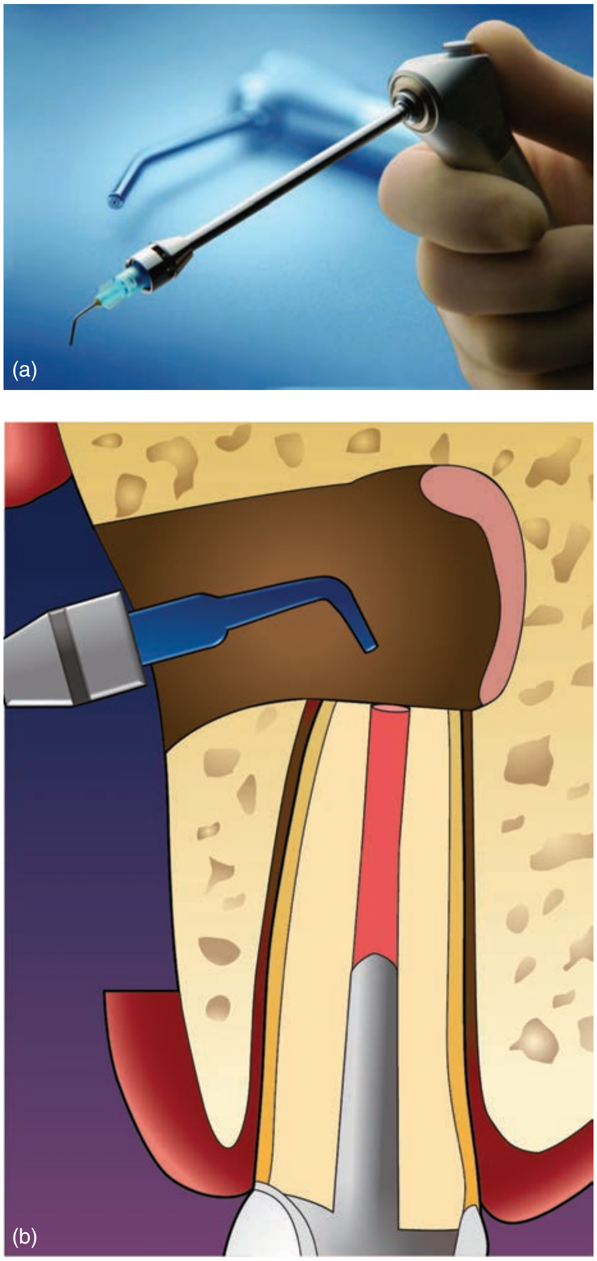

Figure 9.1 Stropko irrigator with an attached blunt needle: (a) Stropko irrigator; (b) schematic drawing of the drying of the root surface.

- All staining is then rinsed with isotonic saline and dried thoroughly with a Stropko irrigator/drier.
- The whole stained area is inspected under a high magnification of the microscope; higher than the rest of the procedural steps (×16 to ×25).

Following that, a micromirror is placed at 45 degrees to the resected surface and the reflected view of the root surface shows every anatomical detail of the canal system (Figure 9.3).

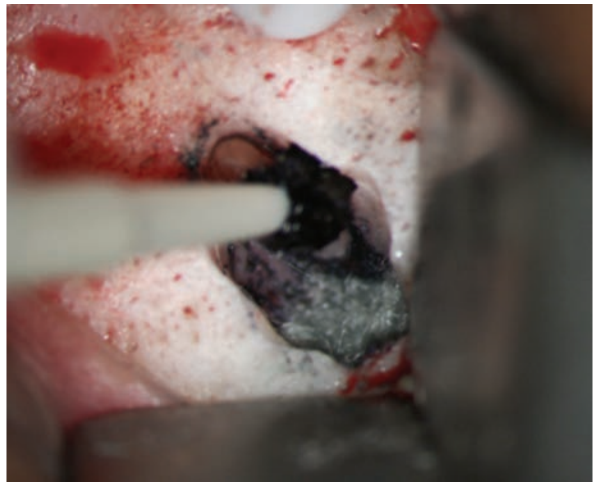

Figure 9.2 Staining of the resected surface of the mesial root of tooth #19 with 1% methylene blue in order to facilitate inspection (magnification ×10).

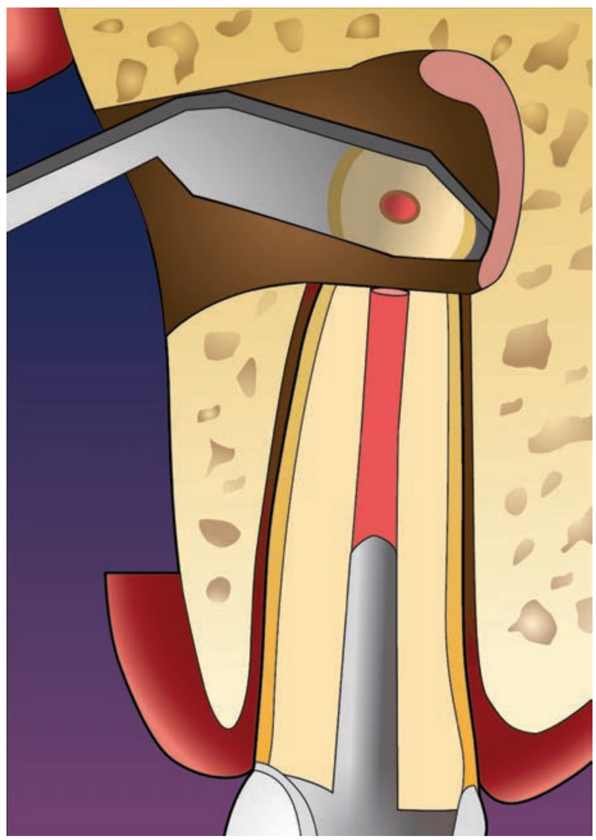

Figure 9.3 During inspection, the micromirror is placed at 45 degrees to the resected surface and the reflected view of the root surface shows every anatomical detail of the canal system. A high magnification of the microscope is used at ×14 to ×26.

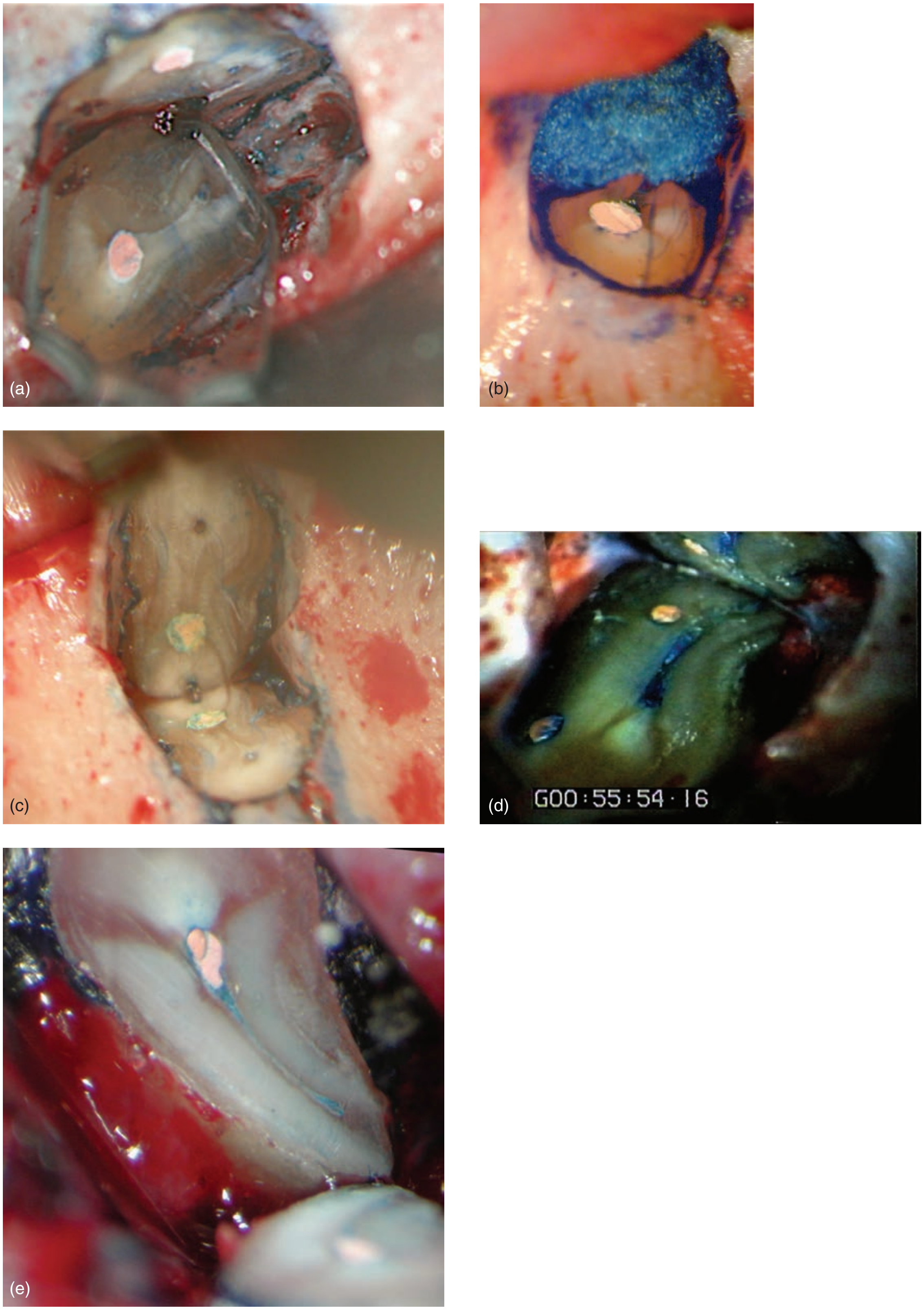

Figure 9.4 Inspection is done under a high magnification of the microscope (×16 to ×26). (a) Missed lingual canal and unprepared isthmus; (b) vertical root fracture; (c) multiple accessory canals; (d) unfilled isthmus; (e) missed buccal canal.

All these findings are obvious reasons for failure of the non-surgical endodontic treatment.

A careful inspection is critical for the success of the surgery. This step becomes more important in failed previous surgical cases, where the cause of failure has to be identified. A recent study showed that many of the reasons for failure of a surgical procedure involve a failure in inspection and identification of the cause of the failure. It is clearly shown that due to the lack of careful inspection under the microscope, traditional apical surgery can be a highly inadequate and unpredictable procedure. Some examples of complex anatomical entity, which was the cause of failure, are shown in Figure 9.4.

The findings and anatomical details that can be identified during inspection were classified into macrofindings and microfindings. Macrofindings included isthmuses and missed canals, while microfindings included craze lines, which are defined as dark lines that appear to disrupt the integrity of the dentine, cracks, the areas of "frosted" dentine and gaps (Figure 9.5). "Frosted" dentine was defined as a whitish or opaque dentine as opposed to the normal greyish or yellowish dentine, and cannot be stained with MBS (Figure 9.6).

A careful differential diagnosis between a craze line and a fracture line can be done with a microexplorer and staining with MBS. The fracture line is a fissure

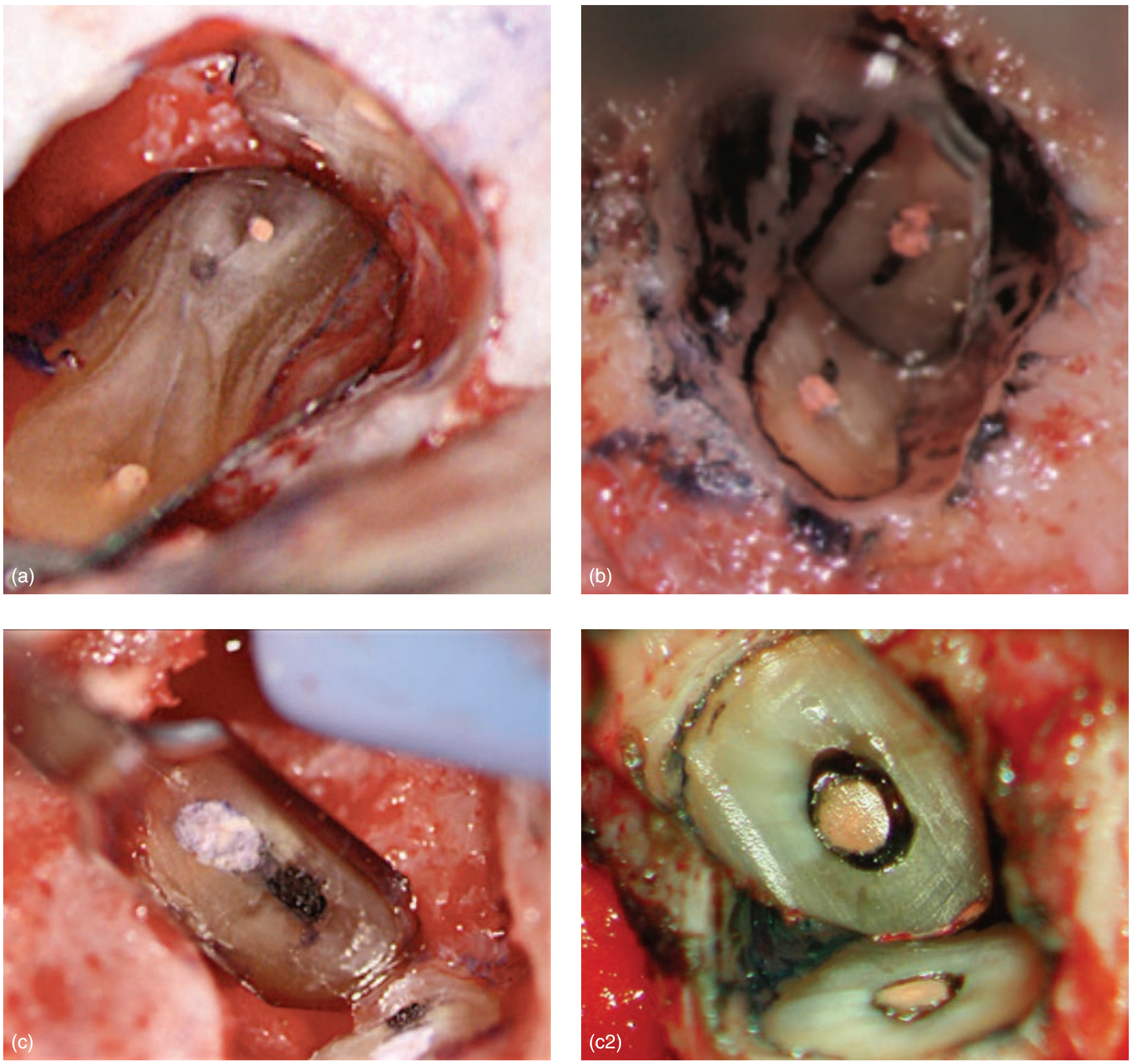

Figure 9.5 Inspection reveals obvious reasons for failure of the endodontic treatment (magnification ×16 to ×26). (a) Missed middle mesial canal and unprepared isthmus; (b) canal transportation; (c) a gap in the filling.

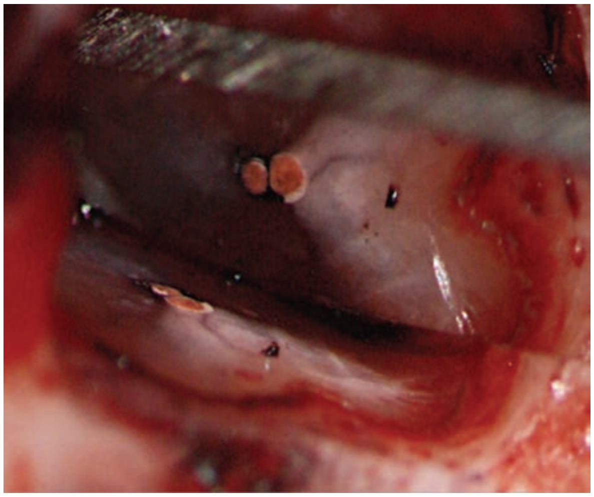

Figure 9.6 "Frosted" dentine on the buccal segment of the resected surface of an upper second premolar. Frosted dentine is always demarcated by craze lines.

line on the dentine surface and the microexplorer will get a catch upon scraping it. Fracture lines have to be eliminated as opposed to craze lines. Fracture lines are stained by MBS whereas craze lines are not. In addition to those entities, a careful inspection can reveal calcified canals, leaky previous root end filling materials, separated file fragments, missed multiple accessory canals, unprepared parts of the canal that extend from the main canal to the lingual or palatal side, particularly in teeth with oval-shaped roots, such as premolars or the distal root of a lower molar.

9.1.2 Isthmus

The term "Isthmus" derives from the Greek word "Ισθμός", which describes a narrow strip of land connecting two larger land masses. Endodontically speaking, an isthmus is defined as a narrow, ribbon-shaped communication between two root canals that contains pulp, or pulpally derived tissue.

Frequently, a tooth with a fused oval-shaped root has a web-like connection between two canals. This connection is called an isthmus, and it is either complete or partial (Figure 9.7). Identification and management of the isthmus was absent in the traditional old apical surgery.

9.1.3 Types of Isthmus

Isthmus was classified by Weller *et al.* (1995) as complete or partial. A complete isthmus was one with a continuous, narrow opening between the two main root canals. A partial isthmus was defined as an incomplete communication with one or more patent openings, through the section, between the two main canals. The opening could be of any size.

Hsu and Kim (1997) described five different types of isthmus. Type I was defined as either two or three canals with no noticeable communication. Type II was defined as two canals that had a definite connection between the two main canals. Type III differs from type II in that there are three canals instead of two. Incomplete C-shapes with three canals were also included in a type IV isthmus. Type V is identified as a true connection or corridor throughout the section (Figure 9.8).

9.1.4 Incidence

At the 3-mm level from the original apex, an isthmus was found at 90% of the mesiobuccal roots of maxillary first molars, 30% of the maxillary and

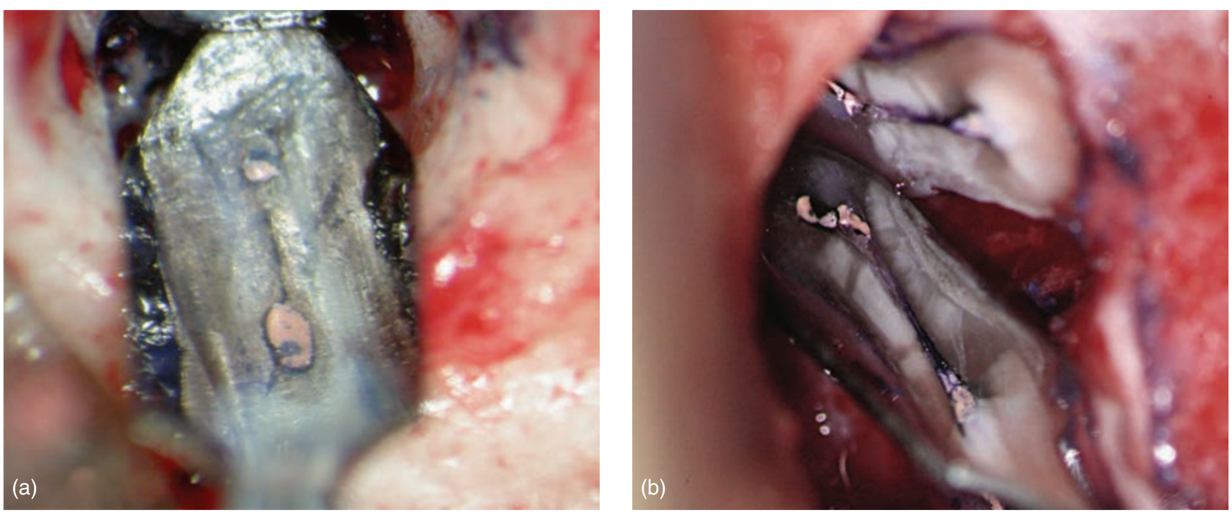

Figure 9.7 Various types of isthmuses are seen in all teeth resected root surfaces (magnification between ×16 and ×24).

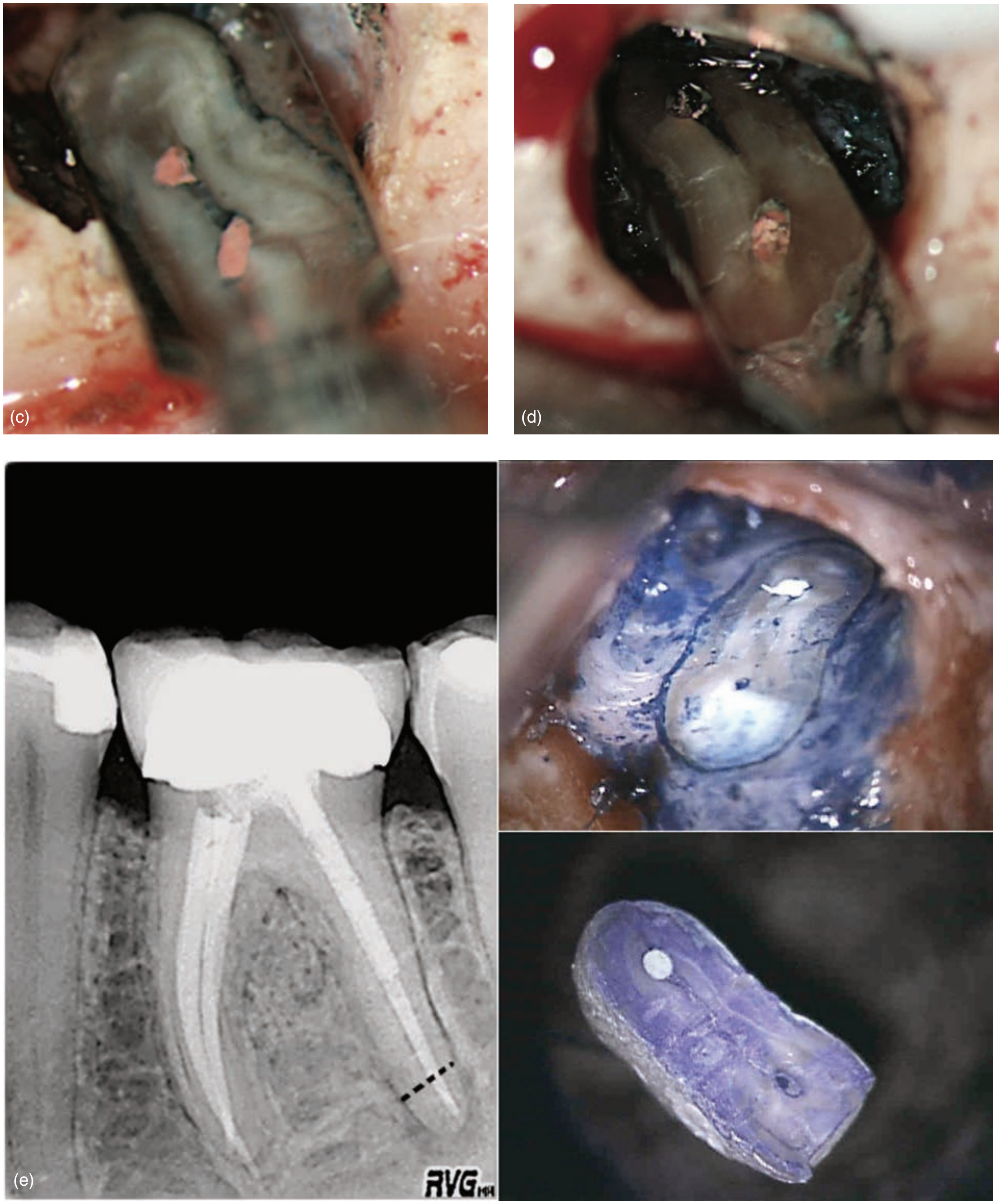

Figure 9.7 (*Continued*)

mandibular premolars, and over 80% of the mesial roots of the mandibular first molars (Figure 9.9).

All this evidence shows that the isthmus is a part of the canal system and not a separate entity. Therefore, it must be cleaned, shaped, and filled as thoroughly as possible. The surgeon should be aware of the high incidence of isthmuses in premolars and molars when performing apical surgery. Even mandibular anteriors

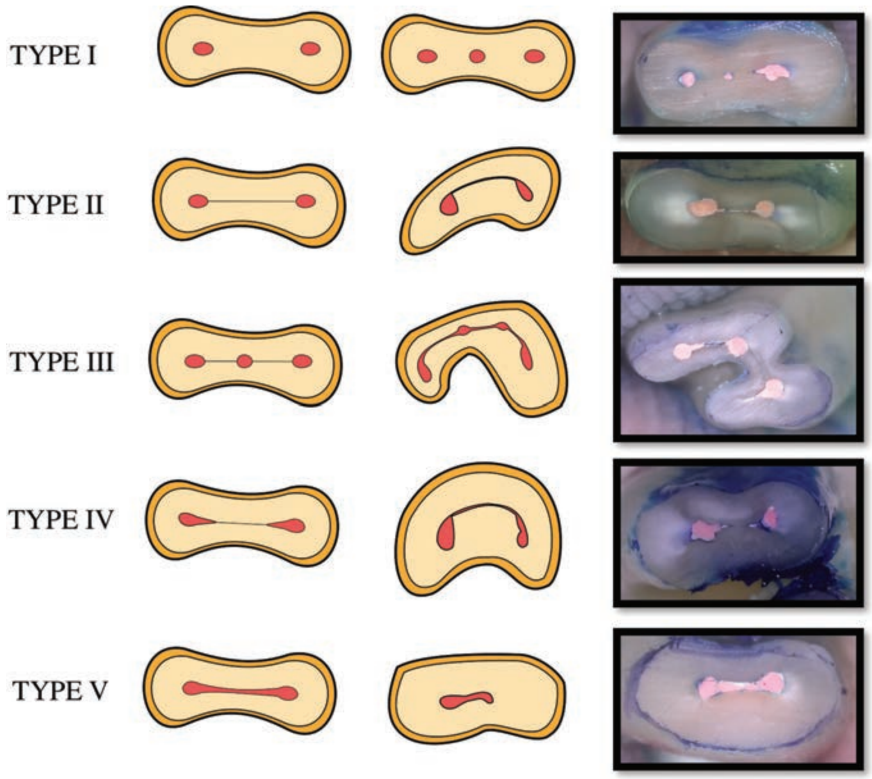

Figure 9.8 Types of isthmuses: type I, two or three canals with no noticeable communication; type II, two canals that had a definite connection between the two main canals; type III differs from type II in that there are three canals instead of two; type IV are canals that extend into the isthmus area; type V, a true connection or corridor throughout the section.

have isthmuses in cases where failure of endodontic therapy persists despite an excellent radiographic root canal filling.

9.1.5 Histological Findings of Isthmus

A histological examination of the resected root surface where an isthmus is found revealed some interesting and important findings. Isthmuses are present anywhere around the main canals and their shape is diverse. Even a tiny dot under high magnification (Figure 9.10) showed a huge concentration of bacteria and its byproducts as shown in TEM. Thus, we cannot ignore even a dot on the resected root surface during the surgery. Thus, proper cleaning of these isthmuses using an ultrasonic tip during the surgery is an essential step in microsurgery (Figure 9.11).

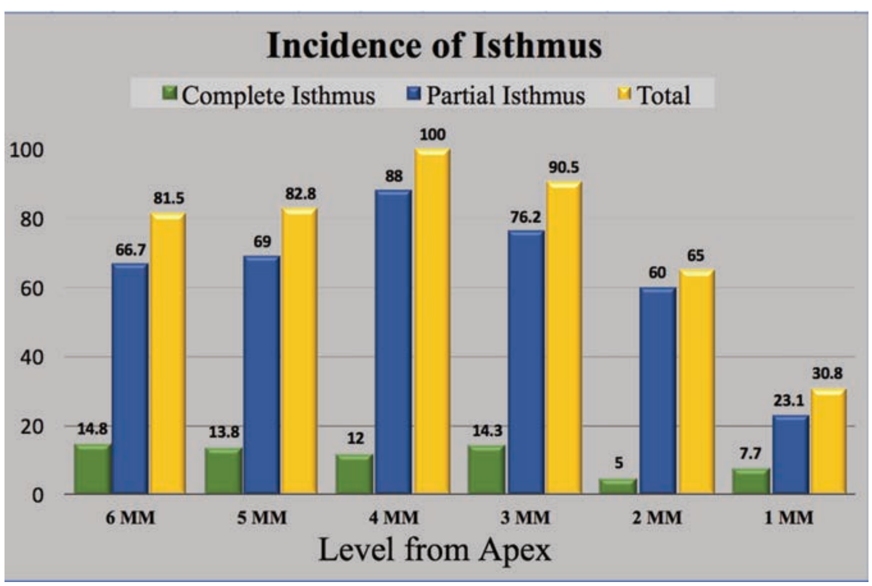

Figure 9.9 At the 3- and 4-mm level from the apices of the mesiobuccal roots of maxillary first molars, a complete (type V) or partial (type IV) isthmus was present 90% and 100% of times, respectively. (Modified from Weller *et al.*, *J Endod* 1995.)

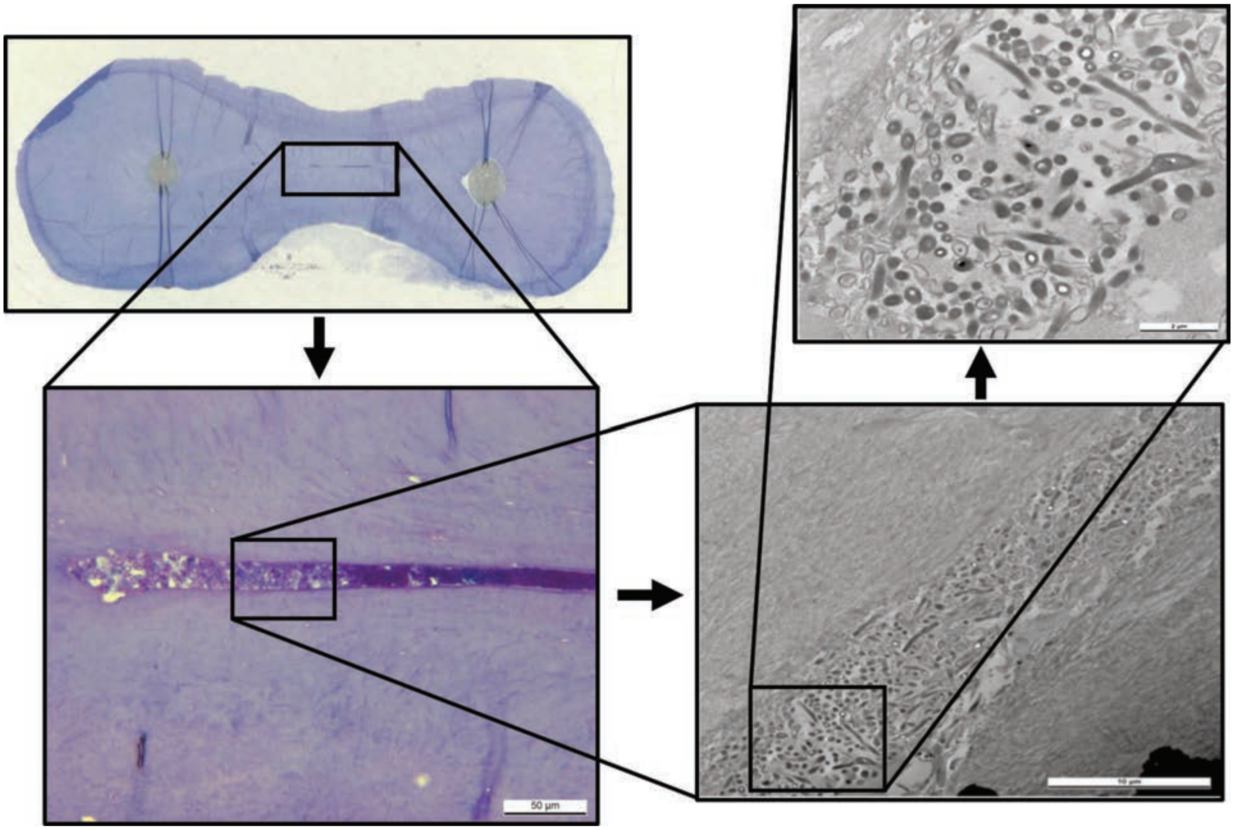

Figure 9.10 A histological examination of the resected root surface where an isthmus is found revealed a huge concentration of bacteria and its byproducts. (Courtesy of P.N.R. Nair.)

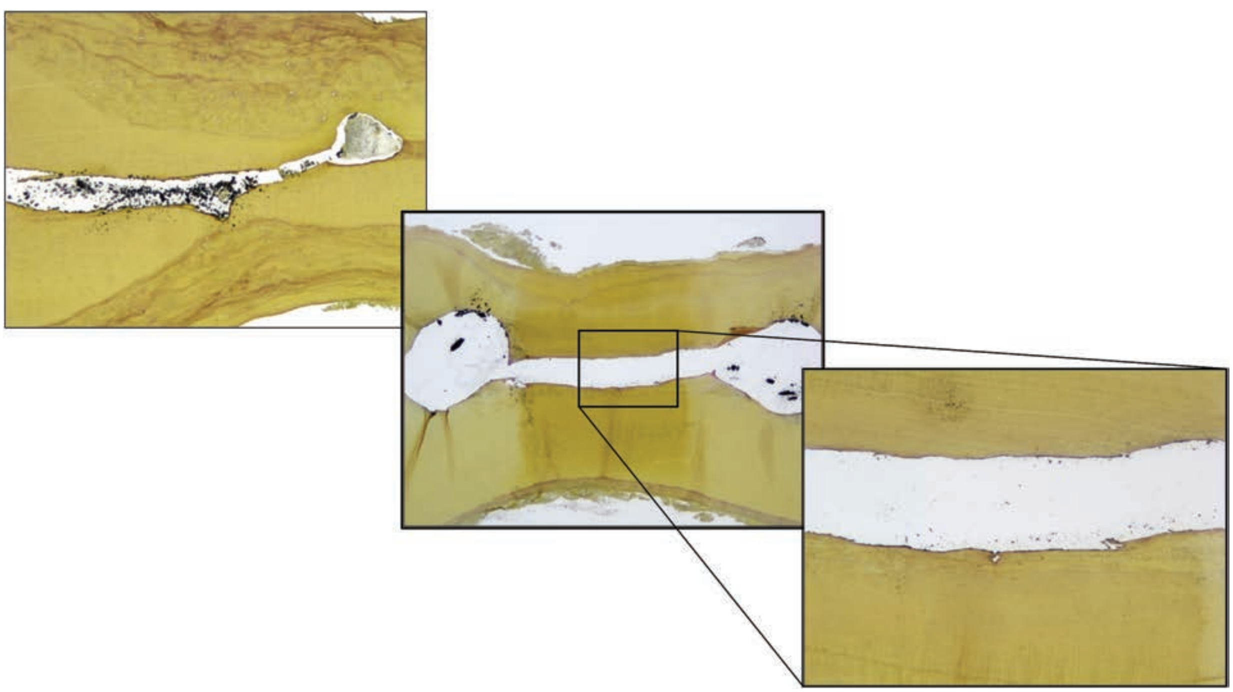

Figure 9.11 A histological examination of the resected root surface where an isthmus is found revealed a huge concentration of bacteria and its byproducts and another one of instrumented canals and a cleaned isthmus. (Courtesy of Ricucci and Vera, reproduced by permission.)

These findings prove that the isthmus tissue appears to be the Achilles' heel of conventional endodontic treatment. Moreover, this is one of the reasons why apical root resection alone, without root end preparation and root end filling of canals and isthmuses, usually fails.

9.1.6 Clinical Significance and Management

Identification of un-negotiated canals and isthmuses is the first and most important step after root end resection. If these anatomic features remain undetected, recurrence of infection and failure of apical surgery are unavoidable. For this reason, the isthmus should be identified and treated under the microscope with ultrasonics and microinstruments. Even in cases where canal exits seem to be separate under enhanced vision, they are found to be connected microscopically when examined under scanning electron microscopy. Therefore, inspection of a hairline, not clearly defined isthmus becomes important and the operator's clinical experience plays a major role in its identification and management. It is essential that the entire canal and isthmus be prepared to a depth of 3 mm (see the section on root end preparation in Chapter 10). Clinical experience has shown that the main cause of failure after surgery in maxillary and mandibular premolars, mesiobuccal roots of maxillary molars, and mesial roots of mandibular molars, done with a bur and amalgam, is the inability to treat the isthmus. In this way, the root end filling offers an inadequate seal to the root canal system and obvious leakage is detected around its margins (Figure 9.12).

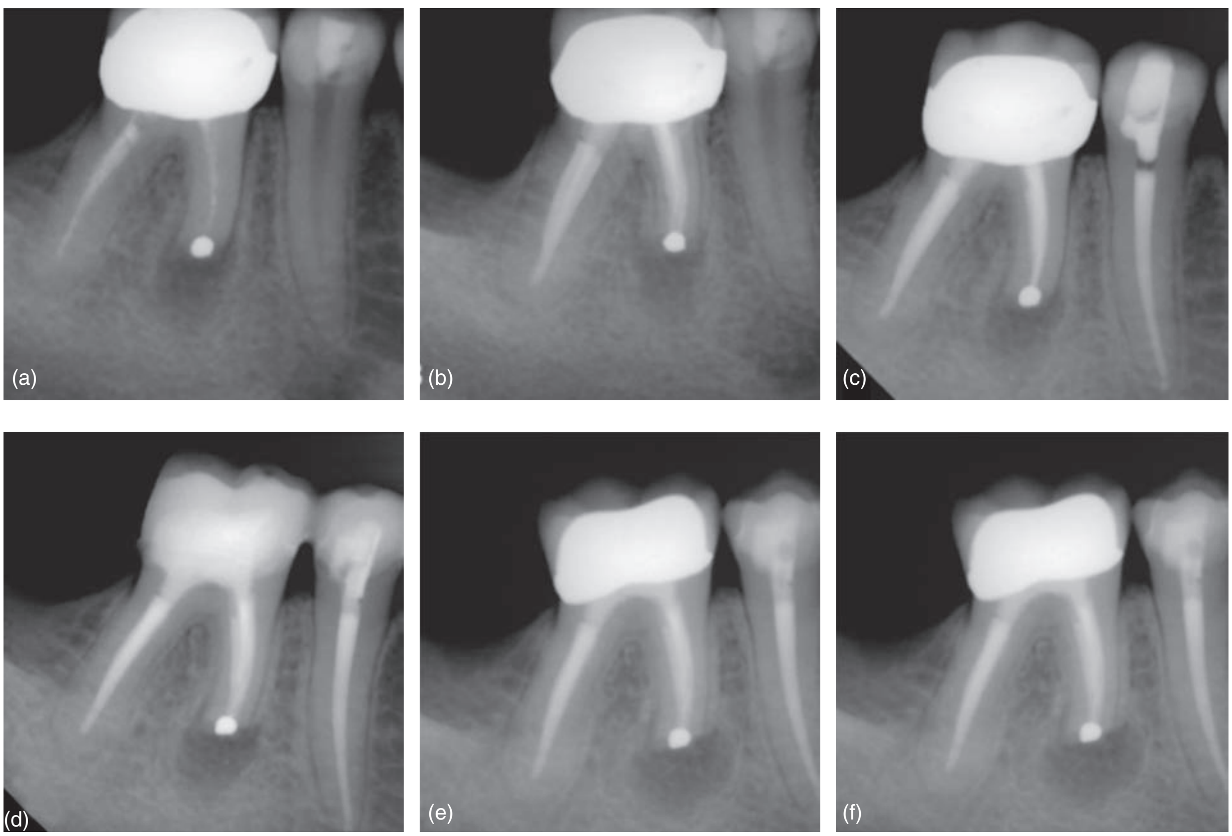

Figure 9.12 Amalgam placed as a root end filling material on a previous failed surgery done with the traditional technique on tooth #30. Non-surgical retreatment was performed, but periapical lesion persisted. A second apical surgery using microsurgical technique was done and the periapical pathology was eliminated. It is obvious that the cause of the persistent periapical lesion was a long, type V isthmus. (a) Preoperative radiograph; (b) non-surgical retreatment; (c) 6 month recall radiograph; (d) 1 year recall radiograph; (e) 2 year recall radiograph showing persistence of the periapical lesion on the mesial root; (f) preoperative radiograph of the second periapical surgery.

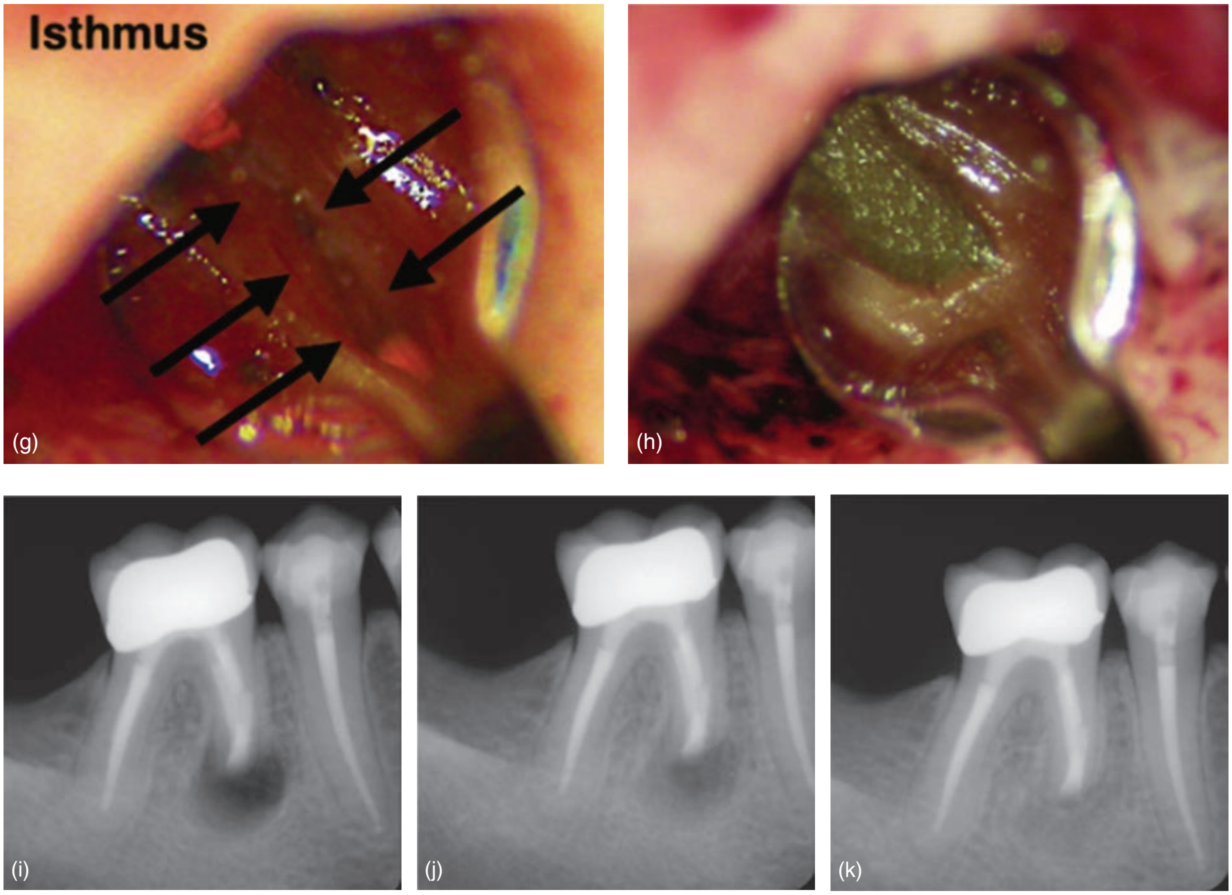

Figure 9.12 (*Continued*) (g) Inspection after 3-mm root resection of the mesial root revealed a long type V isthmus (black arrows) (magnification, ×16); (h) root end filling with MTA (magnification, ×16); (i) postoperative radiograph; (j) 6 month recall radiograph; (k) 1 year recall radiograph showing complete healing of the lesion. (Case courtesy of Dr Helmut Walsh.)

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10

Ultrasonic Root End Preparation

Spyros Floratos and Syngcuk Kim

KEY CONCEPTS

- During root end preparation a Class I cavity coaxial with the root is made by use of ultrasonic tips with walls parallel to and within the anatomic outline of the root canal space.
- Root end preparations are made at least 3 mm deep into root dentine.
- Root end preparation begins with aligning a selected ultrasonic tip along the root prominence on the buccal plate under low magnification (×4 to ×8) to ensure that the preparation follows the long axis of the root.
- Once the ultrasonic tip is aligned, the preparation is carried out under midrange magnification (×10 to ×12).
- Ultrasonic tips are used in a light, sweeping motion; short forward/backward and upward/downward strokes result in effective cutting action. Interrupted strokes are more effective than continuous pressure on the dentine surface.

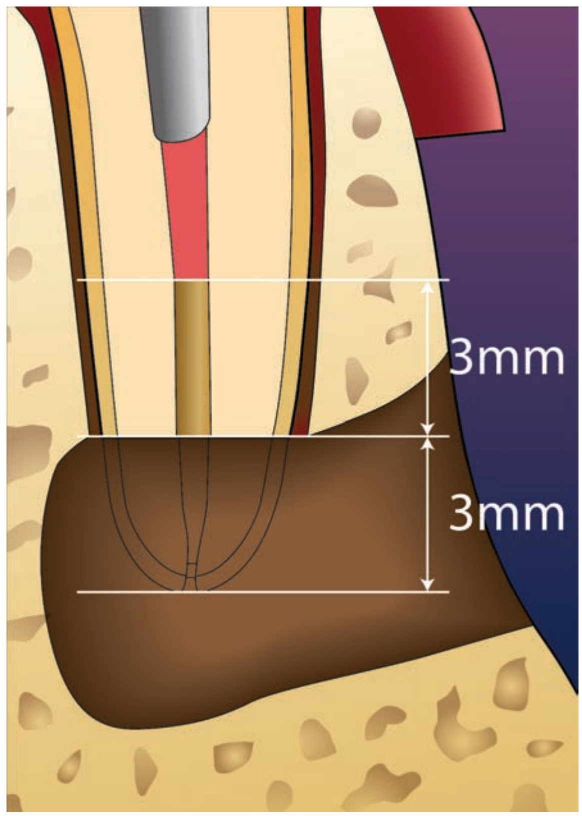

Figure 10.1 The ideal root end preparation can be defined as a Class I cavity at least 3 mm into root dentine after the apical root tip of 3 mm is resected, with walls parallel to and within the anatomic outline of the root canal space.

10.1 Armamentarium

- Ultrasonic root end tips: Microprojection Jet tips (BNL, Biotech) or KiS surgical tips (Obtura/Spartan)
- Spartan (Cranston, Rhode Island), W&H, (Bürmoos, Austria)
- Micromirrors: 2 mm, 3 mm & 4 mm rectangular
- Microcondensers
- Microexplorers
- Stropko irrigator/drier

One of the most important changes in modern periapical surgery was the use of ultrasonic root end tips instead of burs for the root end preparation. The aim of the root end preparation is to remove the filling material, irritants, necrotic tissue, and remnants from the canals as well as the isthmus and create a cavity that can be properly filled. The ideal root end preparation can be defined as a Class I cavity at least 3 mm into the root dentine, with walls parallel to and within the anatomic outline of the root canal space (Figure 10.1).

This clinical demand can no longer be satisfied by use of rotary burs in a microhandpiece, which was the common practice in traditional surgical techniques.

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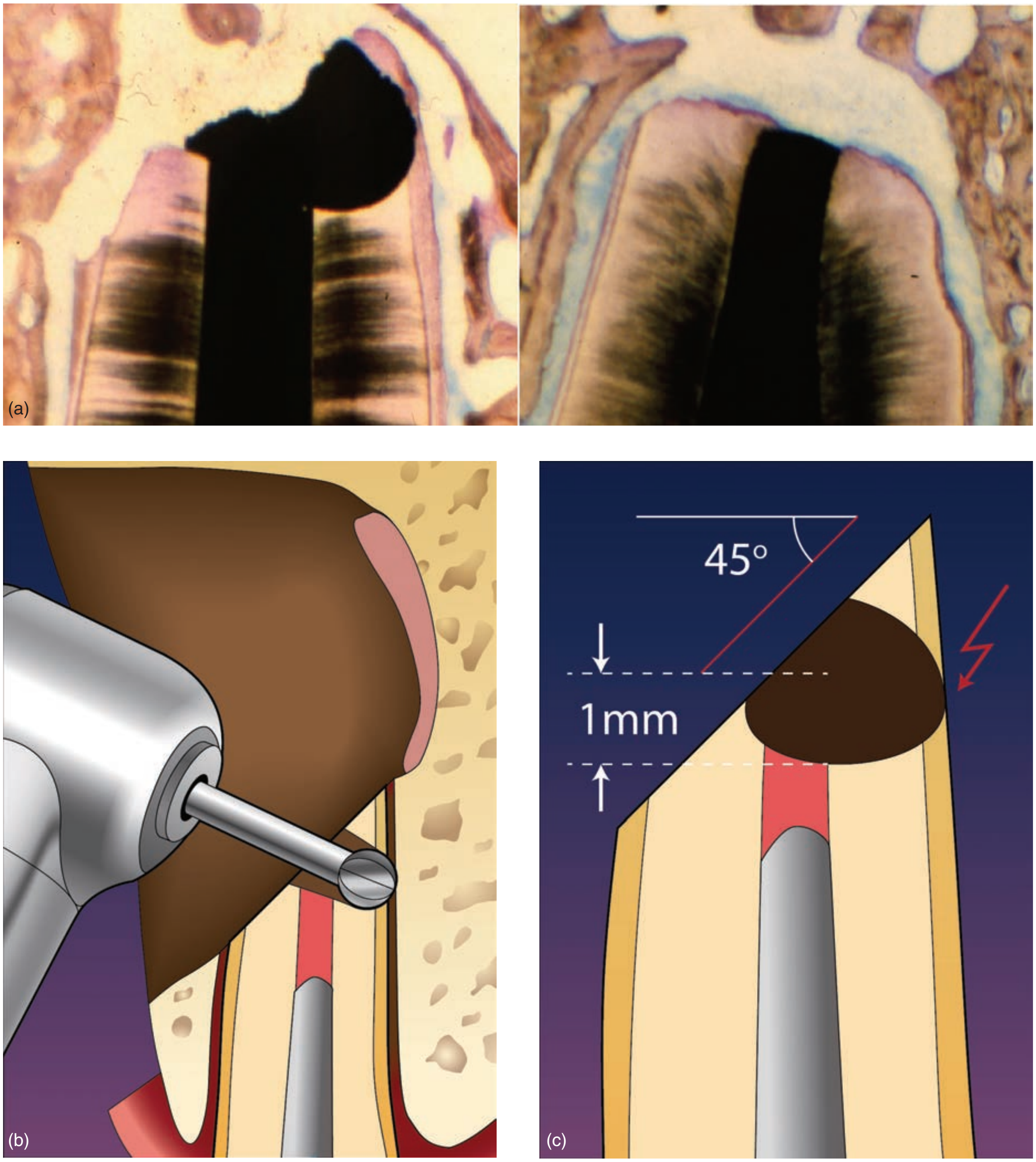

Figure 10.2 Preparation with an old microhandpiece. (a) Histological images of root end preparations in dog teeth by a bur (left) and ultrasonic tip (right). The bur preparation nearly resulted in a lingual perforation, while the ultrasonic preparation preserved the integrity of the root apex and remained along its long axis. (b) and (c) Preparation with a bur ends up in a dome-shaped preparation rather than a Class I cavity preparation and therefore retention of the root end filling material is compromised.

The use of rotary burs presents the following drawbacks in comparison with ultrasonic tips (Figure 10.2):

- Limited access to the root end.
- High risk of perforation of the lingual or palatal wall of the cavity preparation when it does not follow the original canal path. Preparation with a bur ends up in a dome-shaped preparation rather than a Class I cavity preparation and therefore retention of the root end filling material is compromised.
- The depth of preparation is insufficient and for this reason increases the risk of potential microleakage and failure of the surgery.

- The root end resection procedure exposes dentinal tubules.
- Necrotic isthmus tissue cannot be removed.

Before root end preparation in microsurgery, the operator uses a low-range magnification (×4 to ×8) of the microscope to align the ultrasonic tip with the long axis of the root. Following that, ultrasonication is performed. What is clinically important for an efficient ultrasonic preparation is not the brand or type of tip, but how the tip is used. In terms of pressure during ultrasonic preparation, the key is an extremely light touch in a repeated fashion. A lighter touch increases the cutting efficiency, whereas a continuous pressure, similar to the way a handpiece is used, decreases the cutting efficiency. That is because ultrasonics work through vibration, not through pressure. If resistance is met during ultrasonication, then a typical high pitch sound is produced. This means that the tip is cutting against dentin. At that point the operator should stop the preparation, go to a low-range magnification of the microscope, realign the tip with the long axis of the root and start again (Figure 10.3). If this step is not taken, then transportation or a perforation of the root might occur either on the lingual or distal dentinal wall (Figure 10.4). Thus, it is important that the tip alignment has to be parallel to the long axis of the canal (Figure 10.5).

Figure 10.6 shows perfect alignment and fill on the distal root and off-angle preparation on the mesial root.

The risk of transportation is higher when root end preparation is done in a case where the canal is completely calcified, not negotiated, and therefore no canal filling exists. In this case, the surgeon should work under a low magnification, have a direct view of the resected surface, and constantly confirm that the ultrasonic tip is coaxial to the root (Figure 10.7).

When root end preparation is done in the correct direction, no sound is heard and gutta percha is "walking" out of the preparation (Figure 10.8).

A larger tip in diameter should be used in cases where instrumentation and obturation was done to a large size, as in teeth with wide or oval-shaped canals, and a smaller diameter tip should be used for thinner canals.

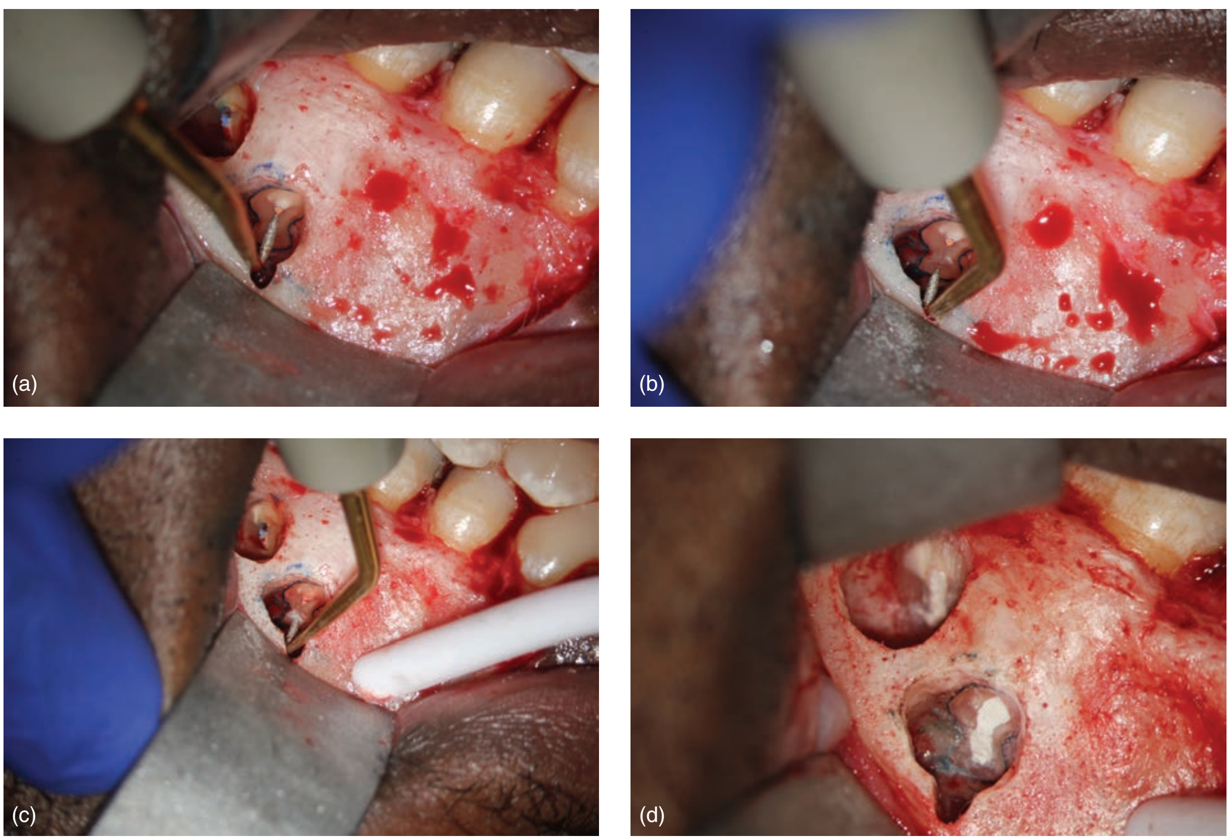

Figure 10.3 Root end preparation during surgery on a tooth. (a) Proper alignment of the tip, coaxial with the root, is done at a low magnification of the microscope before preparation starts MB canal; (b) ML canal; (c) ultrasonic preparation begins on ML canal; (d) final view with MB, ML, DB, DL root end preparations sealed with Bioceramic putty. (Courtesy of Dr Kaname Yokota.)

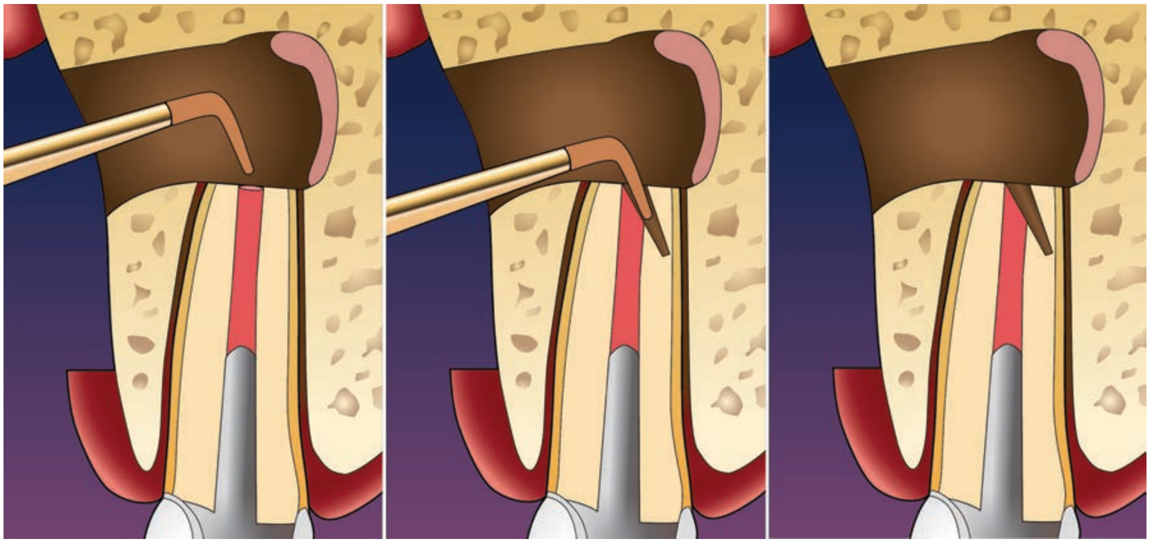

Figure 10.4 Schematic drawing showing an off-angled preparation resulting from wrong angulation of the ultrasonic tip alignment. This mistake sometimes results in lingual perforation.

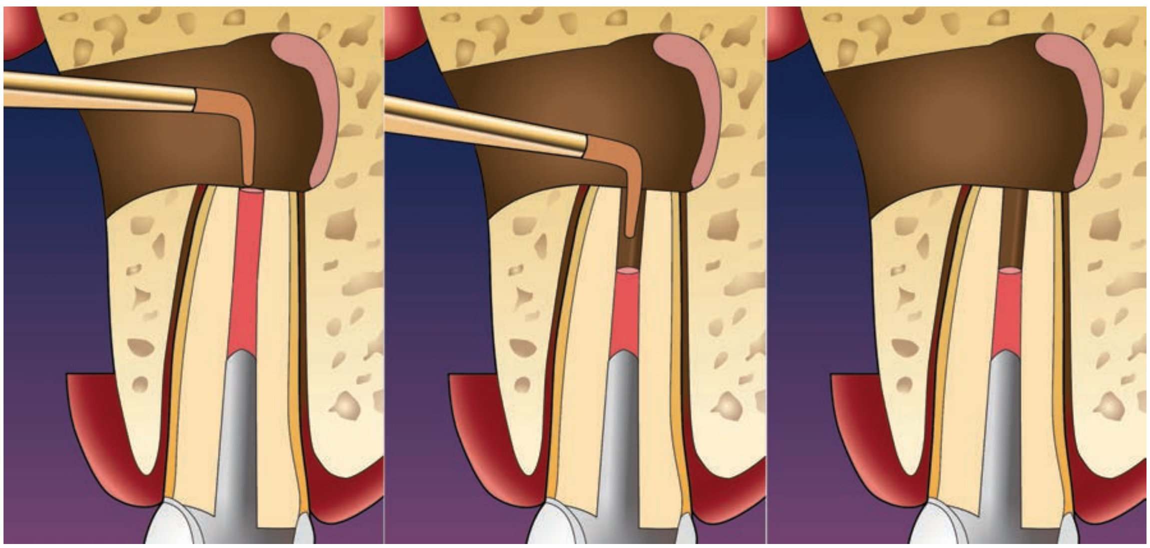

Figure 10.5 Schematic drawing showing ideal root end preparation when the ultrasonic tip is aligned along the long axis of the root.

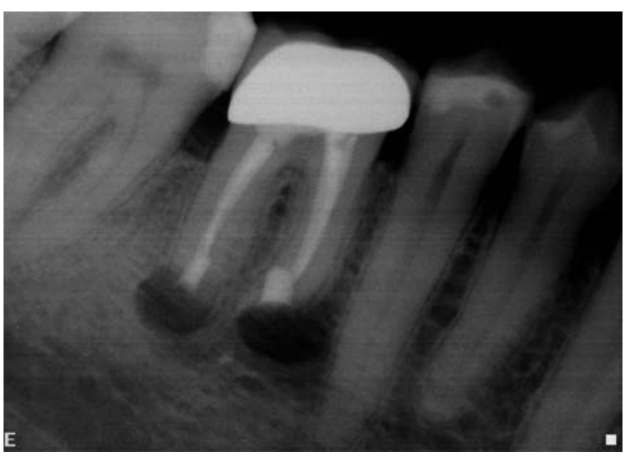

Figure 10.6 Radiographic appearance of two root end preparations. The mesial root end preparation was done at a wrong angle. The distal preparation was done following the long axis of the root.

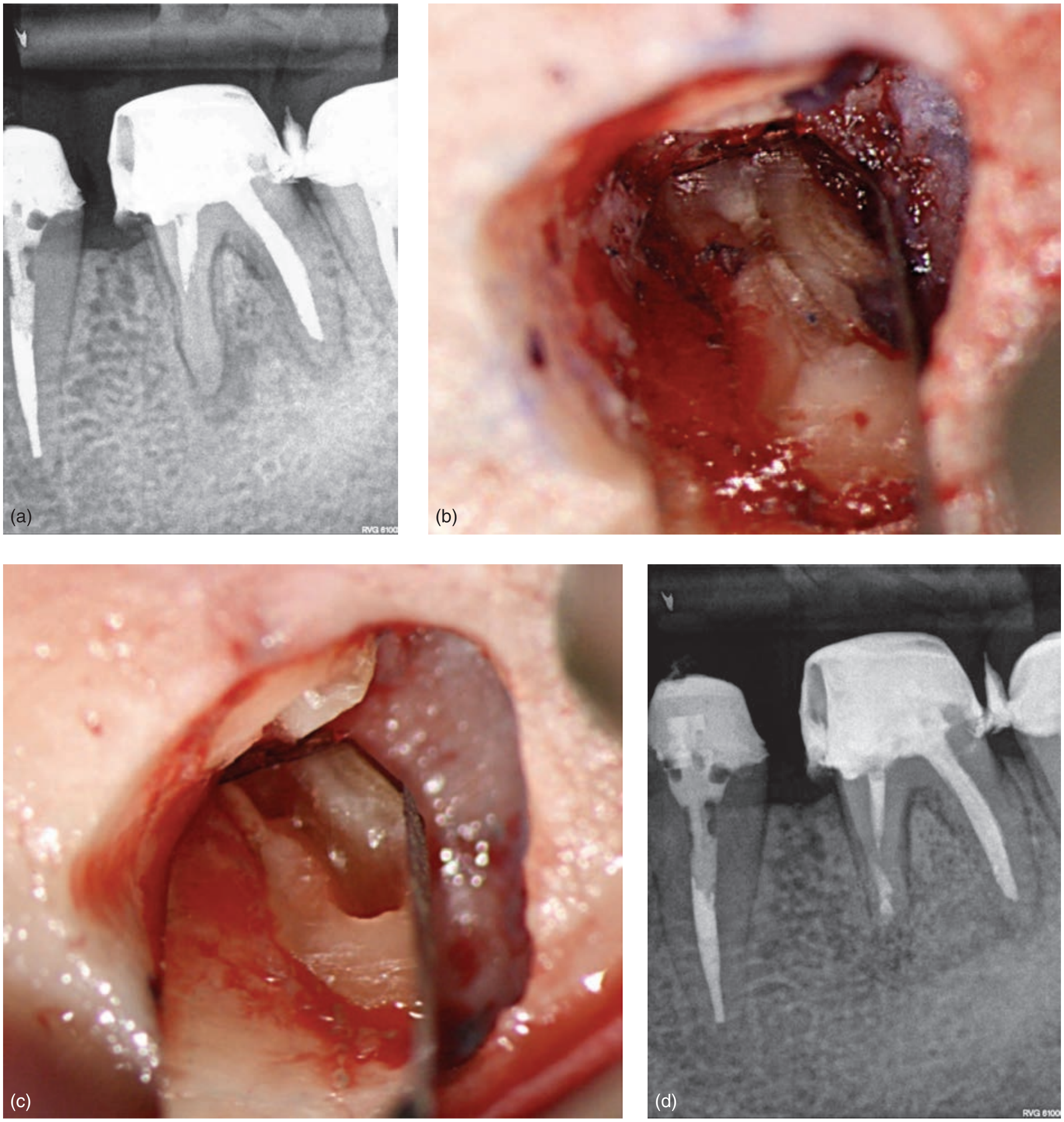

Figure 10.7 Apical surgery on the mesial root of tooth #19. (a) Preoperative radiograph showing calcified mesial canals; (b) inspection revealed complete obliteration of the mesial canals and isthmus due to calcification (magnification ×16); (c) root end preparation was done (magnification ×16); (d) Postoperative radiograph shows that preparation and root end filling are coaxial with the canals.

Often when an oval-shaped or large-diameter canal is prepared, it is a frequent observation, even to an experienced surgeon, that there is a small part of gutta percha that is left on the buccal wall of the prepared root end cavity (Figure 10.9). This part of gutta percha and debris, if not removed before placement of an apical seal, may potentially cause leakage and therefore failure of the surgery. In order to remove this excess gutta percha, the ultrasonic tip can be tilted buccally so that the end of the tip will vibrate against the facial wall, and gradually loosen the remaining filling material (Figure 10.9).

Alternatively, the facial wall can be scraped with a microexplorer to detach the remaining gutta percha and compact it with a microcondenser.

Adjustment of water spray is also important so that cutting efficiency as well as visibility is obtained. Root end preparation can start without water spray to allow

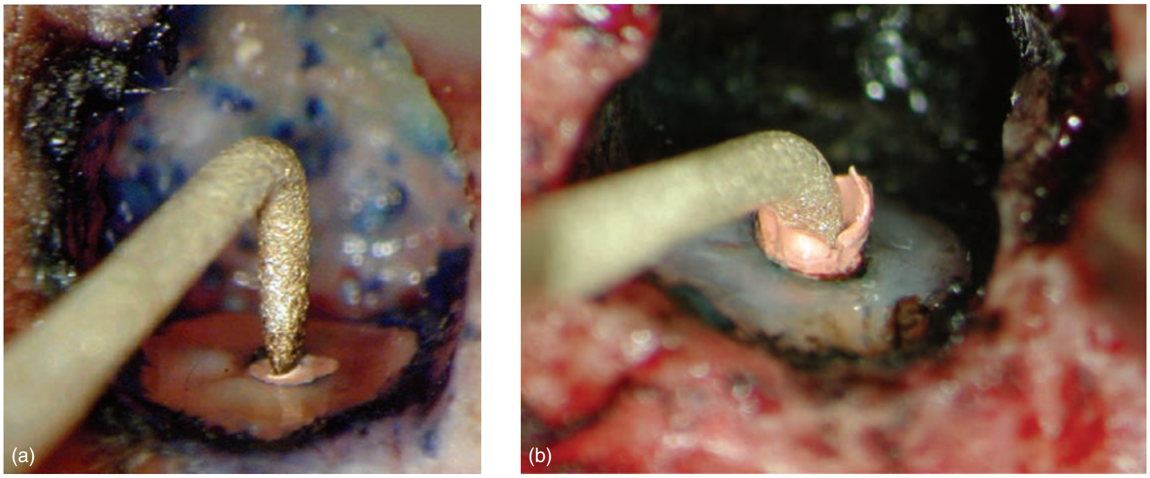

Figure 10.8 Tooth #7: (a) root end preparation on tooth #7 (magnification ×16); (b) when root end preparation is done in the correct direction, gutta percha is "walking" out of the preparation (magnification ×16).

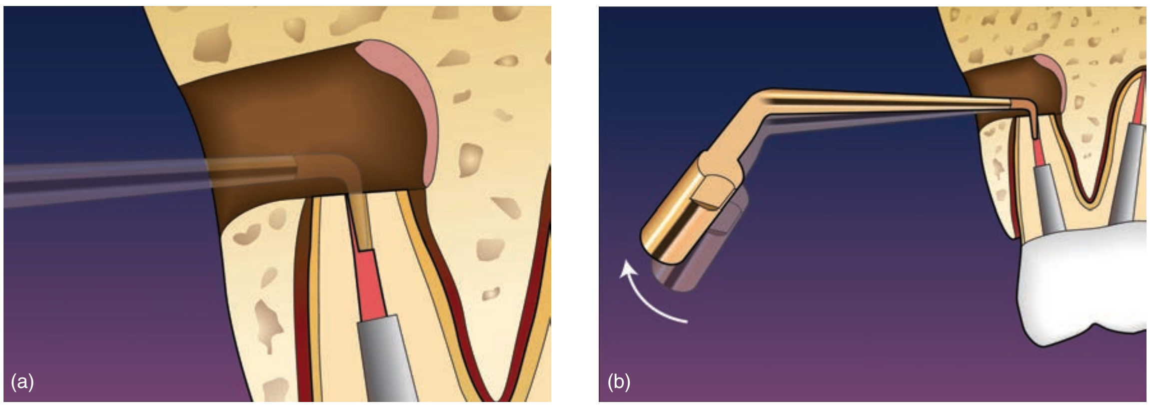

Figure 10.9 Inspection of root end preparation. (a) A small part of gutta percha is left (arrow) on the buccal wall of the prepared root end cavity. (b) In order to remove this excess gutta percha, the ultrasonic tip can be angled buccally so that the end of the tip will vibrate against the facial wall and gradually loosen the remaining filling material.

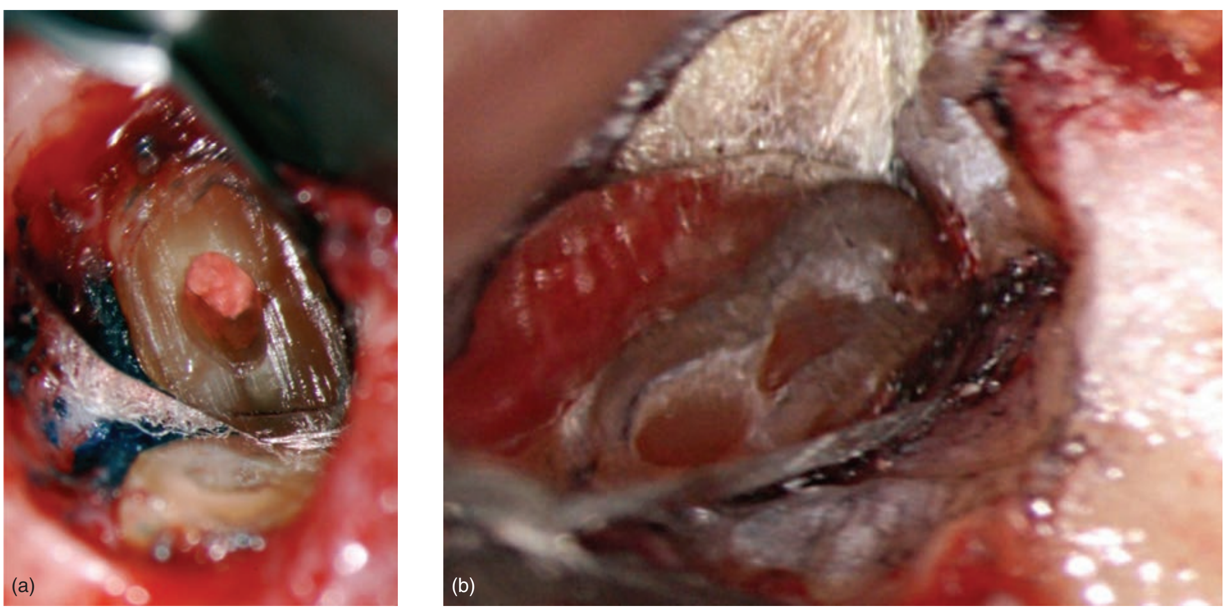

Figure 10.10 Prepped canals. (a) Perfectly prepared single root both in angle and depth reflected on a micromirror. (b) There are two apices next to each other; preparation at the correct angle and depth.

the initial formation of a path coaxial with the root or to mark the initial preparation of a distinct, hairline isthmus. An initial dry preparation of short duration can also be performed to define the position of a missed, unprepared, or obliterated canal. Following that, preparation should be done under water irrigation to avoid overheating the tooth and periradicular tissues.

Once the apical preparation has been completed, gutta percha should be compacted with a microcondenser and the preparation should be dried and inspected with a micromirror. Traditionally, root end cavities were dried with paper points before root end filling. This technique, however, is incorrect as particles of paper may be left in the preparation, remaining debris will be compacted in the preparation, and a thorough drying of the cavity may not be obtained. A controlled blast of air in the cavity is now accomplished by use of a Stropko Irrigator (see Chapter 9).

The irrigator allows for the directional administration of air and water.

Upon inspection of the preparation, there should be a dry and clean Class I cavity coaxial to the root, with no debris or tissue remnants and no filling material left on the axial walls (Figure 10.10).

Modern ultrasonic tips can facilitate the preparation of a 3, 6, or even 9 mm root end cavity depending on the length of the unprepared canal space or the presence of intraradicular restorations (see Chapter 7, Figure 7.7).

Suggested Readings

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11

MTA and Bioceramic Root End Filling Materials

Sujung Shin, Ian Chen, Bekir Karabucak, SeungHo Baek, and Syngcuk Kim

KEY CONCEPTS

- Advantages of MTA and newer Bioceramics are their excellent sealing ability and biocompatibility.
- There are potential bioactive actions such as biomineralization with MTA and Bioceramics.
- Drawbacks of MTA include a long setting time, difficulty in manipulation and potential tooth discoloration, which might be overcome with newer Bioceramics.
- Other types of root end filling materials include: Intermediate restorative material (IRM), super ethoxybenzoic acid (SuperEBA), and resin-based materials such as Geristore and Retroplast.

The main purpose of placement of a root end filling material is to provide an adequate apical seal that inhibits the leakage of irritants that might remain in the root canal after root resection and root end preparation, which may cause surgical failure. Besides sealing ability, other essential properties for an ideal root end filling material are:

- Well tolerated by periapical tissues
- Bactericidal or bacteriostatic
- Dimensionally stable
- Easy to manipulate
- Does not stain teeth or tissue
- Non-corrosive
- Resistant to dissolution
- Adheres to the tooth structure
- Dentino, osteo, and cementogenic
- Radiopaque

The most important objective of filling the root end preparation is to hermetically seal it from bacteria or byproducts entering or leaving the canal. Thus the ideal filling material should completely adhere to the dentinal walls. It should also maintain its long-term structural integrity upon setting and not dissolve or corrode in contact with tissue fluids, as amalgam does. The sealing ability is further enhanced if the root end filling is bacteriostatic or preferably bactericidal. As the success of the surgery depends on complete bone and periodontal ligament reconstitution, the root end filling material should also promote dentin and cementum formation at the resected root surface. Of all the desired characteristics mentioned above, lack of toxicity and excellent sealing ability are the two most important requirements of an ideal material. Other attributes, like some degree of radiopacity of the material, will help the operator assess the quality of the fill in a postoperative radiograph. Root end filling materials should be readily available, easy to manipulate, have an adequate working time, and be reasonably priced. Thus, the ideal properties should satisfy biological, physical, practical, and economic criteria.

In the past several materials have been used for root end filling: Amalgam, gold foil, zinc oxide eugenol cements, Diaket (ESPE GmbH, Seefeld, Germany), glass ionomer cements (GICs), composite resins, intermediate restorative material (IRM, Caulk/Dentsply, Milford, DE, USA) and SuperEBA (Keystone Industries, Gibbstown, NJ). Mineral trioxide aggregate (ProRoot MTA, Dentsply Interantional, Dentsply-Tulsa Dental, Tulsa, OK, USA), and EndoSequence Root Repair Material (EndoSequence root repair material (RRM) Brasseler, USA. The same product marketed as IRoot and TotalFill in different countries.) are the recent materials popular amongst surgeons. Although none of the above satisfy all the requirements of an ideal root repair material, MTA and in recent years newer Bioceramics have the most potential in terms of sealing ability, biocompatibility, and bioactivity. The materials are discussed in detail below.

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11.1 Mineral Trioxide Aggregate (MTA)

MTA was originally developed from Portland cement as a gray powder by Dr Torabinejad (Loma Linda University, CA, USA) and sold as "ProRoot MTA", manufactured by Dentsply International (Tulsa, OK, USA). Later, a tooth-colored formula was introduced due to esthetic concerns ("White MTA"). The principle compounds of gray MTA are tricalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide, mineral oxide, and bismuth oxide. Bismuth oxide is added to increase radiopacity. White MTA mainly differs from the original gray MTA in the absence of iron.

The powder consists of fine hydrophilic particles that set in the presence of water. The initial setting time for MTA mixture is approximately 4 hours. Hydration of the powder leads to formation of a colloidal gel, which then solidifies to a hard structure. The characteristics of the set material depend on the particle size, the powder to water ratio, setting temperature, presence of water, and pH of the environment. However, at least 48 hours are needed to create permanently set cement.

11.1.1 Advantages of MTA

11.1.1.1 Sealing Ability

A large number of leakage studies on MTA exist. MTA appears to be the most resistant root end filling material to dye, fluid, and bacterial penetration when compared to amalgam, IRM, or SuperEBA. However, MTA's excellent sealing ability exists only when the proper setting is achieved. Teeth stored in an acidic environment during setting show a lower resistance to leakage than teeth stored at a high pH. Saliva contamination during white MTA placement showed increased bacterial leakage as well. Recent investigations show formation of an hydoxyapatite (HA) layer on the MTA surface in contact with tissue fluid during MTA setting, also known as "biomineralization". This HA layer is anticipated to create a biologic seal between the MTA and dentin interface and enhance the sealing ability of MTA in the long term.

11.1.1.2 Biocompatibility and Bioactivity

Several human, animal, and *in vitro* studies have proven MTA's excellent biocompatibility when compared with other materials. Little or no inflammation was noted histologically when MTA was used as a root end filling material in animal models. Some histological observations also found periodontal ligament cell and fiber alignment along MTA and the surrounding bone, indicative of regeneration of new cementum directly over MTA. University of Pennsylvania also tested MTA in a dog model and found new bone and cementum growth over MTA root end filling (Figure 11.1). The cytotoxicity and biocompatibility of MTA were also tested in *in vitro* cell culture studies. The results showed excellent cell attachment and growth of various types of cells (MDPC23, mouse primary osteoblasts, PY1A, human cementum derived cells, and DPSC) when these cells were grown on either gray or white MTA (Figure 11.2). MTA is reported to stimulate cytokine release, which controls inflammatory responses and hard tissue formation. MTA increases the levels of IL-6, IL-8, and osteocalcin

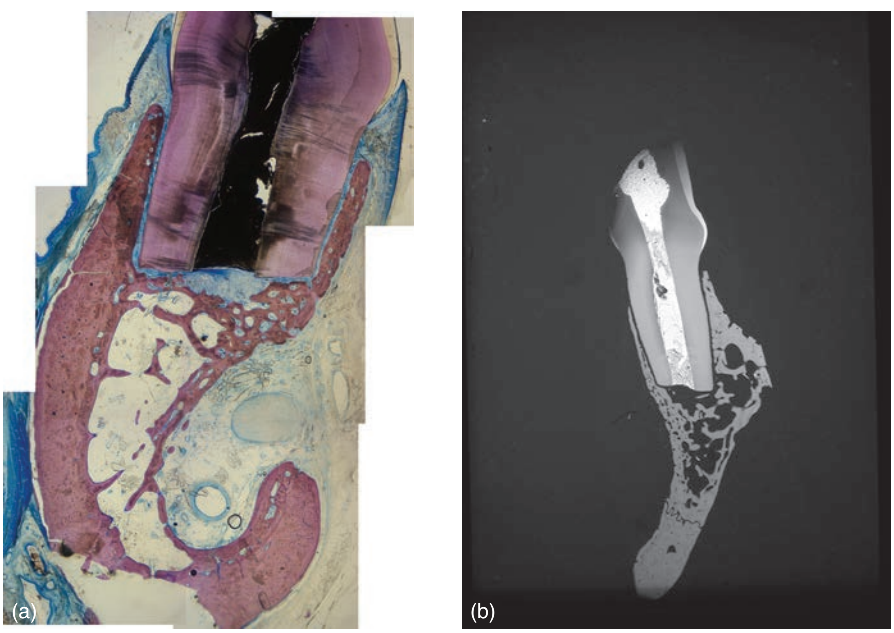

Figure 11.1 Dog root apex filled with ProRoot MTA: (a) histology slide; (b) micro CT.

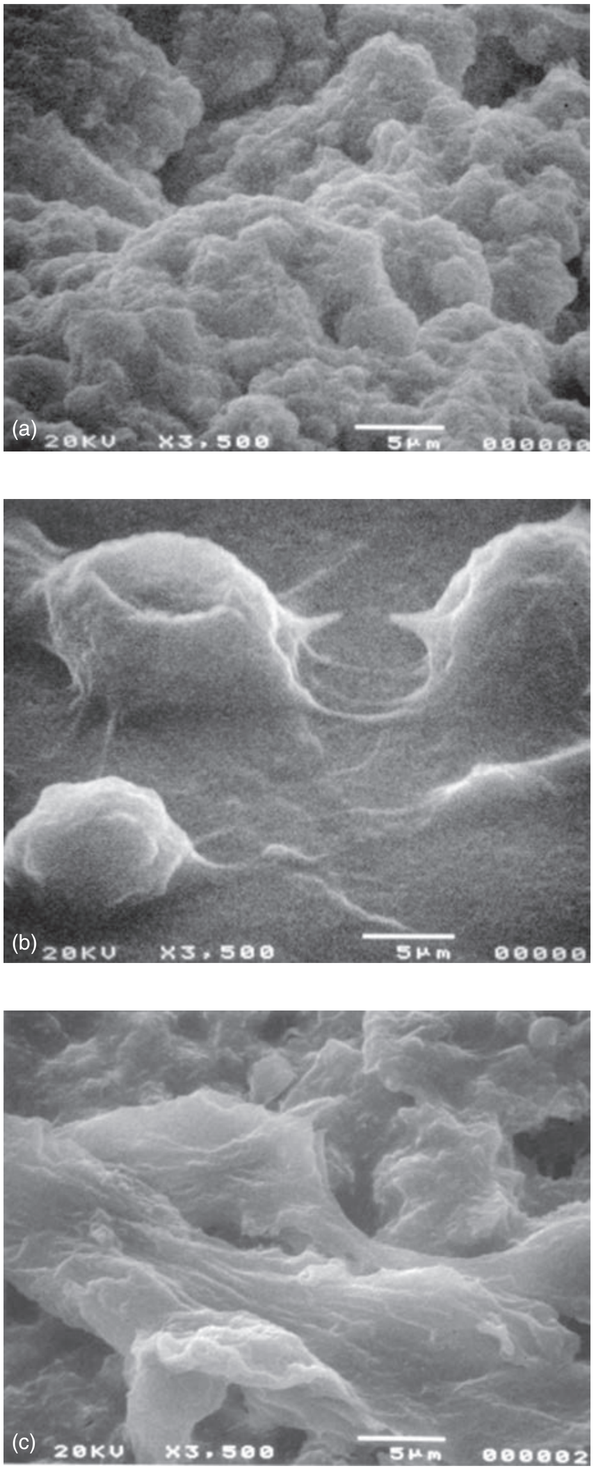

Figure 11.2 SEM pictures of MDPC 23 cells on (a) plastic plate. (b) and (c) ProRoot MTA; high magnification of cell grown on ProRoot MTA.

expression. It may actually promote bone turnover by increasing osteoclastic and osteoblastic activity. MTA appears to induce cell proliferation and differentiation of PDL fibroblasts, osteoblasts, and pulp cells. In addition, HA crystals formed on the surface of MTA while it sets may have hard tissue inductive properties. High pH of MTA, like that of calcium hydroxide, may also contribute in induction of hard tissue formation. In fact, the regeneration of new cementum and bone growth over MTA was reported in several studies; however, the exact mechanism is unknown.

11.1.2 Drawbacks of MTA

The major disadvantages of MTA are handling difficulties, heavy metals in the powder, long setting time, high cost, and possible discoloration of the remaining tooth structure. Because the MTA mixture is a sand-like paste, MTA is difficult to place in the prepared root-end cavities. In addition to these handling difficulties, freshly mixed MTA can wash out if exposed to excessive fluids due to its long setting time having a detrimental effect on its sealing ability. The setting time of MTA is approximately 3–4 hours, which is considered to be a disadvantage in many clinical situations. To circumvent these problems, additives such as methylcellulose, calcium chloride, and dibasic sodium phosphate have been used to decrease the setting time. However, these compounds can change MTA's physical and/or biological properties. For example, adding calcium chloride solution decreases the setting time, but also lowers the ultimate compressive strength.

11.2 Bioceramics

Bioceramics refers to a wide range of specially designed ceramics used for the repair, reconstruction, and replacement of diseased or damaged parts of the body. In dentistry, Bioceramics are frequently used for orofacial region reconstruction, implant surface coating, and fabrication of crowns and bridges. Zirconia and hydroxyapatite are two common examples in dentistry. MTA was the first generation Bioceramic used in endodontics. It belongs to the category of tricalcium silicate-based cements. Sealability and biocompatibility of MTA are attributed to the presence of tricalcium silicate. However, a major drawback of MTA is its handling properties, long setting time, and discoloration of the remaining tooth structure. In recent years other bioactive tricalcium silicate and phosphate cements have been introduced that claim to overcome these limitations.

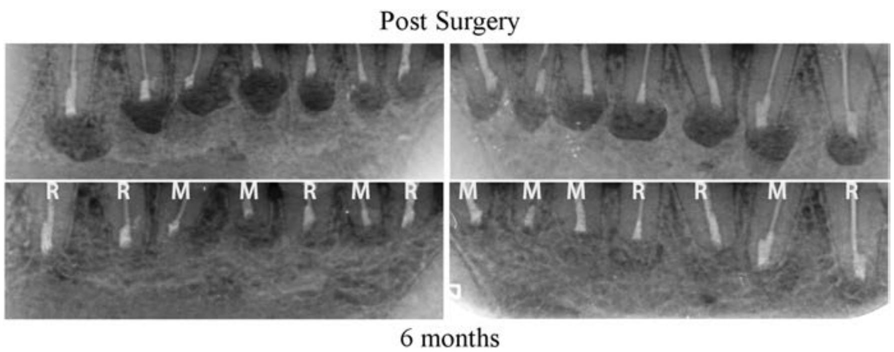

Figure 11.3 Periapical radiographs taken after apical surgeries on bilateral premolars in canine. Top: root end cavities were randomly filled with RRM (R) and MTA (M) while the root canals remained infected. Bottom: X-ray after 6 months of healing. All roots demonstrated complete healing using Rud's and Molven's criteria.

EndoSequence root repair material (RRM) (Brasseler USA, Savannah, GA, USA. The same product marketed as IRoot and TotalFill in different countries.) is a Bioceramic material developed for endodontics. The indications are similar to MTA, including root end filling, pulp capping, apexification, repair of root resorption, and perforation repair. According to the manufacturer, it is composed of calcium silicates, zirconium oxide, tantalum pentoxide, and calcium phosphate monobasic and filler agents. The material is ready to use, premixed, and comes as a paste in a syringe or putty in a jar. An advantage of RRM, based on clinical experience, is its handling properties, similar to that of Cavit (3M, St. Paul, MN USA). RRM is biocompatible, hydrophilic, insoluble, dimensionally stable, a high PH, has 30 minutes of working time, and as short as 2 hours setting time. Studies show that there are no significant differences between RRM and ProRoot MTA in terms of antimicrobial effects, biocompatibility, and sealing ability. In an animal study (Figure 11.3) using RRM and MTA as a root end filling material, no or minimal inflammation was seen at the surgical site upon healing. Cementum-like tissue was observed adjacent to RRM (Figure 11.4), similar to that with MTA. Using histometric analysis, significantly more cementum-like, PDL-like tissue and bone were found adjacent to the resected root end surfaces filled with RRM than MTA, indicating the material is biocompatible and has good sealing ability. RRM performed significantly better in regards to higher healing scores on microCT and CBCT in this study when compared with MTA. It is speculated that RRM may have better mineralized tissue inductive/conductive properties,

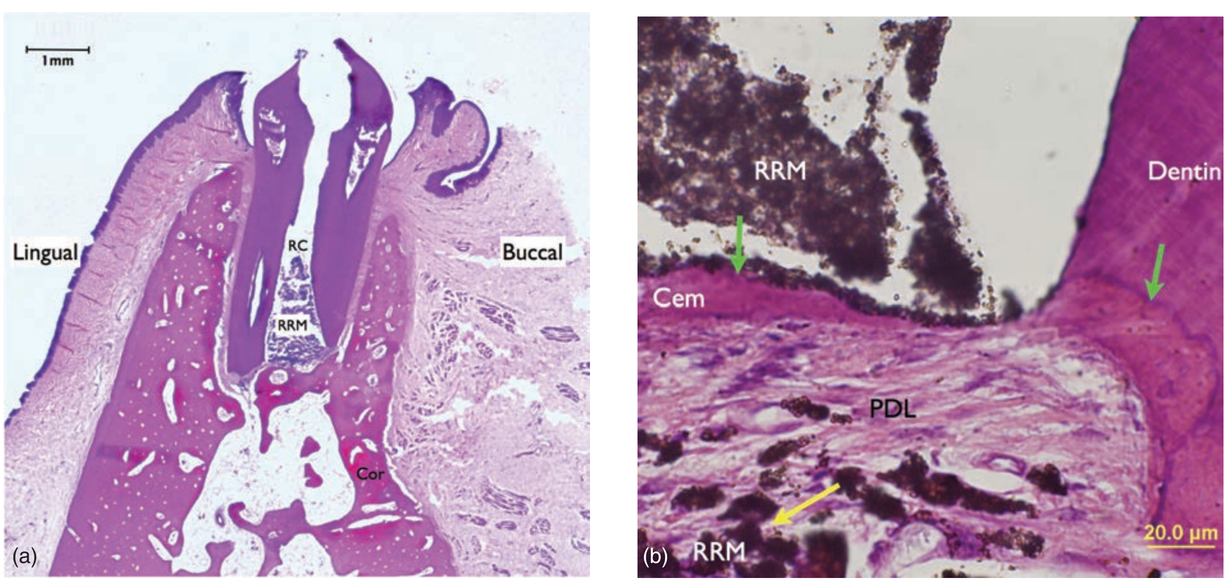

Figure 11.4 Periapical tissue response in root filled with EndoSequence Root Repair Material. (a) Overview of cross-section: re-establishment of buccal cortical plate and periapical tissue reformation. (b) Magnified view of the root end surface. No inflammatory cells were found in the periapical area near the exit of the root canal. RRM remnant in periapical tissue did not induce inflammatory reaction (yellow arrow). Cementum-like tissue formed on the resected root end surface and RRM root end filling (green arrow) with fibrous insertion from the adjacent PDL-like tissue.

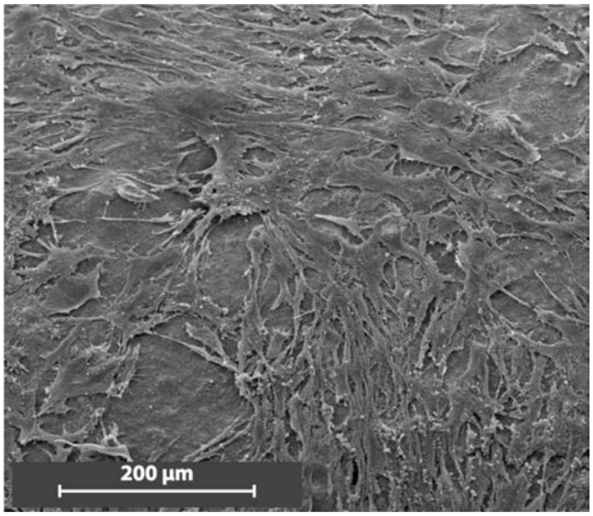

Figure 11.5 PDL stem cells attach and spread well on the surface of RRM, suggesting the material is biocompatible.

thus accelerating the deposition of cementum-like tissue on a root end surface accompanied by PDL-like tissue and bone. This hypothesis is partly supported by the data from Chen's *in vitro* cell culture studies (Figure 11.5), in which RRM showed a proliferative effect on osteogenic/odontogenic cells and induced osteoblastic/cementoblastic differentiation in those cells. Based on the available data, RRM is a suitable alternative to MTA for apical surgery.

11.3 MTA and Bioceramic Application During Apicoectomy

Although both these materials are hydrophilic in nature, complete hemostasis should be established in the osteotomy site before placement. Sterile Racellet pellets can also be placed as a barrier in the crypt to prevent pieces of the MTA or Bioceramic from sticking to the bony wall.

The ratio of MTA is 3 parts powder to 1 part sterile water. After 30 seconds of mixing, the mixture should exhibit a putty-like consistency. MTA is a loose granular aggregate, similar to concrete cement, and does not stick very well to itself or any instrument. Therefore, it cannot be delivered to the cavity using a normal cement carrier but has to be carried with a messing gun, amalgam carrier, or another specially designed carrier. For delivery of the MTA, many clinicians use a syringe-type carrier or MTA block. The MTA block (G. Hartzell & Sons, Concord, CA, USA) was designed by cutting grooves into a 0.5 inch × 0.5 inch × 2 inch plastic block. The mixed MTA is filled into a groove in the MTA block, and a small amount of MTA is scooped out of the grooves using a special carrier (Figure 11.6). After the MTA is placed into the prepared cavity, micropluggers are used to gently condense the mixture. A light condensing force is needed (Figure 11.7).

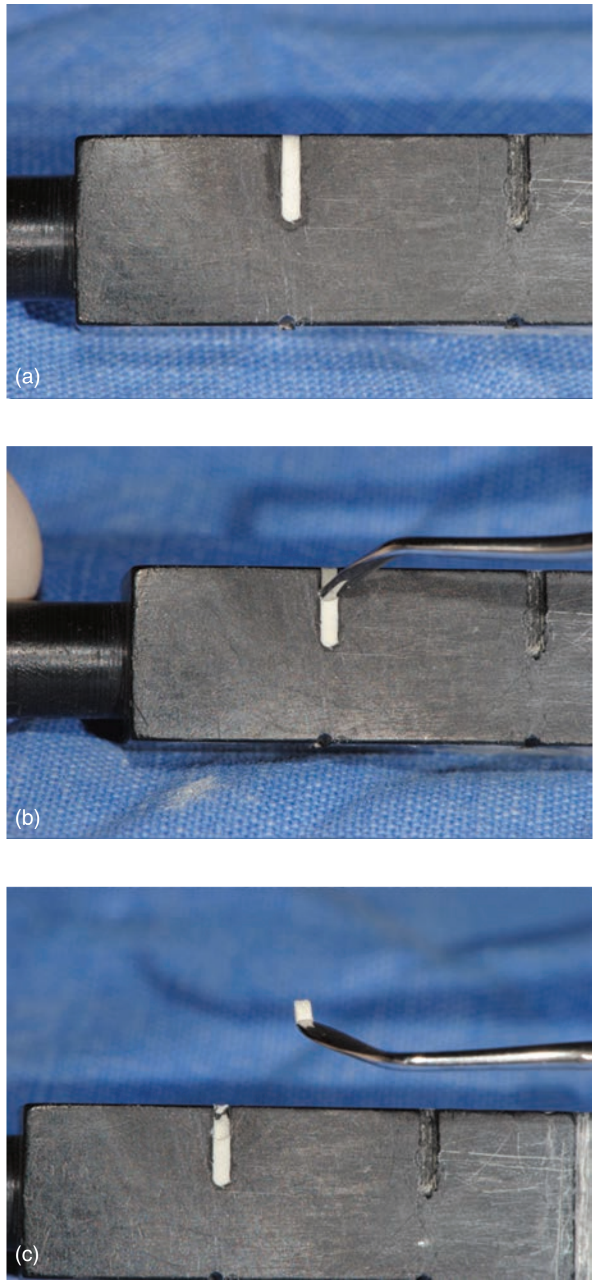

Figure 11.6 Use of MTA block. MTA block was designed by cutting grooves into a 0.5 inch × 0.5 inch × 2 inch plastic block. (a) Mixed MTA is filled into a groove of the MTA block. (b) and (c) Small amount of MTA pellet is scooped out of the grooves using a carrier.

As for a Bioceramic, the premixed putty material can either be rolled out on a glass slab and small

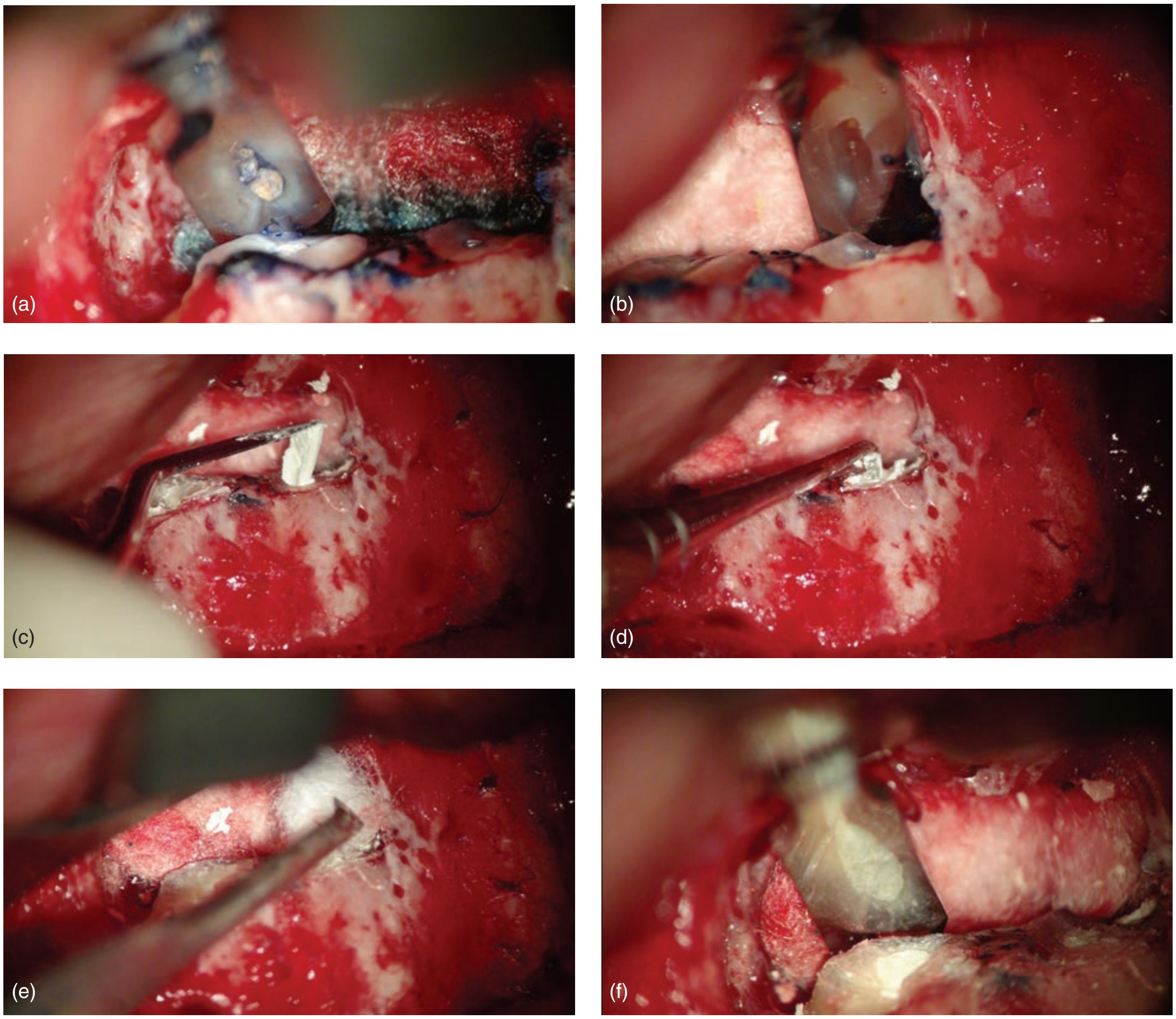

Figure 11.7 Clinical presentation of the root end filling procedure using Bioceramic RRM. (a) Inspection of the resected root surface at high magnification; (b) inspection of the root end preparation in order to ascertain clean walls; (c) placement of Bioceramic RRM with a carrier; (d) condensation of the material with plugger; (e) cleaning of the resected root surface with a wet cotton pellet; (f) inspection of the root end filling material to ensure well-adapted margins.

rope-like pieces delivered to the root end preparation with a specifically designed hand instrument carrier or MTA block grooves can be filled with Bioceramic putty to scoop up just the right amount of putty to be placed in the cavity as well (Figure 11.8). Micropluggers are used to gently condense the mixture. A light condensing force is needed (Figure 11.7).

The thickness of the retrograde filling material affects the sealability of MTA and Bioceramic putty; a minimum of 3–4 mm thickness is recommended. A moist cotton pellet is used to clean the resected surface, removing any excess MTA or Bioceramic putty. After completing the root end filling, the boney crypt cannot be irrigated when MTA is used as it will wash out, but if Bioceramic putty has been used the surgeon has the advantage of washing out the area with sterile saline.

11.4 Other Types of Cements for Root End Filling

A wide variety of materials has been used for retrograde fillings. Amalgam was the most popular and widely used root end filling material for many years. Amalgam is toxic, corrodes, results in tattoos on soft tissue, and causes microcracks in the root. IRM and

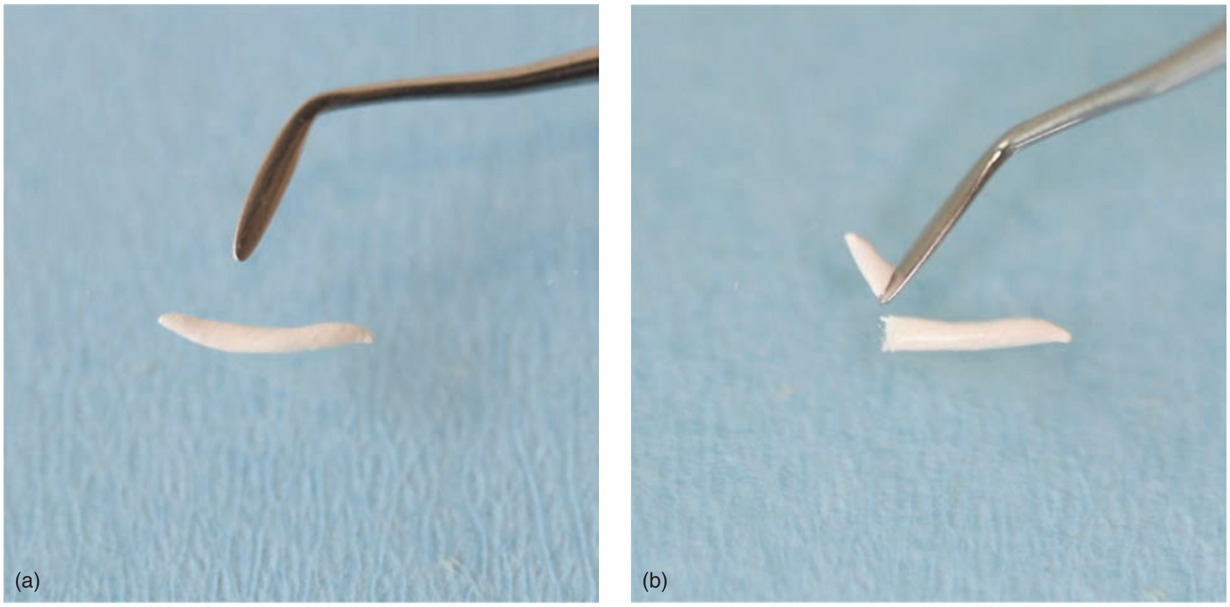

Figure 11.8 Bioceramic putty can be rolled to form a cylinder with the desired diameter. The operator can use MTA carrier to pick up the adequate length of Bioceramic and place it into the root-end cavity.

SuperEBA replaced amalgam and are still being used, even though MTA has become the most popular material.

11.4.1 Intermediate Restorative Material (IRM)

IRM is a modified ZOE cement that is reinforced by addition of polymethacrylate to the powder. The reinforcement has eliminated the problem of absorbability and IRM is more biocompatible than unmodified ZOE cement. In a tissue tolerance study, it was found that IRM elicited little to no inflammatory effects after 90 days, which led to the conclusion that the oral tissue was just as tolerant of IRM as it was of any other retrograde filling material.

11.4.2 Super Ethoxybenzoic Acid (SuperEBA)

SuperEBA is a modified form of ZOE cement with ethoxybenzoid acid cement. Ethoxybenzoic acid was developed in an attempt to alter the setting time and increase the strength of basic ZOE cements. The cement was modified by the partial substitution of eugenol liquid for orthoethoxybenzoic acid and the addition of fused quartz or aluminum oxide (alumina) to the powder. Stailine SuperEBA (Stailine and Staident, Middlesex, England) contains 60% zinc oxide, 34% silicone dioxide, and 6% natural resin in the powder component and 62.5% ethoxybezoic acid plus 37.5% eugenol in the liquid. In the United States, the most common formulation is Bosworth's SuperEBA cement (Keystone Industries, Gibbstown, NJ), which has the same contents except silicone dioxide is replaced by 37% alumina, making the cement stronger.

Tissue tolerance studies show that SuperEBA and eugenol cements produce similarly mild reactions. It has been demonstrated *in vitro* that ethoxybenzoic acid cement produces a tight seal compared to amalgam, glass ionomer cement, and hot burnished gutta percha. Leakage studies demonstrated that SuperEBA allowed significantly less leakage than amalgam. Also, SuperEBA adapts very well to canal walls compared with amalgam, which appears to be well condensed but has poor adaptation. However, SuperEBA can be a difficult material to manipulate because the setting time is short and greatly affected by humidity. The material tends to adhere to all surfaces and it may be difficult to place and condense.

In summary, SuperEBA is well tolerated by tissues, is fast setting, polishable, dimensionally stable, and provides excellent apical seals. The disadvantages of SuperEBA are that it is difficult to manipulate, sensitive to temperature and humidity, and only moderately radiopaque.

For application, the liquid and powder are mixed in a 1:4 ratio. The powder is mixed into the liquid slowly in small increments. Once the rolled SuperEBA mixture loses its shine and the tip does not droop when picked up by a carrier, the mixture has the right consistency.

11.4.3 Geristore and Retroplast

Gerisotore (Den-Mat, Santa Maria, CA, USA) is a dual-cured hydrophilic modified composite resin. Geriostore has been used as retrograde filling, repair material for subgingival or subosseous defects, and a barrier for guided tissue regeneration (GTR). Geristore may be advantageous because it releases fluoride ions, adheres to the dentine walls, and is stable in oral fluid. It is also reported to enhance cell attachment and proliferation. It has been shown that human gingival fibroblasts attached and spread well on Geristore, which demonstrates that Geristore might be less toxic than IRM and Ketac-Fil. Geristore is used mainly in North America, while in Europe a composite resin-type material named Retroplast (Retroplast Trading, Dybersovej, Denmark) was introduced in endodontic surgery with favorable long-term results.

The root end management with these materials is different from that in endodontic microsurgery. These materials are placed on a concave root resected surface, rather than being packed into a Class I cavity prepared with ultrasonic tips. The major disadvantage of these resin-type materials is difficulty in avoiding blood/moisture contamination. Like other resin-based materials, these root end filling materials will not provide an adequate seal if contaminated. This has been proven in randomized clinical trials comparing MTA with Retroplast, showing a lower success when Retroplast was used. The materials are technique-sensitive and can be unforgiving in the hands of an inexperienced operator. Some researchers also claim handling problems with Geristore due to accelerated setting, especially when exposed to light and heat from the microscope. Hence the materials are not as popular as hydrophilic substances such as MTA and Bioceramics.

11.4.4 New Types of Cements for Root End Filling

Several modified types of MTA-like materials have been developed and marketed, including MTA Angelus (Angelus and Rondriana, PR, Brazil), MTA Bio (Angelus and Rondriana, PR, Brazil), CPM (Egeo, Buenos Aires, Argentina), OrthoMTA (bioMTA, Seoul, Korea), and Endocem MTA (Maruchi, Seoul, Korea). The drawback of these relatively new products is the lack of research-based conclusions.

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12

Flap Reposition and Suturing

Francesco Maggiore and Meetu Kohli

KEY CONCEPTS

- The continuous sling suture and the single knot interrupted suture are the most commonly used types of suture in endodontic microsurgery.
- The sling suture is generally used in molar surgery.
- The single knot interrupted suture is generally used when a submarginal flap has been incised or when we would like to secure an extended intrasulcular incision.
- An intrasulcular incision is generally sutured using a 5.0 monofilament or chromic gut suture.
- A submarginal incision is generally sutured using a 6.0 or 7.0 monofilament suture.
- Investigations on the wound healing mechanism during apical surgery suggest that it is advisable to remove the sutures after 48–72 hours.

Once the apical microsurgery has been completed great care has to be taken in repositioning and suturing the elevated soft tissue. In fact, the ultimate esthetic result of the soft tissue manipulation depends on several factors such as the type of tissue, the type of incision, the choice of instruments used to incise, elevate, and retract the flap as well as careful reapproximation and a proper suture technique.

It is recommended to moisten the soft tissue with a wet gauze (sterile water or saline) before it is repositioned. The soft tissue can become dehydrated during the procedure and rehydrating it will return its natural elasticity and allows for easier reapproximation.

Of the several suture techniques often used in periodontal surgery, two are commonly used in endodontic microsurgery: the continuous sling suture and the single knot (interrupted) suture (Figure 12.1).

The sling suture is generally used in the molar region when an intrasulcular triangular flap has been raised. During placement of the sling suture the needle enters the gingiva at the base of the papilla mesial to the treated tooth from the buccal into the lingual (Figure 12.2a). It progresses at the base of the papilla mesial to the treated tooth, moves around the lingual aspect of the tooth, passes under the distal contact point, and penetrates the distal buccal papilla from the inner side (Figure 12.2b). The needle then goes back under the distal contact point, around the lingual aspect of the tooth (Figure 12.2c), passes under the mesial contact point, and the knot is tied at the mesial-buccal aspect of the treated tooth (Figure 12.2d).

The advantage of the sling suture is that it is relatively quick to place, but it relies on a single knot. If the knot does not stay in place during the healing process, the entire suture becomes loose. The sling suture is commonly done with a 5.0 mono- or polyfilament, or a chromic gut suture.

The single knot, interrupted suture is used when a submarginal flap has been incised or when the surgeon desires to secure an extended intrasulcular incision. In such cases the needle enters the gingiva at the base of the papilla from buccal to lingual (Figure 12.3a), passes under the contact point, re-enters the lingual gingiva from lingual to buccal (Figure 12.3b), moves back under the contact point, and the knot is tied on the buccal aspect of the gingiva (Figure 12.3c).

The single knot suture has the advantage of being a stable, precise suture and allows for primary closure. On the other hand, it requires time and meticulous application, especially while suturing a submarginal flap in the anterior region.

12.1 Suture Removal

One of the most debated questions among practitioners performing endodontic microsurgery is when to remove the sutures. The concept of leaving sutures in for one week or longer are extrapolated from periodontal literature. In periodontal surgery, the soft tissue is raised in order to reach pathologic hard

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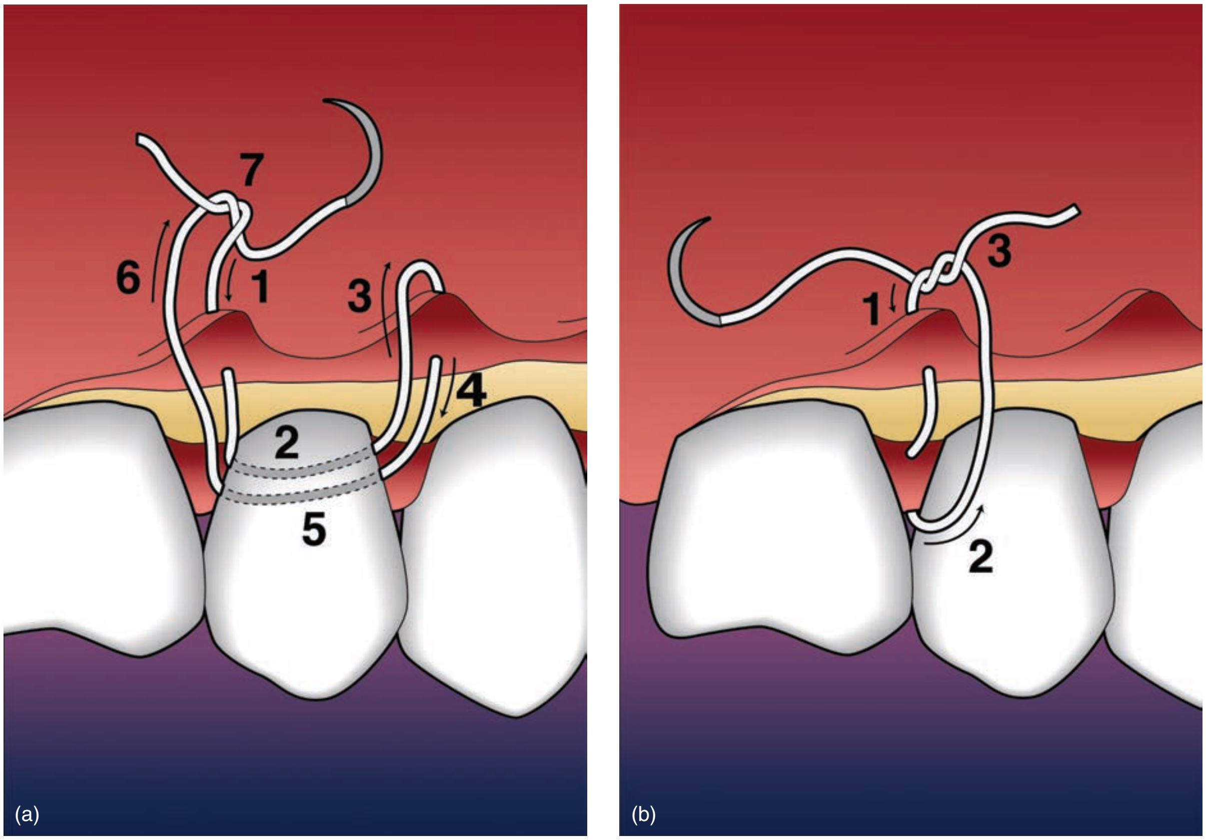

Figure 12.1 (a) Continuous sling suture. (b) Single knot, interrupted suture.

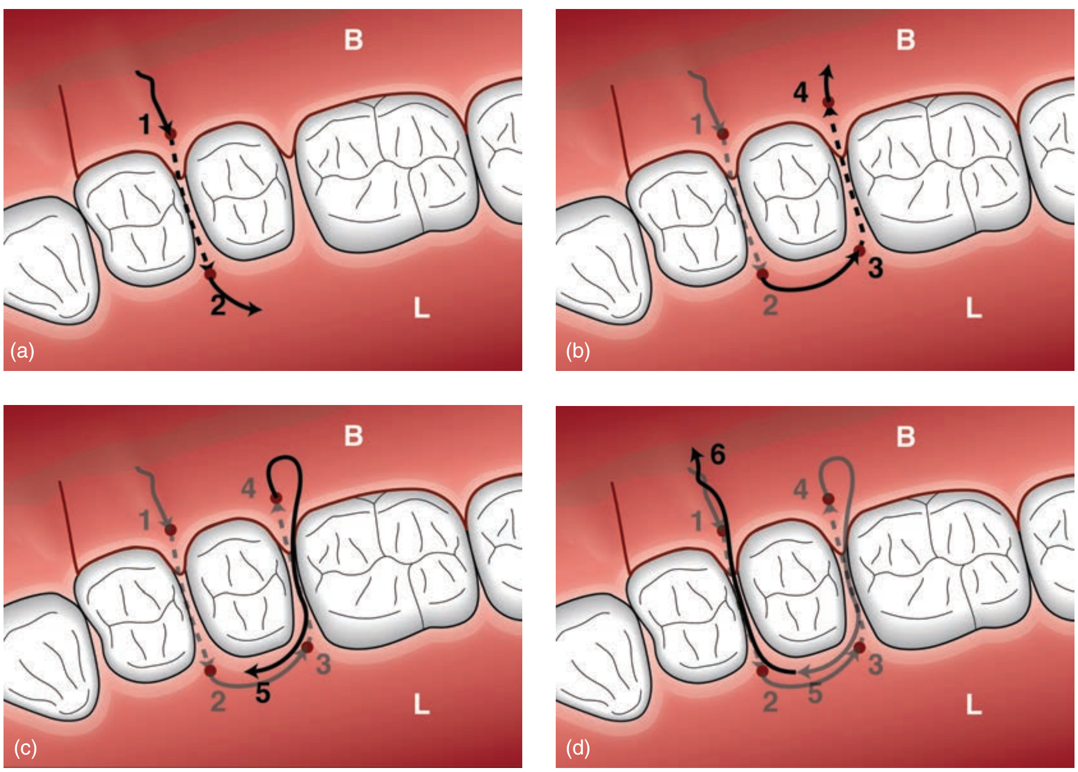

Figure 12.2 Sequence illustrating a continuous sling suture.

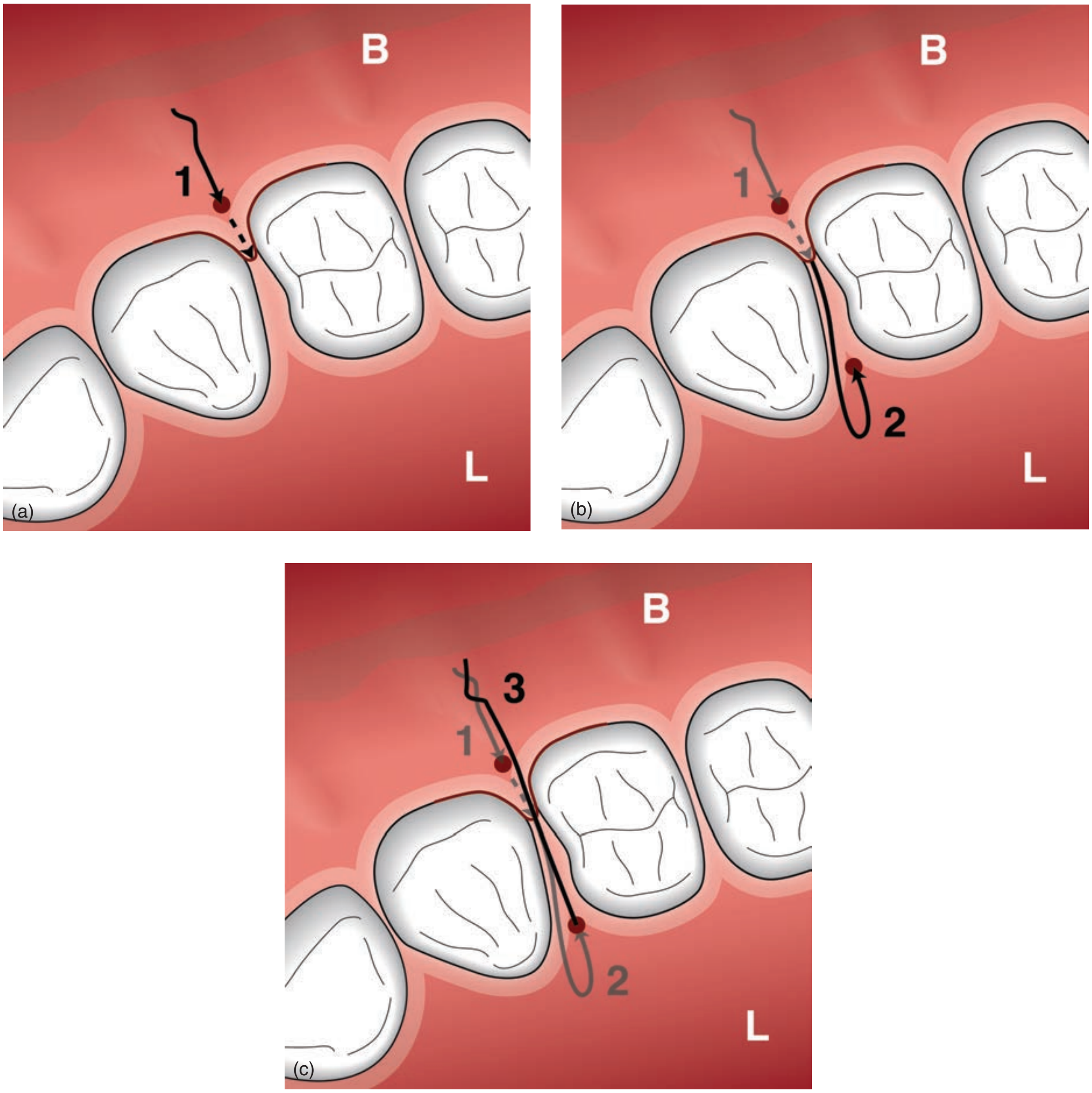

Figure 12.3 Sequence illustrating a single knot, interrupted suture.

tissue that has to be treated by curettage and excision. The flap is often sutured in a position different from its initial location: either apically or coronally. The periodontal healing often occurs with the formation of a new epithelial attachment. This process implies healing by secondary intention and requires approximately 2–4 weeks.

In endodontic microsurgery, the flap is elevated to access the underlining root apices. The coronal portion of the root and the cervical bone are generally not altered. The soft tissue is repositioned exactly in its original position. The healing of the repositioned periodontal tissue often occurs by reattachment and implies healing by primary intention.

The wound healing mechanism consists of four phases: phase I: clotting and inflammation; phase II: epithelial healing; phase III: connective tissue healing; and phase IV: maturation and remodeling.

Surgical endodontic wound healing studies show that clotting and inflammation generally occur in the first 20 hours. The epithelial healing occurs with the formation of an epithelial seal followed by the formation of an epithelial barrier. These mechanisms occur after 21–36 hours. The connective tissue healing implies the formation of reparative tissue and occurs in the second to fourth day. Finally, the maturation and remodeling take place in the fifth to seventh day. Of particular interest is the formation of the epithelial

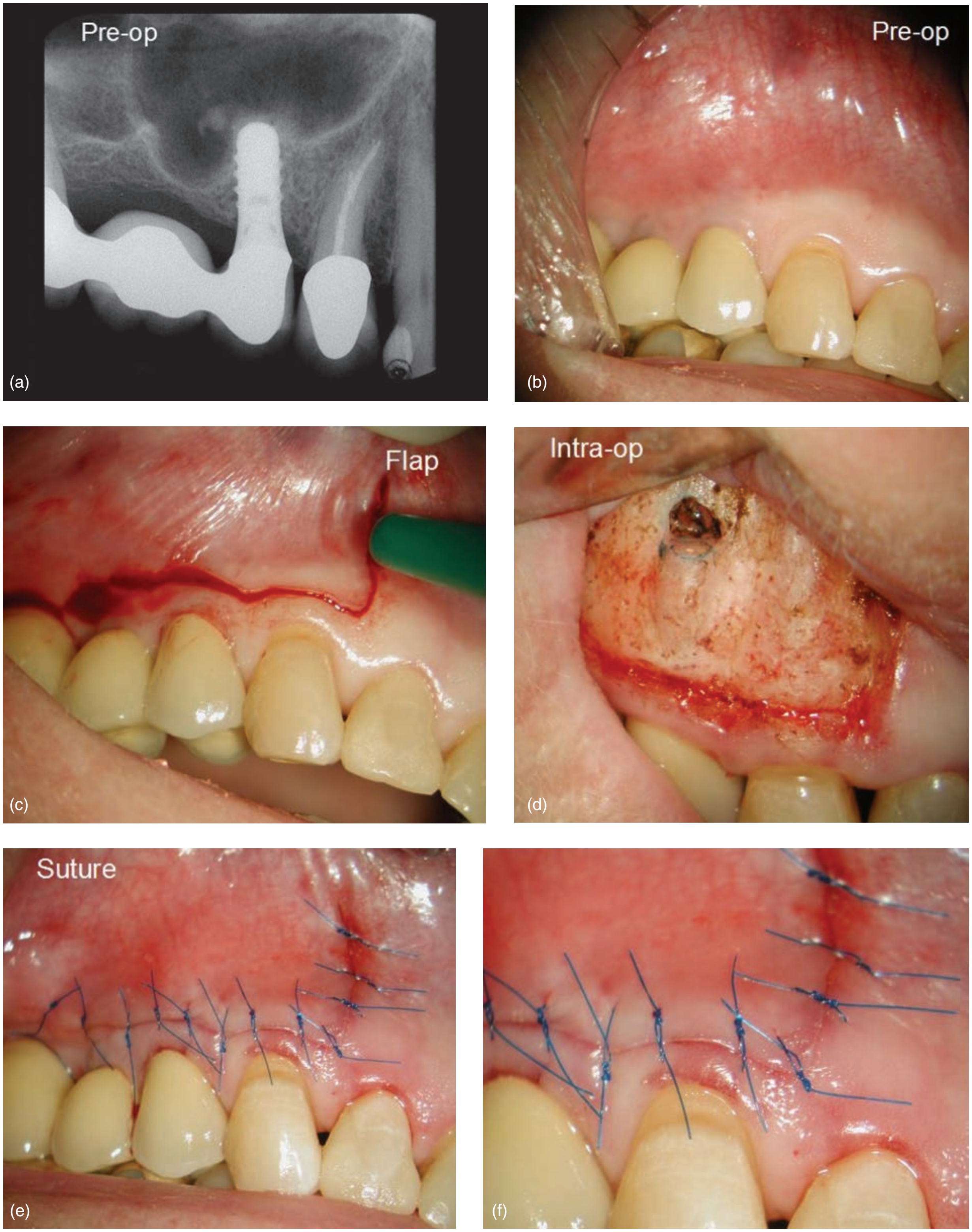

Figure 12.4 A triangular submarginal flap was raised to reach and curettage the apical third of tooth #5. (a) Preop radiograph; (b) pre-operative presentation of the soft tissue; (c) incision; (d) flap elevation; (e) to (h) synthetic monofilament 6.0 sutures, where knots are not tied on the incision line; (i) to (l) sutures removed after 72 hours.

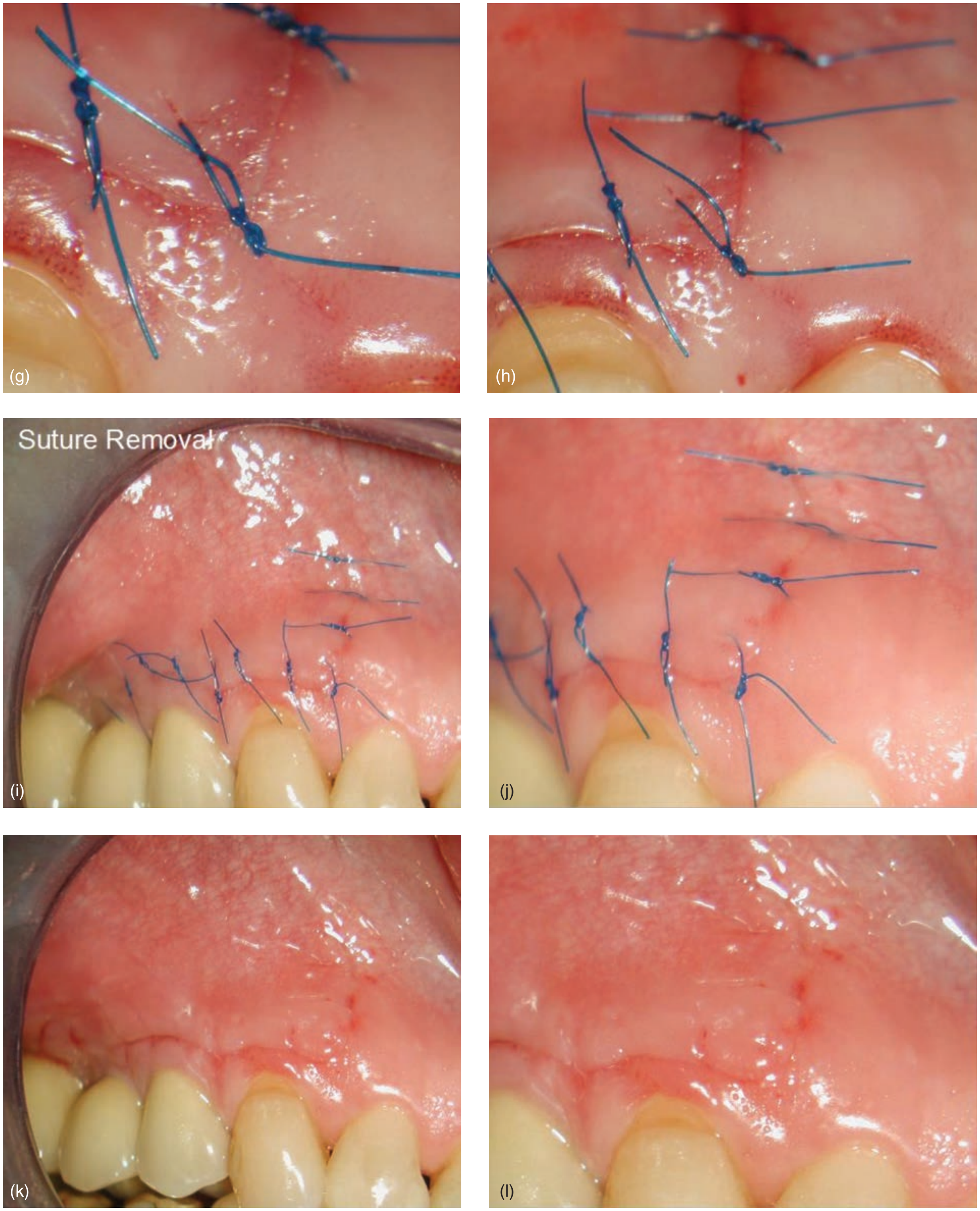

Figure 12.4 (*Continued*)

Figure 12.4 (*Continued*) (m) and (n) 2 month follow-up; (o) and (p) 4 month follow-up. The incision line not visible.

barrier. Its function is to prevent ingress of oral irritants into the surgical wound, to inhibit egress of tissue fluids from the surgical wound, and to increase wound strength. From a biological point of view, once the epithelial barrier is formed the function of the suture ends. The suture, in fact, has to keep in position the opposite wound edges until the physiologic mechanisms of body repair provide a seal of sufficient strength to proceed without further "help". Since the epithelial barrier seems to occur 24–48 hours after the incision with endodontic microsurgery it is advisable to remove the sutures after 48–72 hours. Prolonged maintenance of the sutures does not offer any advantage, and actually may cause a delay in healing because of possible food and plaque retention as well as the absorption of irritating oral fluids by the suture itself.

Recently, an increased use of augmentation procedures has been reported in endodontic microsurgery. At the present time, there is a lack of studies investigating the suture removal time after endodontic microsurgery incorporating augmentation procedures. Without sound scientific evidence, in cases where bone grafting/membrane have been used, it seems reasonable to leave the sutures in a little longer, perhaps two to three more days.

Once the flap has been sutured it is recommended to gently press wet gauze on the soft tissue. The gentle pressure eliminates possible air bubbles trapped in the soft tissue and promotes the reattachment of the raised flap.

Clinical case 1: Tooth #5, demonstrating soft tissue healing after microsurgery (Figure 12.4).

Clinical case 2: Tooth #11, an uncommon presentation of an endo-osseous implant. The tooth was symptomatic. Periapical film shows a lesion at the apex. Non-surgical and surgical retreatment were done to manage the apical third (Figure 12.5).

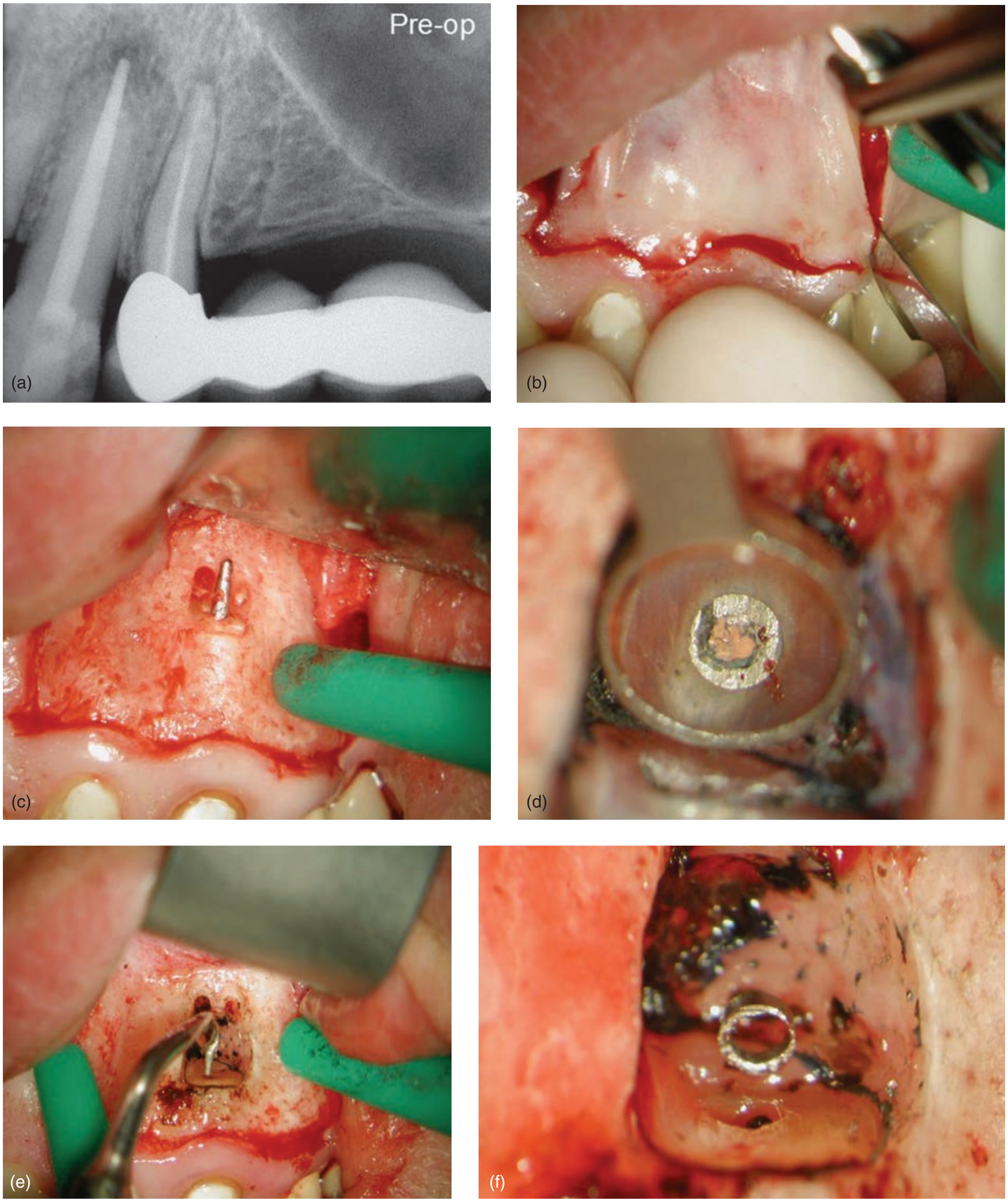

Figure 12.5 Apical surgery of a maxillary left canine. (a) Preop radiograph; (b) submarginal incision; (c) flap raised and endo-osseus implant visible; (d) exploration of the resected root surface under high magnification (×20); (e) ultrasonic preparation; (f) and (g) metal object removed; (h) retropreparation complete; (i) MTA root end filling; (j) postop radiograph; (k) and (l) 7.0 monofilament sutures.

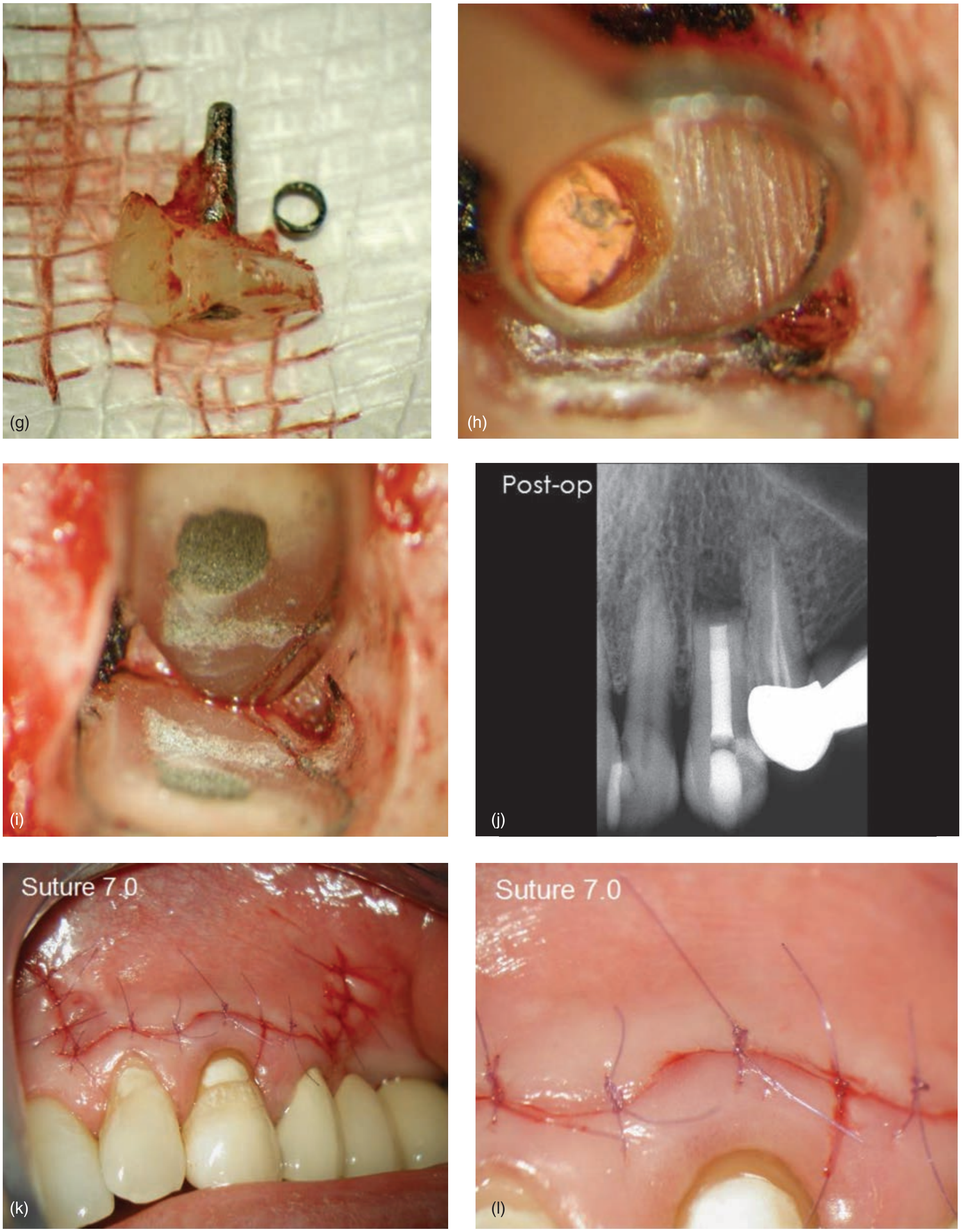

Figure 12.5 (*Continued*)

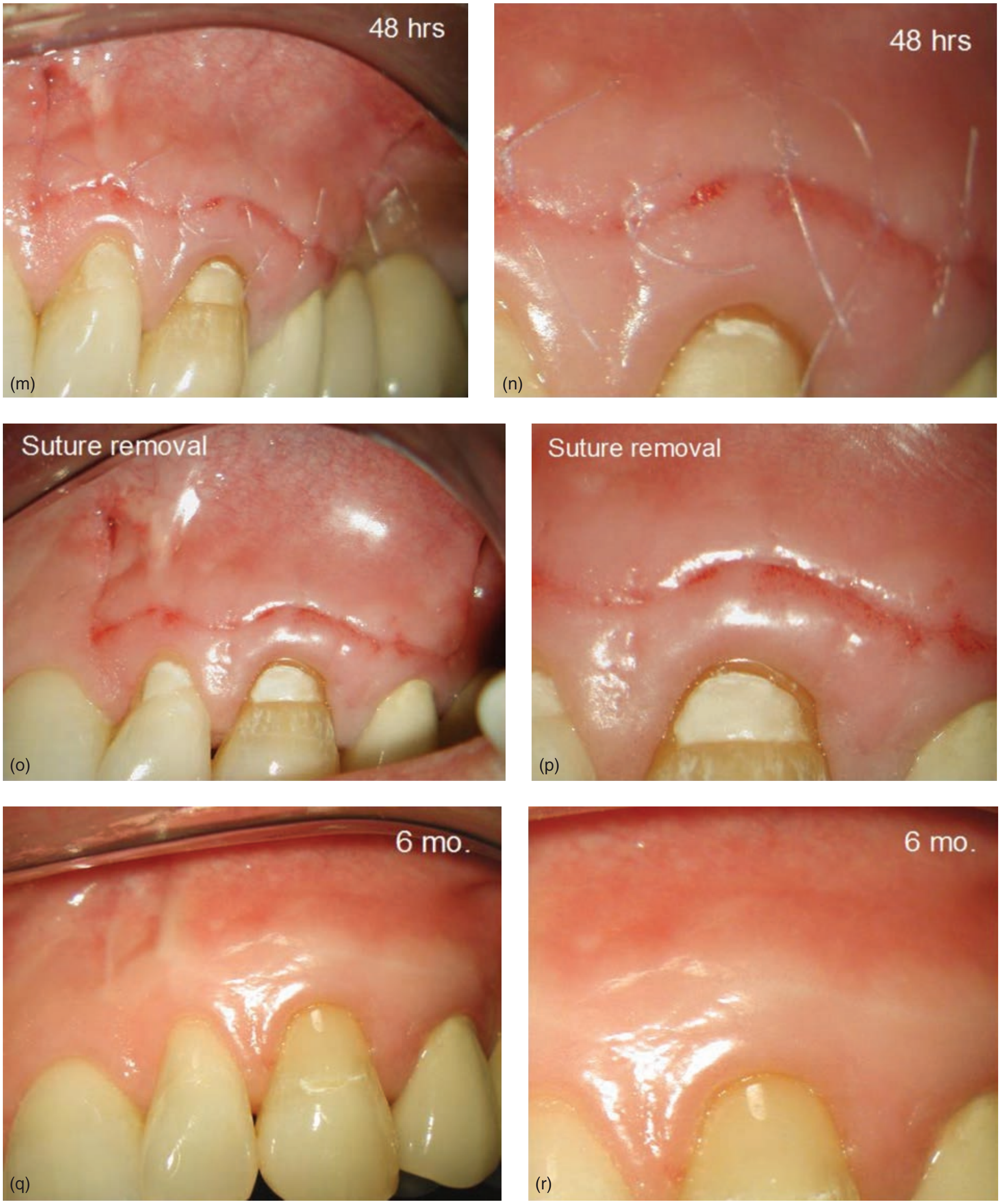

Figure 12.5 (*Continued*) (m) to (p) Sutures removed at 48 hours; (q) and (r) 6 month follow-up.

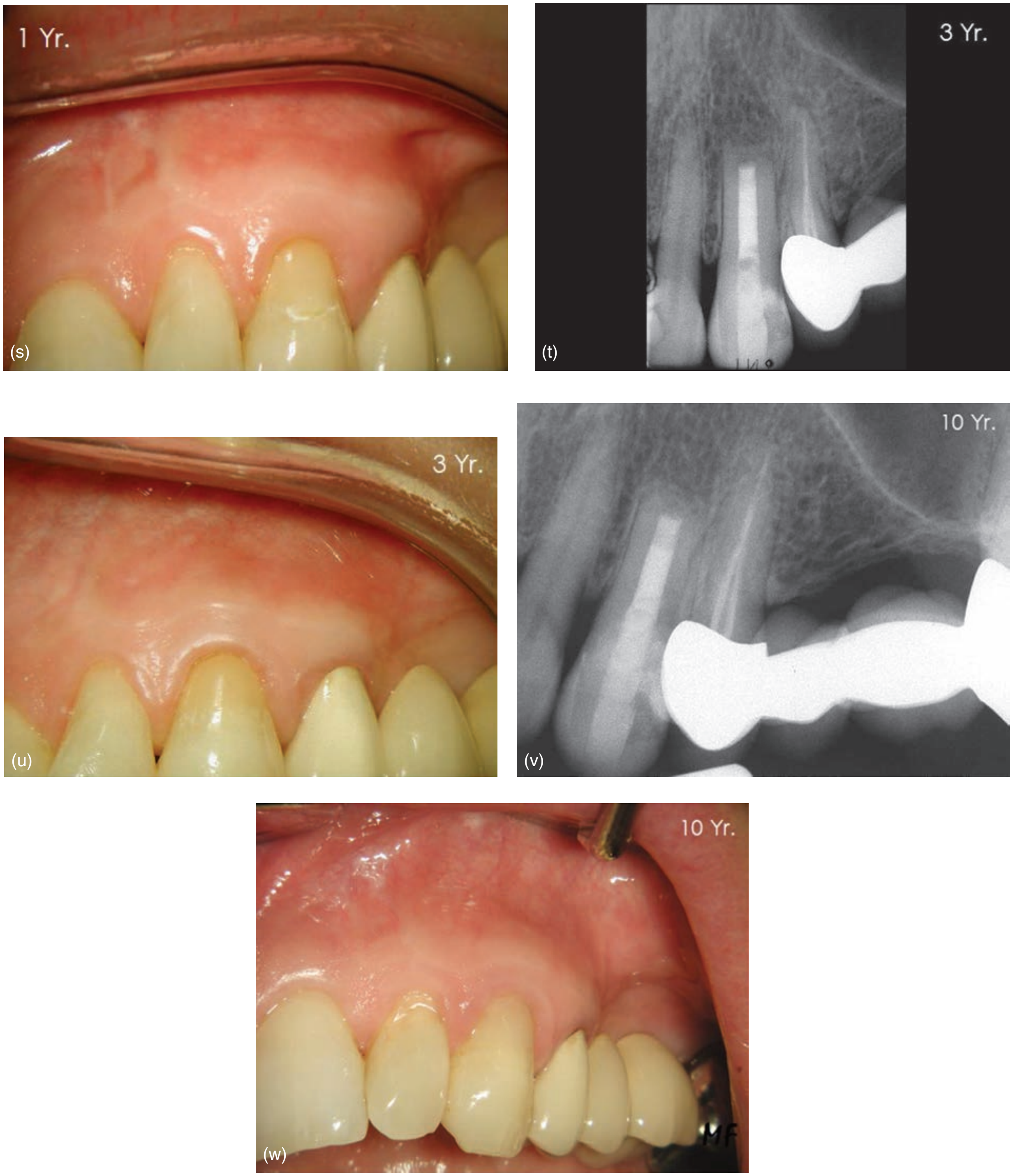

Figure 12.5 (*Continued*) (s) 1 year follow-up; (t) and (u) 3 year follow-up; (v) and (w) 10 year follow-up.

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13

Periapical Wound Healing

Ingrida Dapkute, Georges Bandelac, Chafic Safi, and Frank Setzer

KEY CONCEPTS

- Wound healing is the host's programmed immunoinflammatory defense mechanism in response to infection or injury.
- The same principles of wound healing apply to both non-surgical root canal therapy and apical microsurgery.
- Two-dimensional radiographs may not allow for correct healing assessment.
- CBCT is more sensitive in detecting apical periodontitis and assessing healing.

13.1 Principles of Wound Healing

Almost the same principles of healing apply for both non-surgical root canal therapy (NSRCT) and apical microsurgery. The primary difference is that healing after surgery requires a blood clot formation. Surgical excision may result in a faster healing process compared to NSRCT, which exhibits slower healing dynamics. After successful NSRCT, periapical inflammatory tissues will be eliminated, mainly by phagocytic debridement.

The basic phases of wound healing can be divided into three overlapping stages: inflammation, proliferation, and remodeling. Within these three broad phases a complex and coordinated series of events occur that include chemotaxis and phagocytosis during the inflammatory phase. Neocollagenesis, epithelialization, and angiogenesis result in the formation of granulation tissue during the proliferation phase. During the final remodeling phase, there is active collagen remodeling and tissue maturation that culminates in either repair or regeneration (Figure 13.1).

13.2 Healing after Apical Microsurgery

Following apical microsurgery, there is healing in two components: (1) osseous healing involving trabecular and cortical bone and (2) dentoalveolar healing that results in repair or regeneration of apical attachment apparatus (alveolar bone, periodontal ligament, and cementum) (Figure 13.2). After apical surgery, the resected cavity is occupied by a coagulum, which is slowly replaced by granulation tissue originating from the periodontal ligament and endosteum. The formation of new bone begins in the internal area and progresses externally toward the level of the former cortical plate. As newly laid woven bone reaches the lamina propria, the overlying membrane becomes functional periodontium (osseous healing) (Figure 13.3). Progenitor cells from the periodontal ligament differentiate into periodontal ligament cells and cementoblasts to cover the resected root surface and lead to regeneration of the cementum and the periodontal ligament (dentoalveolar healing).

13.3 Incomplete Healing/Scar Formation

Scar tissue formation after apical surgery has been extensively studied. It was demonstrated that 26% of defects radiographically larger than 10 mm resulted in scar formation after apical surgery. Furthermore, when the bony defect perforated both cortical plates ("through-and-through lesion"), the incidence of scar tissue formation may reach 60%. However, there is a lack of clinical evidence to indicate that large or through-and-through lesions will always result in scar tissue formation, even when no barrier membrane is used after apical surgery.

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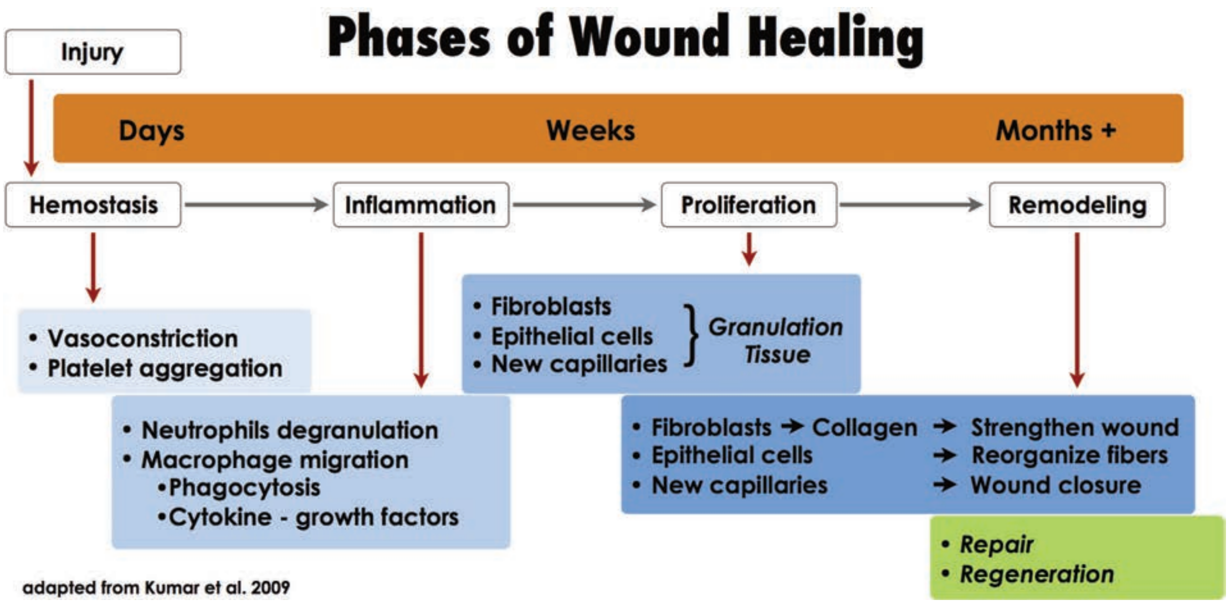

Figure 13.1 Three basic phases of wound healing: inflammation, proliferation, and remodeling.

Radiographically, scar formation has been characterized by a typical sunburst appearance due to bone trabeculae radiating from a center of the lesion that may remain radiolucent indefinitely (Figure 13.4). To this day the mechanisms of scar formation are not fully understood. Nevertheless, during incomplete healing, the healing is periosteal in nature and progresses from the outside of the lesion towards the inside, resulting in a residual defect and accumulation of nonfunctional fibrous tissue.

13.4 Evaluation of Healing after Apical Surgery

Histologically, three modes of healing after apical surgery have been observed: (1) healing with reformation of the PDL and mild or no inflammation; (2) healing with fibrous scar tissue, occasional ankylosis and various grades of inflammation; and (3) moderate or severe periapical inflammation without scar tissue formation. Furthermore, when histologic findings

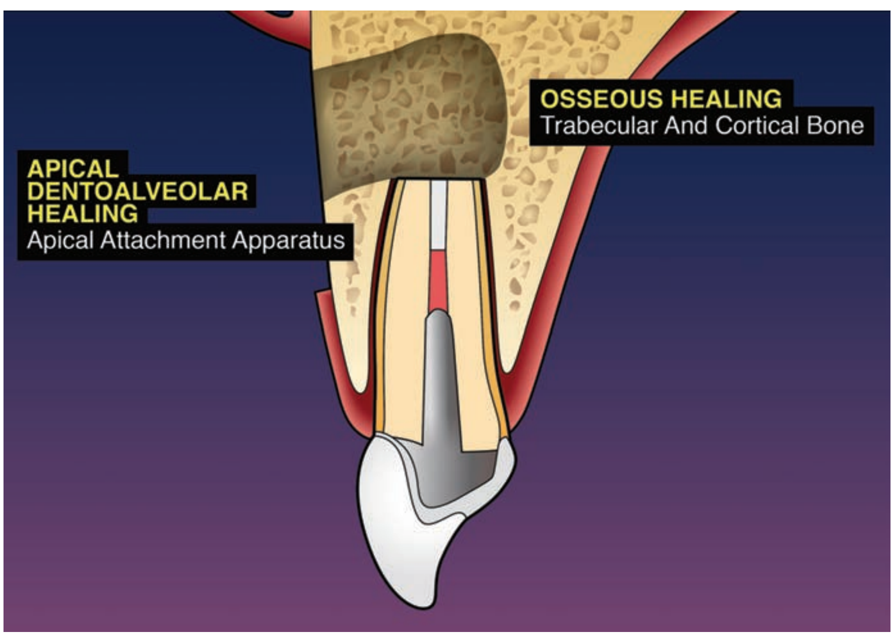

Figure 13.2 Wound healing after apical microsurgery: apical dentoalveolar healing and osseous healing.

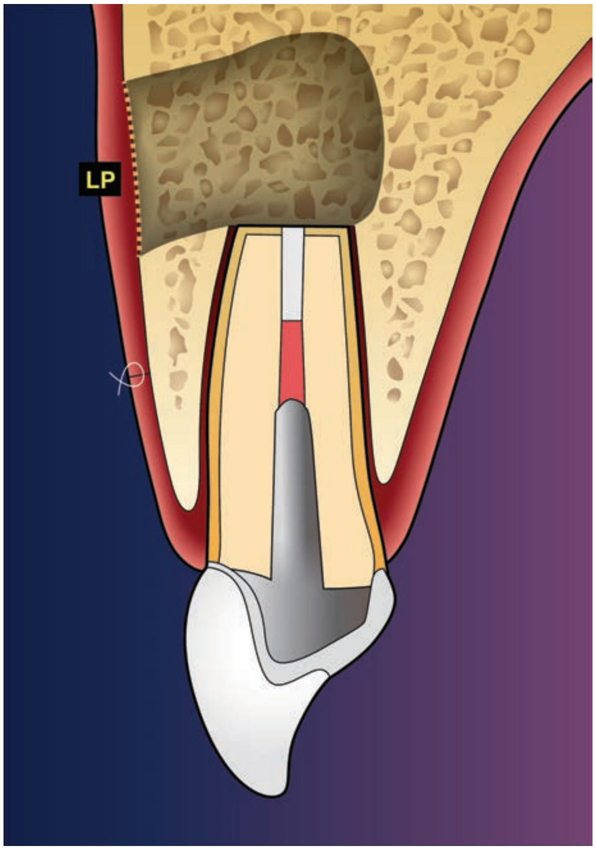

Figure 13.3 Wound healing after apical microsurgery: The cavity is filled with a coagulum that will become replaced by granulation tissue. The formation of new bone begins from internally and progresses externally towards the level of the original cortical plate. When newly laid woven bone reaches the lamina propria, the overlying membrane turns into functional periodontium.

were correlated with two-dimensional radiographic appearance, cases were defined as complete healing, incomplete healing (scar tissue formation), uncertain healing, and unsatisfactory healing.

It is also important to note that if a radicular cystic lesion has been treated surgically, recurrence will not take place even if the epithelial lining was not completely enucleated. Remnants of epithelial tissues omitted during the removal process have the potential to regress, possibly by the mechanism of apoptosis.

13.5 Healing Evaluation Using CBCT

CBCT imaging offers superior visualization of anatomic features in three dimensions, as well as the assessment of osseous defects and wound healing. One of the features of CBCT is that it illustrates the defects in cancellous bone and cortical bone separately, making it a more sensitive tool to identify apical periodontitis.

Furthermore, image reconstruction occurs in a multiplanar reformation mode, which allows the highlighting of specific anatomic regions and structures around the resected root surface, such as periodontal ligament space, lamina dura, and cortical plate. Moreover, it allows for differentiation between various bone densities.

The aforementioned anatomic structures are central to current criteria used to assess apical surgery healing on CBCT. For example, complete healing is attributed to those cases where the periodontal ligament space and the lamina dura have completely reformed over the resected root surfaces (Figure 13.5).

Other interesting healing patterns observed on CBCT include complete healing in the immediate vicinity of the resected root surface, along with a complete cortical bone repair in width and density; however, the trabecular bone adjacent to the resected root is of low density (Figure 13.6). These cases can be attributed to limited healing, which is considered a successful outcome.

This differentiation between various bone densities is unique to CBCT. It has been hypothesized that reduced radiolucent areas represent either scar tissue, immature bone, or bone-like tissue without adequate mineralization, which at this particular stage of healing would not be radiopaque enough to be detected by CBCT.

Another interesting observation concerns tooth position in the bony architecture. This is where presurgical assessment using CBCT becomes an essential step in treatment planning. It was noted that there was superior healing in teeth positioned deeper in the dental architecture (i.e., surrounded with bone except in the apical area, where there was radiolucency and fenestration of the cortical plate) than in teeth positioned far buccally, where roots were too prominent and a very thin cortical plate covered them, even though there was no fenestration of the cortical plate (Figure 13.7).

In these cases, the placement of a bone graft and/or a collagen-based membrane can help in the healing process. The bone graft will permit thickening of the cortical plate, whereas the collagen membrane will contain the bone graft material and exclude epithelial cells from penetrating the osteotomy site. Recent developments in grafting material suggest the usage of a collagen-based augmentation material that functions as both a bone graft and membrane.

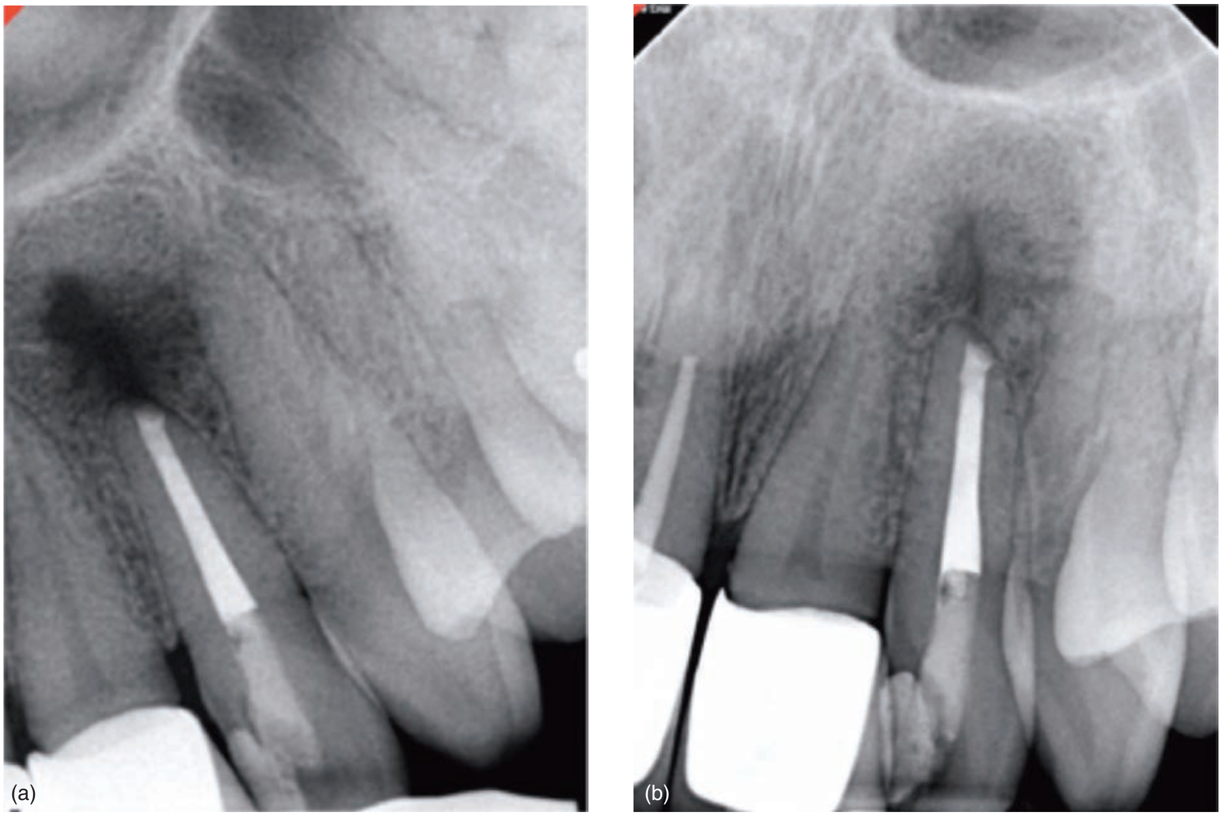

Figure 13.4 Incomplete healing (scar tissue) after endodontic surgery. The sunburst appearance is due to bone trabeculae radiating from the center of the defect that remained radiolucent. (a) A 10 month follow-up; (b) a 17 month follow-up.

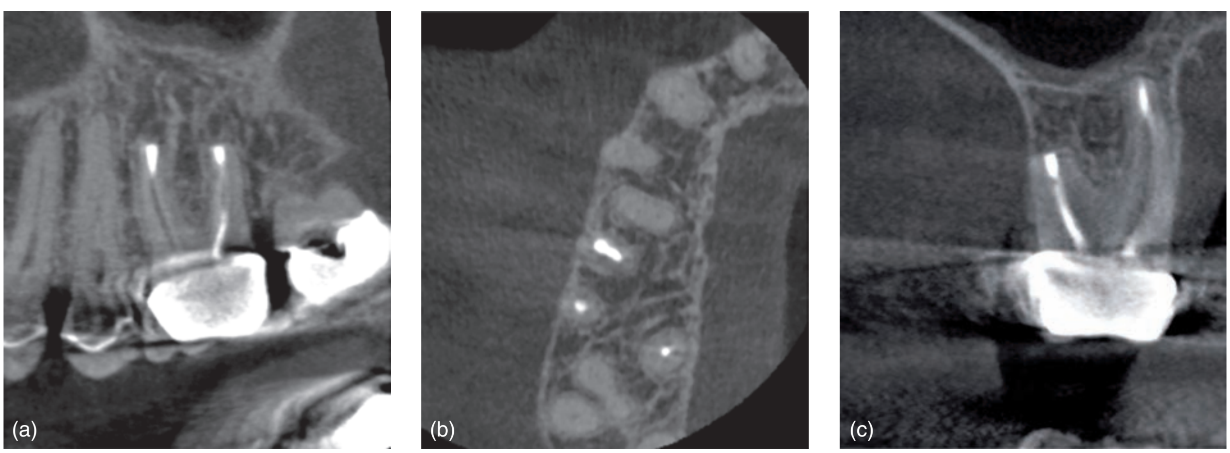

Figure 13.5 Example of complete healing after endodontic microsurgery: CBCT analysis and 2.5 year follow-up of maxillary first molar. (a) Sagittal view; (b) axial view; (c) coronal view.

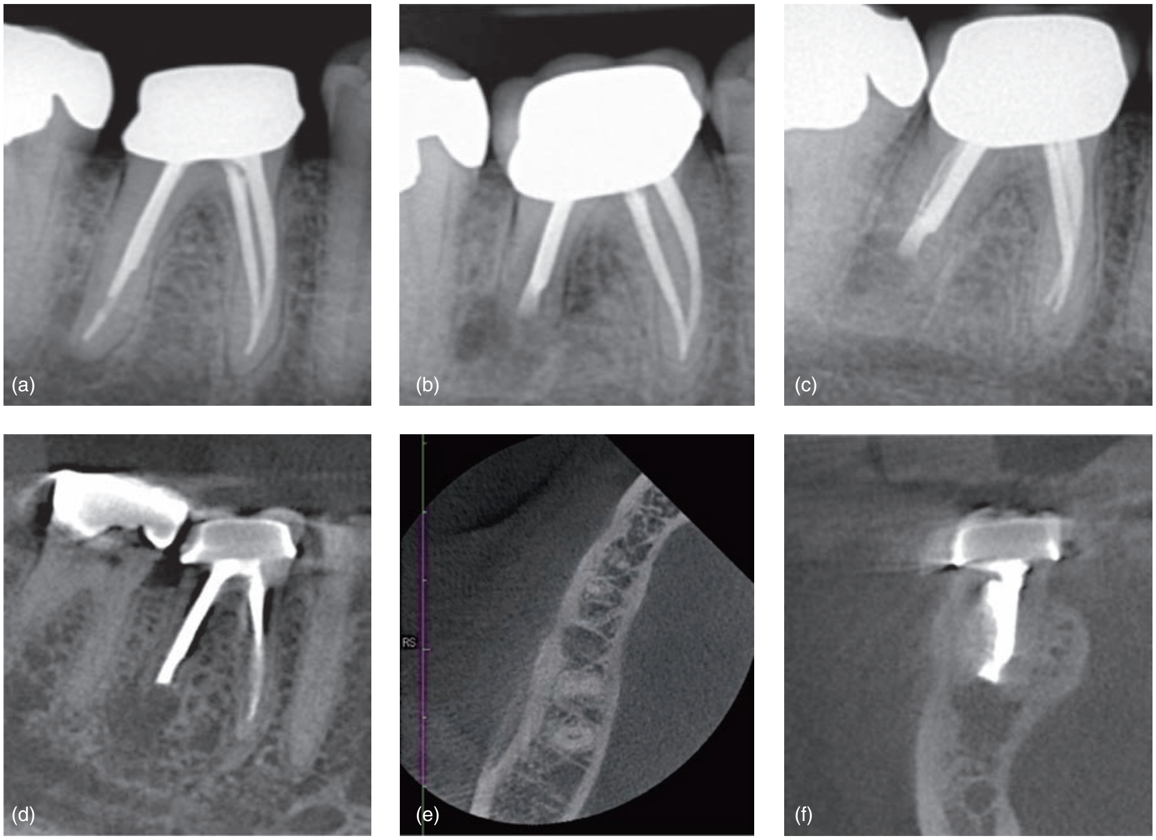

Figure 13.6 Comparison of two-dimensional (2D) versus three-dimensional (3D) analysis after surgery on the distal root of a first right mandibular molar: (a) preoperative radiograph; (b) postoperative radiograph; (c) 1 year follow-up, classified as uncertain healing according to Molven's criteria (2D); (d) 1 year follow-up CBCT sagittal view, classified as limited healing according to PENN 3D Criteria (note that the complete bone fill within the previous osteotomy is in direct contact with the resected root surface and root end filling material, but is of lower bone density in comparison to the original mature bone surrounding the osteotomy); (e) axial view (3D); (f) coronal view (3D).

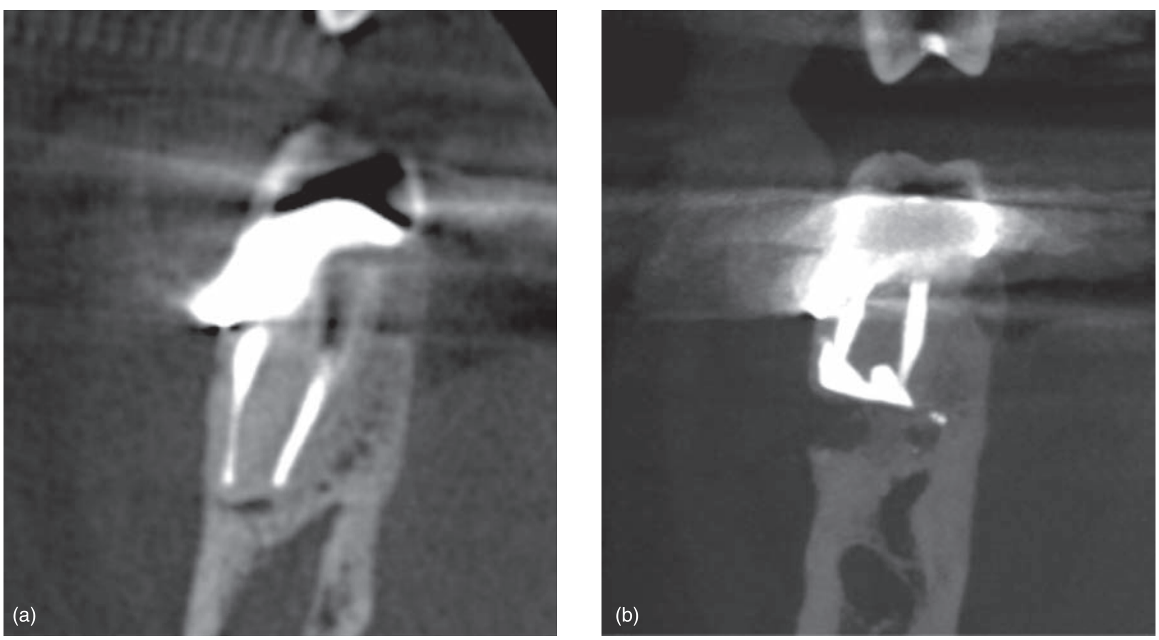

Figure 13.7 CBCT analysis of endodontic microsurgery on a first right mandibular molar, mesial root. (a) Preoperative coronal view; note the prominent buccal position but absence of fenestration. (b) A 1 year follow-up coronal view. Note the complete cover of the resected root surface by newly formed bone, but the low density area is inferior to the layer of bone and does not show bone reformation. This is limited healing according to PENN 3D Criteria.

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14

Cone Beam Computed Tomography

Garrett Guess, Fouad Al-Malki, Meetu Kohli, Bekir Karabucak, and Samuel Kratchman

KEY CONCEPTS

- Cone beam computed tomography (CBCT) has revolutionized dental imaging. It enables clinicians to easily view areas of interest in any plane and not be restricted by two-dimensional conventional radiography.
- CBCT is needed for cases with primary treatment failure to help the clinician decide whether to retreat surgically or non-surgically.
- A CBCT scan is recommended for most surgical cases to eliminate the guesswork.

Dental radiographs provide essential information for every aspect of endodontics. They are the basis for reviewing root anatomy, but are a two-dimensional representation of a three-dimensional structure. Goldman *et al.* in 1972 stated that radiographs are interpreted and not read. The data interpretation is so subjective that the examiner when given the same radiograph to study again after 6–8 months will agree with his/her previous conclusion only 72–88% of the time.

Bender and Seltzer (1982) showed that periapical lesions are not discernible on a radiograph unless the cortical plate is encroached upon. Patel *et al.* (2009) recommended taking angulated X-rays along the horizontal plane, to help provide a better depth perception and spatial arrangement of the area being studied. Another concern listed by Patel *et al.* is the anatomic noise: a superimposition of radiopaque or radiolucent areas over the field of interest, leading to misrepresentation of the actual anatomy. For example, overlay of incisive foramen or mental nerve on the root tips of neighboring teeth may suggest a presence of a lesion while none is present. Lastly, the reproducibility of similarly aligned X-rays over periods of time to evaluate prognosis is questioned. If a stent or bite registration is not used the healing or failure of a periapical lesion can be misrepresented.

In the field of endodontics, investigators have explored various techniques in order to solve these limitations. MRI and ultrasound have been evaluated in a research environment and found to be fairly accurate for some cases, but their routine use is prohibitive, due to availability, size, and cost.

Computed tomography (CT) is an X-ray imaging technique that has been used in medicine for many years, where a three-dimensional (3D) image of an object is mathematically reconstructed by using a series of two-dimensional (2D) image datasets acquired during an X-ray scan. This system measures the attenuation of X-rays entering the body from different angles. The computer then reconstructs the parts in a series of cross-sections or planes. The interval between each slice may be varied; closely approximated slices will give better spatial resolution, but will result in an increased radiation dose to the patient. The biggest setbacks to use of CT scans in an endodontic practice have been the large radiation dose to the patient and inconvenient access to a scanner, as the machine is mostly available in a hospital setting. The high cost of the scan, along with a very high dose of radiation, do not translate well into an acceptable risk–benefit ratio for the patient.

The next step in evolution of the CT is the cone beam computed tomography (CBCT) or the digital volume tomography (DVT). CBCT has revolutionized dental imaging. For the first time, the clinician is able to use a patient-friendly imaging system to view areas of interest in any plane easily and not be restricted by two-dimensional conventional radiography. CBCT imaging technology was introduced in the US market in 2001.

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14.1 How CBCT Works

Familiarity with the operational parameters of the apparatus can help the practitioner in two key clinical applications: radiation dosage and image quality. Radiation safety is paramount when a new imaging technology is introduced. The manufacturers are competing with each other in order to improve performance of their respective machines, to get the best possible image with a minimal radiation dose.

The raw signal is converted into a single cylindrical or spherical digital volume described by its smallest subunit called the voxel, which is stacked in rows and columns for visualization. The data are projected in three planes: axial, sagittal, and coronal. The clinician is obligated to review the image as a whole and not zero in on the presumed pathology or a specific point of interest. The clinician is legally responsible for the entire information presented in the scan, therefore a systematic review will avoid overlooking other aberrations.

14.2 Indications and Clinical Applications

In no aspect of endodontics is a scan more useful than in surgical retreatment. The following clinical cases will present the irrefutable advantage of this imaging technique in the decision-making, preparation, and execution of the surgery. The CBCT acts as the clinician's GPS system, guiding him/her throughout the surgery.

A preoperative CBCT can help us to avoid putting the patient through an unnecessary procedure when an extraction is indicated. Once a surgical intervention is treatment planned, the software allows the clinician to make all necessary measurements, such as where to initiate the osteotomy if a bony fenestration is not present, utilizing root length and thickness of cortical bone. This shortens the duration of the surgery, making it a precise, well-targeted, and predictable procedure. Important landmarks can be identified and complications avoided, such as proximity of the mental foramen, mandibular canal, sinus cavity, proximity to neighboring vital teeth, etc. Surgical intervention is a necessity in cases that are being treated for external resorptive defects. The CBCT is irreplaceable in cases like this, because it allows the practitioner to see if there will be adequate access to approach the defect, if the tooth needs a root canal in addition to the resorptive repair, and is the tooth salvageable if the defect is removed completely. Similar applications of the CBCT apply for cases that necessitate repair of iatrogenic errors such as perforations, separated files, etc.

Cases that validate the above-mentioned indications are presented below:

Case 1. Treatment option between non-surgical and surgical retreatment (Figure 14.1).
Case 2. Treatment option between non-surgical and surgical retreatment (Figure 14.2).
Case 3. CBCT diagnosis of a possible periapical pathology (Figure 14.3).
Case 4. Proximity to mental nerve and treatment decisions (Figure 14.4).
Case 5. Proximity to various anatomical structures (Figure 14.5).
Case 6. Evaluation of root anatomy for intentional replantation (Figure 14.6).
Case 7. Microsurgical procedure planning (Figure 14.7).
Case 8. Evaluation of previous root canal filling and extent of the periapical pathosis (Figure 14.8).
Case 9. CBCT evaluation for palatal root surgery (Figure 14.9).
Case 10. Perforation location and repair (Figure 14.10).
Case 11. Cervical root resorption evaluation and repair (Figure 14.11).
Case 12. Cervical root resorption extent and treatment decision (Figure 14.12).
Case 13. Surgical root resorption repair (Figure 14.13).
Case 14. Root fracture (Figure 14.14).
Case 15. Resurgery case evaluation (Figure 14.15).
Case 16. CBCT evaluation of traumatic injury (Figure 14.16).
Case 17. 5.5 years CBCT follow-up of a microsurgery case (Figure 14.17).

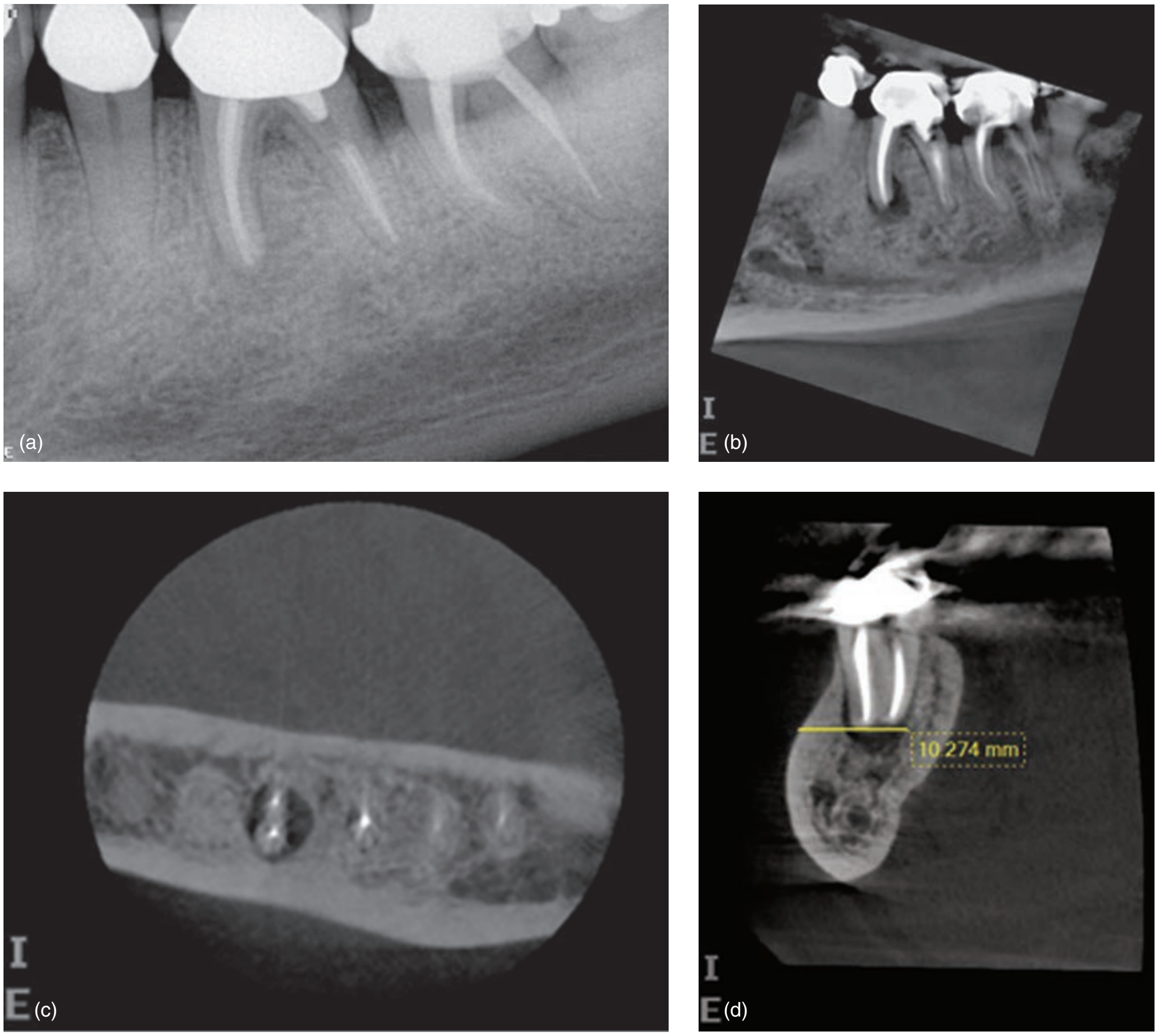

Figure 14.1 Previously treated mandibular first molar with apical periodontitis. (a) Periapical radiograph shows well-filled root canals and well-fitted crown restoration with a post in the distal canal. (b) Sagittal view showing large low-density area around the mesial root. (c) Axial view showing a well-defined, large low-density area limited to the mesial root. The buccal cortical bone is thick and intact. (d) Coronal view showing a thick buccal cortical bone and the location of the mesial root. Distance from the buccal cortical bone to the end of the mesial root exceeds the length of a Lindemann surgical bur and may limit full root resection. Therefore, non-surgical retreatment was chosen.

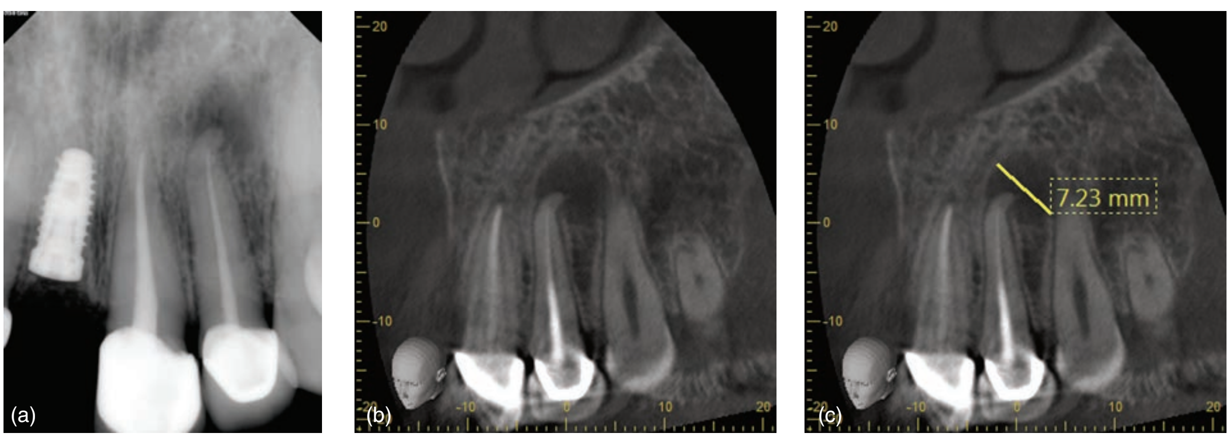

Figure 14.2 Previously treated maxillary lateral incisor with apical periodontitis. (a) Periapical radiograph showing crown restoration and root canal filling. Apical radiolucency is visible on the radiograph. (b) Sagittal view confirms apical sharp curvature. Root canal filling is not following the apical curvature. (c) Sagittal view showing a larger low-density area compared to periapical radiograph. Due to severe apical curvature, surgical retreatment was chosen.

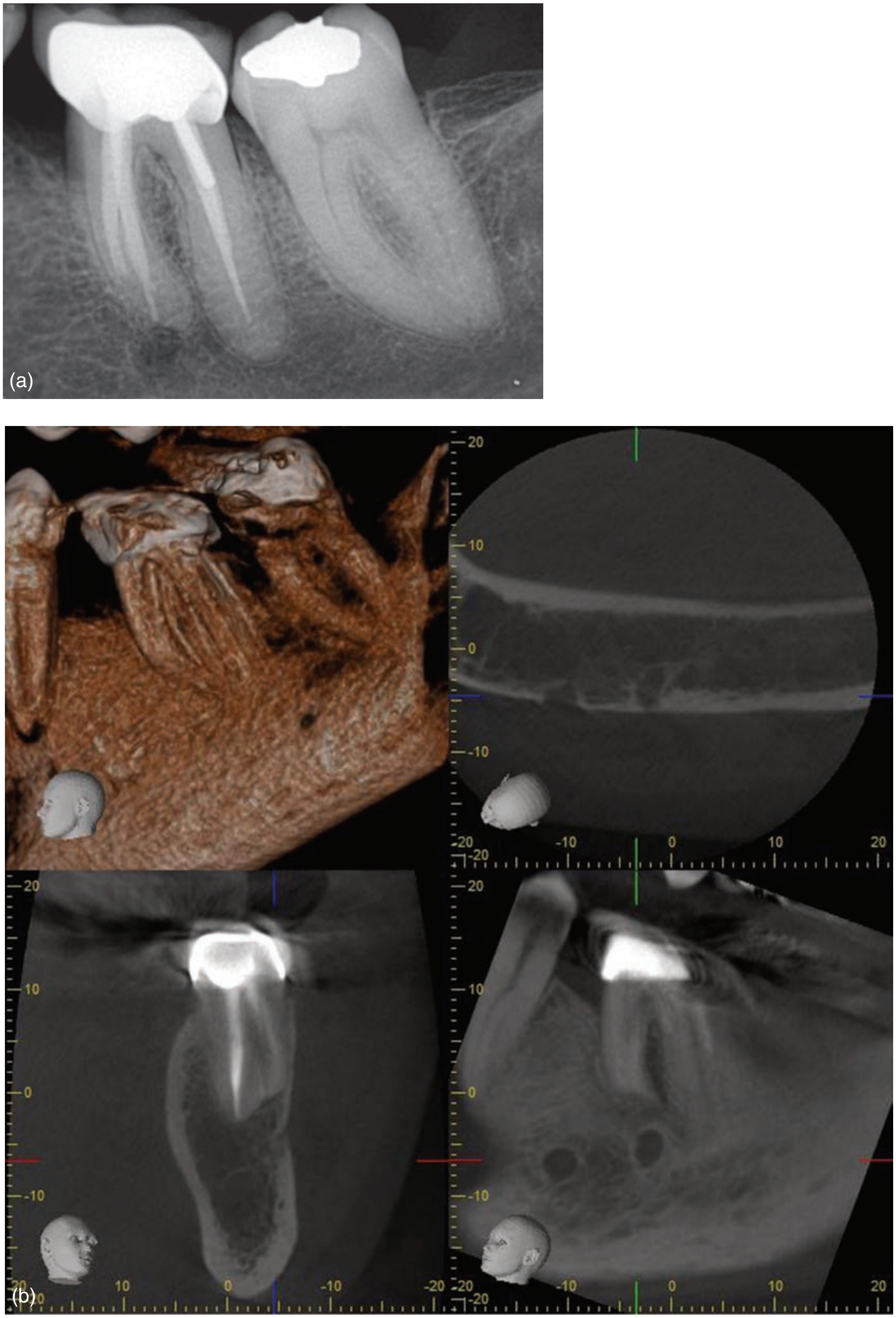

Figure 14.3 Previously treated mandibular molar. Tooth was asymptomatic. Patient was referred for possible endodontic treatment. (a) Periapical radiograph showing apical radiolucency around the mesial root. (b) Coronal view shows mesial root anatomy. Axial and sagittal views showing unusual mental foramen anatomy with two exits. Endodontic treatment was not necessary.

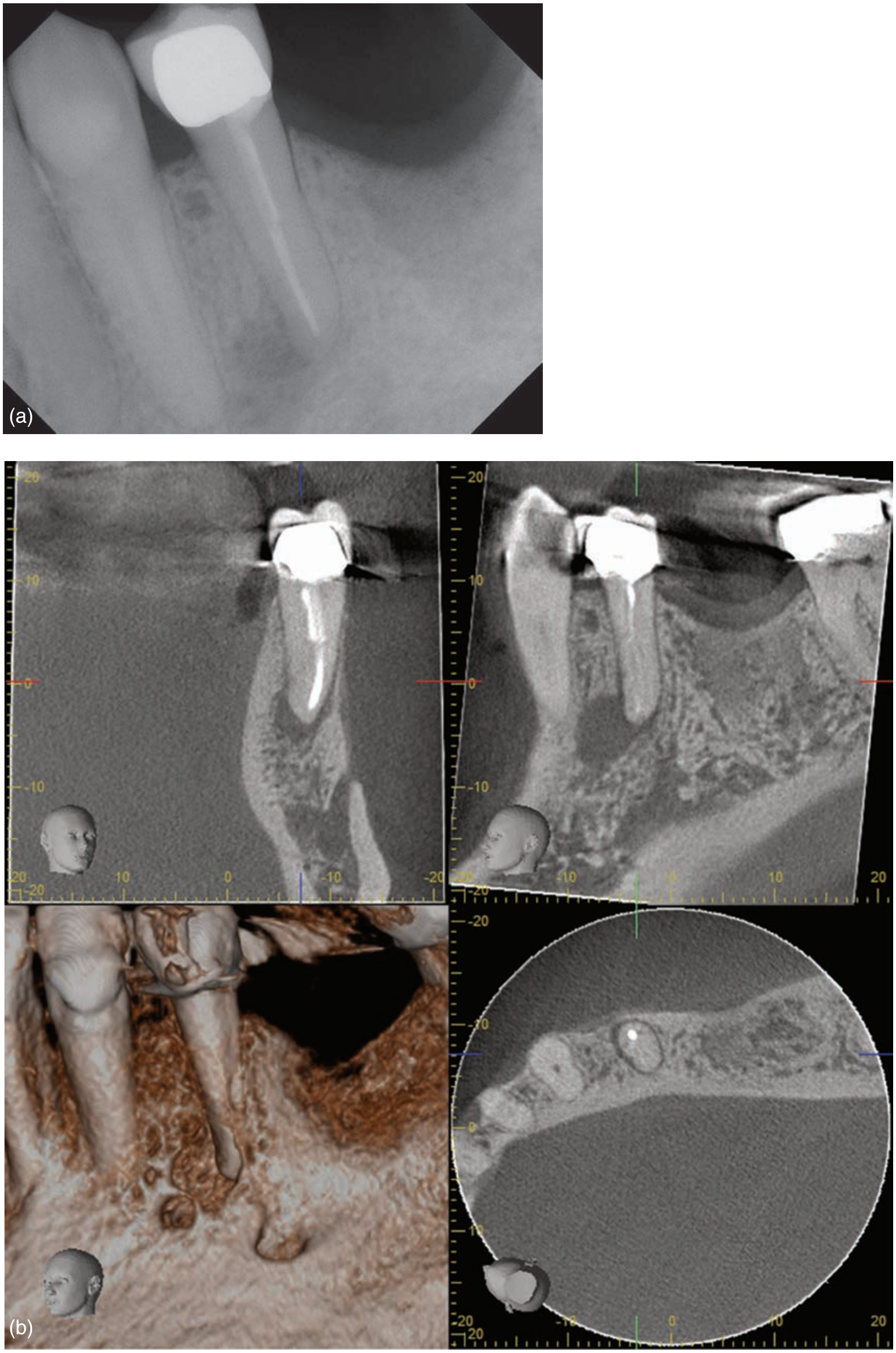

Figure 14.4 Previously treated mandibular premolar. (a) Periapical radiograph showing apical pathology. The tooth was restored with a PFM crown. (b) CBCT images show lesion associated with the tooth and close proximity to the mental foramen. Due to the location of the mental foramen non-surgical treatment was chosen.

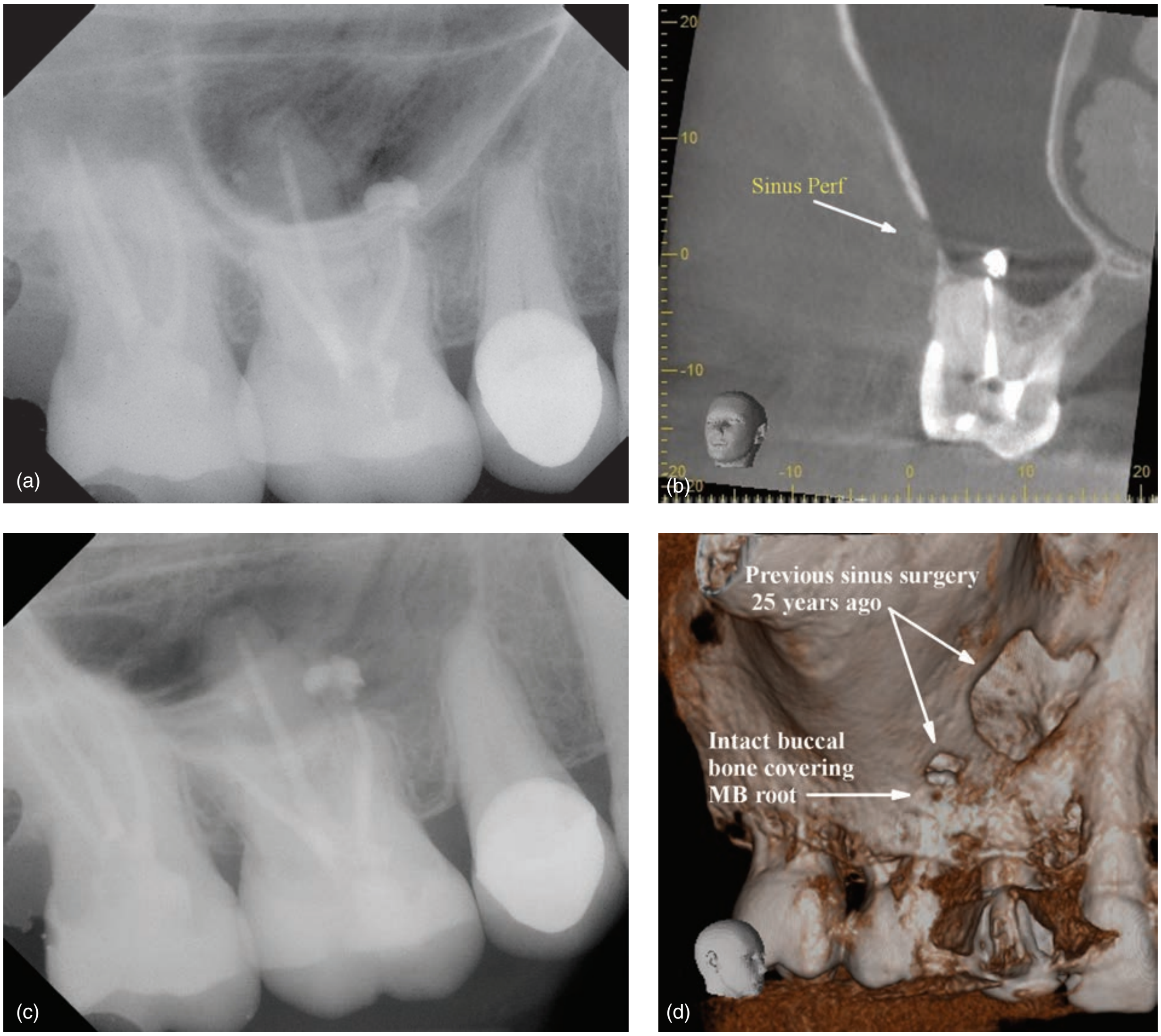

Figure 14.5 Cases representing sinus exposure, mandibular nerve, and mental foramen. (a) Previously treated maxillary first molar. Patient was symptomatic. Patient's medical history revealed previous sinus surgery. Preoperative radiograph showing previous root canal treatment and extruded filling material from the mesial canal. (b) Coronal view showing missed MB-1 canal, extruded material in maxillary sinus, and sinus perforation at the previously surgerized site; (c) Postoperative radiograph. Due to missed MB canal, non-surgical retreatment was opted for. (d) CBCT 3D rendering, showing buccal cortical perforations and the site of previous sinus surgery.

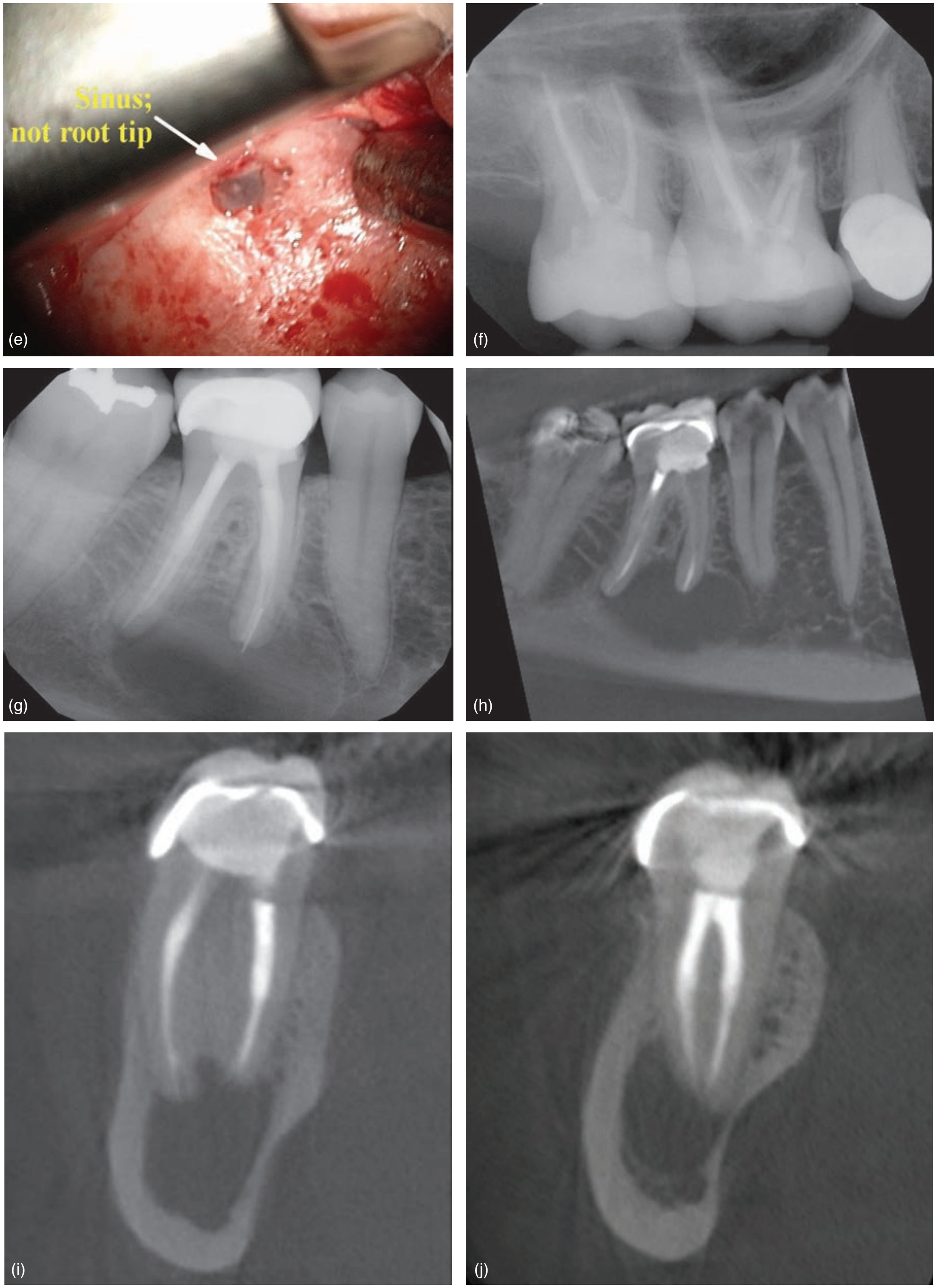

Figure 14.5 (*Continued*) (e) Due to patient's persistent symptoms, surgical retreatment was planned. Intraoral picture showing exposed sinus from a previous sinus surgical site. (f) Postoperative radiograph showing resected MB root and root end fillings. (g) Periapical radiograph showing mandibular molar with a separated instrument and large radiolucent area. Due to the location of the separated instrument and the size of lesion, a surgical approach was opted for. (h) Sagittal view showing a large low-density area including the mandibular nerve. (i) Coronal view showing the extent of lesion around the mesial root. (j) Coronal view showing the extent of lesion around the distal root.

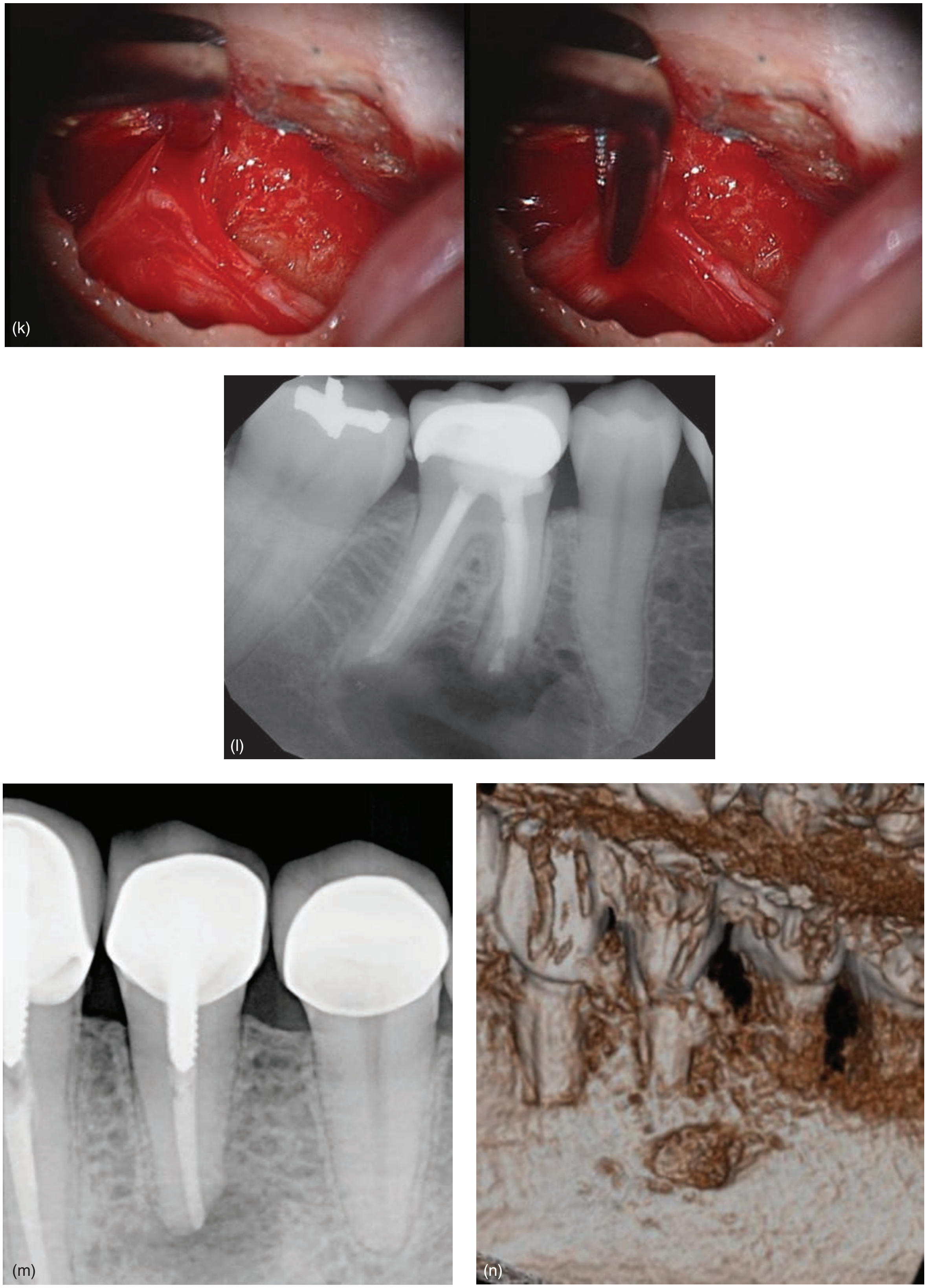

Figure 14.5 (*Continued*) (k) Surgical pictures showing the extent of lesion and exposed mandibular nerve. (l) Postsurgical radiograph showing resected mesial and distal roots with root end fillings. (m) Periapical radiograph showing the mandibular premolar with apical radiolucency. The tooth was previously treated and restored with a well-fitted PFM crown and post. (n) and (o) CBCT images showing the close proximity of the mental nerve to the root end. Intentional replantation was chosen. (p) Postreplantation radiograph showing root end resection with root end filling.

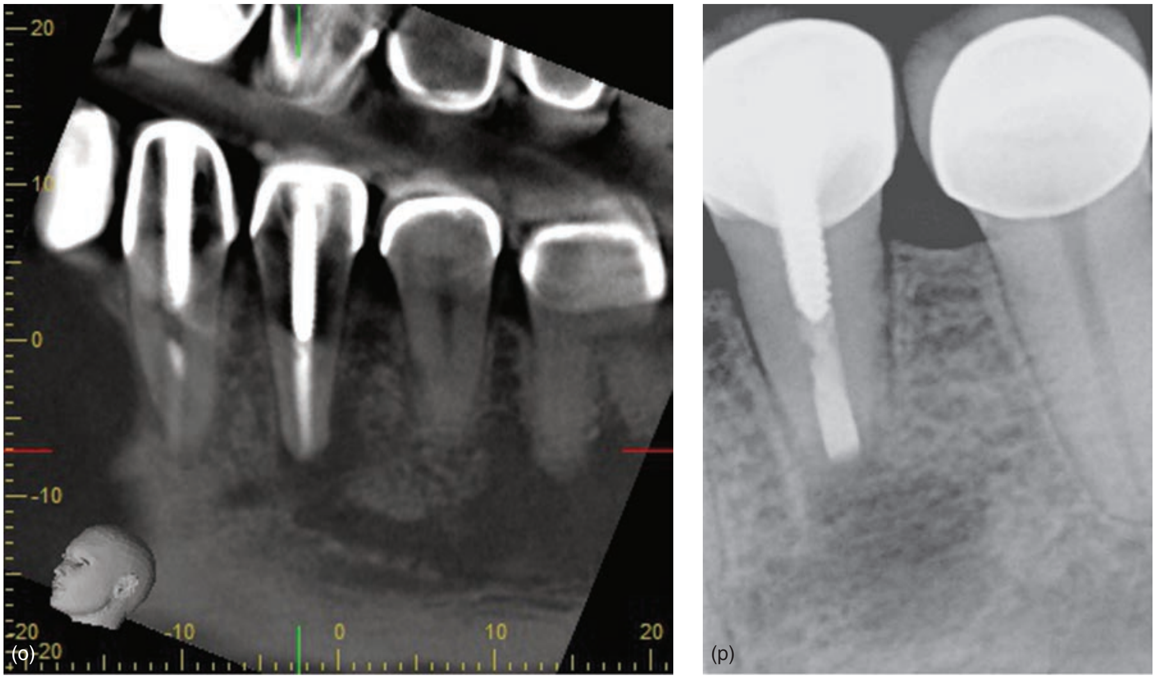

Figure 14.5 (*Continued*)

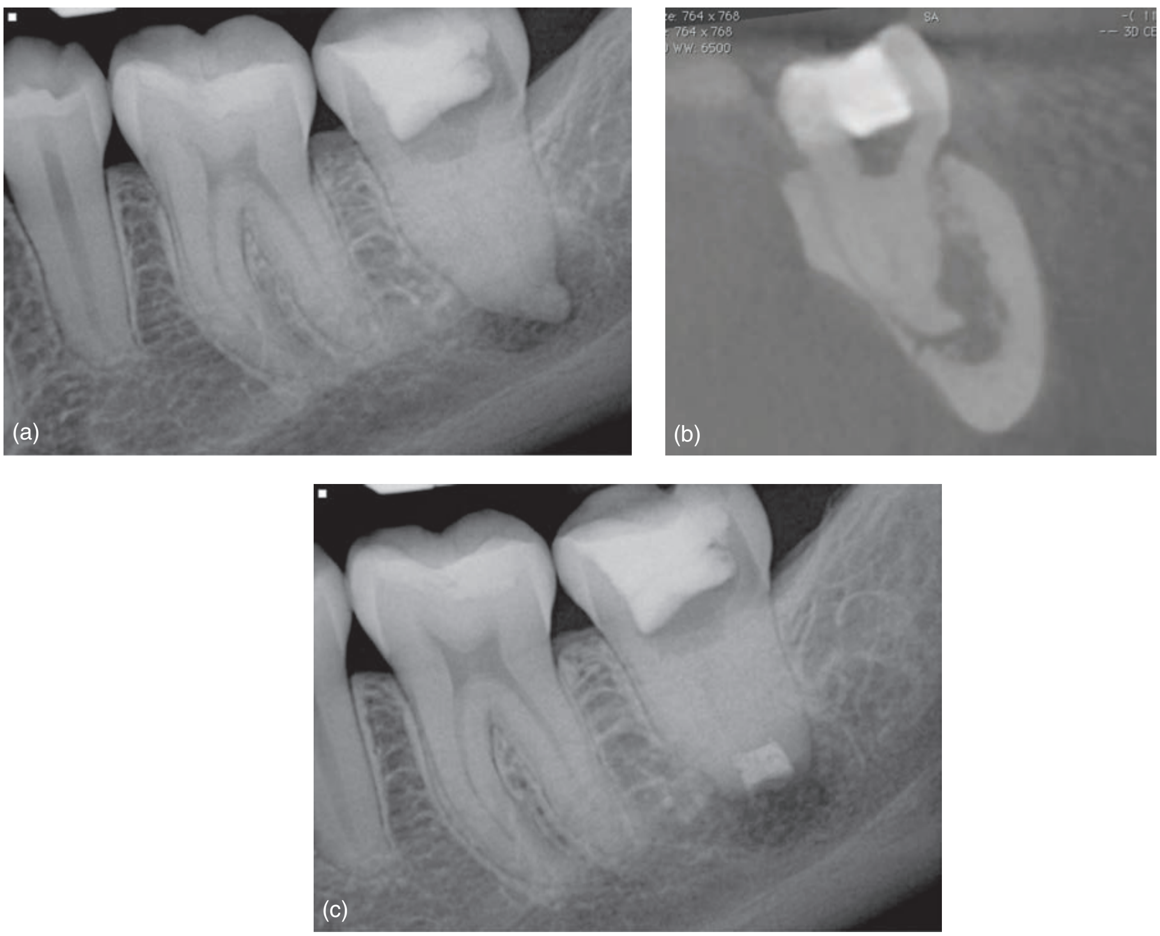

Figure 14.6 Periapical radiograph showing the mandibular second molar. An attempt to locate calcified canals was unsuccessful. Intentional replantation was chosen. (a) Preop radiograph. (b) Coronal view showing apical curvature rotating towards buccal. Curved roots cause difficulty during extraction, resulting in root fracture. With the information obtained from CBCT, the tooth was rotated towards buccal and removed without damaging the root. (c) Postoperative radiograph showing successful replantation of the tooth, root resection, and root end filling.

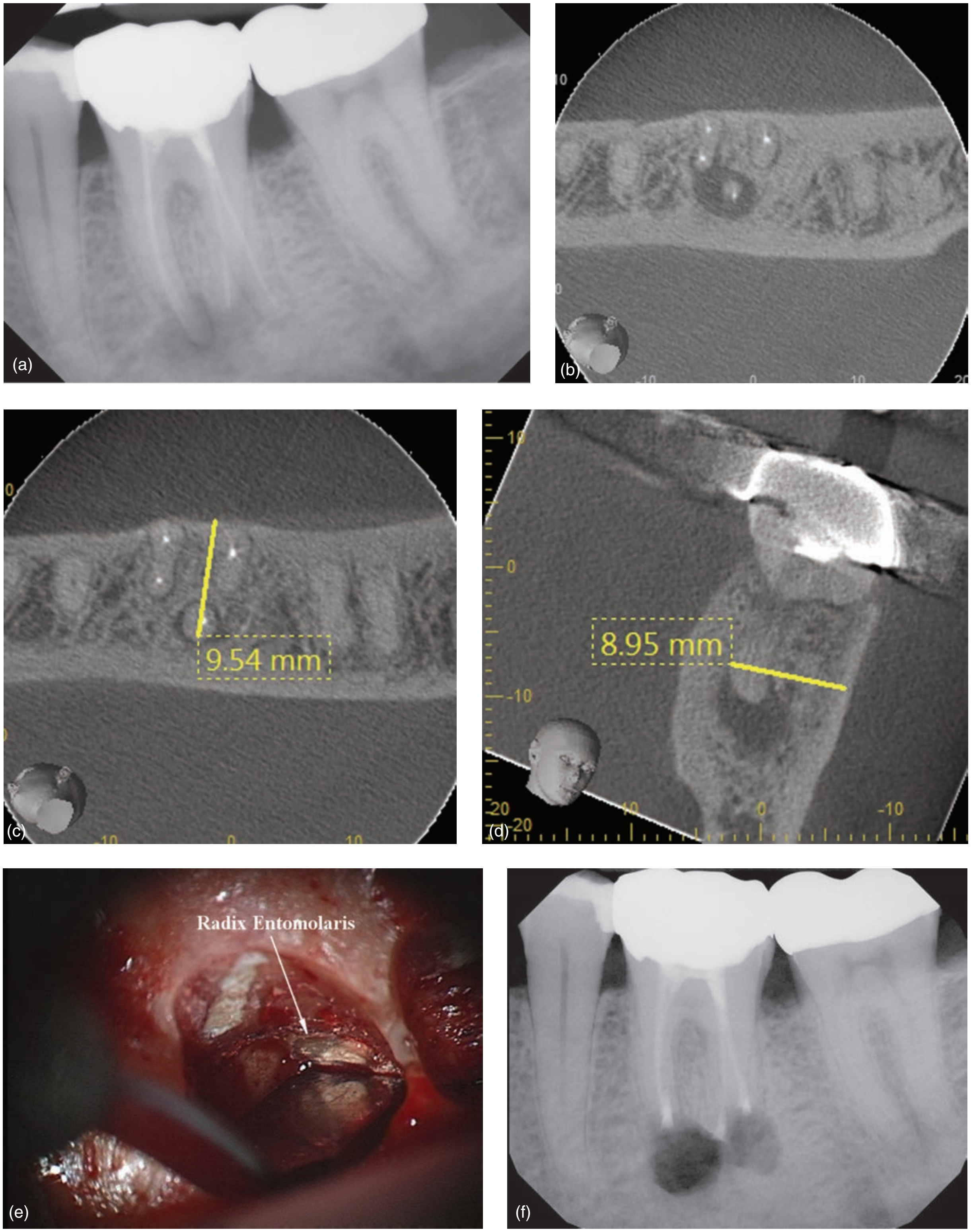

Figure 14.7 Lower molar with Radix Entomolaris. (a) Radiograph showing previously treated mandibular first molar with apical radiolucency. (b), (c), and (d) Axial view confirming low-density area only around the additional distolingual root. Distance between the buccal cortical bone to radix was measured on axial and coronal views. Images confirmed that the distolingual root can be reached. Therefore, surgical retreatment was opted for. (e) Distolingual root was resected and root end filling was placed. (f) Postoperative radiograph showing root end resections and fillings.

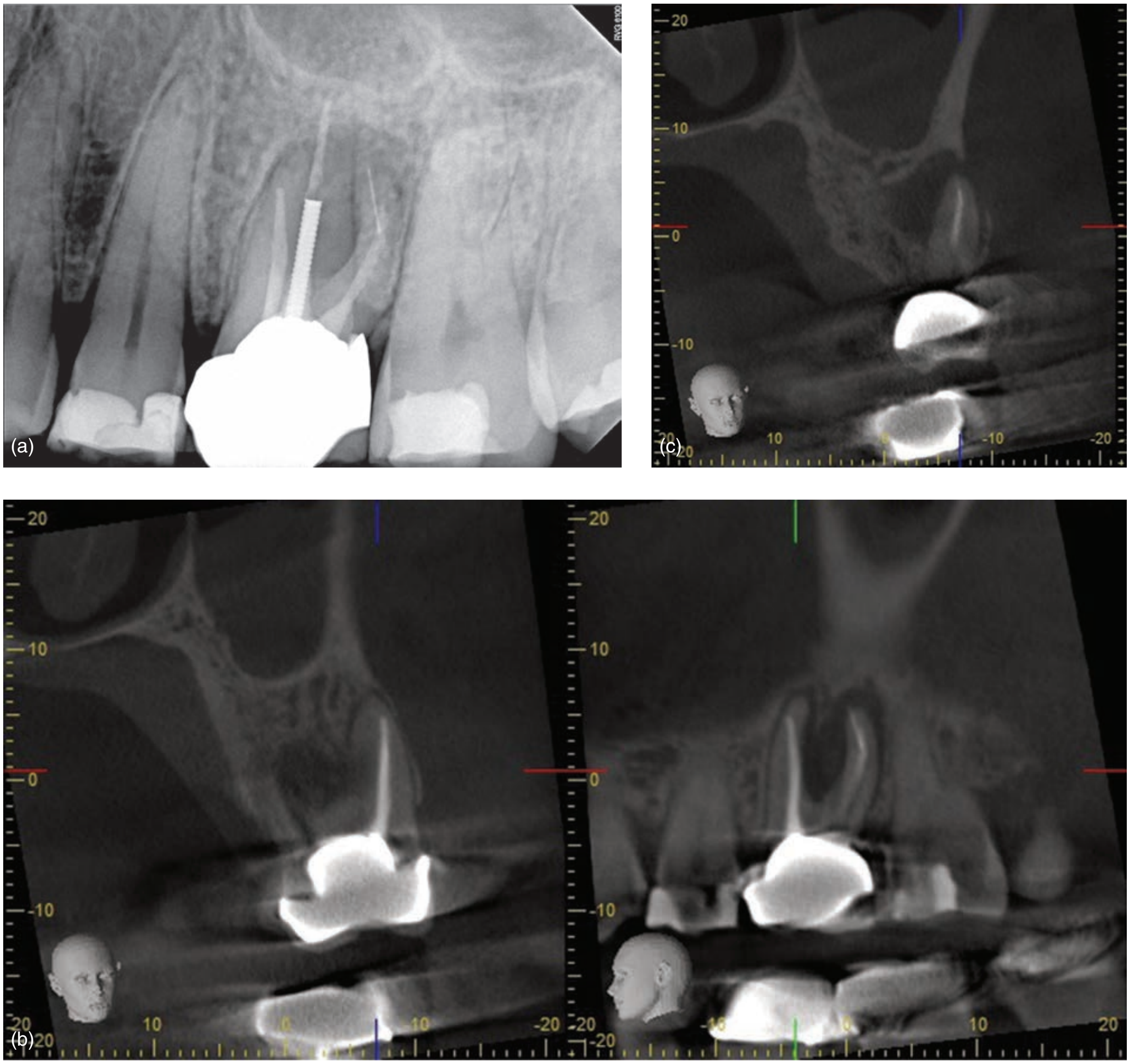

Figure 14.8 Previously treated maxillary first molar with apical periodontitis. (a) Periapical radiograph showing a large radiolucent area around mesial and distal roots, separated instrument in the distal canal, and apical transportation of the MB root. (b), (c), and (d) CBCT images showing a large low-density area extending into the furcation area and postperforation in the palatial root.

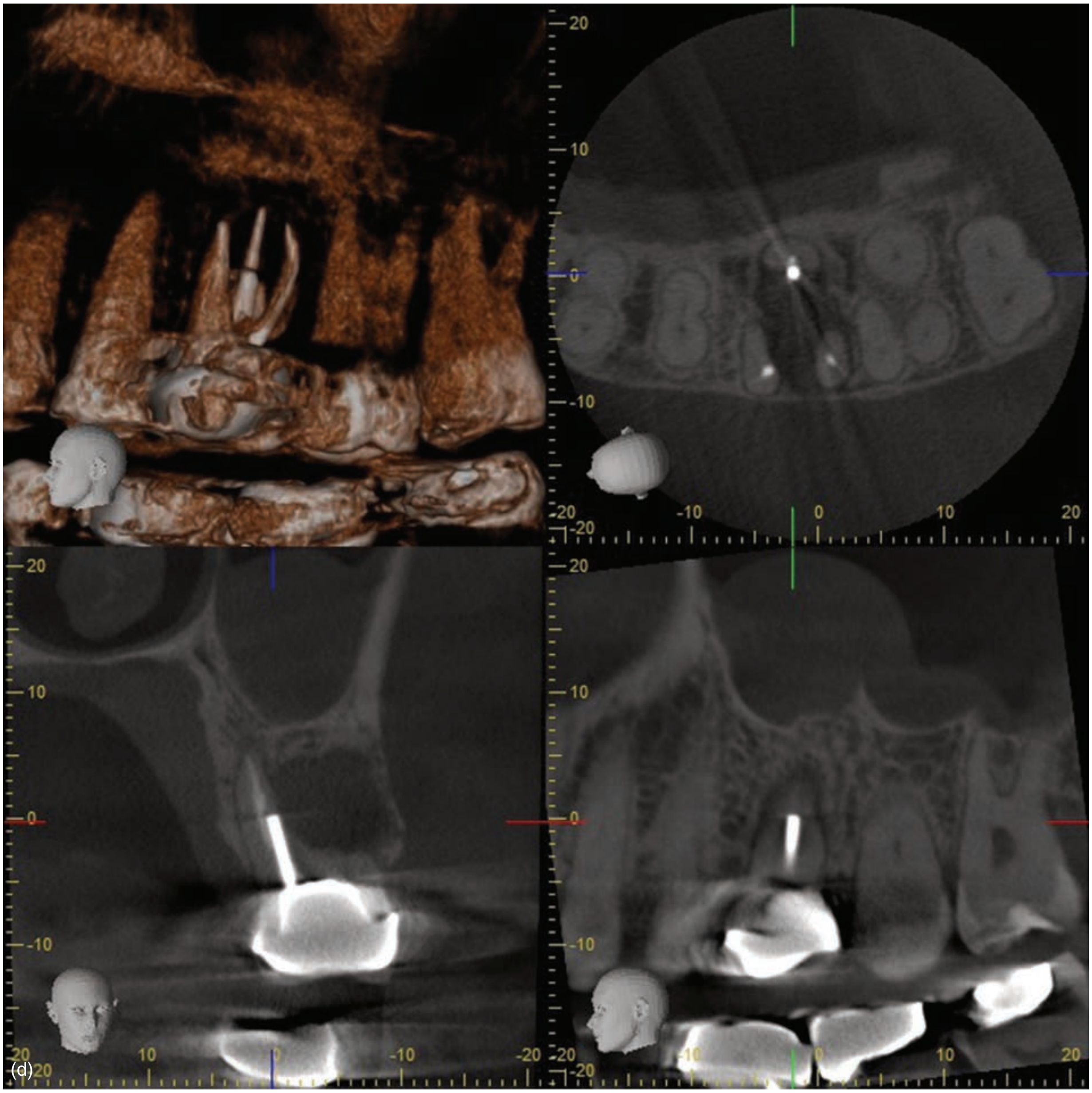

Figure 14.8 (*Continued*)

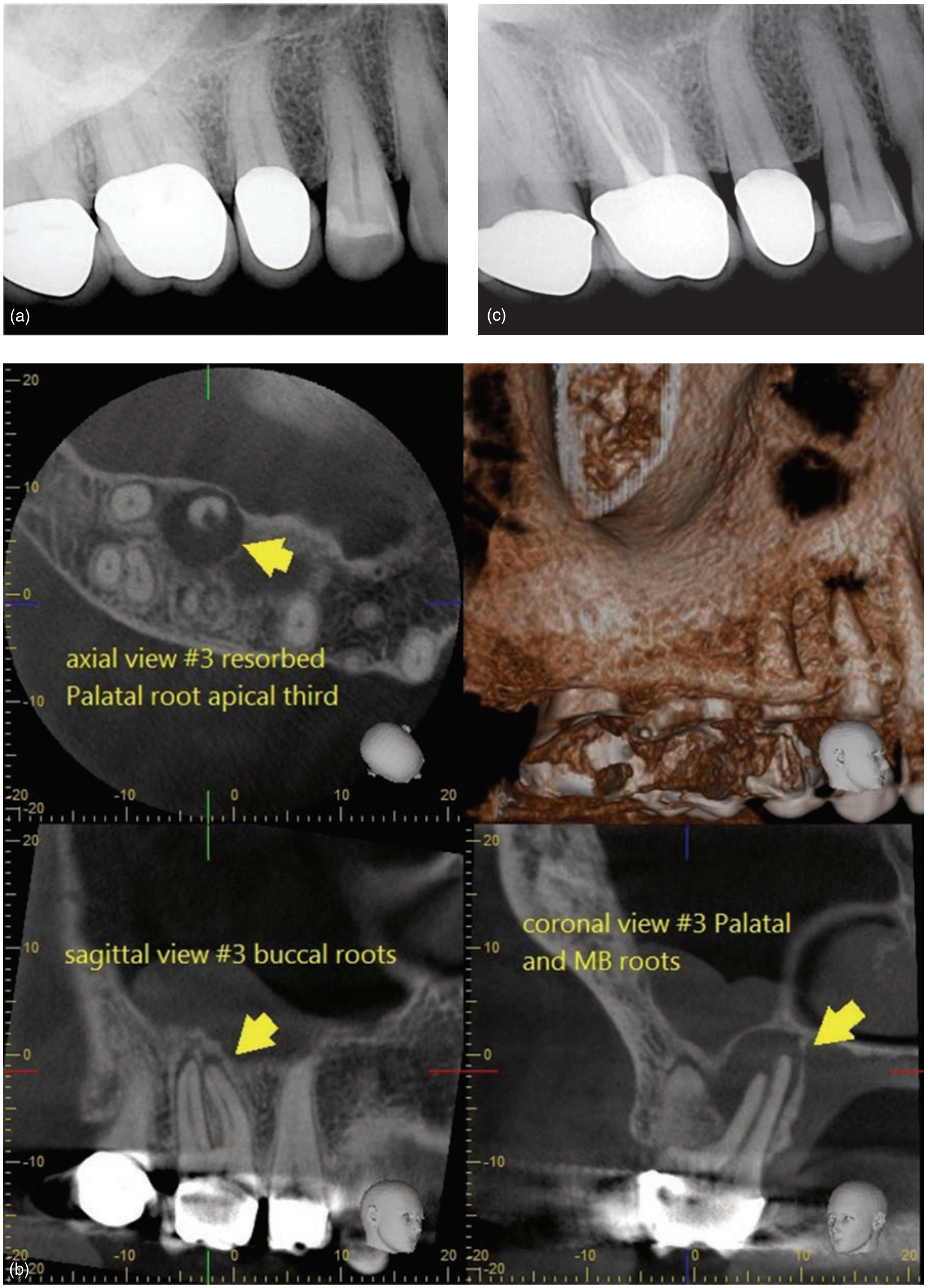

Figure 14.9 Palatal surgery maxillary right first molar. (a) Radiograph showing maxillary first molar requiring root canal treatment. (b) CBCT images showing a large low-density area around the palatal root and resorbed apex of the palatal root. (c) Postop palatal apico.

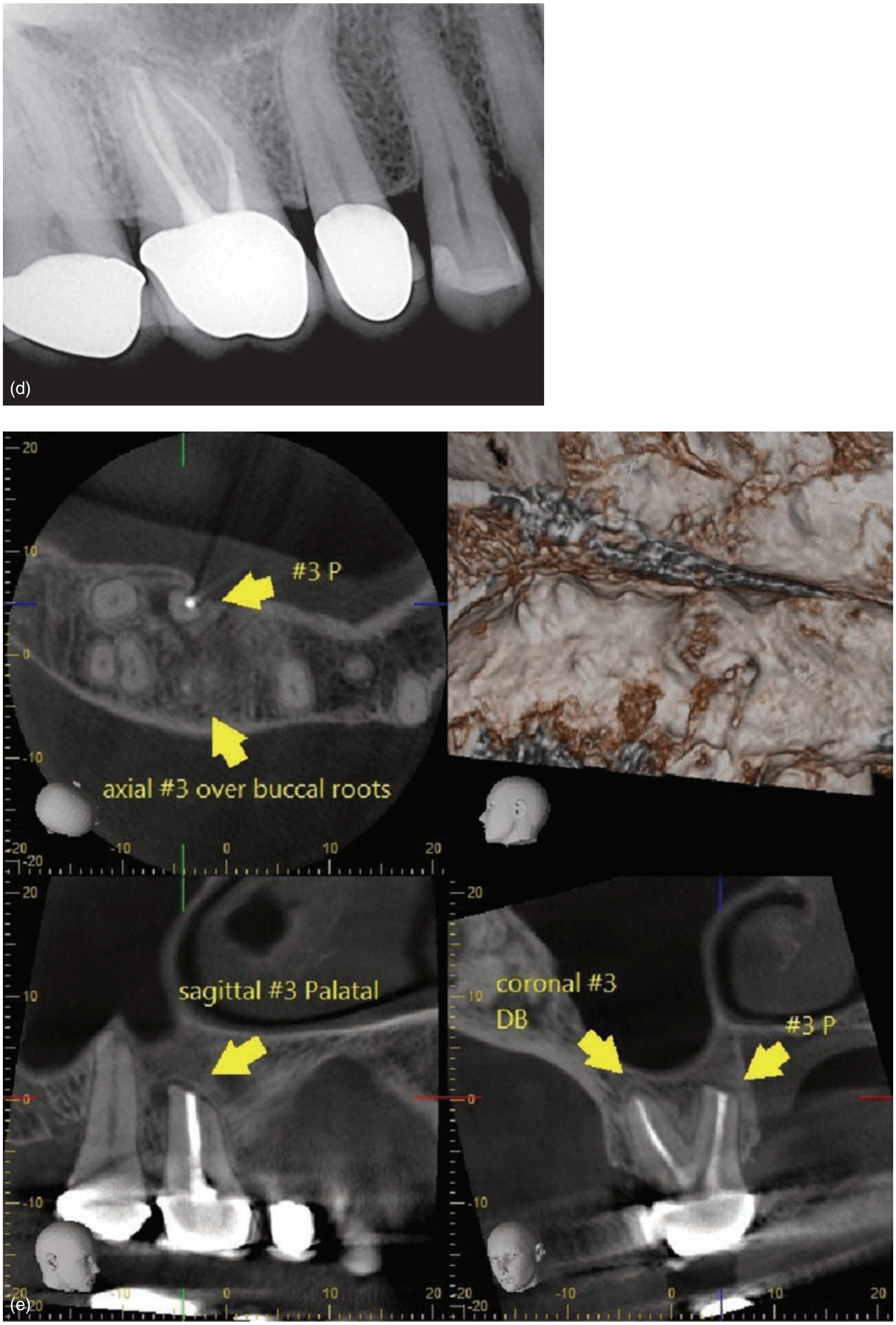

Figure 14.9 (*Continued*) (d) One year follow-up. (e) One year follow-up CBCT images of the surgical site showing cortical bone healing and reconstitution of PDL space.

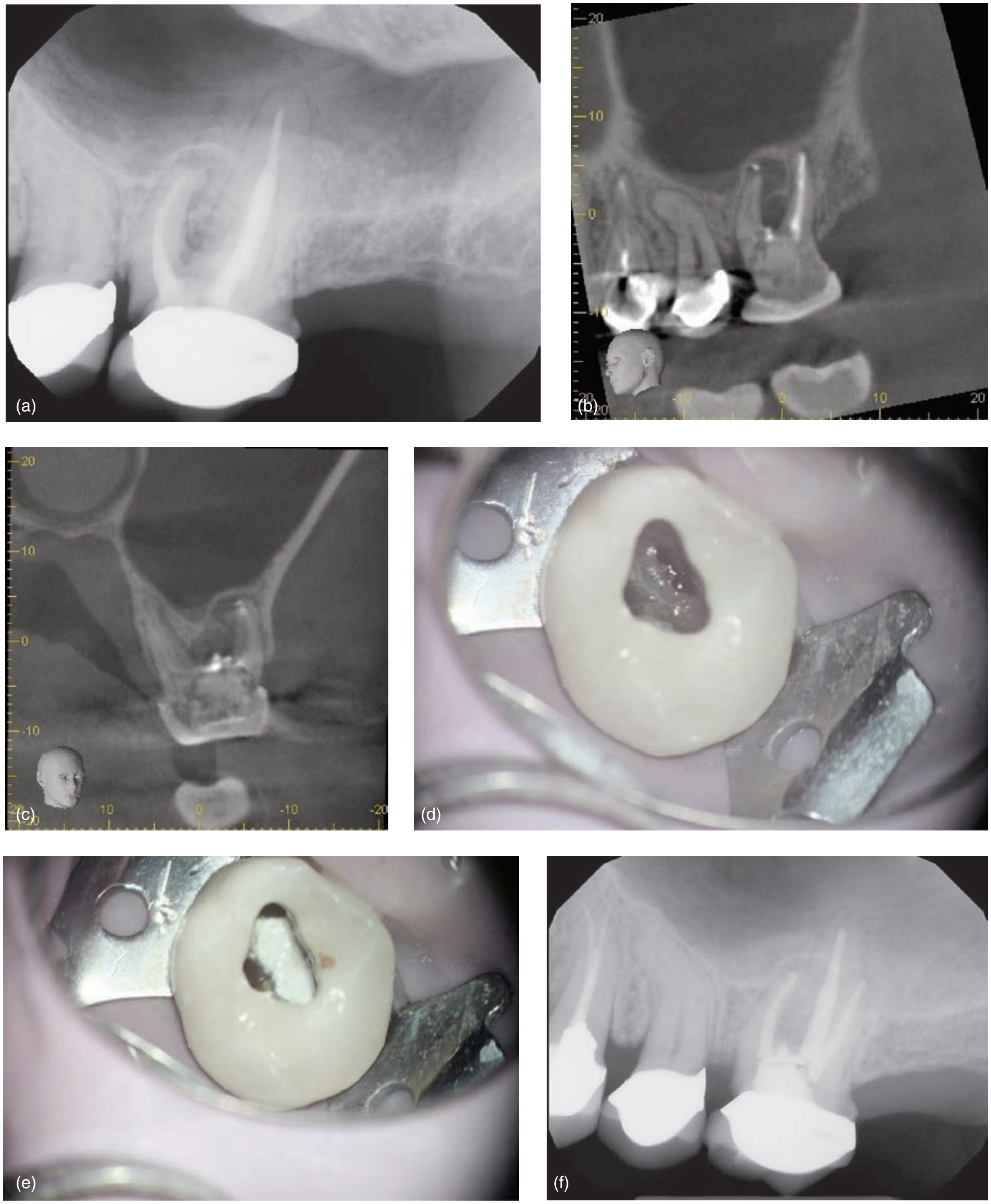

Figure 14.10 Previously treated maxillary first molar with furcation involvement. (a) Periapical radiograph showing periradicular radiolucency extending into the furcation area. (b) and (c) CBCT images showing apical and furcation low-density areas. Furcation perforation and a previous repair attempt were identified on CBCT scans. (d) and (e) Intraoral pictures showing furcation perforation and second repair with a Bioceramic putty. (f) Postoperative radiograph showing successful root canal treatment with furcation perforation repair.

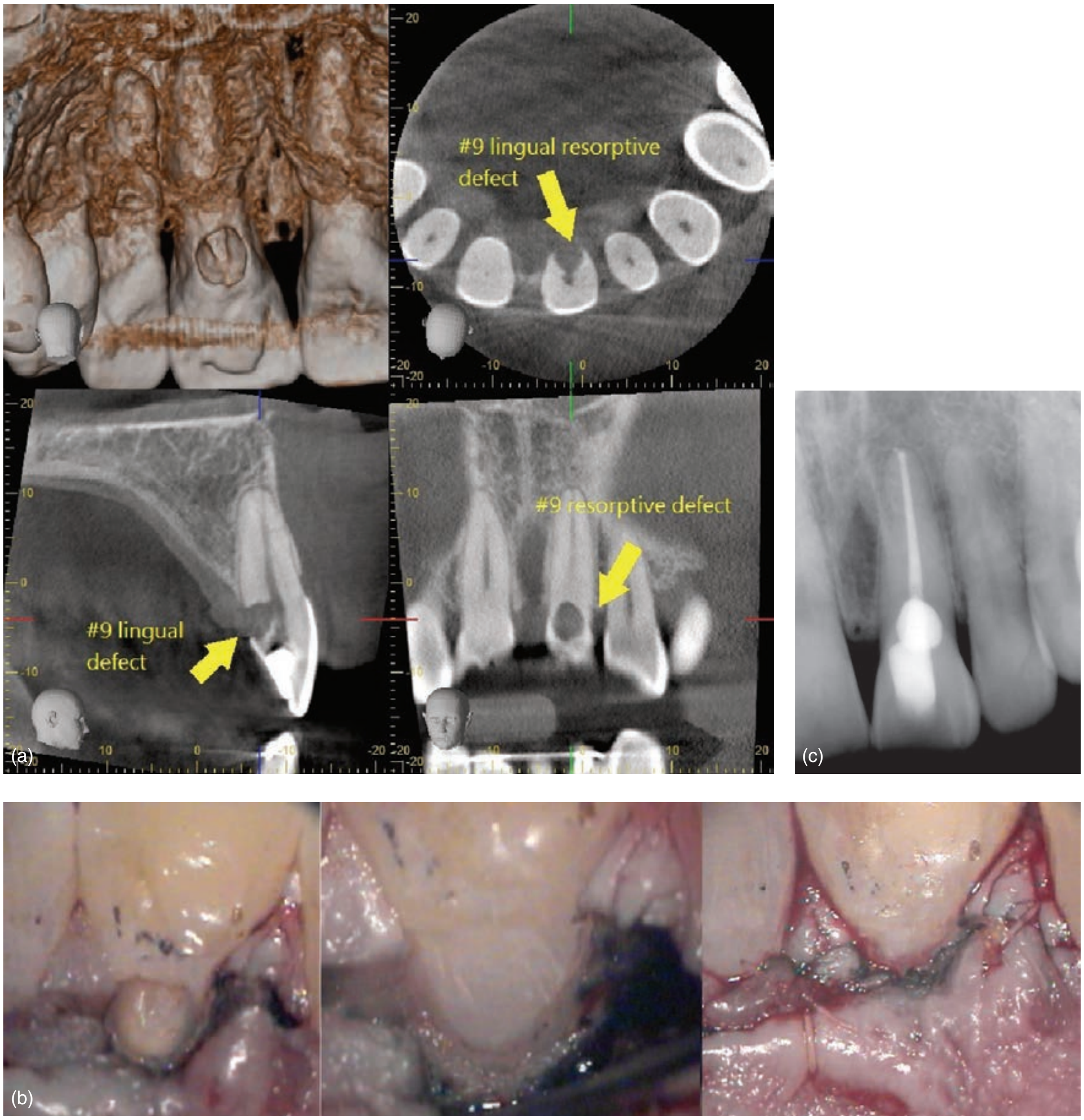

Figure 14.11 Palatal resorption. (a) CBCT images showing a maxillary incisor with palatal cervical resorption. (b) Intraoral pictures showing cervical resorptive defect and repair with Geristore. (c) Postoperative radiograph showing root canal treatment with coronal and cervical fillings.

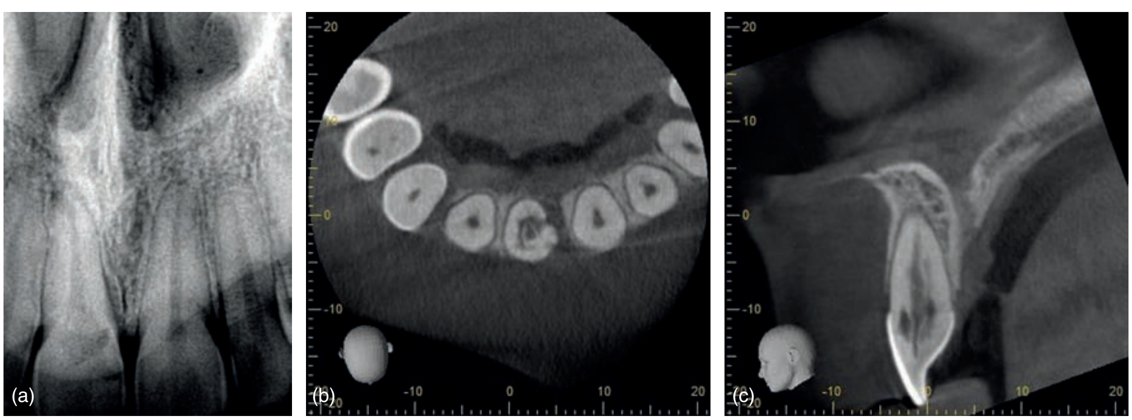

Figure 14.12 Cervical resorption. (a) Periapical radiograph showing the maxillary right incisor with cervical radiolucency indicative of resorption. (b) Axial view. (c) Coronal view shows advanced external root resorption. Due to the extent of the resorptive defect, endodontic treatment could not be performed.

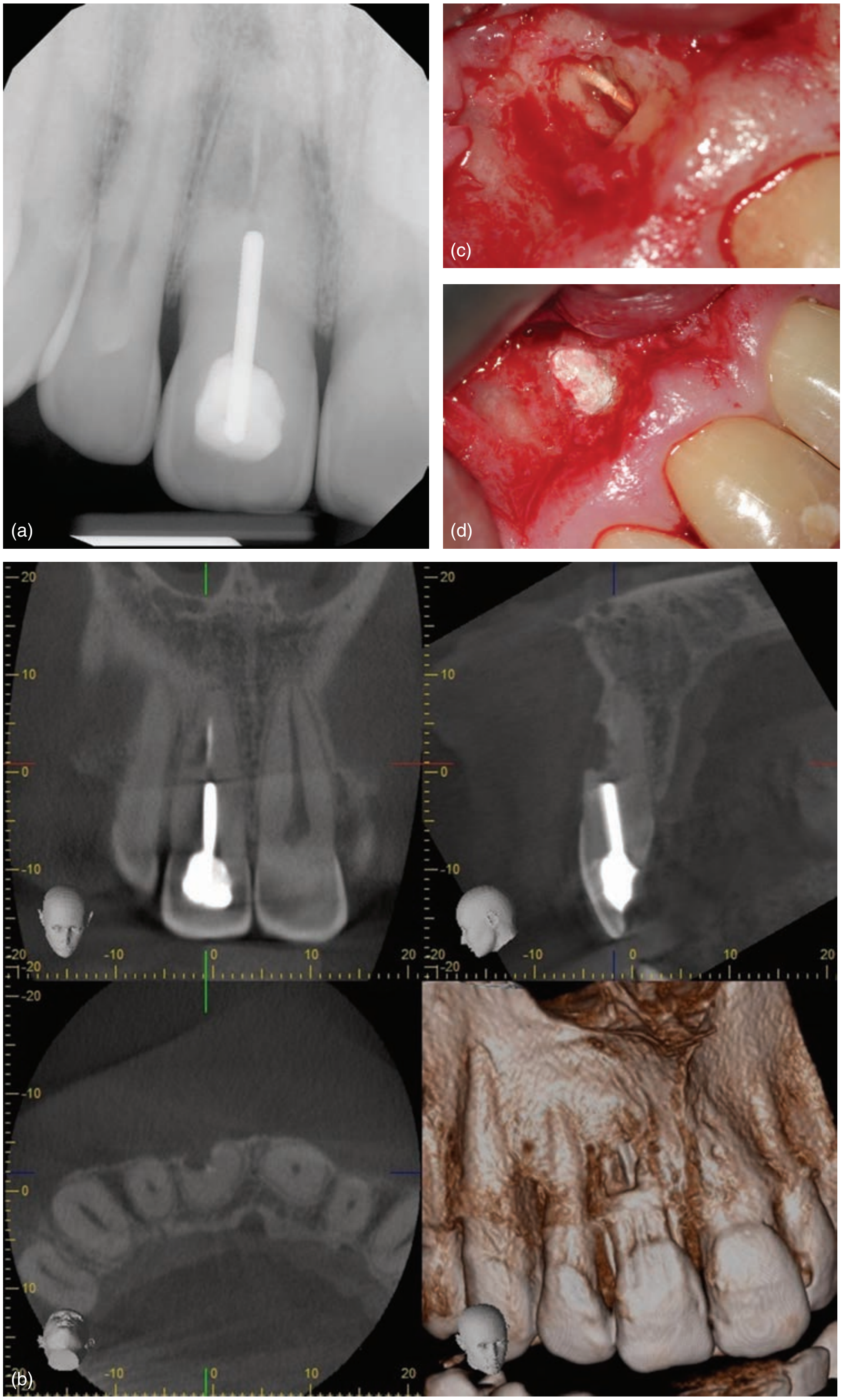

Figure 14.13 Previously treated maxillary central incisor with a large post and root resorption. (a) Preop radiograph. (b) CBCT images showing buccal mid-root root perforation with denuded buccal cortical bone. (c) and (d) Intraoral pictures showing the resorptive defect and the repair with Bioceramic root repair material. Due to the location of the bone defect and intact apical bone, apical resection was not performed.

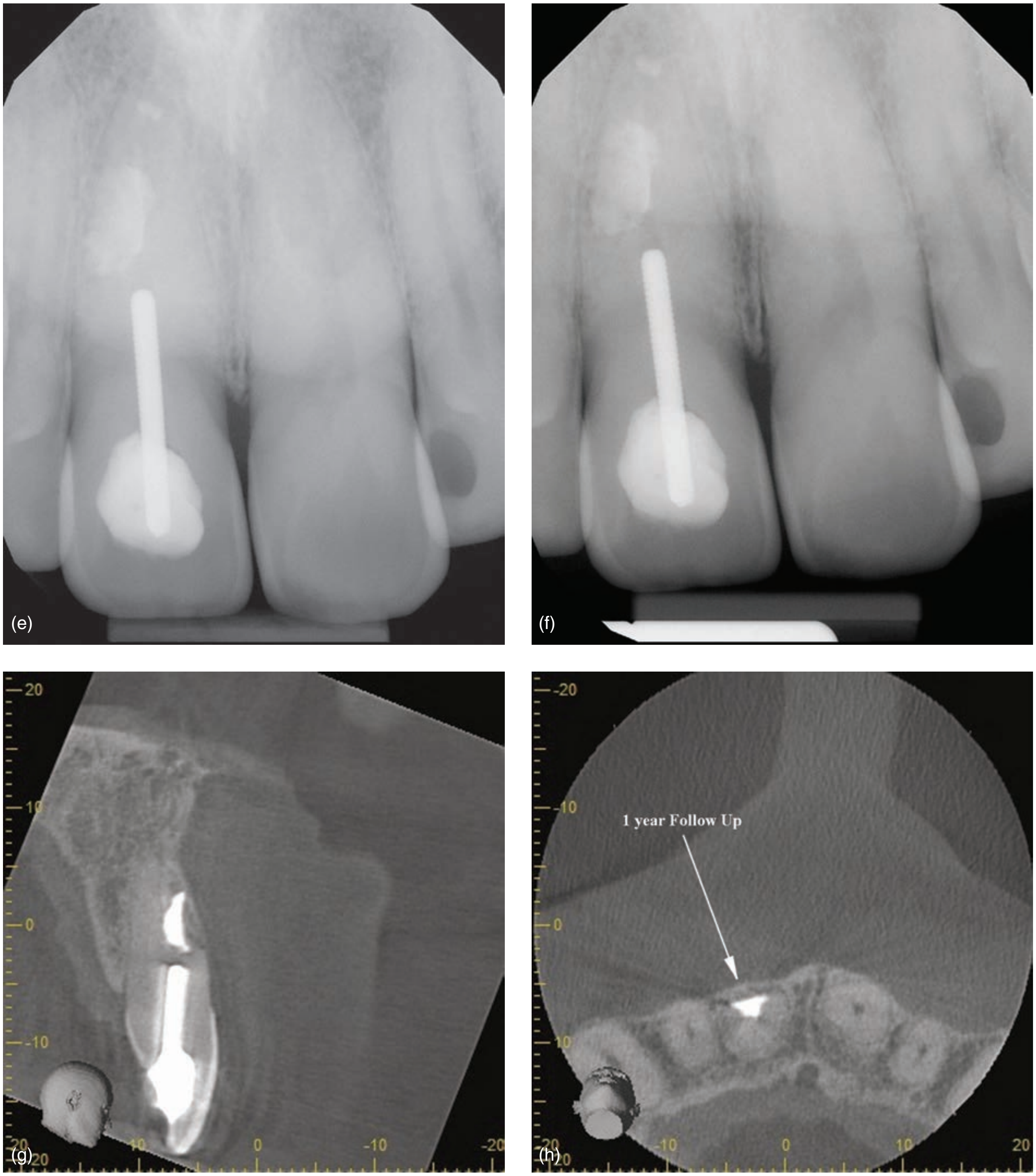

Figure 14.13 (*Continued*) (e) Postoperative radiograph. (f) One year follow-up radiograph. (g) Coronal view showing cortical bone healing around the root repair material at 1 year follow-up. (h) axial view showing cortical bone healing around the root repair material at 1 year follow-up.

Figure 14.14 Diagnosis maxillary first molar. (a) Periapical radiograph showing maxillary first molar requiring root canal treatment (b) and (c) CBCT images showing palatal root fracture that could not be identified on periapical radiograph.

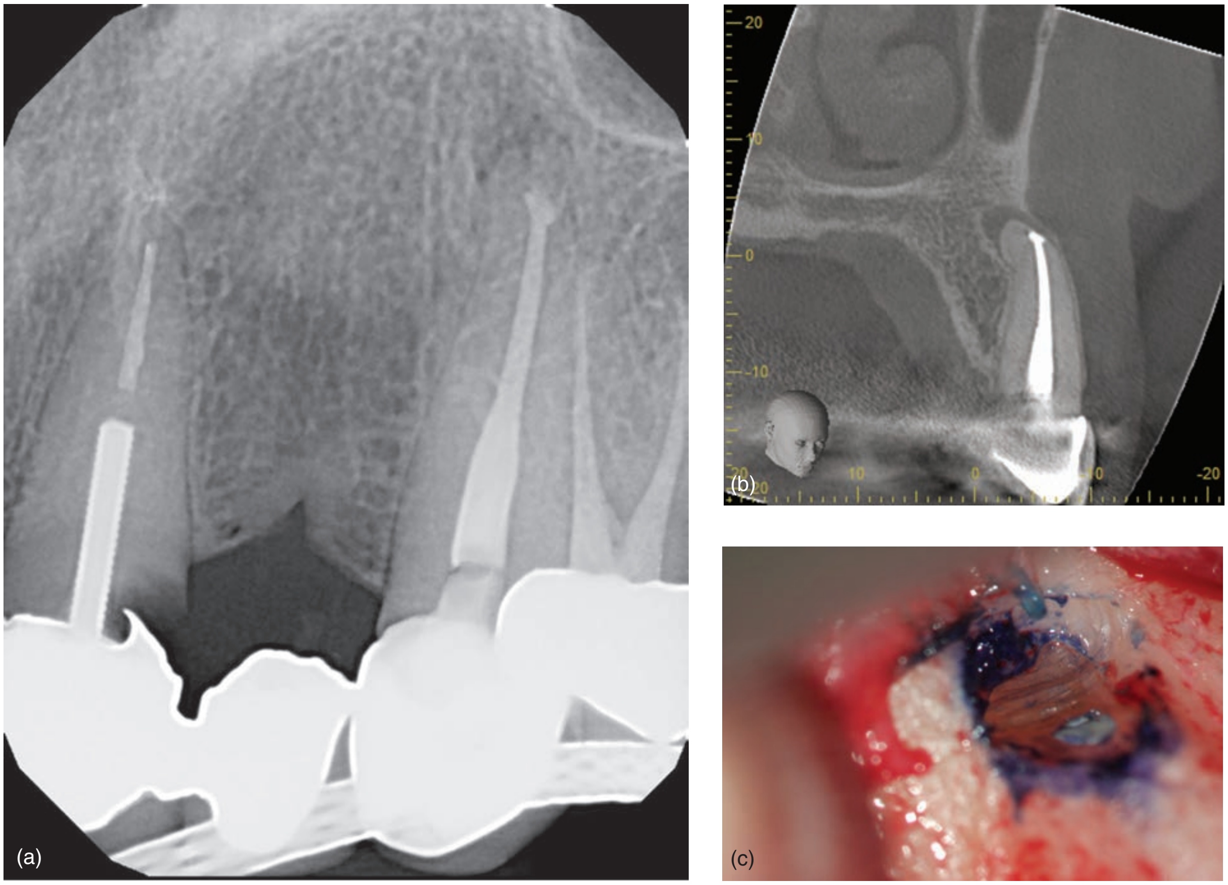

Figure 14.15 Maxillary canine with previous apicoectomy. (a) Periapical radiograph showing a previously surgerized maxillary canine. Previous root end surgery was unsuccessful. (b) Coronal view. (c) Intraoral image shows previous root resection with root end filling. The root end was not resected completely and the root end filling was inadequate to seal the root canal.

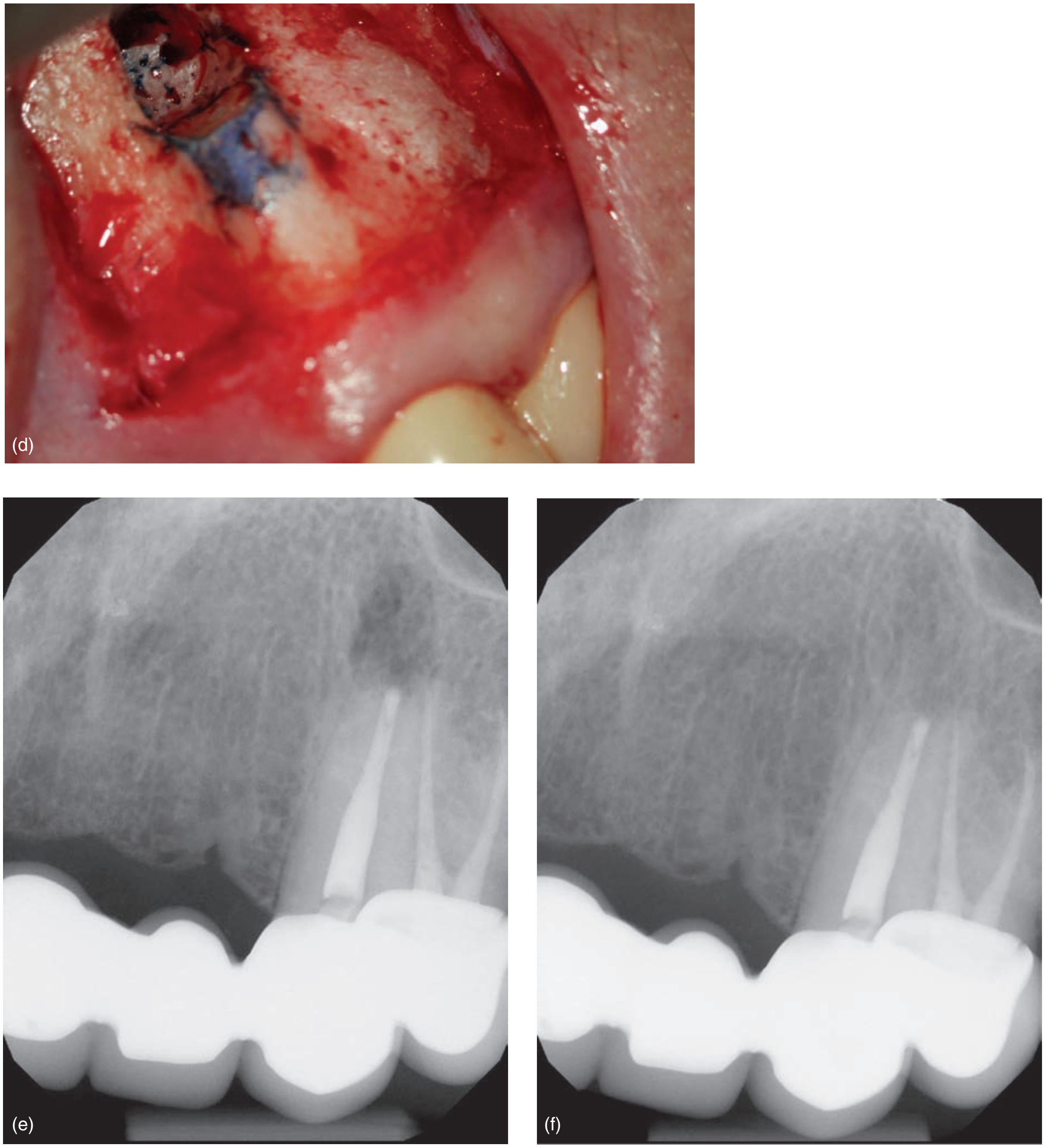

Figure 14.15 (*Continued*) (d) Root resection was corrected. (e) Postsurgery radiograph showing sealed root end. (f) Eight month follow-up.

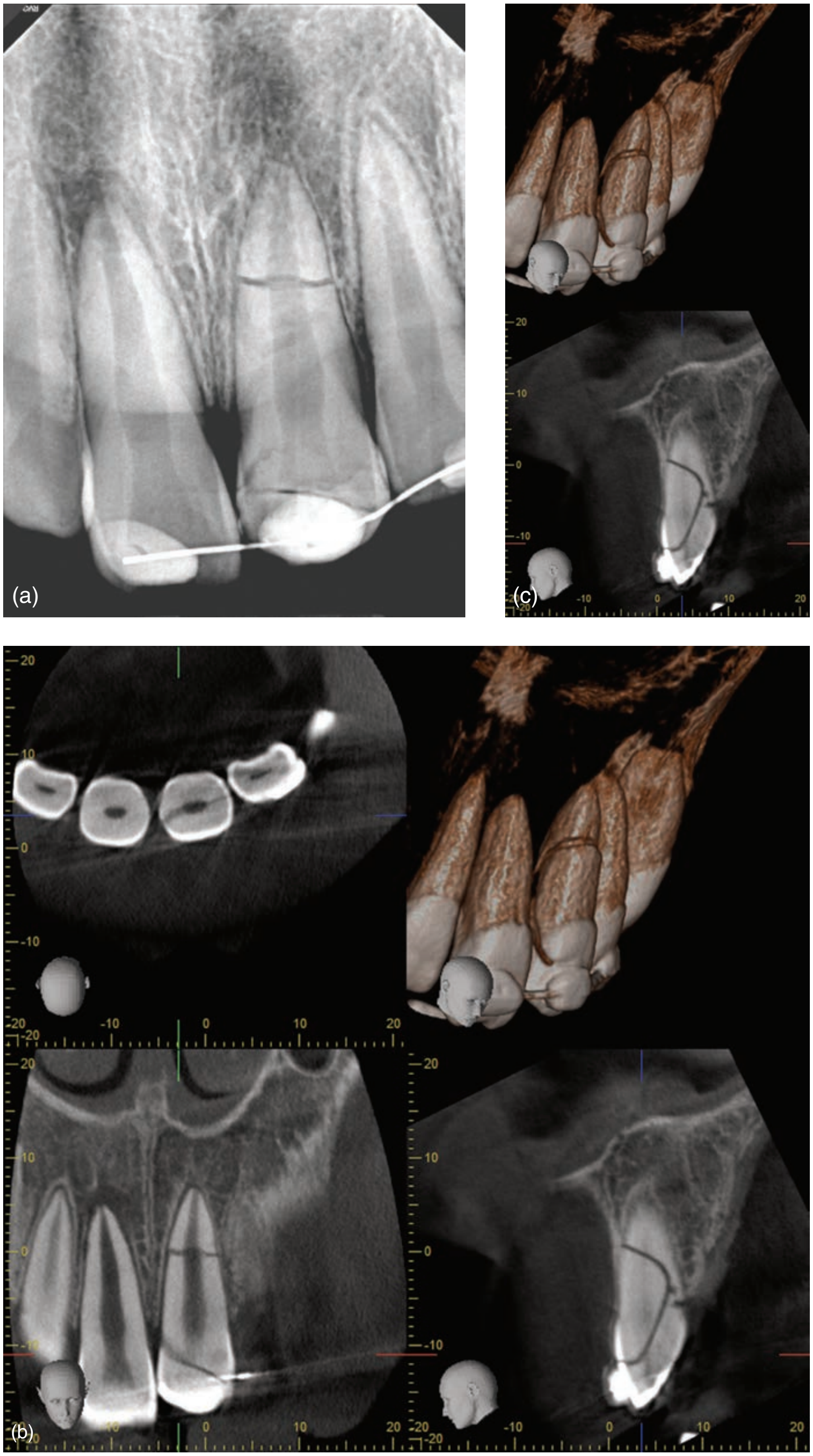

Figure 14.16 Trauma to maxillary central incisor of 9 year old patient. (a) Radiograph showing horizontal root fracture located at the apical third of tooth. (b) and (c) CBCT images showing the extent of root fracture. The tooth will need to be extracted as opposed to just observation.

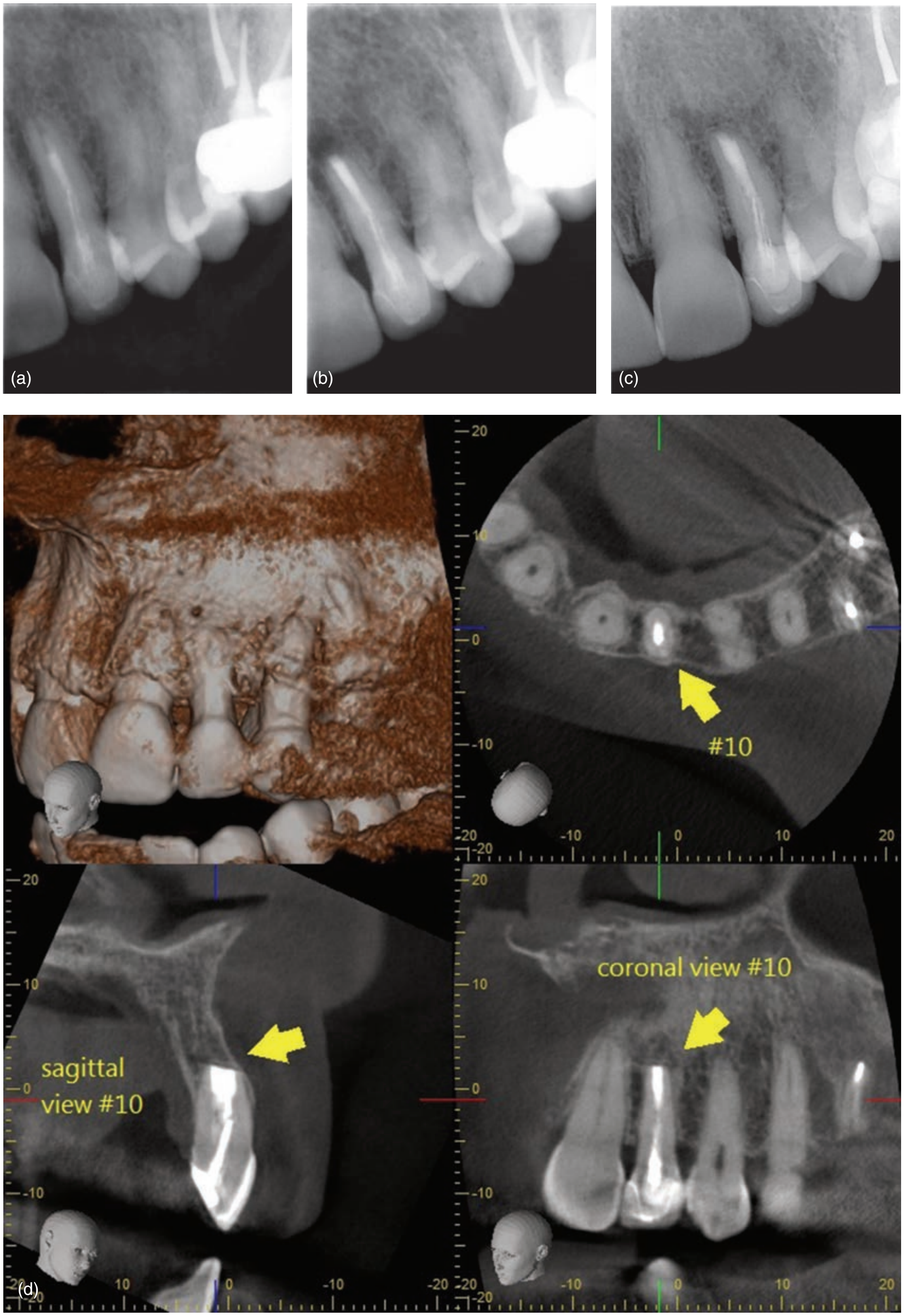

Figure 14.17 Symptomatic, previously treated maxillary lateral incisor. (a) Due to a long post and well-fitting crown, surgical treatment was planned. (b) Postsurgical radiograph showing root resection and root end filling. (c) A 5.5 year follow-up radiograph. (d) A 5.5 year CBCT shows complete apical and cortical bone healing and reconstitution of PDL.

Suggested Readings

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15

Mental Nerve Management

Paula Mendez-Montalvo, Fouad Al-Malki, and Syngcuk Kim

KEY CONCEPTS

- The mental foramen is most frequently located by the apex of the second mandibular premolar or less frequently near the apices of the first premolar and the first molar.
- A CBCT offers the most precise location of the mental foramen.
- The mandibular bone groove technique allows for a stable anchor for the retractor and protects the mental nerve from possible damage during surgery.
- The clinician should ascertain the level and extent of neurosensory dysfunction, if present, and it should be documented and followed up frequently.

15.1 Armamentarium

- CBCT
- Piezo surgery device and tips
- Kimtrac surgical retractors

The surgeon should have a profound knowledge of the anatomical landmarks of the oral cavity. When dealing with the mandibular posterior area, the most important anatomical landmarks to consider are the mental foramen/nerve and inferior alveolar nerve. An insult to any of these landmarks could result in an array of neurosensory alterations that could vary from short-term to permanent side effects. Awareness of these landmarks and presurgery assessment of their locations by taking a CBCT can prevent both the surgeon and the patients from unfavorable outcomes and undesirable side effects.

15.1.1 Mental Foramen and Nerve

The mental nerve is the terminal branch of the inferior alveolar nerve (Figure 15.1), a major branch of the mandibular nerve (MN, V3), which is one of the three branches of the trigeminal nerve (fifth cranial nerve). The mental nerve is entirely sensory in function and divides into three branches deep to the depressor anguli oris muscle, to innervate the skin and mucous membrane of the lower lip, the skin of the chin, and the vestibular gingiva mesial to the first mandibular molar. The distribution area of the MN is divided into angular, medial inferior labial, lateral inferior labial, and mental branches. The mental branch is important for endodontic microsurgery.

15.1.1.1 Location

Many studies have investigated the position of the mental foramen (MF) by examining collections of dried skull cadavers, clinical radiographs, and more recently CBCT. These studies revealed that the mental foramen is most frequently located by the apex of the second mandibular premolar or less frequently near the apices of the first premolar and the first molar (Figure 15.2).

On average, the MF is 5.0 mm from the closest root (the range is 0.3–9.8 mm); however, the MF may even be located at the same level or even coronal to the apices of adjacent roots in a rare situation.

15.1.1.2 Anterior Loop

The anterior loop (AL) is an extension of the mandibular canal mesial to the MF and curving backward before exiting the MF. Its size or how often it occurs is not well known. During periapical surgery of

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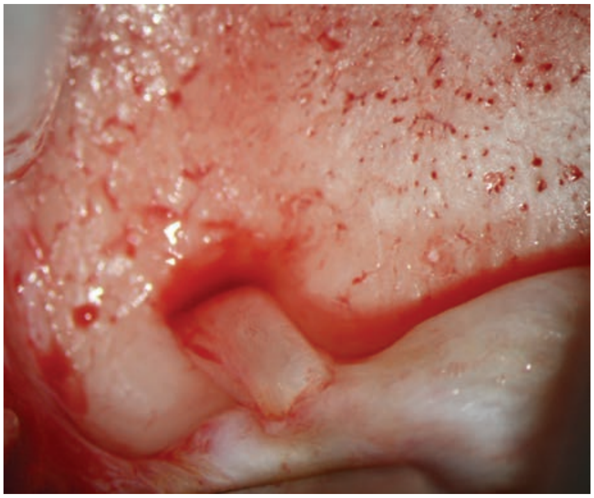


Figure 15.1 Mental nerve bundle exiting the mental foramen.

mandibular premolars, the possible presence of an anterior loop should always be considered. Again, a CBCT is a reliable tool in determining the extension of the loop. The anterior loop has been found up to 2.63 mm long, which is consistent with a 3-mm safety margin necessary to avoid damage to the MN in apical surgery.

15.1.1.3 Number of Mental Foramina

The mandibular nerve can bifurcate in the inferior superior or medial lateral plane. Thus, a bifurcated mandibular nerve will have more than one mental foramen.

Accessory mental foramina (AMF) (Figure 15.3) are rarely observed with periapical or panoramic radiographs because the size is generally less than 1.0 mm, but they can be observed with a CBCT. When an AMF is seen on CBCT, caution should be given not to damage it.

15.1.2 Mental Foramen Detection on Radiographs

Periapical radiographs from different angulations and **panoramic films** were used to predict the location of the mental foramen until recently. However, CBCT images are becoming a standard and invaluable requirement prior to any apical surgery and regular radiographs are becoming more and more obsolete in modern day endodontic microsurgery.

15.1.2.1 Periapical Radiograph

Visualization of the mental foramen on intraoral radiographs may be difficult and must be interpreted cautiously. The most common reason for this difficulty

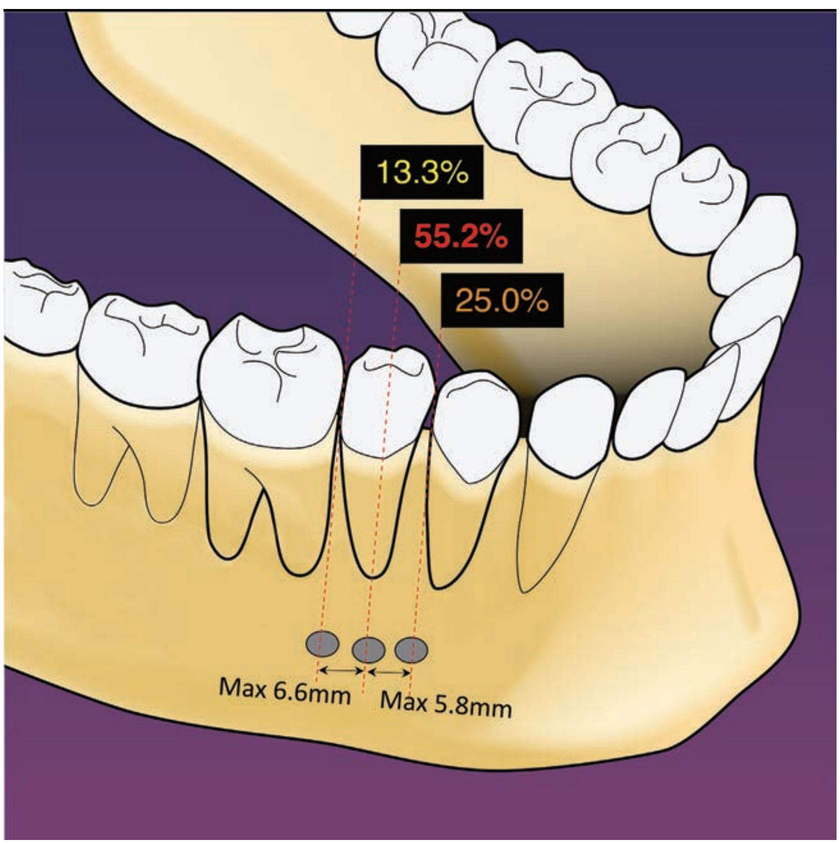
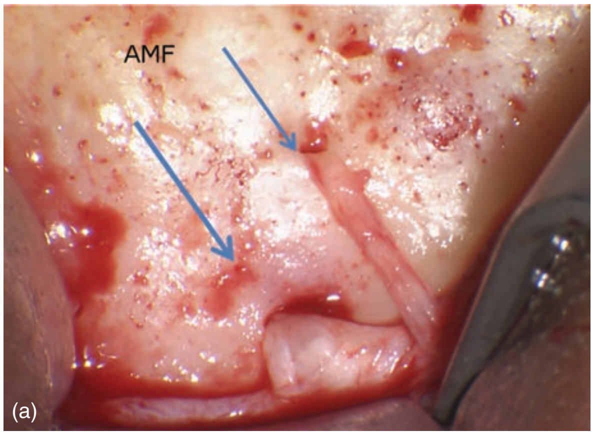


Figure 15.2 The mental foramen is frequently located by the apex of the second mandibular premolar or between the apices of the premolars.



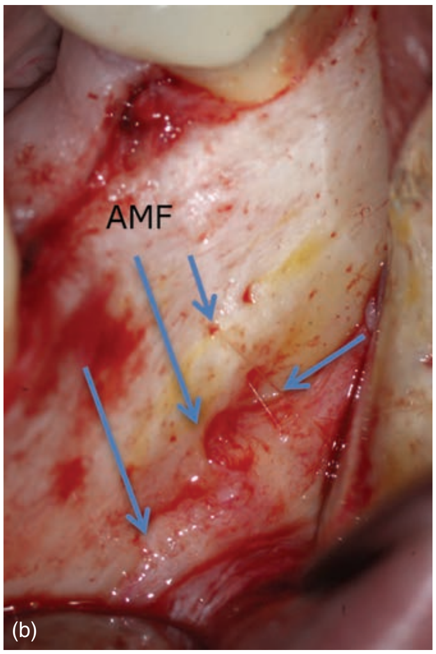


Figure 15.3 Accessory mental foramina (AMF). (a) Large AMF. (b) Small AMF in the surrounding area of the mental foramen that tends to exist in the apical area of the first molar and posterior or inferior area of the mental foramen.

is when it is in proximity to periapical radiolucencies. Patients with a small mouth, large mandibular tori, a shallow floor of the mouth, or malpositioned teeth may prevent proper placement of the film for exposure of the mental foramen. Cases such as these may require multiple radiographs to visualize the foramen (Figure 15.4).

15.1.2.2 Panoramic Films

The foramen can be detected in many cases, but clear visibility is not always possible on panoramic radiographs. Panoramic and periapical films show the actual position of the foramen less than 50% of the time. Panoramic radiographs have a 20%–36% magnification factor, which makes the location of the MF significantly different from the true clinical location (Figure 15.5).

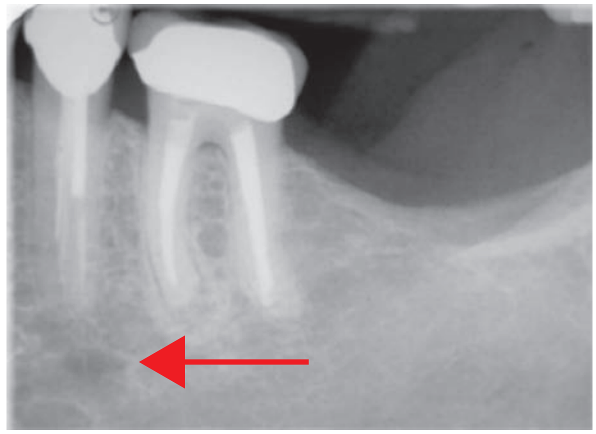


Figure 15.4 Periapical film showing the mental foramen.

15.1.2.3 Cone Beam Computed Tomography (CBCT)

A high-resolution limited view of CBCT is a must for surgical treatment planning. Three-dimensional imaging allows us to clearly identify the anatomy of the tooth, the extent of PA lesions, and their relationship to important anatomical landmarks such as the position of the mental foramen, the inferior alveolar nerve in the mandibular canal, and the accessory nerves (Figures 15.6, 15.7, and 15.8).

15.1.3 Neurosensory Alteration

Because altered sensation of the lower lip, chin, or surrounding skin and mucosa are possible sequelae, patients must be forewarned prior to endodontic surgery in the mandibular posterior region. Iatrogenic paresthesia remains a complex clinical problem with medical/legal implications.

The reported prevalence of neurosensory alterations after apical surgery around the mental area varies due to multiple reasons: procedure performed, osteotomy location, technique used, and the surgeon's experience.

Two types of trauma can produce neurosensory alterations: **indirect** and **direct**. Indirect trauma is a result of inflammatory swelling on the mandibular or mental nerve. Direct trauma results from strain or compression during separation of soft tissue. Fortunately, most neurosensory alteration after apical surgery is transient and lasts from one week to a month.

Figure 15.5 A Panorex film showing the mental foramina.

Paresthesia (numb feeling) and hypoesthesia (reduced feeling) are the most common type of neurosensory alterations related to periapical surgery. Hyperesthesia (increased sensitivity), dysthesia (painful sensation), and anesthesia (complete loss of feeling) are not common sequela.

A rare situation that implies an iatrogenic, careless incision is known as neurotmesis: transection of the nerve with a poor prognosis for resolution of paresthesia.

In the presence of neurosensory alteration, the clinician should perform subjective and objective analyses.

Subjective analysis questions:

1. Do you have normal feeling in your lip, gum, or chin?
2. Is it numb, tingling, or painful?

Objective analysis:

1. Map the affected area on a drawing or photograph of the patient.
2. Determine the ability of the patient to detect the direction of a sweeping motion (1 cm), applying the tip of a rolled-up tissue.

Describe the patient's sensations when a 27-gauge needle is applied to the affected regions with sufficient pressure to indent the skin without penetrating it (Figure 15.9).

15.1.3.1 Surgical Technique to Avoid Iatrogenic Mental Nerve Trauma and Injury

During periapical surgery in the mental region four steps should be carefully executed:

- Flap design and vertical incision placement
- Reflection of the full-thickness mucoperiosteal flap
- Tissue retraction
- Osteotomy and curettage in cases with the lesion in close proximity to the mental nerve

The most common flap design in the mandibular posterior region is the full thickness, triangular sulcular incision. The vertical incision should be done in the mesial interproximal site one tooth anterior to where the mental foramen is located. The location is determined by CBCT (Figure 15.10).

Reflection of the full thickness sulcular incision follows. An elevator is used to reflect the flap carefully and fully to identify the mental foramen. The vertical releasing incision can be extended more apically while the flap is elevated to identify the mental foramen. Once the mental foramen is identified, the vertical releasing incision is adjusted to open the flap anterior to the foramen without touching the foramen.

15.1.4 Groove Technique Using Piezoelectric Surgery

Piezosurgery is useful when the bone must be cut close to important soft tissue areas, such as the mental

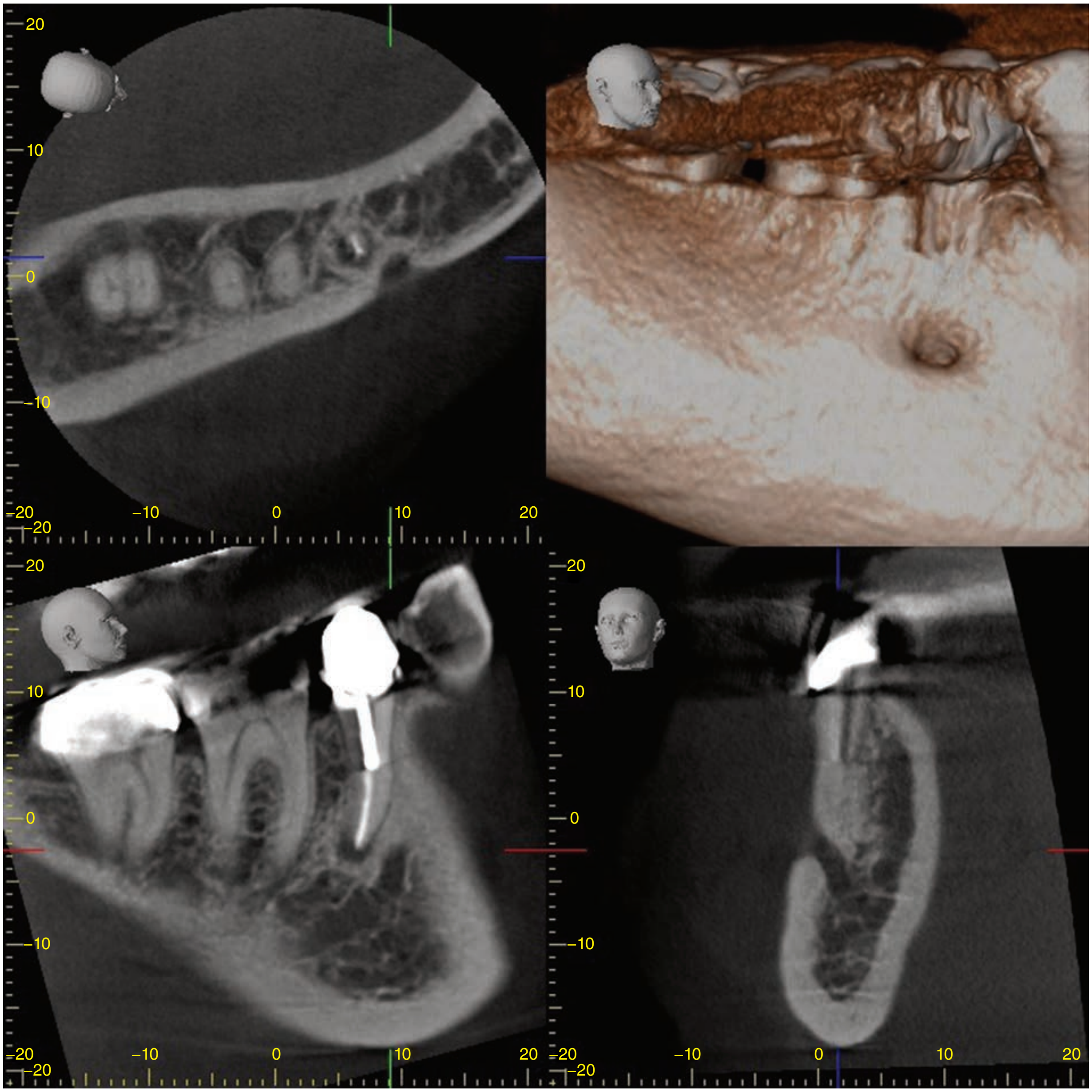


Figure 15.6 CBCT shows coronal, sagittal, and axial views of the mandibular right posterior area, and a clear view of the mental foramen.

neurovascular bundle. Direct exposure of a peripheral nerve to piezosurgery, even in the worst case scenario, does not dissect the nerve.

Piezosurgery uses a specifically engineered surgical instrument approximately 3 times as powerful as a conventional ultrasonic instrument. The vibration frequency (between 25 and 30 kHz), cutting power, and irrigation are adjustable. The flow rate of the cooling solution must be regulated to prevent the bone from overheating. Heating osseous tissue in excess of 47 °C for 1 minute significantly reduces bone formation and is associated with irreversible cellular damage and fatty cell infiltration. Light handpiece pressure and integrated saline coolant spray of piezosurgery maintains a low temperature and allows clear visibility of the surgical site. The main disadvantage of piezosurgery is the cost of the device (Figure 15.11).

The retractors for periapical surgery should have serrated working ends to provide better anchoring on the bone and prevent slippage during retraction.

The new Kimtrac retractors help the clinician obtain a stable retraction in all areas (Figure 15.12).

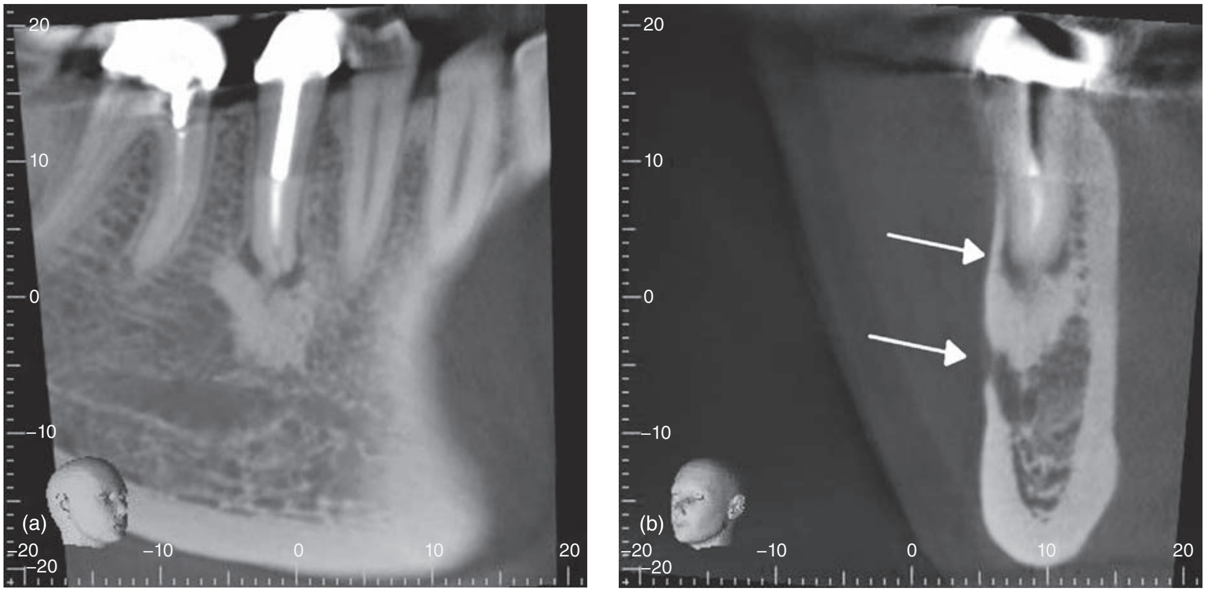


Figure 15.7 CBCT of #29. (a) Clear view of the mental foramen. (b) Arrows point to the apex of the root and the mental foramen. This distance is average.

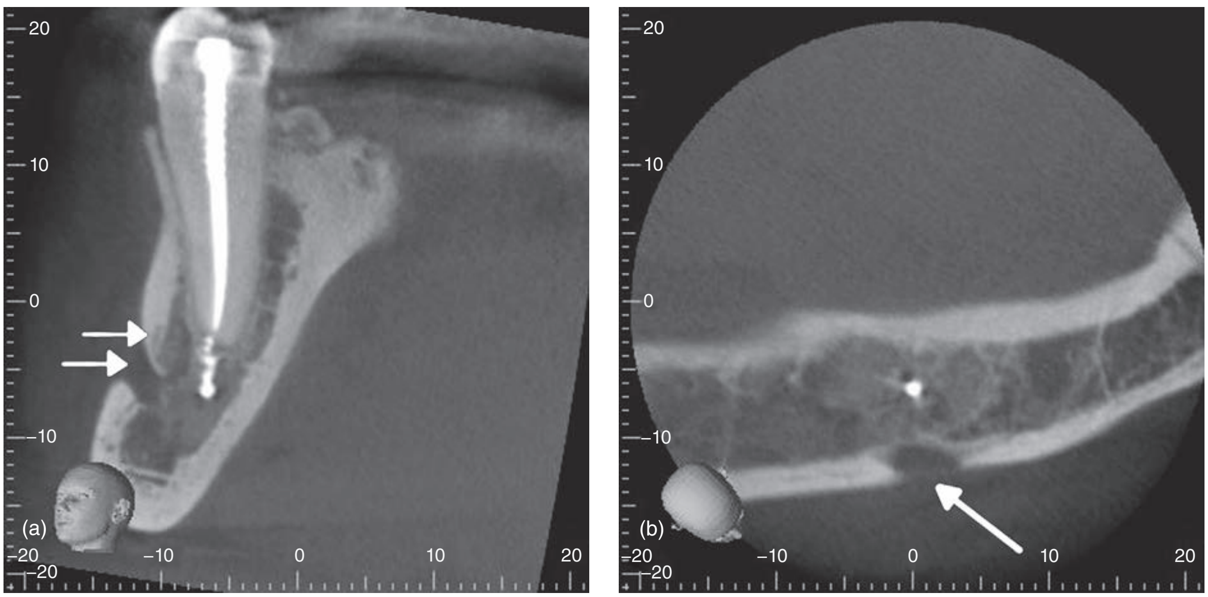


Figure 15.8 CBCT of #20. (a) Coronal view of #20. Note the closeness of the mental foramen with the apex. (b) Axial view showing the entrance of the mental through the buccal cortical bone.

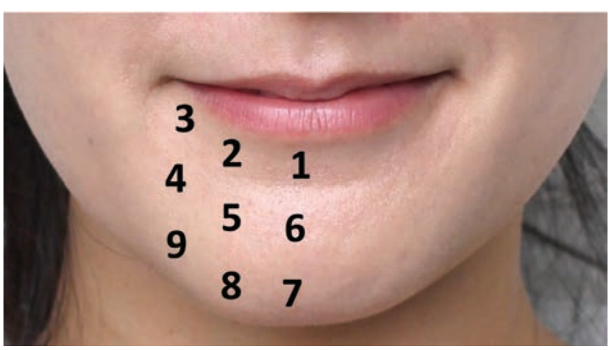


Figure 15.9 Area for the pricking test to assess the degree of paresthesia.

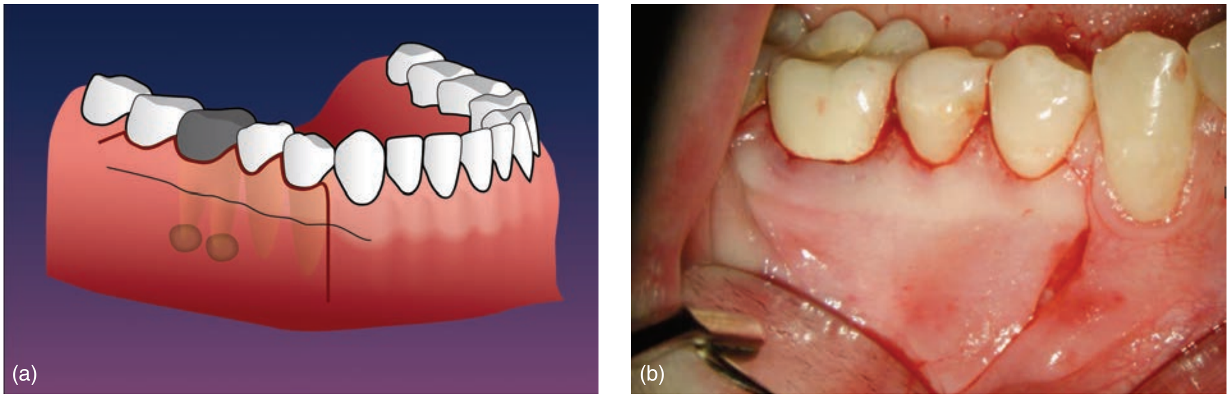


Figure 15.10 Flap design of the lower posterior region. (a) Schematic drawing of the triangular sulcular incision when performing apical surgery on the lower right first molar. (b) Clinical case.

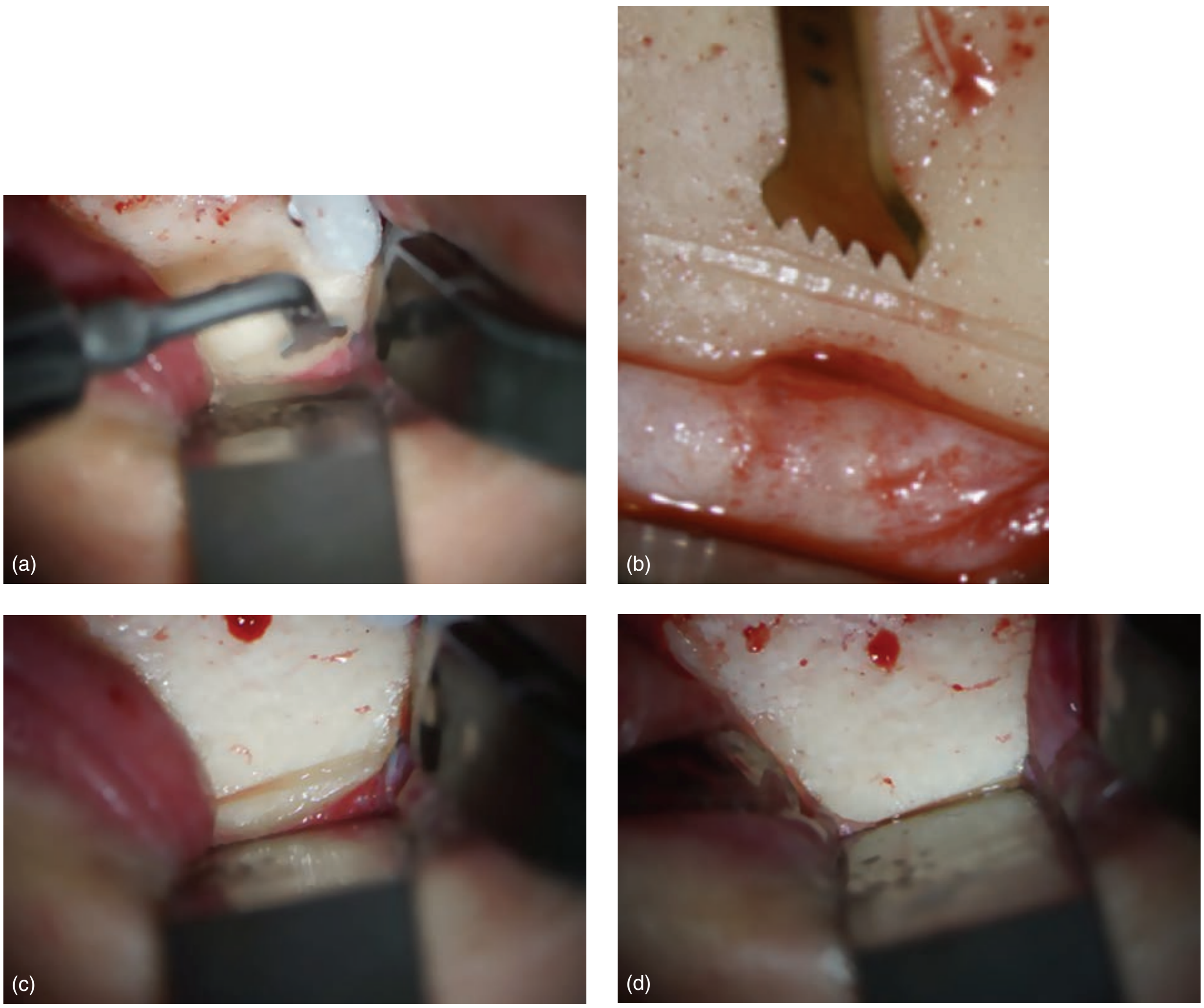


Figure 15.11 The groove technique. (a) The piezotome blade is creating a groove. (b) The blade is positioned just above the mental foramen but far below or apical to the apex. (c) Groove completed. (d) The Kimtrac retractor resting in a groove.

Figure 15.12 Example of the Kimtrac retractor resting on grooves created above the mental foramen.

Suggested Readings

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16

Maxillary Posterior Surgery, the Sinus, and Managing Palatal Access

Garrett Guess and Samuel Kratchman

KEY CONCEPTS

- Maxillary first premolars can be challenging with regards to accessing the palatal root and preparing these thin roots along the proper axis.
- Sinus exposure does not represent a complication, but losing debris into an open sinus cavity can be problematic.
- A palatal approach to treat maxillary molar palatal roots can be effective with proper flap design and patient positioning, to enable access and visualization with the microscope.
- Maxillary second molars present challenges associated with tooth position, palatal inclination, and proximity to the greater palatine bundle.
- Guided tissue regenerative procedures can be helpful to overcome the detrimental effects of thin buccal plates, furcation involvements, and endo/perio problems.

One of the most common teeth requiring endodontic microsurgery surgery is the maxillary molar, due to its complicated anatomy involving the mesiobuccal root. Aberrant anatomy involving the distobuccal root can also occur, especially in cases where the distobuccal may be fused to either the mesiobuccal or palatal roots. A significant number of maxillary premolar teeth can have non-healing apical periodontitis as well. Due to the anatomic and restorative conditions that involve thin-rooted premolar teeth, endodontic surgery can be the preferred procedure in a majority of cases.

16.1 Maxillary Premolars

16.1.1 Access

Maxillary premolars represent some of the simplest cases to treat due to access, and at other times they can be the most challenging teeth to access due to the palatal root. It can present a significant challenge due to its deep palatal location, thin cross-section, and a mesial and superior position of the root tip relative to the operator's view point. In cases of widely spaced buccal and palatal roots of a maxillary first premolar, due to the tooth's buccal-lingual inclination and operator's viewpoint, increased resection of the buccal root is often necessary with the osteotomy extended mesially, close to the adjacent canine in order to access and visualize the palatal root end. Presurgical CBCT planning is essential in locating the palatal root, avoiding damage to the adjacent canine, and preserving the buccal root length.

16.1.2 Instrumentation

Preparation of maxillary premolar root ends is a delicate process due to the very thin structure of these roots, and often the curvature of the roots in the apical third can be abrupt. It can be challenging to determine the correct angle of the ultrasonic tip, and this must be done at low magnification.

16.2 Sinus Exposure

Often during surgery in the maxillary posterior region, one may encounter the maxillary sinus. The most important message is to not panic, but rather to understand the anatomy and be prepared to modify your technique in order to control the environment, and to minimize trauma to the sinus cavity. It is important to recognize the Schneiderian membrane and differentiate between the membrane and granulation tissue, which often is attached to the membrane. The Schneiderian membrane has a bluish hue and under the microscope small vessels can be seen running through the sinus membrane (Figure 16.1). This is different from granulation tissue,

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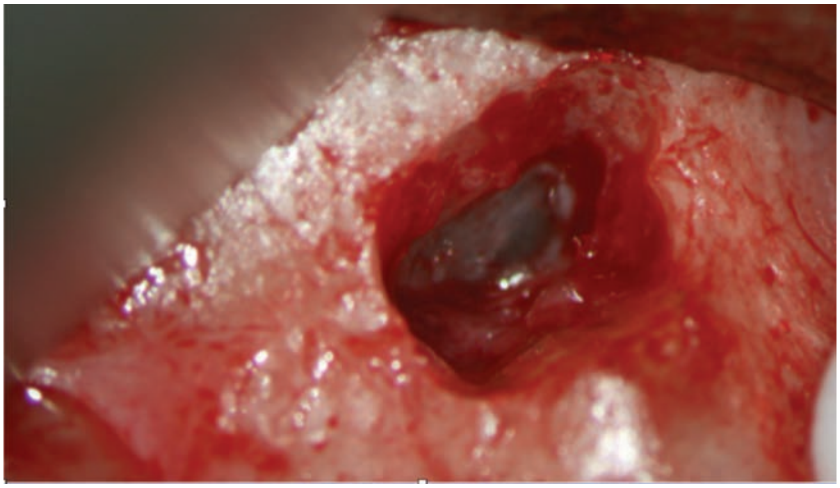

Figure 16.1 Schneiderian membrane seen at maxillary right posterior.

which is red in color, often somewhat fibrotic, and can contain purulent discharge or even granular particles. If unsure whether or not the sinus membrane is present, hold the patient's nose for a moment and ask them to breathe out through their nose, as if clearing their ears in an airplane. The sinus membrane will "flutter" from the negative pressure created while exhaling.

When the root or granulation tissue perforates into the sinus, one of the techniques to protect the sinus from too much debris entering is the "cotton pellet" technique. Estimate the size of the sinus perforation, prepare a cotton pellet slightly larger than the perforation, and place a suture through the cotton pellet. Tie the suture in a knot and cut off the needle, then place the cotton pellet purposefully into the sinus with the suture sticking out, and pull the cotton pellet with the suture until it is wedged up against the sinus wall, behind the root tip (Figure 16.2) Keep in mind that if you now hit that cotton pellet with either a high-speed bur or ultrasonic tip, it will disrupt your work or pull the pellet out. It is advisable to be working under the microscope and therefore being in control to avoid hitting the cotton pellet. When the root end filling is done, remove the cotton pellet by pulling on the suture, and let it wipe across the root end surface, acting as the first step in cleaning the excess material off of the root end.

Another technique when a root tip is clearly in the sinus is to cut the entire 3 mm off the end at once, as opposed to shaving off the root end little by little. This is accomplished by the operator or assistant holding the root tip with college pliers, while the operator cuts off the root tip, removing it in one piece (Figure 16.3). This prevents excess debris from falling into the sinus or from the root tip entering the sinus. One should also be aware throughout the procedure that when the sinus is perforated and the patient is lying supine, excessive irrigation with saline will make the patient feel as if they are underwater and drowning. Whenever you irrigate the surgical site, keep the assistant's suction close by and irrigate gently.

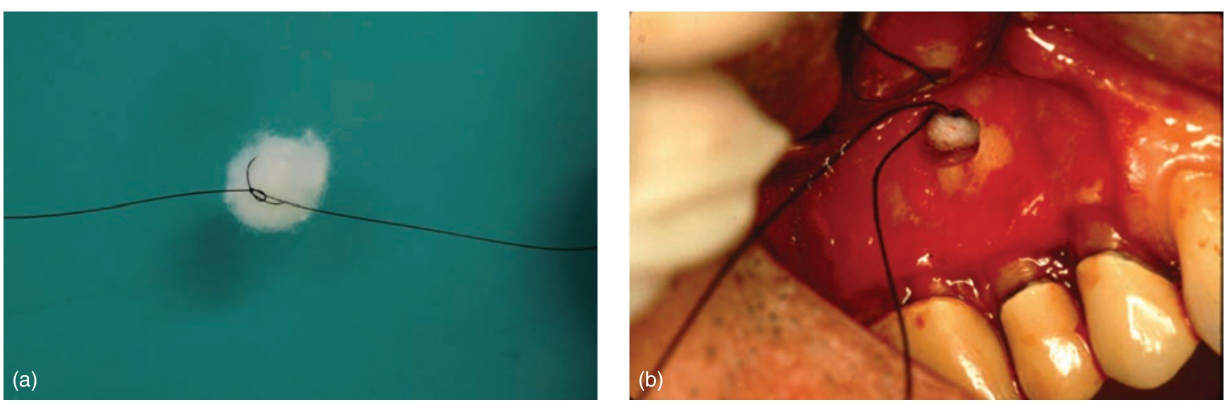

Figure 16.2 (a) Cotton pellet ligated with size 4.0 silk suture. (b) Ligated cotton pellet in place, protecting the sinus.

Figure 16.3 Lesion at apex DB root and symptoms. During apical surgery it was discovered that the DB root was in the maxillary sinus so the 3 mm apical resection was done in one piece while an assistant held on to the root end with college pliers. (a) Preop radiograph; (b) 3 mm of DB root exposed; (c) 3 mm of root tip resected; (d) 1 year follow-up. Bone fill was evident and no symptoms.

Some recommendations when the sinus is perforated are to prescribe an antibiotic after surgery, such as Ciprofloxacin or Augmentum for one week. Consult a PDR for recommended dosages and be aware that the suggested antibiotics may change from year to year. Also it is recommended that the patient take a decongestant such as Sudafed 30 mg and a nasal spray/decongestant such as Neosynephrine 0.25% for one to two days. Both of these medications can be purchased over-the-counter without a prescription. The patient should also be instructed to avoid sneezing or blowing their nose for the next few days, to elevate their head while sleeping, and told about the possibility of nosebleeds.

The prognosis of endodontic surgery is not altered when the sinus has been perforated. It is recommended that a CBCT be taken prior to surgery to clearly delineate the proximity of the sinus to the surgical site, as well as to find out whether the apical lesion perforates the sinus cavity. Even if a periapical lesion is extensive and obliterates the sinus membrane, after surgery to remove the lesion, the sinus membrane can reform (Figure 16.4).

Endodontic microsurgery may be indicated when there is a foreign body, such as a separated file or overfill of gutta percha during conventional treatment (Figure 16.5). A presurgery CBCT will be critical for showing exactly where the foreign body is and if it is in the sinus.

16.3 Maxillary First Molars

16.3.1 Access

Endodontic microsurgery on maxillary molars is also a predictable means to manage persisting apical periodontitis but presents a few more challenges compared to treating premolars. The further posterior a tooth is positioned, the greater the challenge may

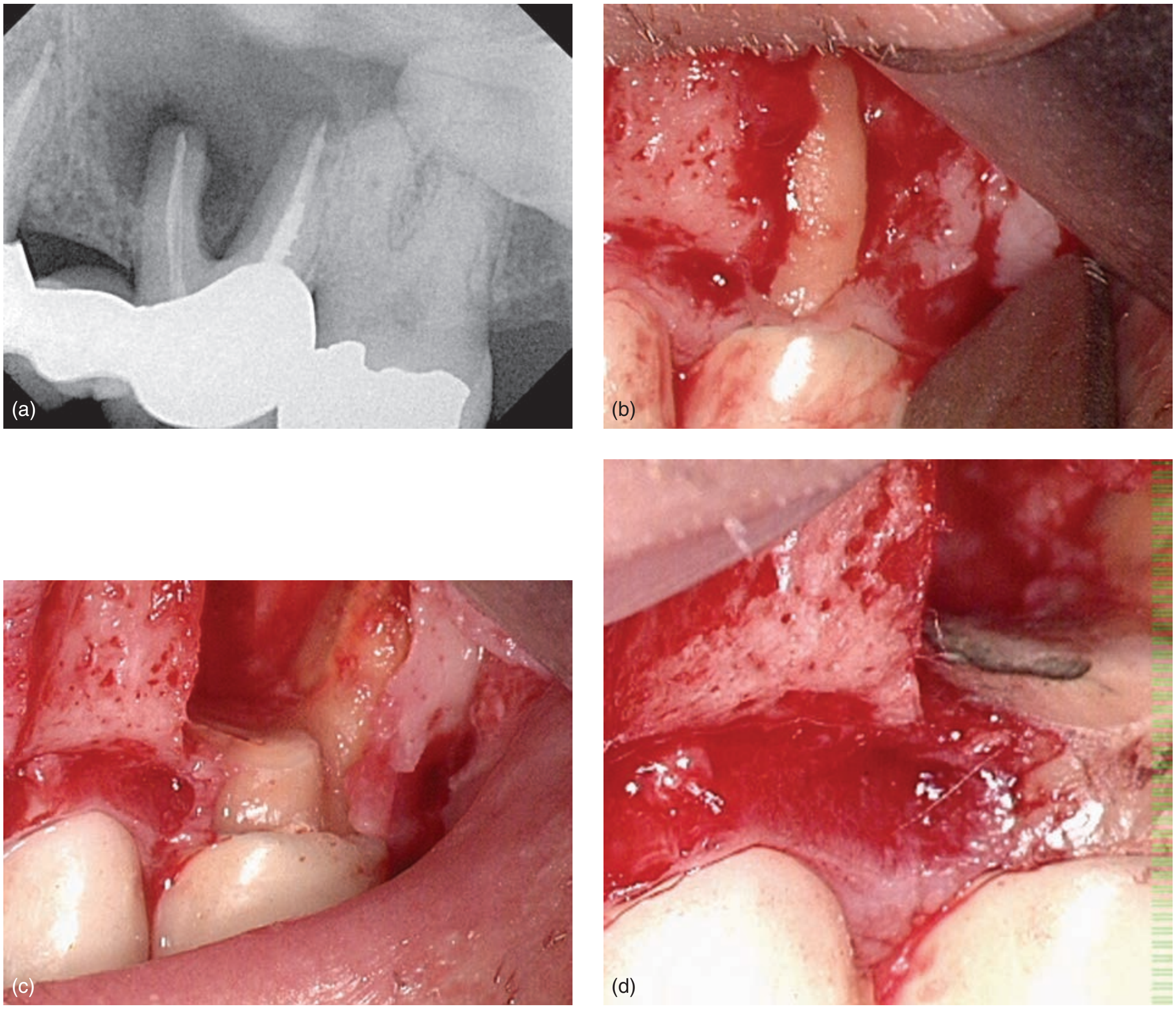

Figure 16.4 History of recent three-unit bridge and acute abscess involving maxillary left first molar. After an emergency incision and drainage and antibiotics, apical surgery was performed, noting that the lesion obliterated the sinus membrane and there was a large sinus perforation with purulence and infected tissue removed. The MB root was resected to the level where some mesial and distal bone remained, and a biopsy of the lesion came back as a radicular cyst. (a) Preop radiograph; (b) after incision, complete fenestration of the MB root was noted; (c) MB root resected leaving approximately 3 mm of root remaining in the bone; (d) gray MTA root end filling.

be. Access can be limited for numerous reasons, but mostly due to tight soft tissues and lips that prevent sufficient retraction in order to reach a handpiece in position while a retractor is also present. The coronoid process can be close to the alveolar bone and prevent access with the handpiece as well. Adjusting the patient's jaw position and the use of different types of retractors that fit the operating space are ways to try to overcome this challenge. Determining if there will be adequate access during a pretreatment consultation is advised. Once access from the buccal can be established, treatment of the buccal roots of maxillary molars present challenges from properly addressing the broad roots that contain multiple canals, especially mesiobuccal roots and distobuccal roots, which are fused to the palatal roots. These roots require significant resection at a near zero-degree bevel. Anatomic studies show that mesiobuccal roots of maxillary molars require 4 mm of apical resection to predictably expose the isthmus between multiple canals so they can be effectively cleaned and filled, but this resection must occur with little to no bevel to reveal the palatal-most canal. The angulation or long axis of the MB2 canal in mesiobuccal roots is usually aimed away from the operator toward the palatal and requires recognition and changing of the ultrasonic

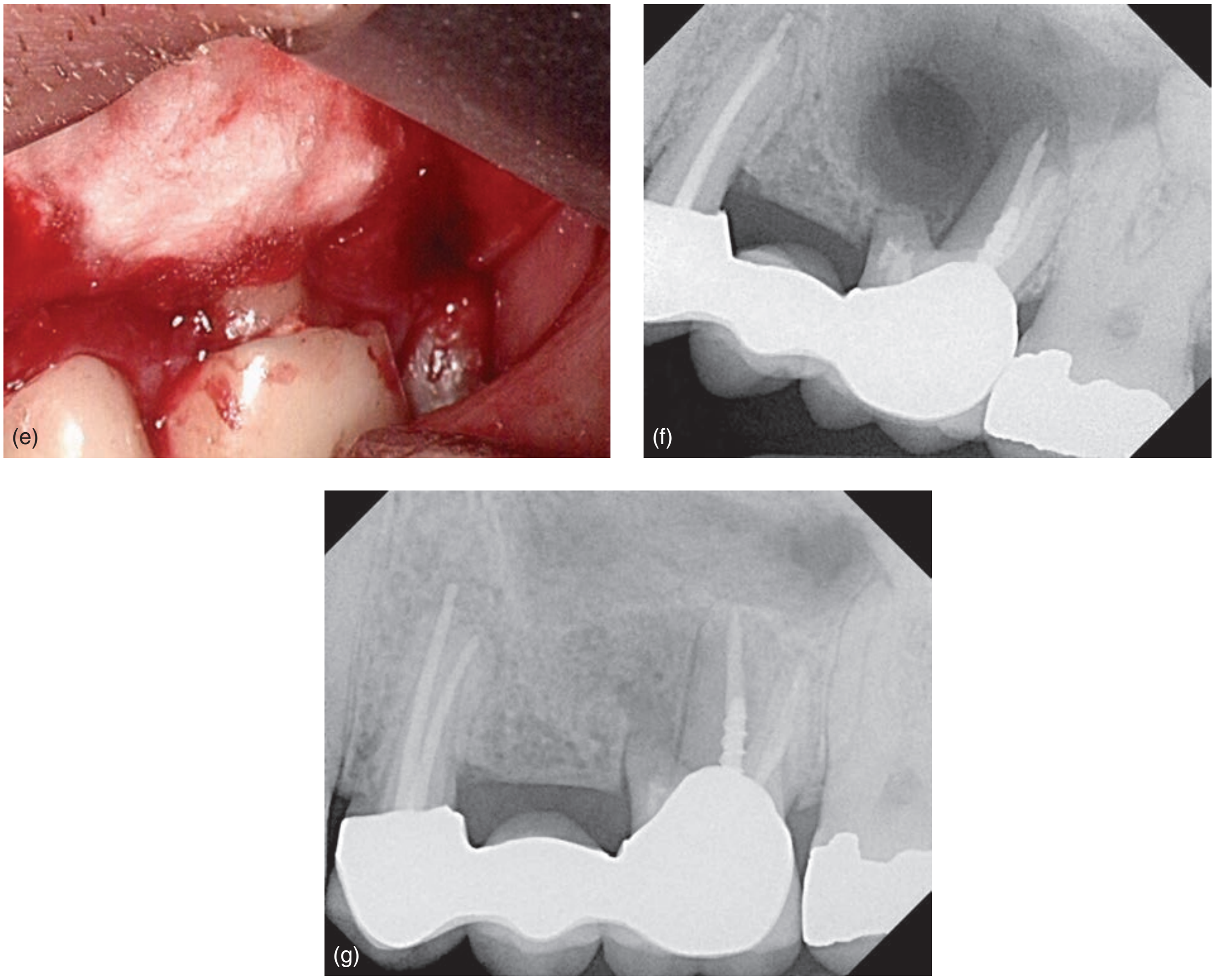

Figure 16.4 (*Continued*) (e) Collacote resorbable collagen membrane; (f) postop radiograph; (g) 8 month follow-up showing bone fill plus reformation of the sinus membrane.

tip during root end preparation to one with an obtuse angle in order to properly prepare the canal along its long axis. Utilization of CBCT imaging provides the operator with the advantage of recognizing the position and angulation of the canal preoperatively.

16.3.2 Palatal Approach

Palatal surgery is something that is important to learn and be able to perform, but even the microscope has limitations when palatal surgery is indicated. The procedure can be awkward, with a longer recovery period due to the location and constant irritation to the roof of the mouth, as well as the difficulty in manipulating such thick tissue. Although it may be necessary to perform both buccal and palatal surgery at the same time, if given the choice, one should consider doing the two surgeries in separate sessions. This will avoid creating a through and through communication if one does not already exist. A CBCT is highly recommended prior to palatal surgery, in order to determine the proximity of the palatal root apex to the bone, as well as determining if the root is in the sinus. Also, depending on how close the palatal root is to the buccal roots, the possibility of a buccal surgical approach to the palatal root may be feasible. For the most part, palatal surgery should be limited to first molars or anterior to that, as second molars can be inaccessible as well as present with more anatomical risks. The greater palatine foramen is located 3–4 mm anterior to the posterior border of the hard palate, with the nerve and vessels running anteriorly in the submucosa (Figure 16.6). While elevating the soft tissue to work on a first molar, the greater palatine nerve and vessels may be included in the flap, but this will present no problems at all (Figure 16.7).

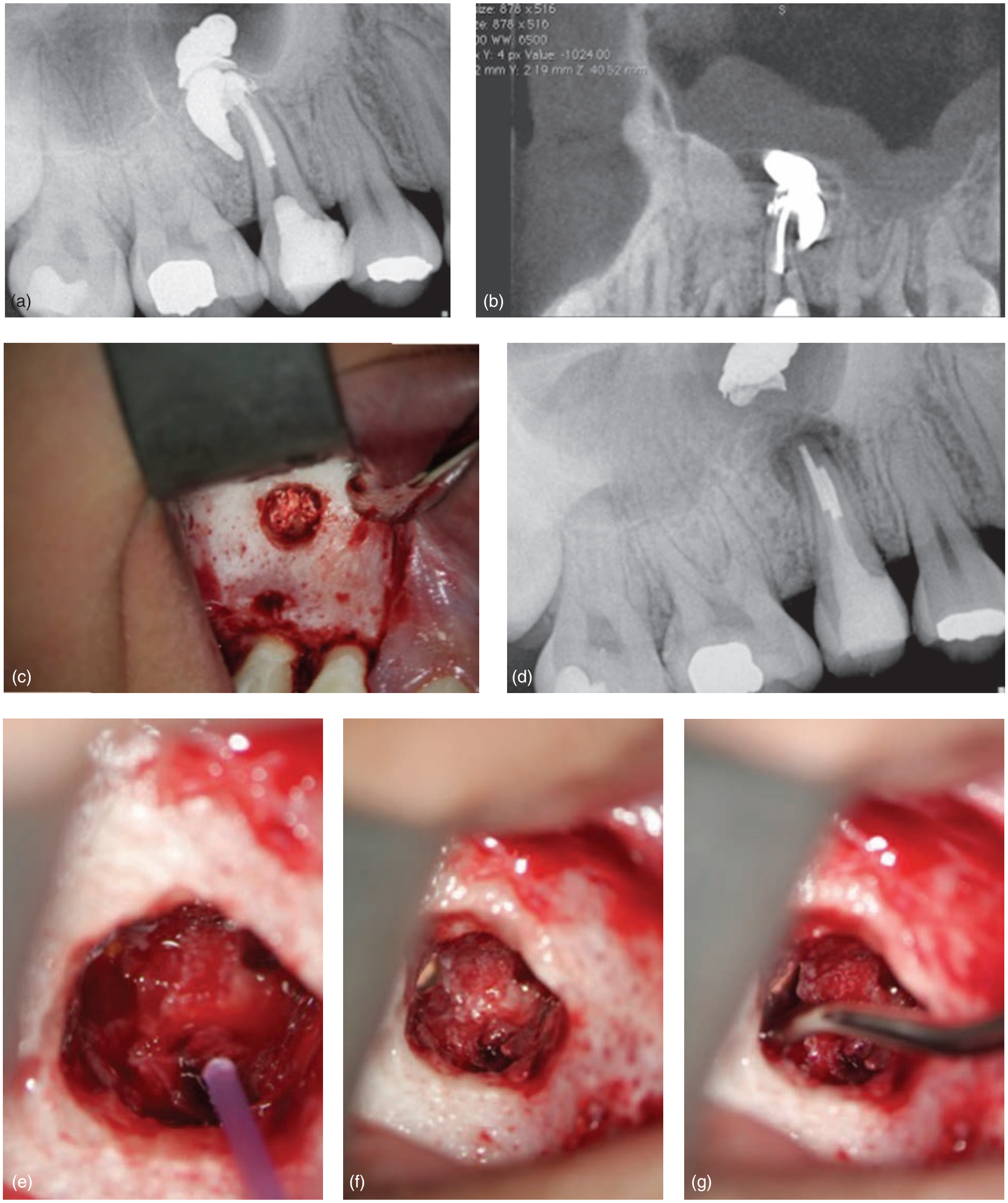

Figure 16.5 Large overfill of maxillary right second bicuspid with gutta percha in the sinus. Upon applying the surgical approach, part of the gutta percha was removed, dislodging the remainder into the sinus. It was possible to retrieve the remainder of the gutta percha using microsuction and cutting a bigger hole into the sinus and then completing apical retropreparation and root end filling. (a) Maxillary right second premolar with gutta percha overfill. (b) Slice of CBCT showing gutta percha encroaching sinus as well as mucositis of the membrane. (c) After surgical incision and osteotomy, excess gutta percha is observed. (d) Upon attempting to retrieve excess gutta percha, a piece separated and went into sinus. (e) Microsuction tip placed into sinus to retrieve gutta percha (f) Gutta percha seen in upper left corner of sinus (g) Back of spoon used to make hole into sinus larger in order to be able to fit the instrument inside to retrieve gutta percha.

Figure 16.5 (*Continued*) (h) Gutta percha retrieved. (i) Bioceramic root end filling. (j) Collacote resorbable membrane. (k) Postop radiograph. (l) 4 month follow-up. (m) Capillary tip (Courtesy of Ultradent, South Jordan, Utah). (n) Luer lock vacuum tip (Courtesy of Ultradent, South Jordan, Utah).

Other recommendations when performing palatal surgery are to extend the flap longer, so as to have easier access to the site and to alleviate some of the pressure on the tissues being elevated. When performing endodontic microsurgery anywhere else in the mouth, it is typically recommended to extend the incision one tooth on either side of the one being treated, whereas with palatal surgery on a first molar, for example, the incision will extend anteriorly to the canine area. Also, one should never place a posterior vertical releasing incision, as this will greatly increase the chance of touching the greater palatine bundle. To compensate for not placing a distal vertical release, the anterior vertical releasing incision will usually be a little longer. After elevating the soft tissue on the palate, place a suture through the anterior portion of this flap, pull the flap toward the opposite side of the maxilla, and "lasso" the suture around a tooth on the opposite side, creating a constant tension that will keep the elevated soft tissue out of the way for the operator

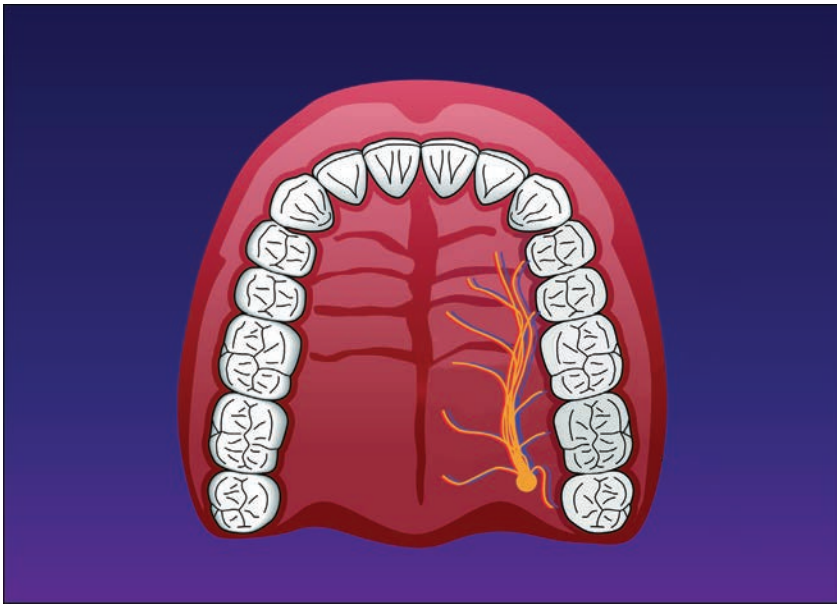

Figure 16.6 Model showing palatal blood and nerve supply.

(Figure 16.8). Now the tissue can be easily managed with a flat retractor, such as the Seldin retractor (Figure 16.9), and on occasion a sterile 2×2 gauze can be pushed down between the bone and the elevated flap in order to maintain the space for visualization, as well as aid in hemostasis. As previously mentioned, the microscope has limitations while working on the palate, and often times indirect vision is required.

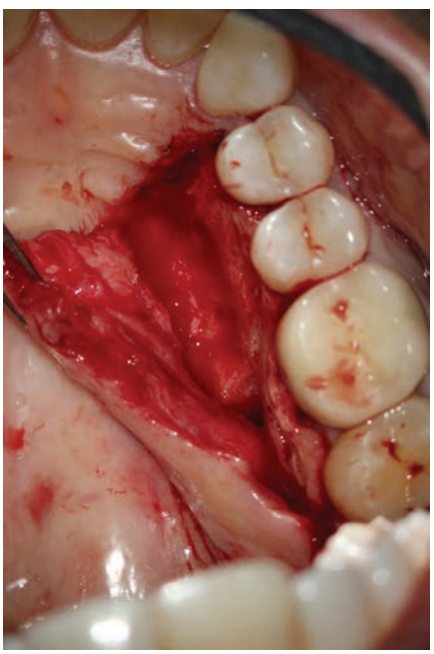

Figure 16.7 Greater palatine artery and nerve bundle exiting the greater palatine foramen and within the elevated soft tissue.

This becomes cumbersome, because while working through a mirror under the microscope, the assistant must constantly keep the mirror dry as well as remembering that any movement by the operator will take him/her out of the visual field. It is therefore recommended that a photo mirror (Figure 16.10) be held by the operator, which broadens the viewing field. It is still necessary for the assistant to be suctioning right next to the photo mirror, trying to keep it as clear as possible. Working with indirect vision anywhere in the mouth slows down the surgery, as there are constant pauses to readjust and to keep the mirror clear. During palatal surgery, the patient is in an awkward position, lying way back, with their chin elevated and mouth wide open. The operator must remain aware of this and be careful protecting the patient's airway while working, especially during irrigation. Keep the assistant's suction close to the irrigating syringe and gently irrigate the site, under the microscope, being sure not to compromise the patient's airway.

As mentioned, second molars are not only difficult to access but are close to the greater palatine artery/nerve bundle. Therefore, instead of attempting surgery on second molars, replantation should be considered. This procedure will be discussed in detail in a subsequent chapter. Palatal surgery is possible on a second molar. A larger portion of the palatal may need to be resected due to accessibility (Figure 16.11).

A CBCT is really a prerequisite for palatal surgery to see the palatal root's proximity to the palatal bone as well as the sinus. If a tooth is treated first conservatively, for example, to seal a perforation, then the root can be filled orthograde with MTA or Bioceramic.

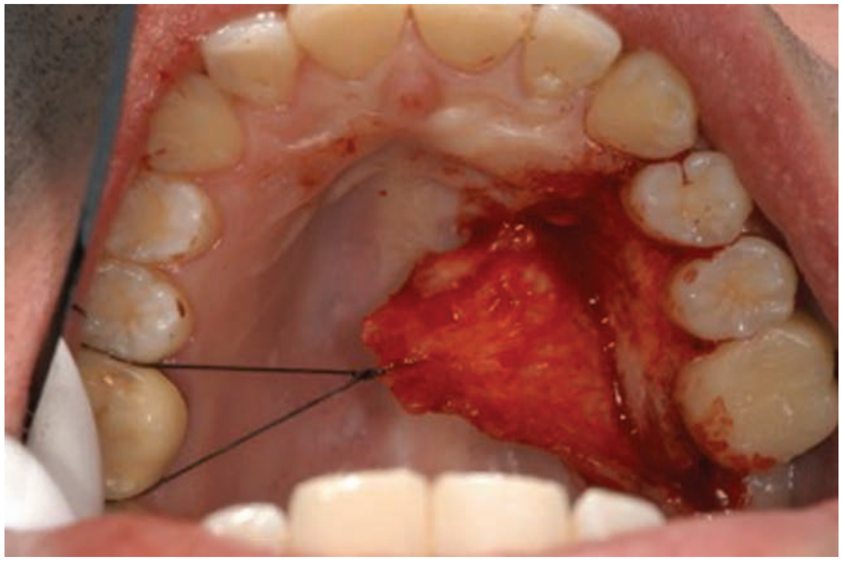

Figure 16.8 Lasso technique to keep palatal tissue elevated and allowing for better visualization of the surgical site.

Figure 16.9 Retractor used for palatal surgery.

Figure 16.10 Photo mirror used to give a broader indirect view during palatal surgery.

Then, during apical surgery, only the palatal root will need to be resected, with no need for an ultrasonic retropreparation and root end filling (Figure 16.12). Even when palatal surgery can be accomplished efficiently, ultrasonic preparation and root end filling can still be awkward. The access and angulation with the ultrasonic tip is tricky, so if the apical portion of the palatal root can be filled conventionally, that would be ideal prior to apical surgery.

16.4 Second Molars

Maxillary second molars are challenging due to the following factors:

Posterior position, which creates access challenges

Tooth inclination where root tips are positioned deeper into the alveolus in a palatal direction

MB root position relative to the first molar's DB root where the apex of the mesiobuccal root of a second molar is behind the distobuccal root of the first molar

Root fusion is common in creating isthmus and fins that must be found and treated

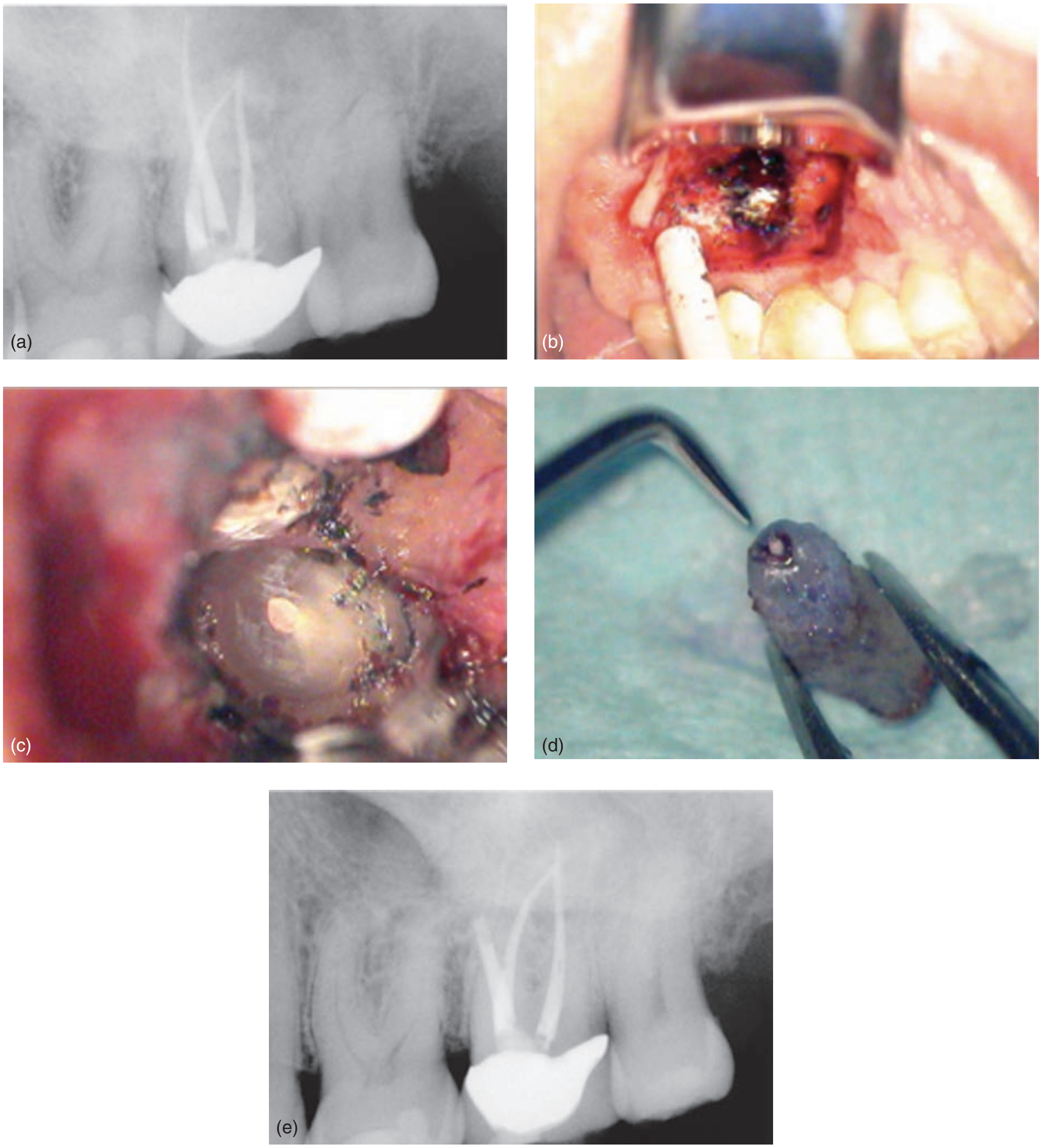

Figure 16.11 Failed endodontic retreatment of maxillary left second molar. Surgical intervention treatment planned. (a) Preop radiograph. (b) Palatal access. (c) View of resected apex with methylene blue dye in a micromirror. (d) Resected root tip. (e) Postop radiograph.

Preoperative evaluation of the surgical site including evaluating the inclinations and proximities of the adjacent roots is essential, especially when attempting apical surgery on a mesiobuccal root of a second molar that is next to a vital first molar distobuccal root. CBCT imaging will provide helpful information regarding the proximity and depth of roots relative to the adjacent teeth, but a clinical exam still needs to be performed to confirm that access is possible given the overlying coronoid process and the patient's degree of opening and soft tissue flexibility. Because the operator position is often at a mesial angle to the tooth versus directly in-line, flexible soft tissues and some space between the roots of the first and second molars

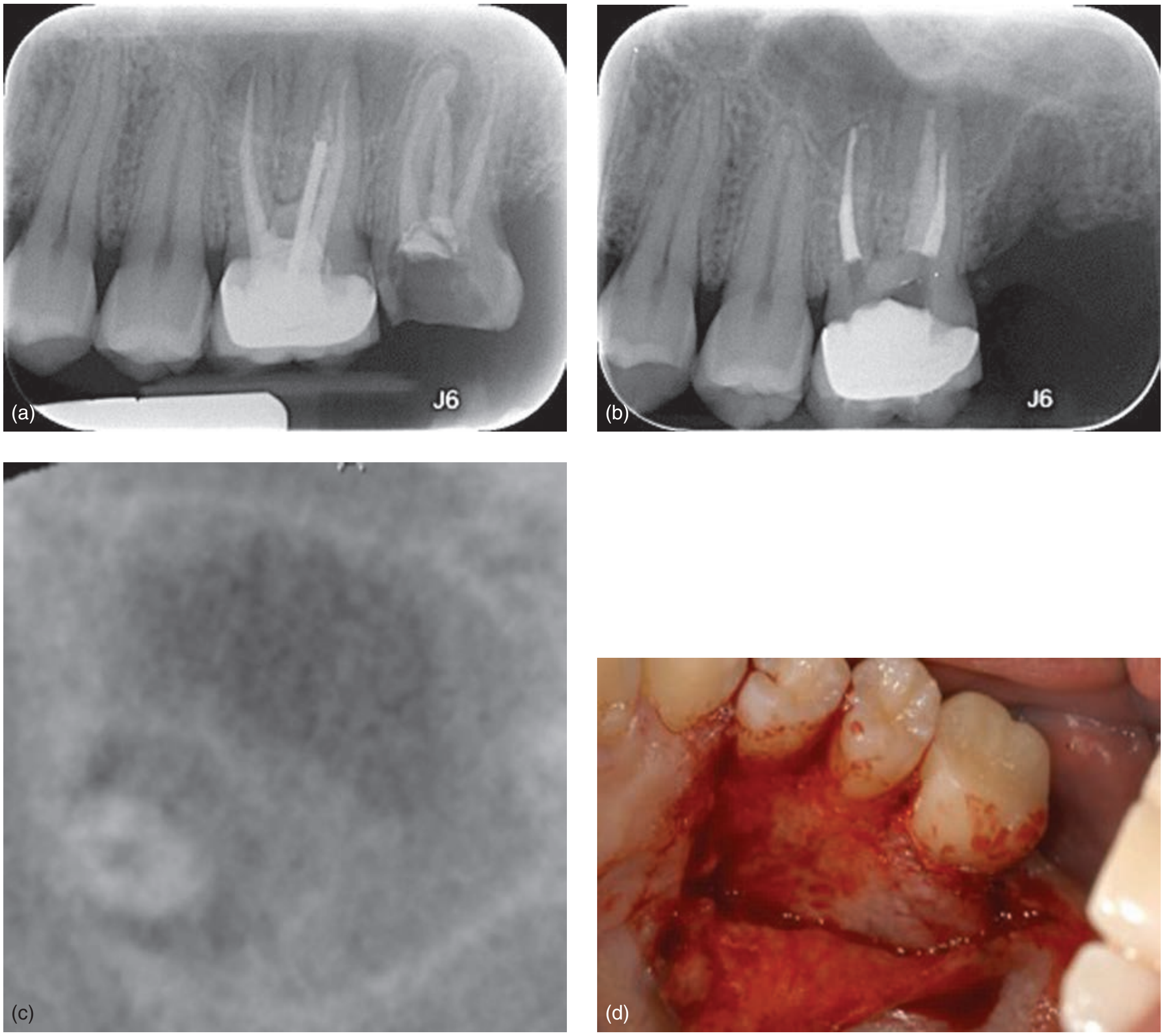

Figure 16.12 History of palatal root postperforation maxillary left first molar; sealed internally with MTA and treatment planned for palatal surgery to remove the apical part of the root with lesion. (a) Preop conventional retreatment. (b) Postop conventional retreatment with MTA orthograde filling in the palatal root. Note that the maxillary left second molar was extracted due to non-restorability. (c) Slice from CBCT showing the palatal root near the palatal bone and not in the maxillary sinus. (d) Surgical site exposed.

is necessary to successfully access a maxillary molar's root ends.

16.4.1 Periodontal Aspects

Maxillary first and second molars frequently have thin buccal plates that may have dehiscences, furcal exposures, and fenestrations, which could result in accelerated future periodontal breakdown. Utilization of guided tissue regenerative procedures can effectively reduce Class 2 furcation defects by turning them into Class 1 defects or sometimes reducing them entirely. Using guided tissue regenerative procedures including grafts, barriers, and bioactive agents can reduce the periodontal impact of surgery and potentially enhance the postsurgical result, especially when an endo/perio defect exists.

Maxillary posterior endodontic surgery is a predictable means to address persisting apical periodontitis. Complications can be reduced and predictability increased when the treatment is combined with the presurgical planning benefit of CBCT imaging and the accuracy afforded by the magnification and illumination of the operating microscope.

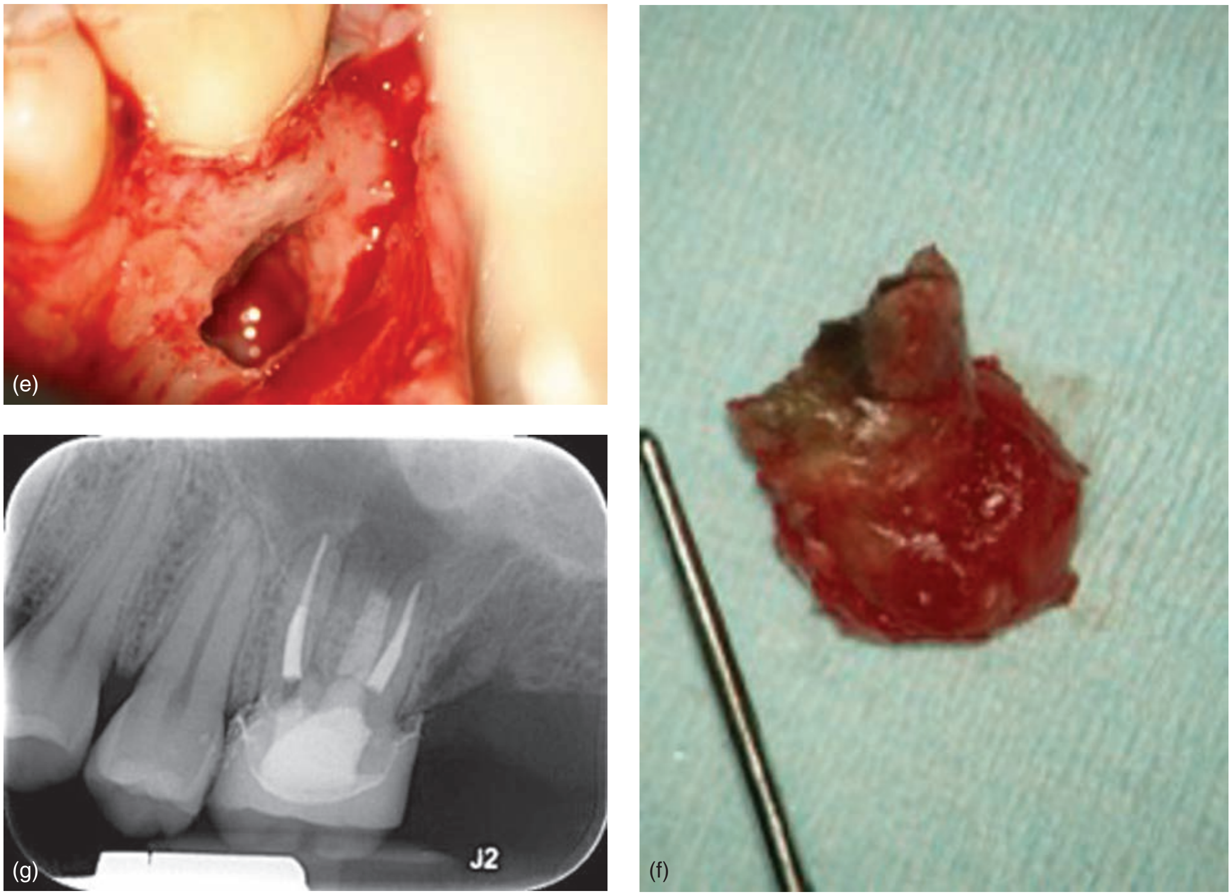

Figure 16.12 (*Continued*) (e) Osteotomy completed. (f) Root tip with granuloma. (g) Postop radiograph. (Courtesy of Dr David Moore.)

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17

Surgical Root Perforation Repair

Raed Kasem, Samuel Kratchman, and Meetu Kohli

KEY CONCEPTS

- Root perforations, if not approached in a timely and organized manner, can often lead to extraction.
- The location of the perforation relative to the bone level as well as the time from perforation until repair are key factors in determining longevity of the tooth.
- CBCT is necessary to determine the exact location and accessibility to a perforation site.
- MTA, Bioceramics, and Geristore (DenMat, Orange, CA) are the materials of choice to seal a perforation. Location as well as the ability to isolate the site are key factors in choosing the proper material.
- When treating resorptive lesions surgically, it is critical to remove the entire defect, achieving clean borders, in order to completely arrest the resorption as well as to adequately seal the defect.

Root perforations have a negative impact on the long-term prognosis of endodontically treated teeth as they lead to destruction of adjacent supportive periodontal tissues and osseous breakdown. Perforations can occur as a result of root resorption or can be a result of an iatrogenic error during endodontic treatment or post space preparation.

Perforation repair can be challenging and if unsuccessful could result in a poor prognosis. Historically, perforation repair has a low success rate, and clinicians often opted to extract than attempt to repair. Due to the anatomy of the root system and limited access to perforation sites through the root canal space, results of non-surgical perforation repair alone can be unpredictable, even when a biocompatible cement like MTA is used. (Figure 17.1). In addition, many perforations caused by post preparation drills or active post systems could result in a strip or oval-shaped perforation that may be impossible to seal completely without surgical intervention (Figure 17.2). However, the use of the cone beam CT, surgical microscope, ultrasonic tips, microsurgical instruments, and biologically compatible materials like MTA and Bioceramics has made perforation repair a predictable treatment option with favorable long-term prognosis.

It has been generally accepted in the past that the longer the time lapse between the perforation and the repair, the poorer the prognosis. That being true, significant healing has also been observed in repairing old perforation sites containing chronic inflammation and epithelial tissue with microsurgical treatment. This tissue can be removed efficiently and predictably allowing for enhanced repair, attachment, and improved long-term survivability of the tooth.

17.1 Possible Challenges to Non-surgical Perforation Repair

1. Inability to discern exact size and shape of the perforation defect.
2. Difficulty gaining access to the perforation site through the root canal system.
3. Difficulty controlling the amount of repair material being extruded into the periodontium and supporting bone, which may increase chances of chronic inflammation and failure.
4. Inability to remove the overextended repair material that is in the periodontal tissue and supporting bone.
5. Excessive amount of bleeding from the perforation site could interfere with the setting of the repair material.

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

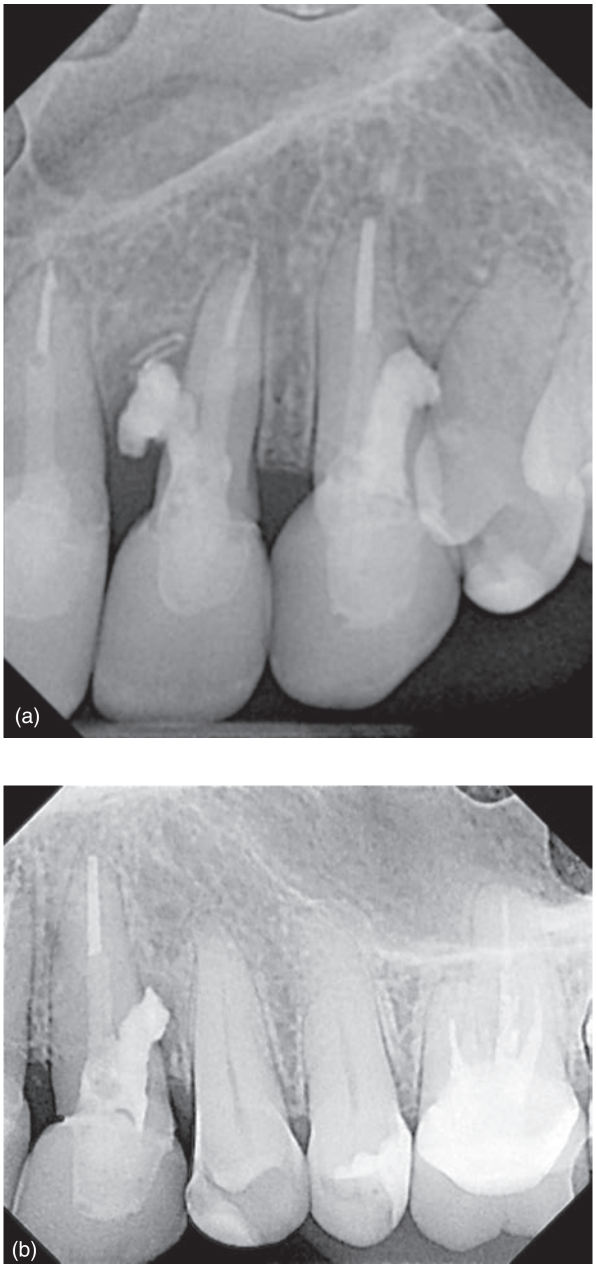

Figure 17.1 Radiographs of two separate cases of perforation repair with MTA showing defects in bone around the repair due to an inability to control the material.

17.2 Factors that Enhance Positive Long-Term Prognosis for Perforation Repair

1. **Complete sealing of the perforation site.** This allows periodontal tissue and bone to rebuild, repair, and possibly attach to the perforation repair material. The complete seal of the perforation site prevents leakage of bacteria and its byproducts, or any other irritants from the root canal system causing inflammation or disease.
2. **Restoration of the original anatomy of the perforated root surface.** This would allow neighboring periodontal and bone cells to reorganize and align themselves as close as possible to their original tissue position.
3. **Biocompatibility of perforation repair materials.** Many restorative materials such as amalgam and composite induce an inflammatory reaction, which may result in the formation of fibrous connective tissue and ultimately could lead to failure. Requirements for perforation repair material are:
   a) Biocompatibility
   b) Ease of use
   c) Non-resorbable
   d) Resistance to marginal leakage
   e) Reasonable setting time
   f) Radiopacity.

   MTA, SuperEBA, Geristore, and Bioceramic are materials that have shown long-term postoperative success for perforation repair. Many studies confirm that MTA cement promotes healing of perforation site repairs. Geristore (resin modified glass ionomer) also shows favorable results when used under certain conditions. Neither one of these materials possess all the requirements for an ideal perforation repair material. The material properties have been discussed in detail in Chapter 11. The feature pertinent to perforation repair but a disadvantage is the long setting time of MTA, making it susceptible to being washed out if used for large root perforations, perforations close to the cervical level, or in those perforations that communicate with the sulcus. Even though MTA's initial adhesion to the cavity site is superior, saliva and blood fluids could easily wash MTA cement out and cause failure. Bioceramic root repair material is now available in a fast set formulation. Although the material sets in 9–14 minutes it does not have the strength to resist scaling and root planning if placed above the gingiva, especially in cervical root repair cases. In cases such as these, Geristore, which is insoluble in oral fluids, has great adhesion capabilities to dentin with low polymerization shrinkage, and high compressive strength, would be the material of choice. Geristore is a stable material, has a quick setting time and a favorable response from adjacent periodontal tissue. However, Geristore could be difficult to manipulate and a completely dry field must be maintained during its application. It should be noted that although periodontal tissue response to Geristore

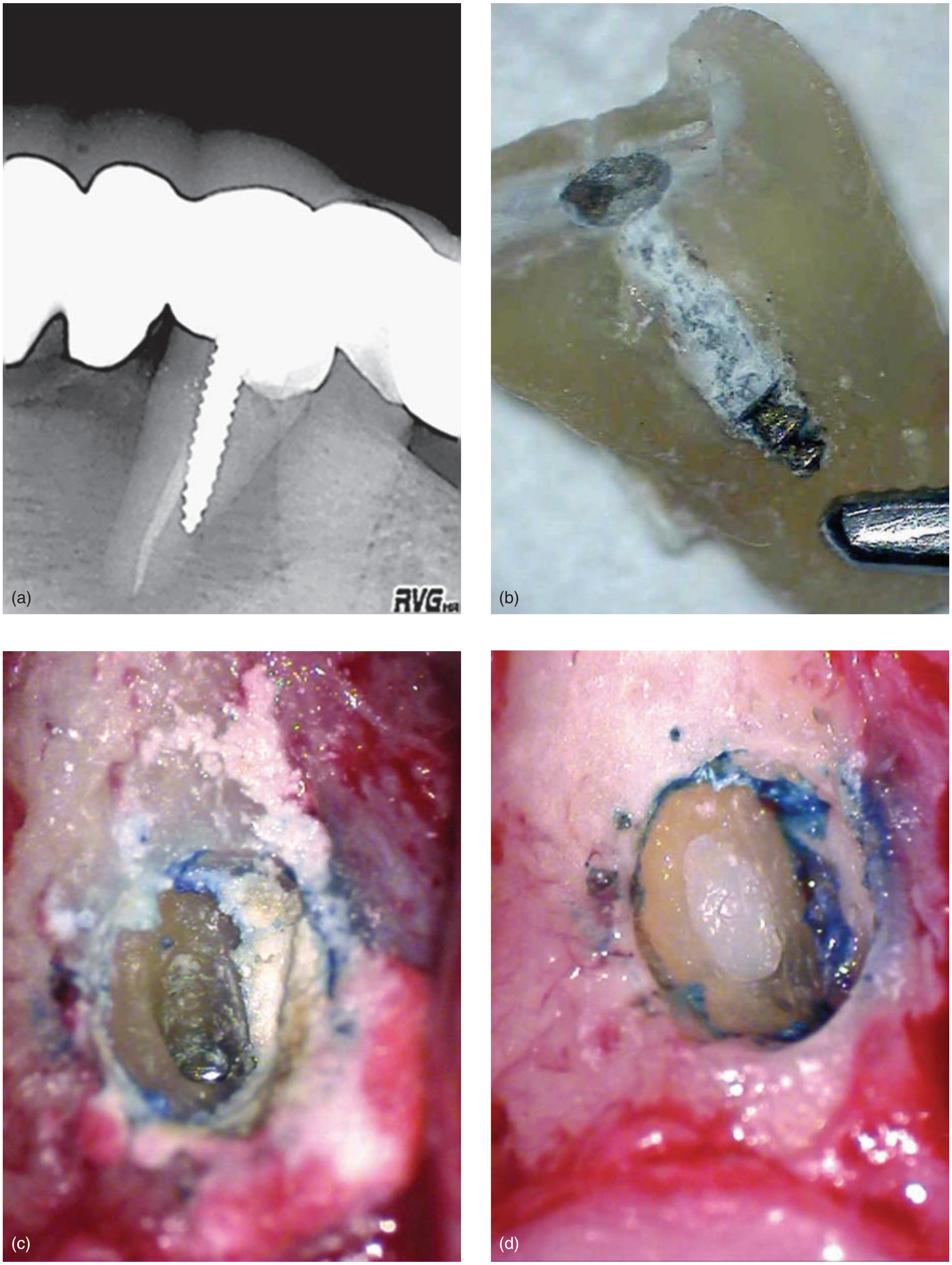

Figure 17.2 Examples of root perforations. (a) Radiograph showing a perforation caused by a screw post. (b) Strip perforation in an extracted tooth shows the extent of the damage caused by a screw-type active post. (c) Oval-shape perforation created by a post space drill. (d) Oval-shape perforation repaired surgically with Geristore.

is superior to many other materials, its interaction with osteogenic cells is not as favorable as that of Bioceramics.

4. **Time of perforation repair.** Perforation repair should be performed as close as possible to the time of perforation. This is an extremely important consideration when the perforation site is close to the cervical level and if it communicates with the sulcus. The chance to have complete repair of surrounding tissue can decrease dramatically if treatment is delayed (Figure 17.3).
5. **Location of perforation.** When the perforation site is completely surrounded by healthy bone, the success rate significantly increases following repair. The healing following a successful treatment of such a lesion is similar to that of an infected root canal with lateral pathology originating from a lateral canal or an apical foramen.
6. **Occlusion.** The treated perforated tooth should have normal to minimal occlusion following perforation repair. Hyperocclusion/traumatic occlusion could jeopardize the treatment outcome.
7. **Lack of tooth mobility.** It is important to keep mobility to a minimum to allow for proper tissue healing. If the treated tooth has a Class II or III mobility, splinting should be considered as part of the perforation repair treatment.
8. **Operator's technical skills.** Attention to detail in surgical perforation repair is crucial for a long-term successful outcome.

17.3 Surgical Perforation Repair Techniques

The main objective of surgical perforation repair is to eliminate inflammation and infection from the perforation site and to establish a healthy environment for bone regeneration. Most mechanical perforations created by post preparation drills are either angled buccally, mesially, or distally to the root surface. Lingual or palatal perforations are less likely to occur due to the angulation of the teeth in the upper and lower jaws. Once a root perforation is identified by radiograph or CBCT, the operator must determine if the perforation repair should be performed by a surgical approach, non-surgical intracanal treatment, or a combination of both. If the perforation site is well surrounded by intact bone, non-surgical retreatment could be the first option for perforation repair by using MTA or Bioceramic with an intracanal approach. A follow-up evaluation is important to determine if microsurgical repair is needed. It is important that the operator avoids root planing of the surface surrounding the perforation defect to preserve the remaining periodontal fibers that could possibly allow for reattachment.

Surgical techniques used in perforation repair depend on the location of the perforation.

1. **Root perforation in the middle to apical third surrounded by intact bone with adequate surgical access.** This is the most predictable and simplest perforation repair if the perforation site is fully accessible to the operator. Sealing of the perforation defect should be similar to an apical root end filling. Once the perforation site is surgically exposed, a retropreparation of at least 2 mm inside the root should be made using the proper ultrasonic tip. If a metal post is protruding out of the perforation site or close to the root surface, the post should be cut down to at least 2 mm inside the root, when possible, using a new 0.25 or 0.5 size carbide round bur. Undercuts can be made inside the root through the perforation opening to allow for better retention of the repair material (Figure 17.4).

   Once the repair material is introduced inside the perforation cavity, it should be contoured with the external root surface. If the perforation site is large and repaired with a material susceptible to wash out, calcium sulfate can be placed on top of the material. Bioceramic root repair material (Brasseler: Savannah, GA) should be considered when there is a concern that MTA could wash out.
2. **Perforation that caused a furcation defect with limited accessibility to perforation site.** In such cases, the best results are achieved by introducing cement repair material through the root canal space or the post preparation space. If a post is already cemented, removal of the post is indicated. Once the channel to the perforation site is thoroughly instrumented and disinfected, biocompatible repair materials such as Bioceramic or MTA can be used to seal this space. The material can be pushed into the perforation site firmly and a postop radiograph should confirm a continuous seal of the perforation without voids. Following complete canal and coronal access sealing, a flap is raised below the level of the perforation site to allow for complete access to remove any excess material. Once the excess material is removed, it is important to restore the original anatomy of the root surface by using microsurgical finishing instruments. This surgical intervention could be done on a second visit about 24 hours after a non-surgical perforation repair to allow for complete setting of the material. Calcium sulfate or collagen can be used as graft material in this space (Figure 17.5).

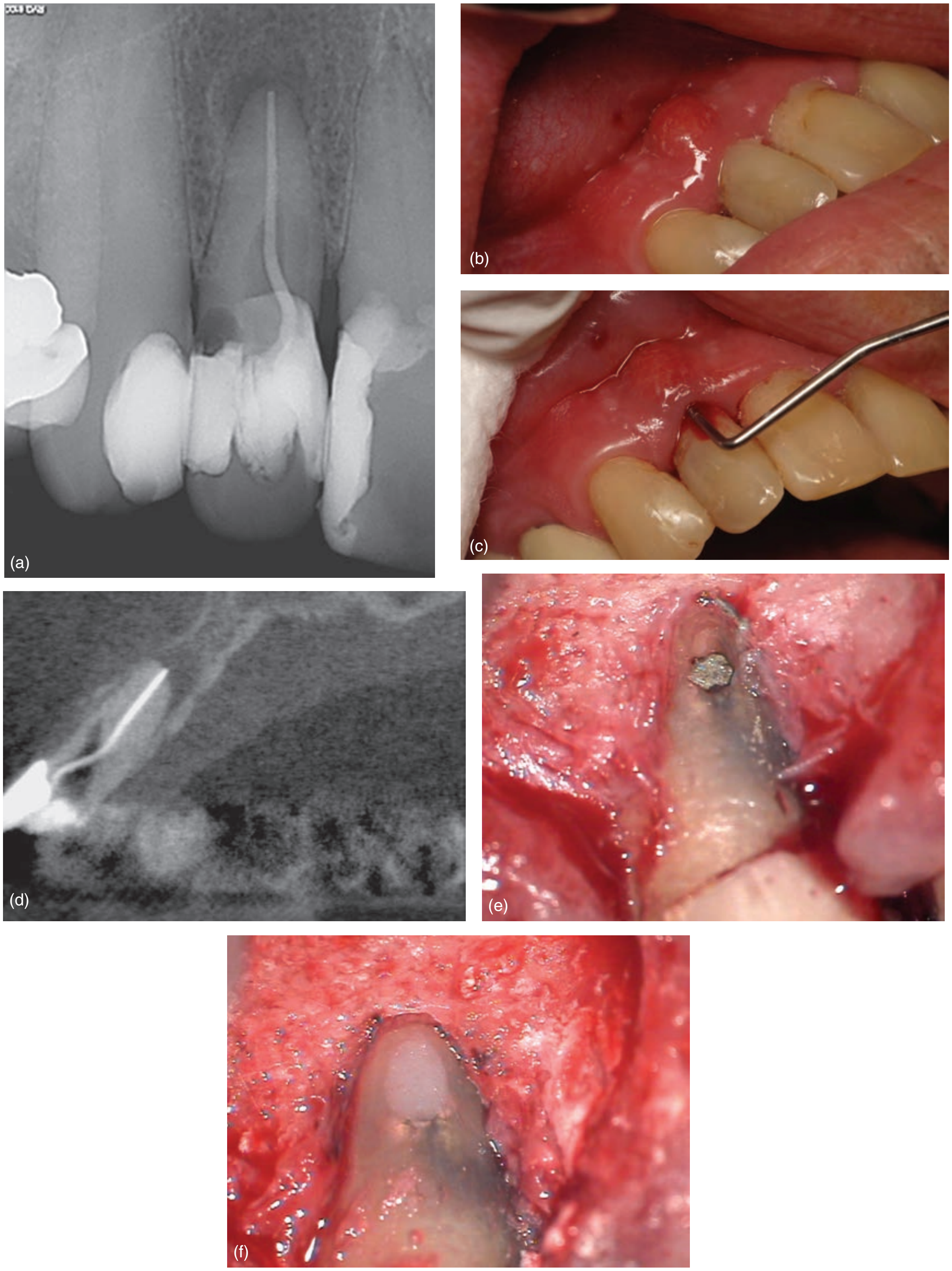

Figure 17.3 Buccal perforation at subgingival level maxillary right lateral. Patient was referred 24 hours following endodontic treatment. Prior to microsurgical treatment, non-surgical retreatment involved removal of gutta percha, disinfection, intracanal medicament, obturating apical portion of canal with gutta percha, and intracanal placement of MTA into the perforation site. Then surgical exposure of the perforation site and repair using Geristore. The rapid healing following surgical perforation repair clearly demonstrates the importance of immediate surgical intervention in such cases. (a) Preoperative radiograph; (b) preoperative photo of buccal swelling; (c) preoperative probing caused by the root perforation; (d) CBCT slice showing extent of buccal perforation; (e) surgical exposure of MTA at the perforation site; (f) perforation repaired with Geristore.

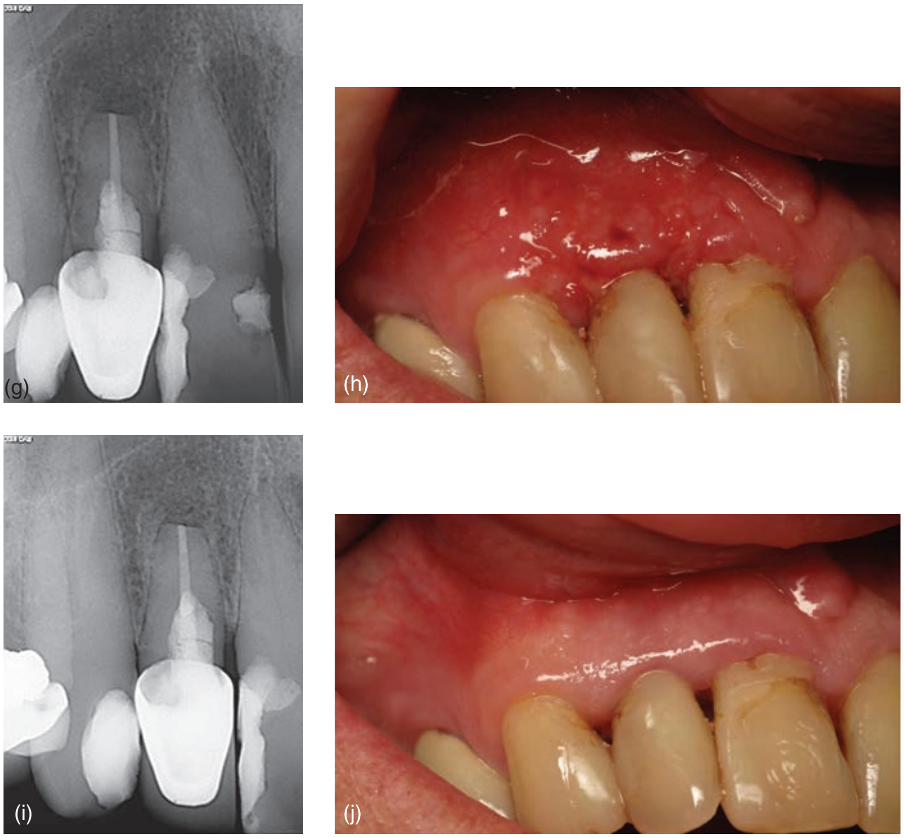

Figure 17.3 (*Continued*) (g) Postoperative radiograph; (h) initial soft tissue healing, 48 hours following surgery; (i) 13 month follow-up radiograph; (j) evidence of soft tissue healing, 13 months following surgery.

3. **Perforation in the interproximal area with limited accessibility to the perforation site.** With such perforations, it is important that the operator preserve healthy bone and avoid damage to adjacent teeth. If the perforation site is not fully accessible during surgical treatment, removal of the restorative build-up would be necessary to have an intracanal path for the repair material to reach the perforation defect. Excess repair material can be removed surgically (Figure 17.6).
4. **Perforation at the cervical level with direct communication to the oral cavity.** This type of perforation is an endodontic/periodontal challenge and repair may be least predictable, mainly due to questionable potential for regeneration and attachment of periodontal tissue. Successful outcome of such perforation repairs is greatly dependent on the time of treatment. The sooner the treatment is performed following this type of perforation, the more successful the outcome could be. The endodontist should inform referring dentists of the importance of referring such cases immediately for proper treatment to reduce such potential complications.

17.4 Surgical Treatment for External Root Resorption

External root resorption is the result of osteoclastic activity on the external root surface, whereas internal root resorption is associated with a long-standing chronic inflammation of the pulp, which in turn results in cellular destructive activity of multinucleated giant cells on the dentinal walls. If internal root resorption is not treated at an early stage with endodontic therapy, it could progress to become external by perforating the root surface and communicating with the periodontal tissue. Surgical treatment for internal root resorption is not indicated following conventional endodontic therapy unless it has caused an external root perforation and non-surgical canal obturation proves to be insufficient for necessary healing of supporting periradicular tissues.

It is important to determine etiology for external root resorption prior to any surgical intervention: first to determine if surgical treatment is indicated and second to prevent potential recurrence of resorption following surgical repair of the damaged root surface. Evaluation and differential diagnosis should include

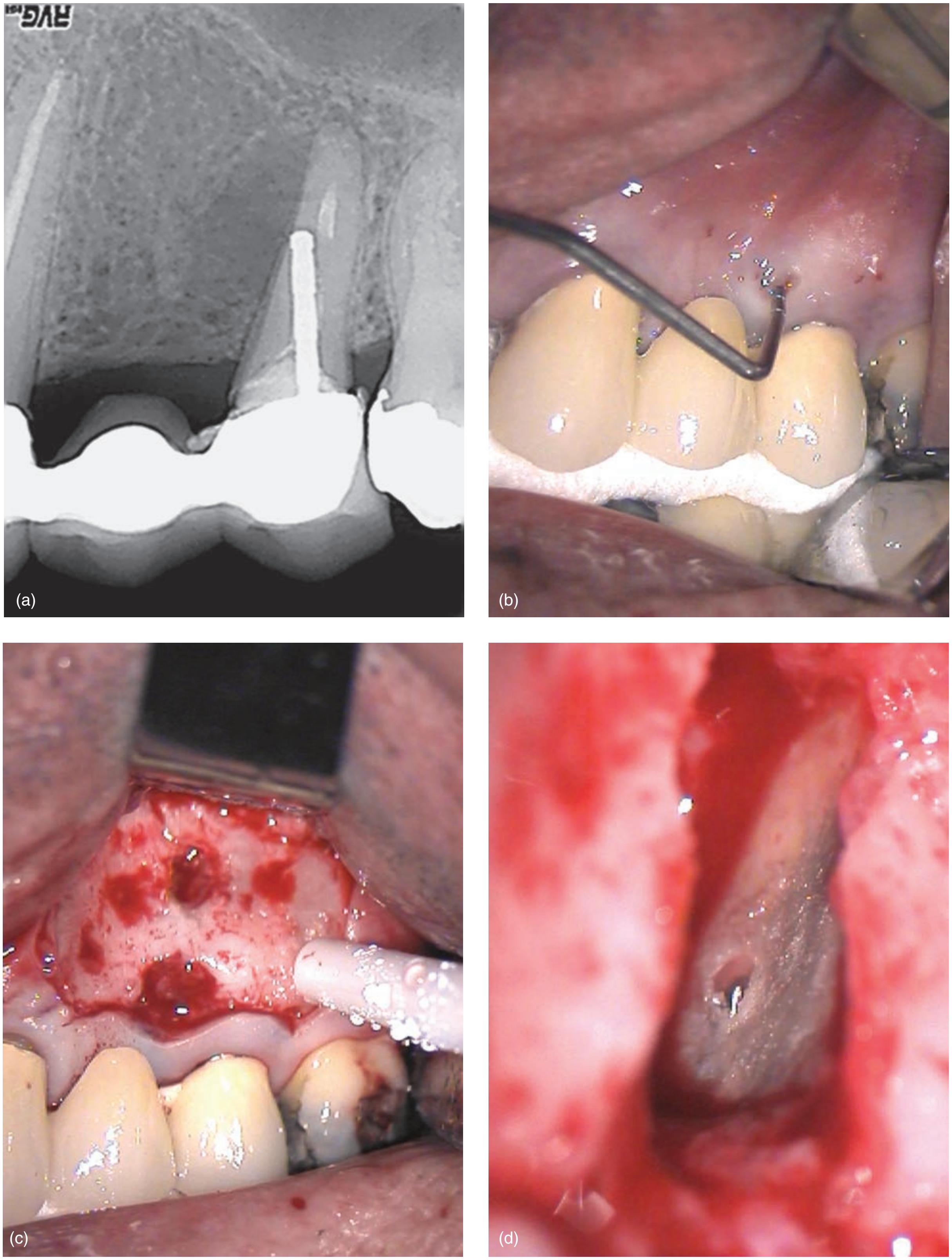

Figure 17.4 Post perforation of a maxillary left second premolar causing lateral periradicular pathology and a buccal sinus tract. Periodontal probing was within normal limits. Perforation was repaired using SuperEBA. (a) Preoperative radiograph shows perforation on the mesial aspect of the root, causing a large periradicular lesion; (b) preoperative probing into the sinus tract; (c) submarginal incision that was extended mesially to allow for proper access to the perforation site; (d) root perforation and the metal post.

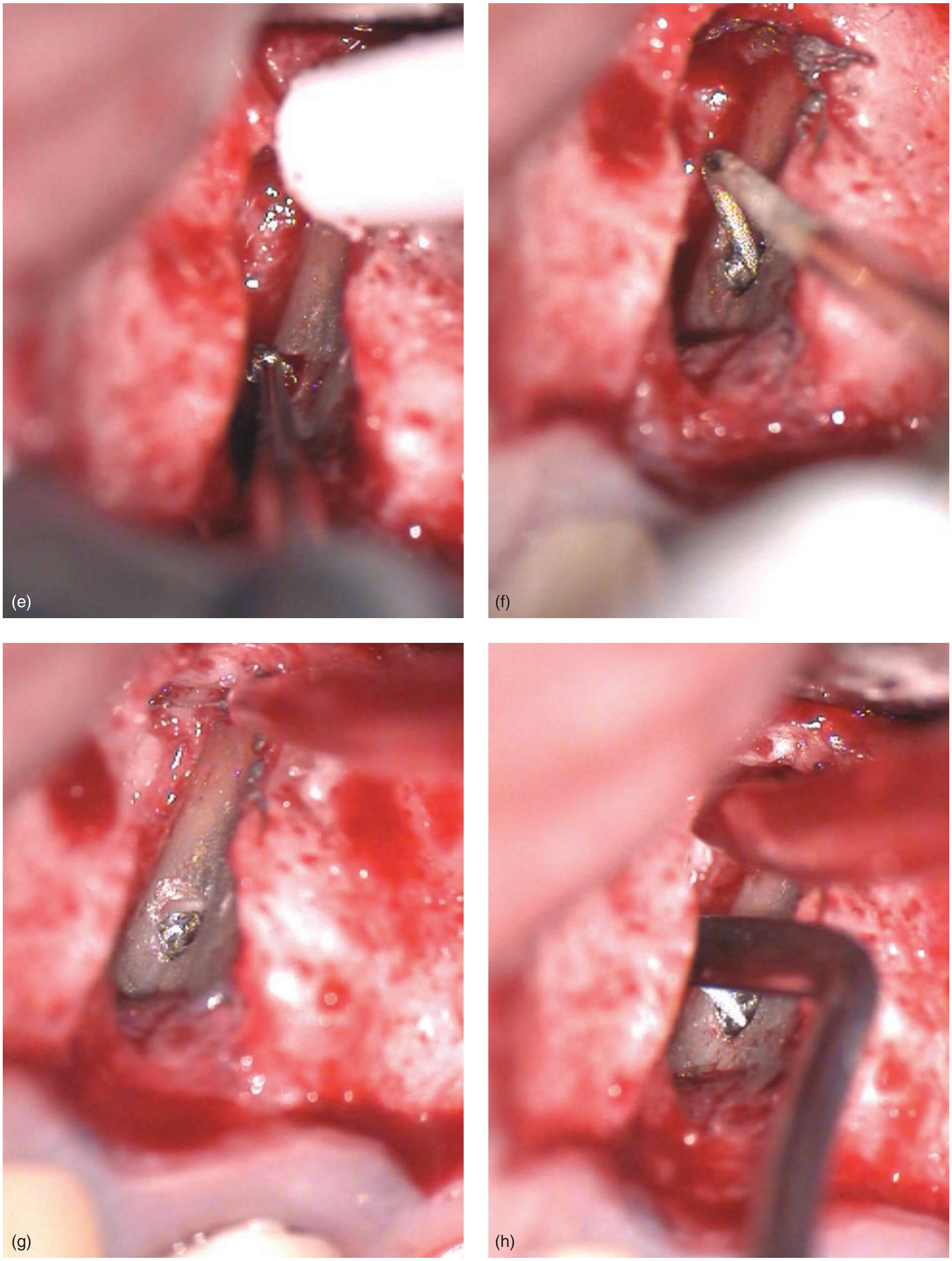

Figure 17.4 (*Continued*) (e) Small round bur used to cut the metal post within the root; (f) ultrasonic tip used to retroprep the perforation site and create undercuts inside the root; (g) prepared perforation site; (h) SuperEBA being placed into the prepared perforation site using a plastic instrument.

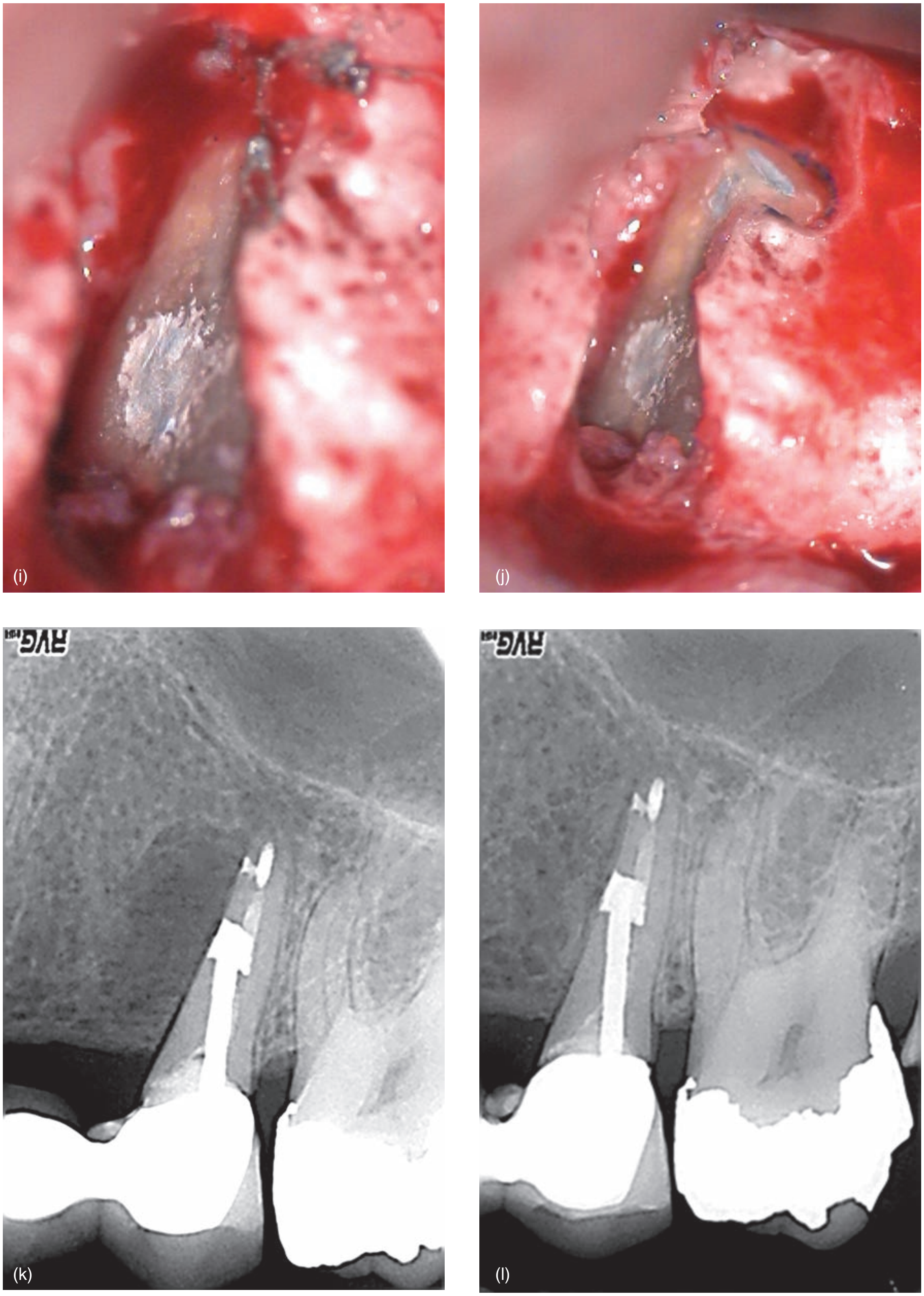

Figure 17.4 (*Continued*) (i) Perforation site repaired with SuperEBA; (j) surgical site and retrofills of the perforation, root apex, and a mesial lateral canal at the apical level (note that the root was not cut below the mesial lateral canal apically to preserve a longer root length for better retention of the three-unit bridge); (k) postoperative radiograph; (l) 6 month follow-up radiograph shows evidence of complete osseous regeneration.

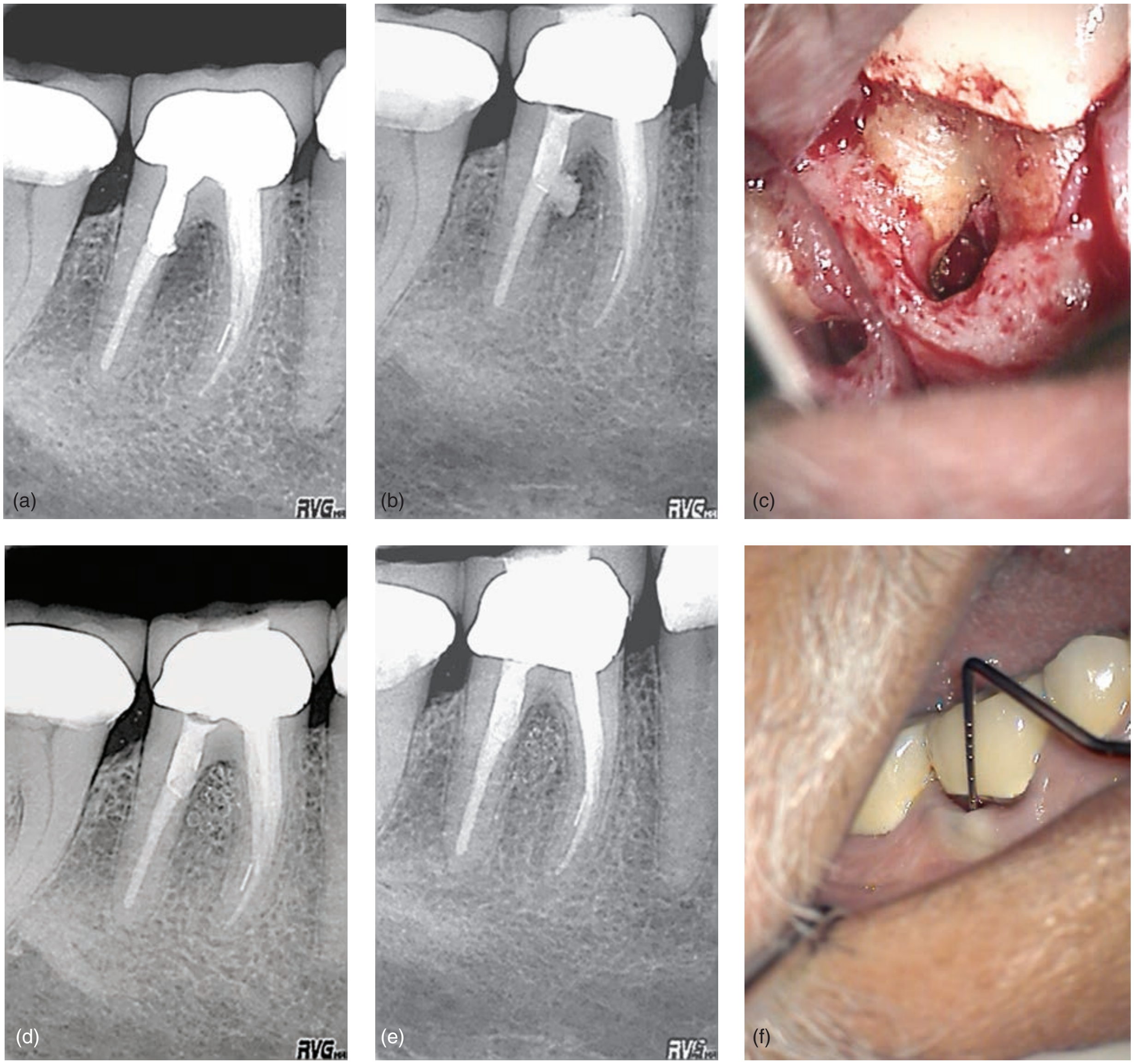

Figure 17.5 Post perforation on the distal root of a mandibular right first molar casing a furcation defect and deep probing. The perforation was repaired with MTA through the distal canal after removing the post and then a surgical approach to remove excess MTA from the furcation area. (a) Radiograph showing perforation of the distal root into the furcation; (b) MTA was pushed through the perforation site and into the bony defect after the post was removed; (c) surgical approach to remove excess MTA; (d) postoperative radiograph showing synthetic graft placed in the furcation; (e) 14 month postoperative radiograph showing complete osseous healing in the furcation; (f) soft tissue healing and normal periodontal probing 14 months following the surgical perforation repair.

a careful review of a potential history of trauma or orthodontic treatment, pulp vitality tests, periodontal probing, CBCT, and evaluation of occlusion. If external root resorption is found to be associated with chronically inflamed or infected pulp tissue, endodontic treatment should precede any surgical treatment to reduce the etiologic trigger factor that may have led to osteoclastic activity. This is common in traumatic injuries that may result in a necrotic pulp and damage to cementum and periodontal ligament. Calcium hydroxide as an antibacterial intracanal medicament increases the pH in dentin and inhibits osteoclastic acid in the periodontal ligament. Teeth do flex under pressure and stress. Tension and compression could eventually cause damage to dentinal tissue and the periodontium. Sustained and frequent excessive occlusal forces may result in cemental resorption in a localized area of concentrated stress on the

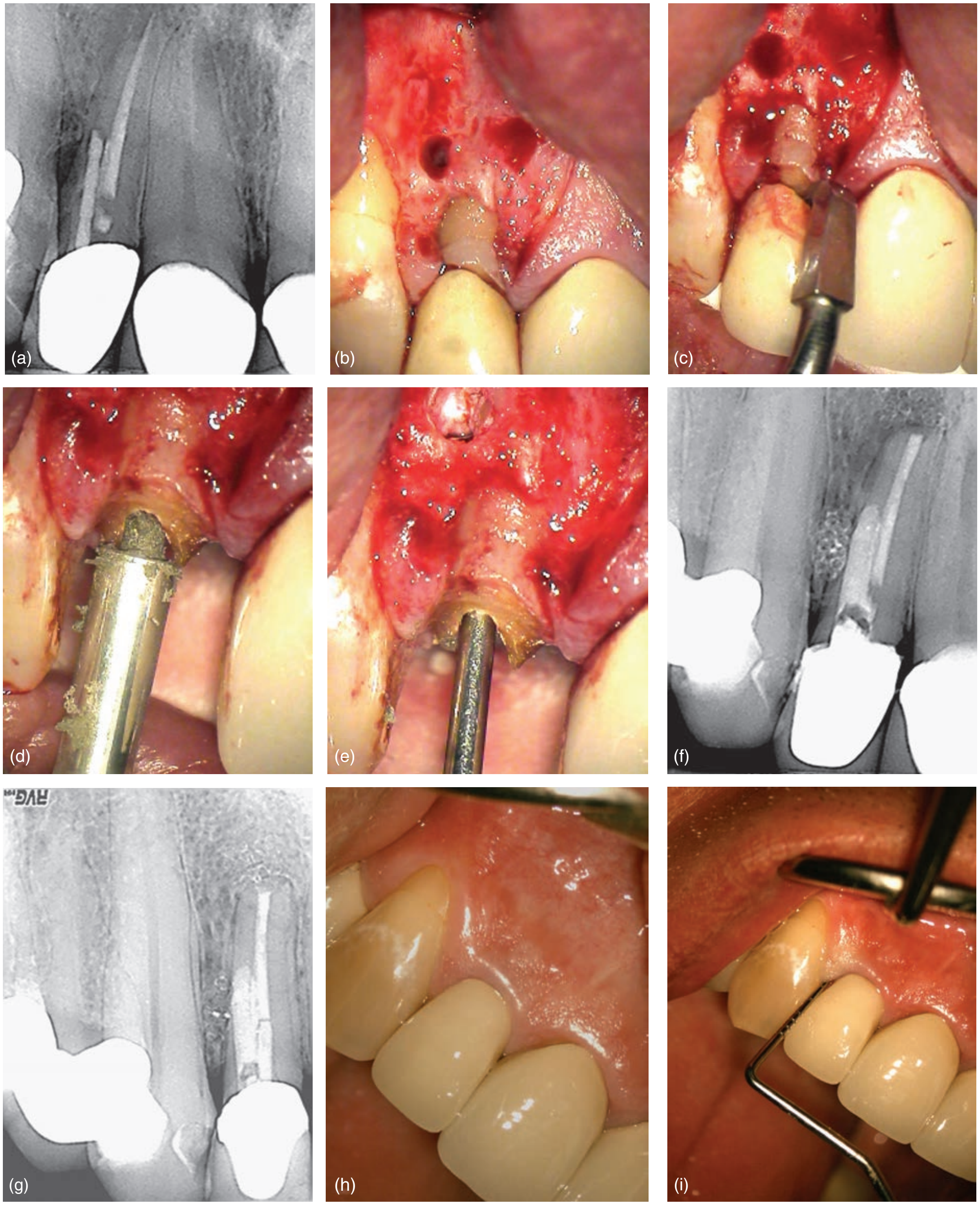

Figure 17.6 Post perforation on distal aspect of maxillary right lateral. The perforation was repaired internally with MTA followed by a surgical approach to perform apicoectomy and graft. (a) Preoperative radiograph showing post perforation and pathology at the mid root as well as the apex; (b) Conservative flap raised to ensure absence of a vertical root fracture and to evaluate access to the bone defect at mid root level, also confirming the presence of supporting osseous tissue coronally; (c) crown and post are removed using a pneumatic crown remover to allow access to the perforation site and to minimize potential damage to the adjacent tooth due to limited accessibility to the perforation site; (d) MTA placed into the post cavity preparation using an amalgam carrier; (e) endoplugger is used to condense MTA into the post cavity preparation and perforation site; (f) postoperative radiograph showing apicoectomy and retrofill along with a synthetic bone graft in distal and apical defects; (g) five year follow-up showing complete bone regeneration adjacent to the repaired perforation site and apically; (h) five year follow-up shows the tooth restored with a new post and crown; (i) healing of soft tissue evident with normal periodontal probing.

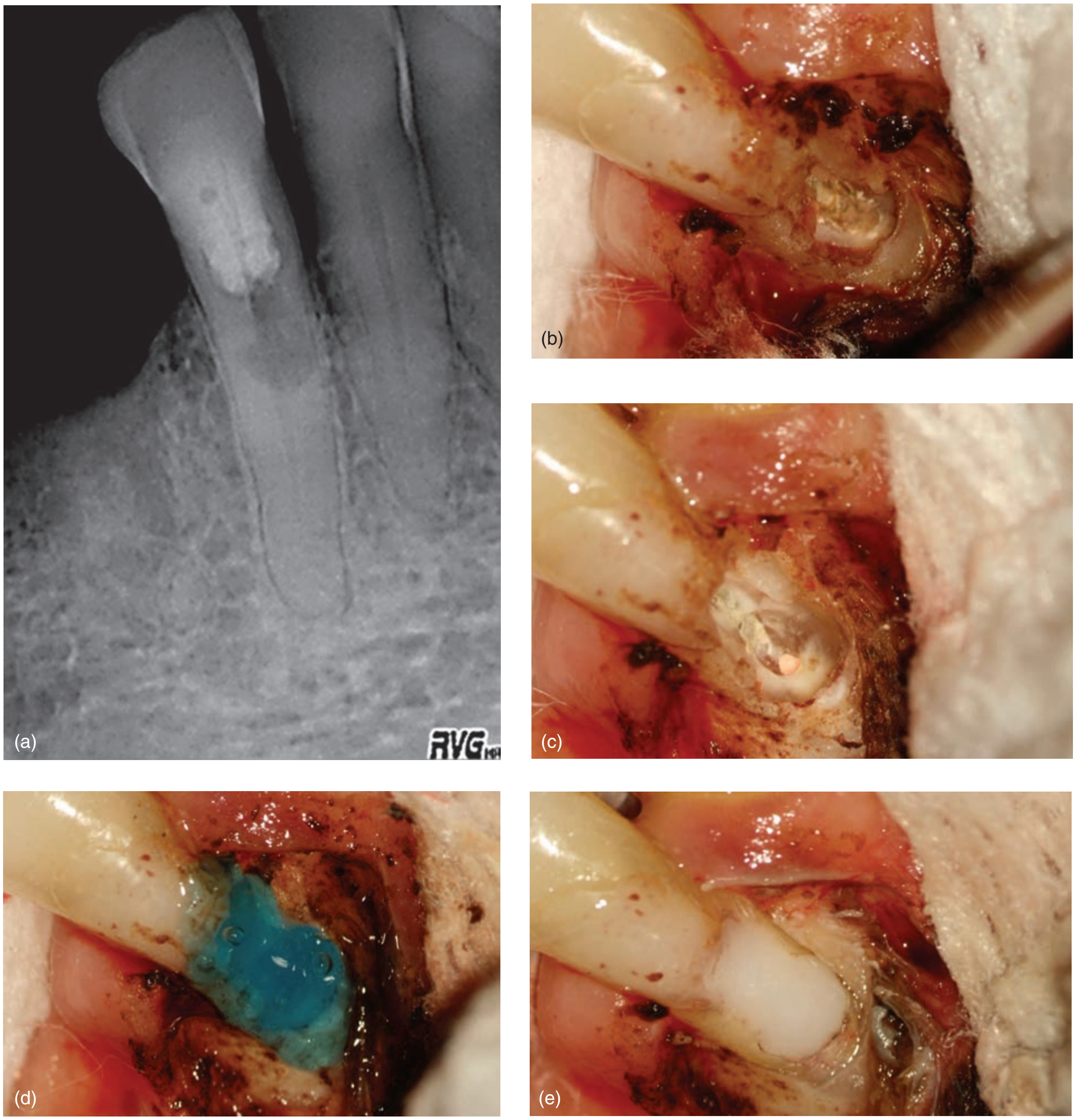

Figure 17.7 Subgingival external root resorption on the buccal of a mandibular right canine, repaired with Geristore. (a) preoperative radiograph showing the extent of root resorption almost to mid-root level; (b) surgical exposure of the defect; (c) inflammatory tissue removed from the resorptive site using an excavator and a small round bur; the undercuts can also be made inside the root using an ultrasonic surgical tip; (d) acid etch applied; (e) Geristore was placed and polished with finishing burs.

root surface, and this in turn could be the trigger for macrophages to differentiate into osteoclasts, which are responsible for external root resorption. In such cases a thorough evaluation of the tooth in occlusion and jaw excursion is warranted.

Root canal treatment may not always be necessary prior to surgical external root resorption repair, if such resorption is not directly associated with the dental pulp tissue or in close proximity to it. Surgical perforation repair caused by external root resorption should be approached similarly to those mechanical root perforations, except the operator must determine the etiology of the resorption as it should be addressed either during or prior to surgery.

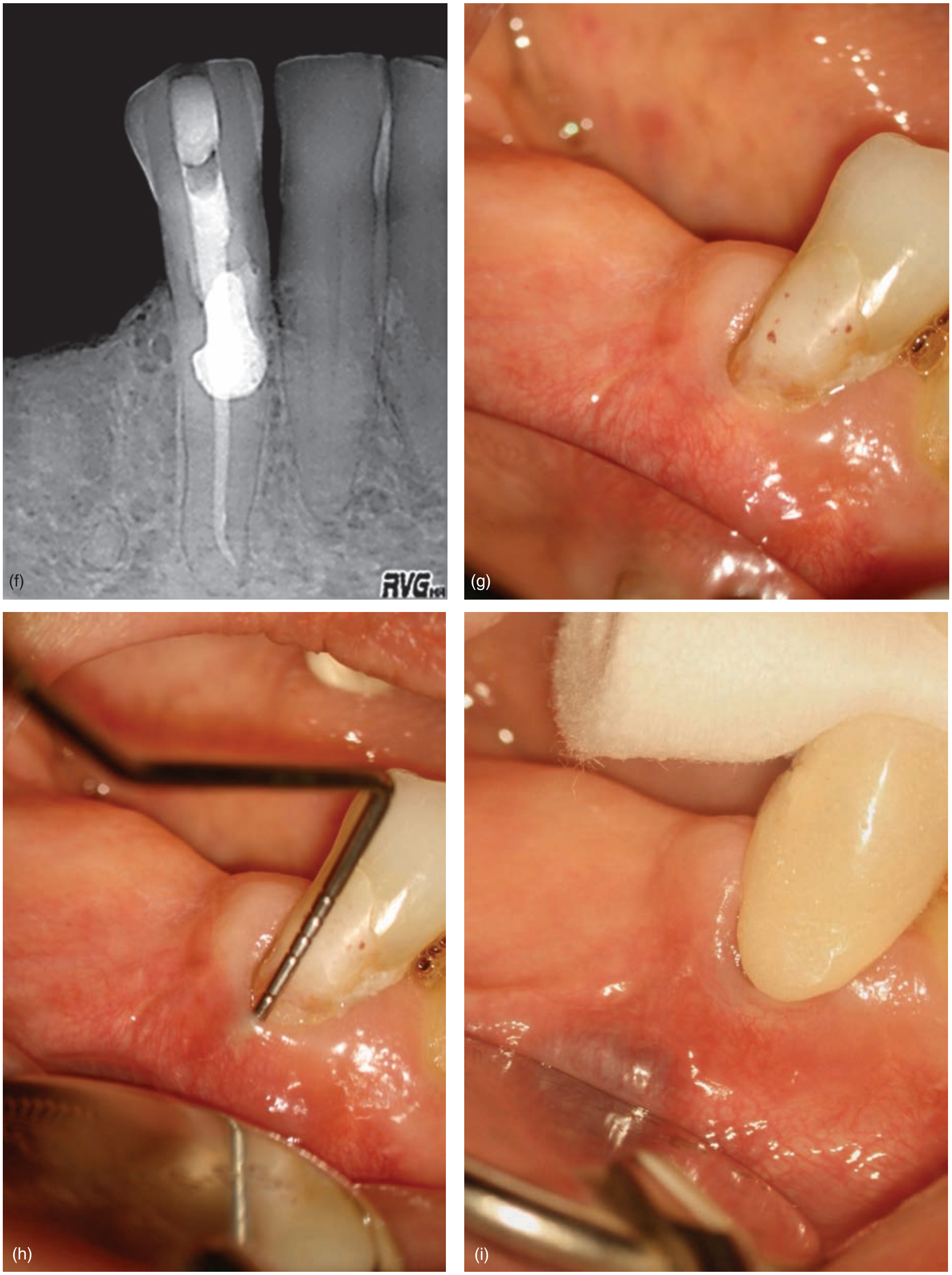

Figure 17.7 (*Continued*) (f) Postoperative radiograph; (g) three month follow-up showing soft tissue healing; (h) normal probing; (i) six month follow-up surgical resorption repair where the tooth was prepared for a crown.

Figure 17.7 (*Continued*) (j) Six month follow-up radiograph showing healthy adjacent bone as the tooth is prepared for a permanent crown.

An adequate diagnostic test should be done to evaluate the cause and extent of lesion. Besides periapical radiographs, CBCT is a must for treatment of resorptive defects. Pulp vitality tests will determine if non-surgical root canal treatment is indicated prior to surgery. Periodontal probing, bone sounding after anesthesia and evaluation of occlusion will help determine treatment protocols as well.

Once the gingival tissues are reflected and access to the resorption is established, inflammatory tissue is usually observed growing into the resorptive defect. This tissue should be removed by using an excavator followed by an appropriate sized high-speed round bur. In cases where hard bony tissue is found growing inside the resorptive defect, such as in dentoalveolar ankylosis (i.e., replacement resorption), it is important to establish a clear border between surrounding bone tissue and sound external root surface by removing and separating the bony tissue inside the defect from surrounding bone tissue, using a high-speed round bur. If necessary, undercuts inside the root surface can be made using surgical ultrasonic tips prior to restoring the prepared defect site. As in surgical perforation repairs, the materials of choice for resorption repair are MTA, Geristore, or Bioceramics. External root resorptive defects communicating with the sulcus are best restored using Geristore, while resorptive defects surrounded by bone tissue are best restored using Bioceramics. Follow-ups are necessary to determine if periodontal complications occur and therefore if future periodontal surgery is indicated (Figure 17.7).

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18

Intentional Replantation

David Li and Samuel Kratchman

KEY CONCEPTS

- Intentional replantation is a viable alternative to extraction.
- Intended for cases where a surgical approach is not feasible.
- Case selection and armamentarium are critical.
- Resorption is minimized using proper extraction/storage techniques.
- Success rate is 88%.

18.1 Armamentarium

- Microscope
- Karl Schumacher #10AS and #222AS surgical forceps
- Hanks balanced solution or pedialyte
- Emesis basin
- Bioceramic fast set putty

Intentional replantation was defined as "the purposeful removal of a tooth and its almost immediate replacement with the object of obturating the canals apically while the tooth is out of its socket".

18.1.1 Success Rate

Success rates of intentional replantation ranged from 34% to 95%. There was a wide range of parameters and a consensus was difficult to obtain. Studies suffered from techniques that are outdated and substandard when compared to modern day methodology. Most recently, a systematic review of articles from 1966 to 2014 stated a success rate of 88%.

18.1.2 Indications

1. **Difficult access.** Surgical access to lower second molars is extremely difficult. As one goes more posteriorly in the mandible, the bone thickens greatly, as a result of the external oblique ridge and the roots of the mandibular second molars incline more lingually than the first molars. The amount of bone that must be drilled through increases significantly (Figures 18.1 and 18.2).

   Access is also an issue when performing apical surgery on palatal roots. A buccal approach to a palatal root is possible when the apex of the root curves more buccally. However, visibility is significantly hampered by the zygomatic arch. In addition, perforation of the sinus is often a concern. A palatal approach is technically challenging. In maxillary teeth with converging roots, replantation is an excellent option, given the relative ease in extraction due to how thin and pliable the maxilla is (Figure 18.3).
2. **Anatomic limitations.** Proximity of the teeth to anatomic landmarks such as the mental foramen or mandibular canal renders surgery risky due to possible postoperative paresthesia (Figure 18.4).
3. **Perforations in areas not accessible surgically.** A traditional surgical approach would necessitate unnecessary removal of bone and root structure to reach the perforation site (Figures 18.5 and 18.6).
4. **Bisphosphonate usage.** Prolonged oral as well as IV bisphosphonates have been documented to potentially cause osteonecrosis when oral surgery is performed. Since replantation involves extraction, this should be considered during treatment planning and may preclude replantation from being an option for these patients.

18.1.3 Replantation or Apicoectomy

There are distinct advantages of replantation over conventional apical surgery. A flap is not required for replantation, thus reducing soft tissue trauma and improving the healing experience. The replanted tooth acts as a natural "bandage" and eliminates

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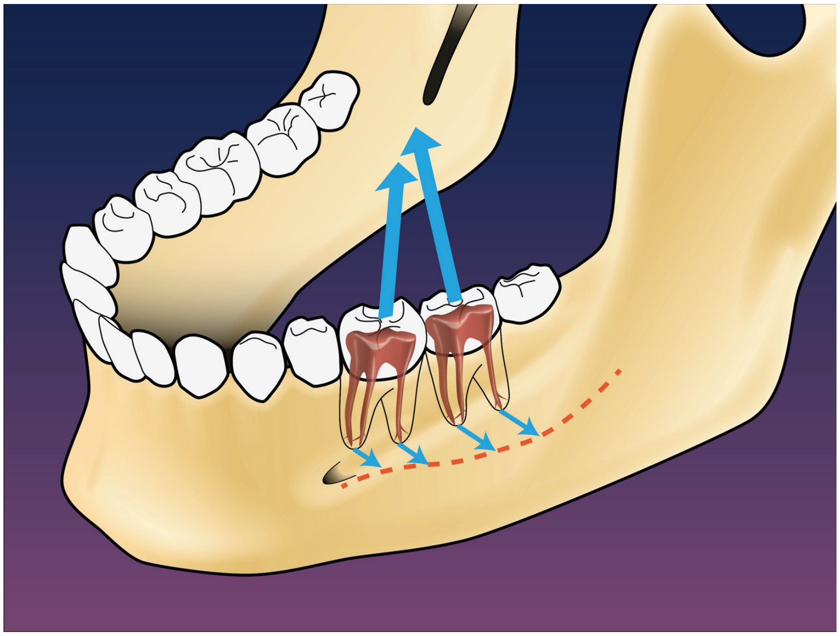

Figure 18.1 The mandible ramps towards the second molar, which is more lingually inclined than the first molar.

any open wound. Since an osteotomy is not needed, replantation does not result in loss of buccal bone. This again facilitates postop healing. During conventional apicoectomy the clinician's field of view is limited by the osteotomy and adjacent structures, such as the zygomatic arch and cheek tissue. Holding an extracted tooth allows total access to inspect the entire root surface and the resected cross-section. Manipulation of microsurgical instruments and ultrasonics are easier with the tooth outside the mouth (Figure 18.7).

Resorption is an undesirable consequence of replantation. The PDL contains not only fibers but also growth and differentiation factors that play a vital role in repair of the damaged PDL postreplantation. The re-establishment of the PDL with little to no resorption ultimately dictates the outcome of the procedure.

Care should be taken throughout the procedure to avoid extensively damaging the PDL. This is a consideration during both extraction and degranulation of the socket. Curettage of the socket walls should be avoided. The presence of PDL cells on either the

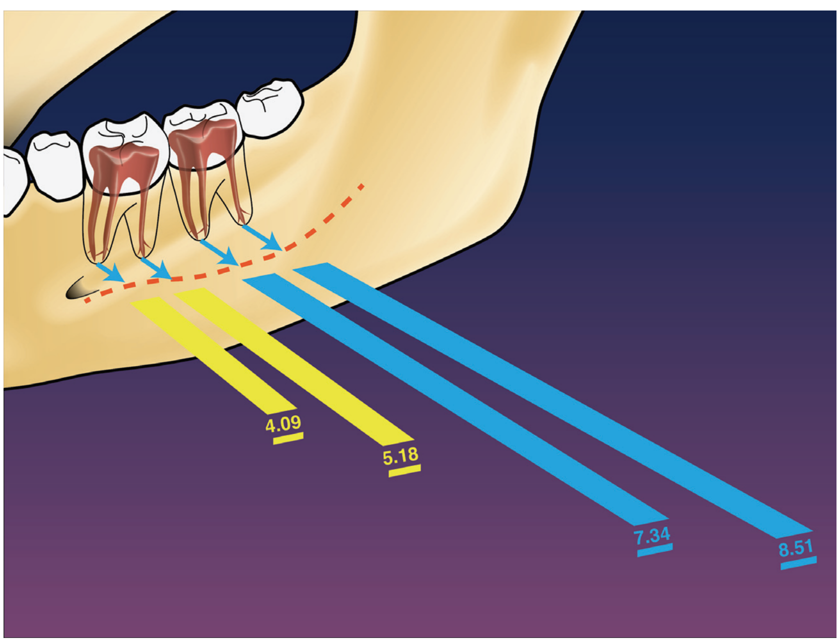

Figure 18.2 The average amount of bone needed to drill through to reach the apices of lower molars, in mm.

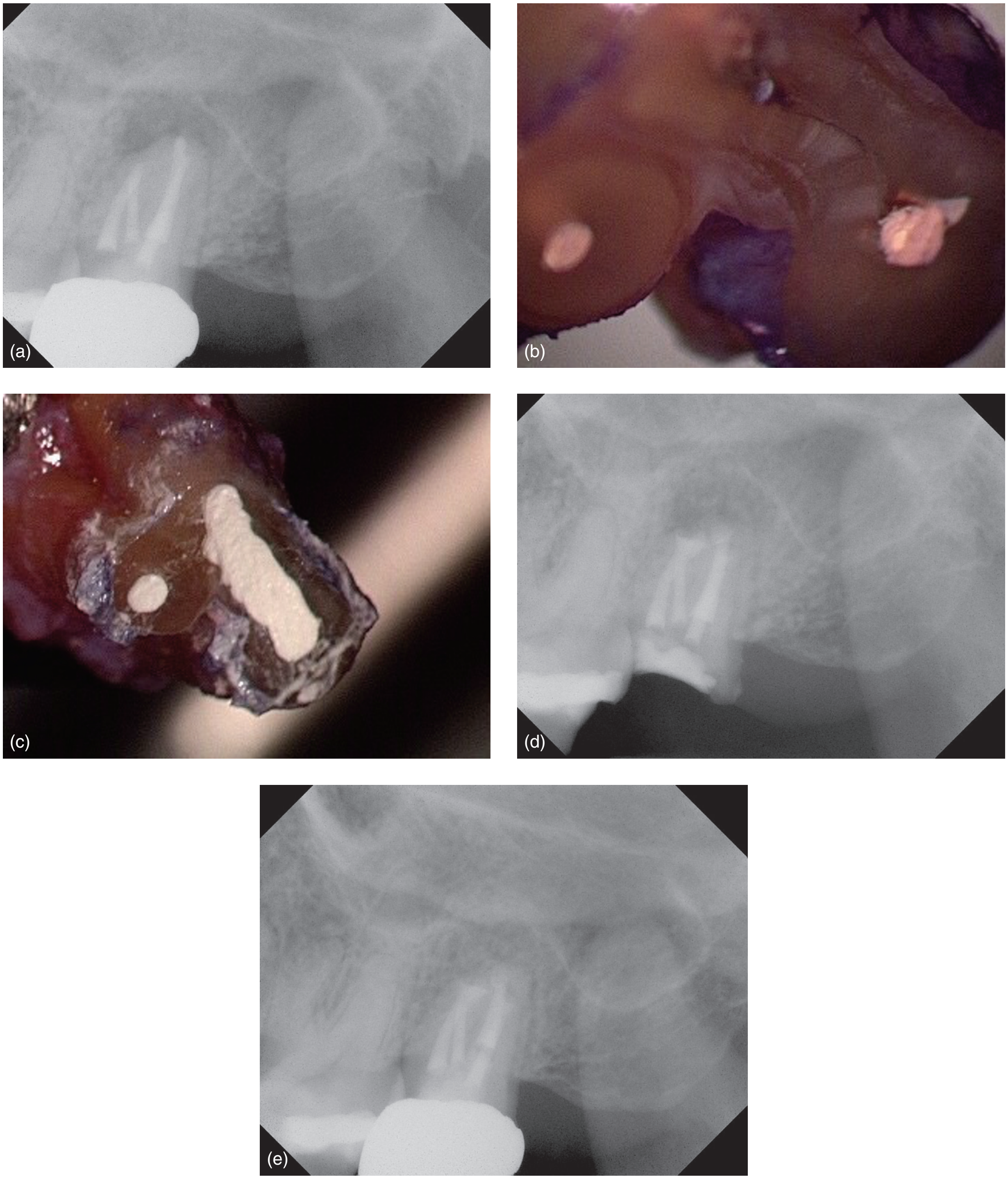

Figure 18.3 Maxillary left second molar with failing endodontic treatment. (a) Preop radiograph; (b) a long fin (isthmus) connecting MB and palatal roots; (c) root end preparations, incorporating the long isthmus, filled with fast-set Bioceramic putty; (d) Postop radiograph (note that the crown had fallen off during the procedure, but was recemented following initial healing); (e) 6 month follow-up radiograph showing osseous healing.

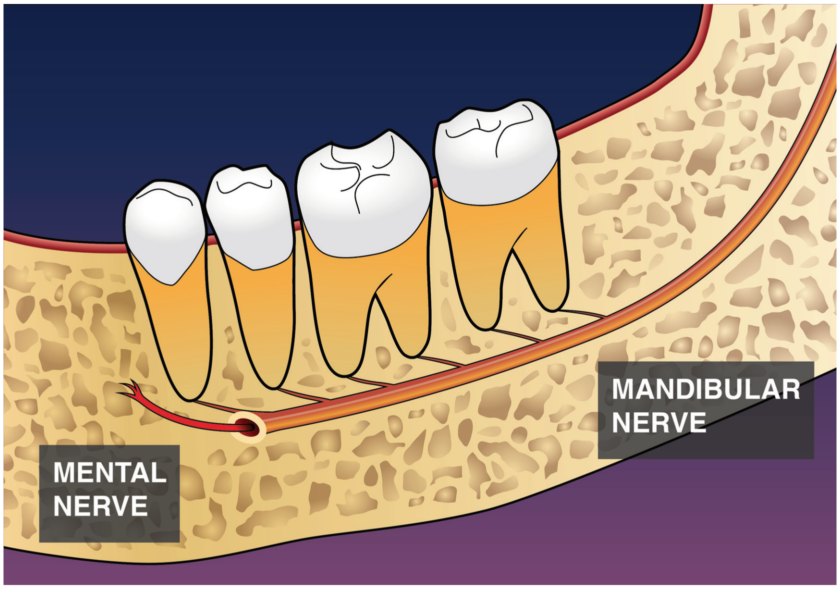

Figure 18.4 Anatomic limitations: Proximity of the teeth to anatomic landmarks, such as the mental foramen or mandibular canal, render surgery risky due to possible postoperative paresthesia.

socket or the root surface is sufficient for PDL re-establishment and prevention of resorption. It should be noted that transient resorption always accompanies replantation. Transient resorption takes place shortly after replantation, peaks in 2–4 weeks, but diminishes beyond 2 months.

18.1.4 Extraction

During conventional extraction, the operator has the option of sectioning the tooth whereas for replantation the tooth has to be removed intact. This is an important consideration during treatment planning. Furthermore, it is important to keep the forceps off the cementum and rest mainly on the crown. A gentle buccal/lingual luxation and slight rotational forces should be used to extract the tooth, attempting to create an acute inflammatory response in the PDL, which results in increased mobility of the tooth. Forceps should be used, which provide a good grip on the crown of the tooth (Figure 18.8).

Of the cases that have failed due to resorption of the replanted tooth, the resorptive process is predominantly on the cervical portion of the tooth. A contributing factor is that the beaks of the forceps had slipped down on to the root surface, damaging important PDL cells (Figure 18.9).

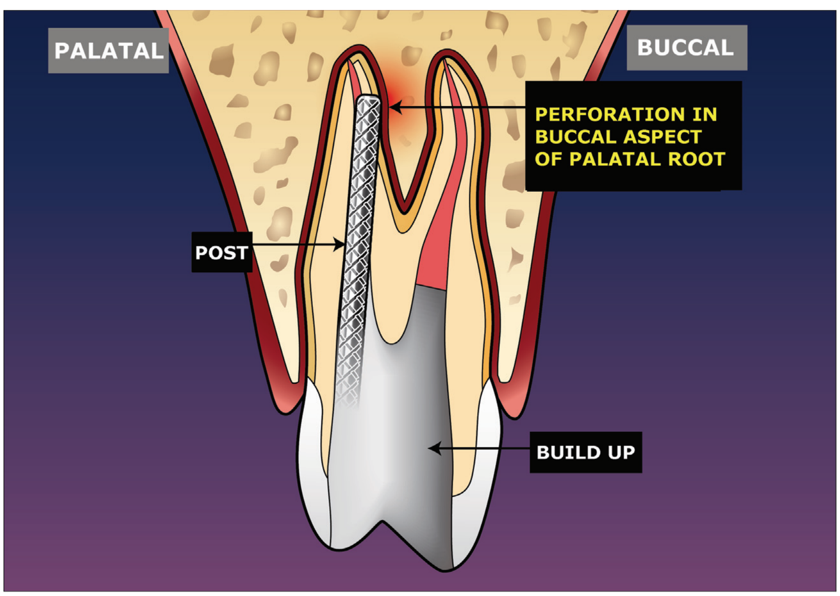

Figure 18.5 Perforation in an area not accessible surgically. A traditional surgical approach would necessitate unnecessary removal of bone and root structure to reach the perforation site.

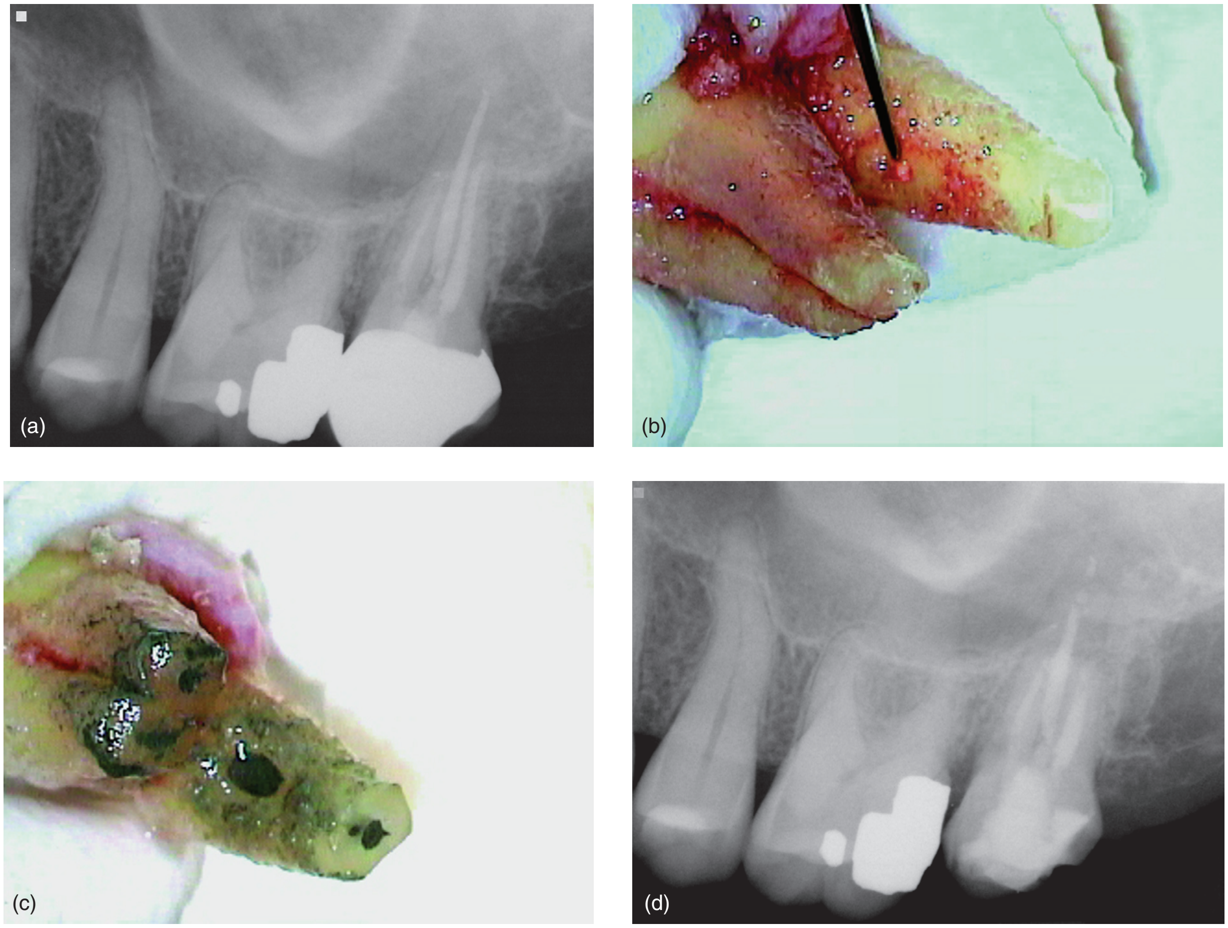

Figure 18.6 Maxillary left second molar with previous endodontic treatment that was always symptomatic and unable to diagnose the source. (a) Preop radiograph; (b) perforation discovered on the furcal side of the palatal root in the mid-root region; (c) root end preps and perforation prepped and filled with grey MTA; (d) postop radiograph.

18.1.5 Extraoral Phase

The working time on the extracted tooth should be kept to a minimum. The longer a tooth is kept outside the socket the more likely the death of PDL cells may occur, thereby increasing the chance of resorption postoperatively. Fortunately, with the extracted tooth, the microsurgical procedure can be efficiently performed and usually there are no time issues.

18.1.6 Storage Medium

Hanks balanced salt solution (HBSS) (Lonza, Inc; Walkersville, Maryland) has been shown to be the most optimal storage medium during the extraoral phase. Pedialyte (Abbott Pharmaceuticals, Abbott Park, Illinois) is an acceptable substitute for HBSS. An emesis basin and HBSS should be ready before the surgery. As soon as the tooth is extracted it should be immediately soaked in HBSS. When manipulating the tooth in the extraoral phase, the tooth can remain held by the forceps on its crown only. Frequent irrigation of the tooth with HBSS in a 12 cc plastic syringe should be carried out so that drying never occurs. Whenever possible keep the tooth immersed in the HBSS if work is not being done to the tooth (Figure 18.10).

18.1.7 Replantation

Care should be taken to ensure the right orientation is observed when replanting. Since the root end has been resected there may be room apically in the socket. This allows the clinician to depress the tooth and have it in infraocclusion. Having the tooth out of occlusion allows for better reattachment of PDL during healing, since occlusal forces are minimized. A “snap” or “pop” may be heard during replantation. This indicates the tooth is now in its correct original position.

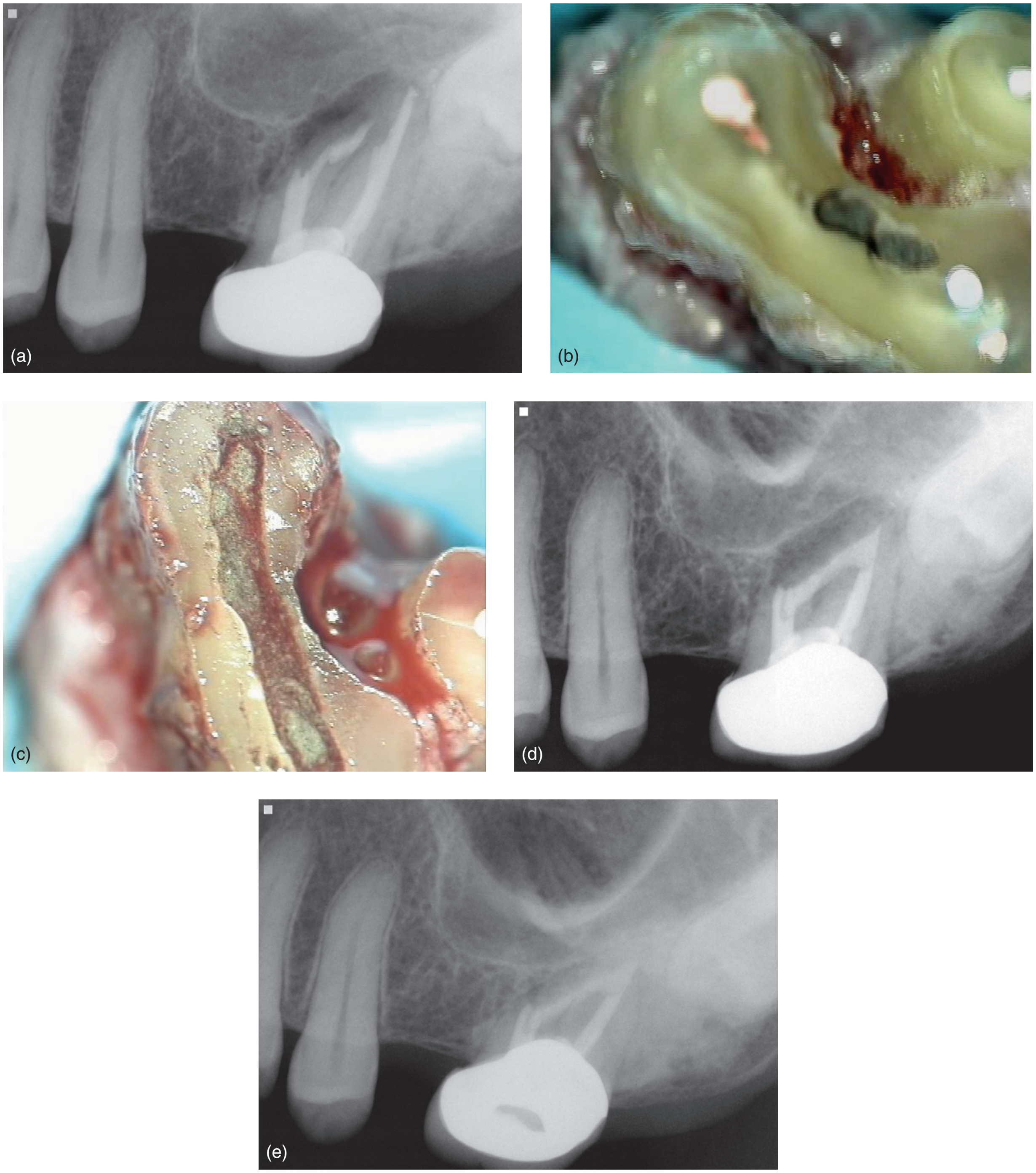

Figure 18.7 Maxillary left second molar with failed apicoectomy. Extraction/implant discussed with patient but patient wanted to try and save tooth. (a) Preop radiograph; (b) upon extraction, it was evident the previous apicoectomy identified an isthmus from MB toward palatal, but due to limitations, did not visualize that the isthmus extended all the way to include the palatal canal; (c) entire isthmus prepared (Bioceramic putty was used to fill the root end preparation); (d) postop radiograph; (e) one year recall with excellent healing.

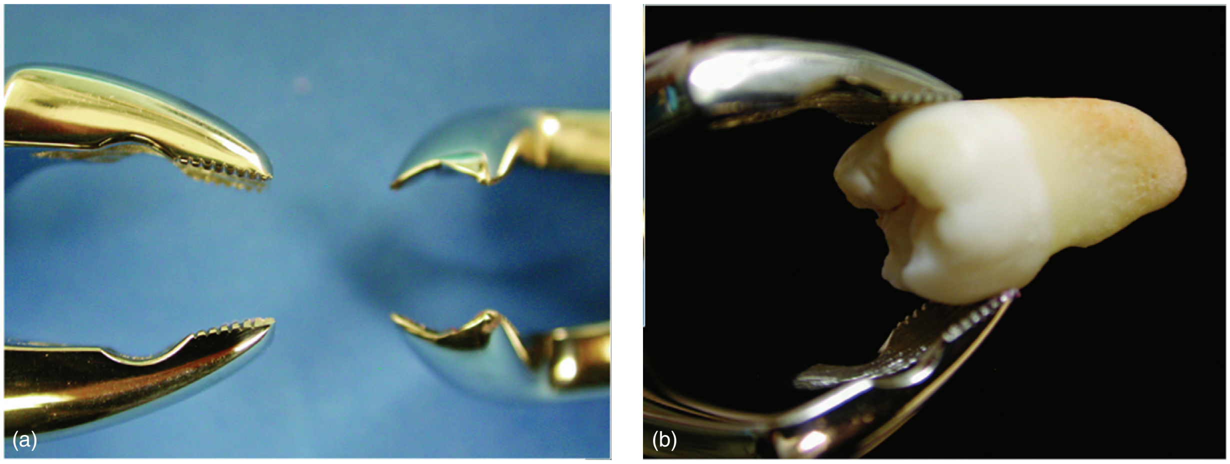

Figure 18.8 Forceps used for replantations. (a) Karl Schumacher surgical forceps #10 AS for maxillary teeth and #222 AS for mandibular teeth (Karl Schumacher: Linden, New Jersey); (b) forceps showing a long gripping surface with many serrations, allowing for a stronger grip.

18.1.8 Splinting

Mobility of a replanted tooth should be kept to a minimum. When the amount of buccal or lingual/palatal bone loss is not extensive, splinting is only a precautionary measure. In these cases, sutures can be used to crisscross the occlusal surface of the tooth in a buccal-lingual orientation. Non-resorbable sutures are recommended. Patients should always be advised to try and not chew on the extracted tooth. In most

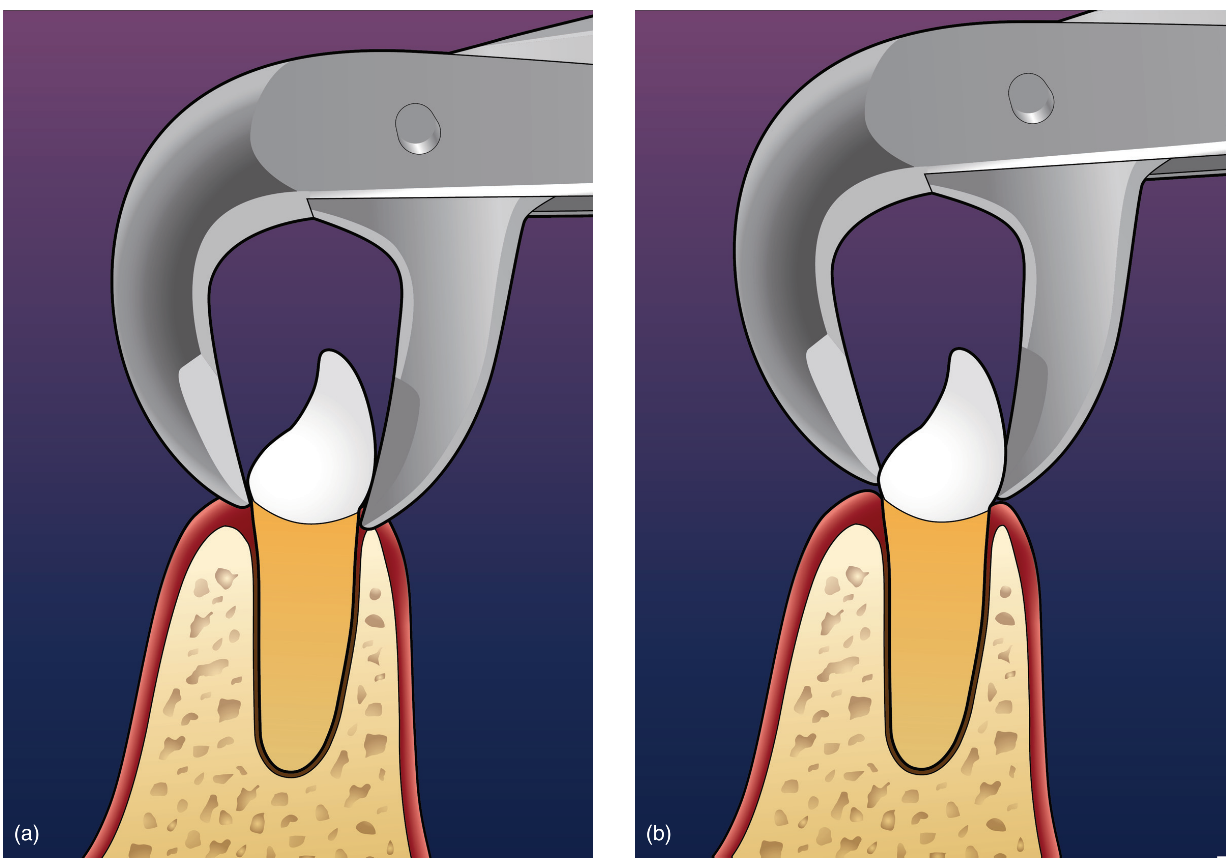

Figure 18.9 (a) Incorrect forcep placement on cementum; (b) correct forcep placement above the CEJ.

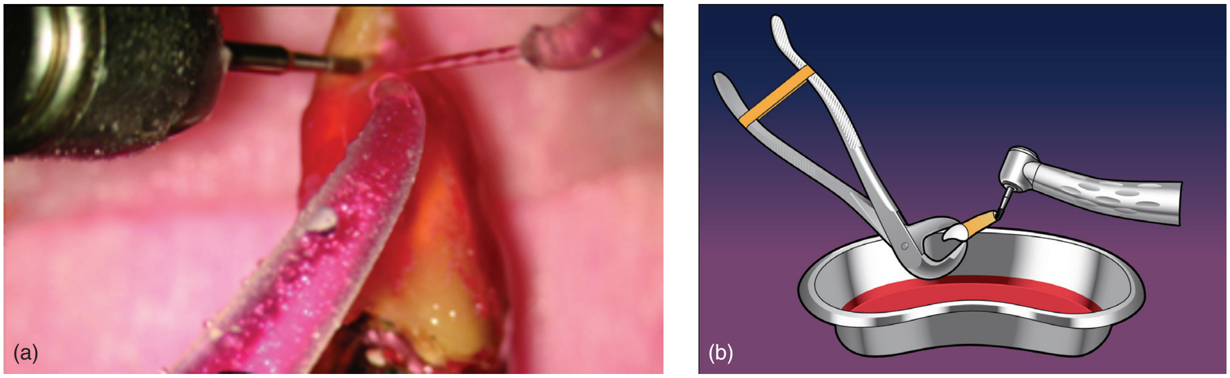

Figure 18.10 (a) HBSS in a 12 cc syringe, keeping extracted tooth moist; (b) emesis basin filled with HBSS in which to bath the tooth during the extraoral procedure.

cases, the sutures can be removed in as early as 7–10 days postop. PDL healing and epithelium reattachment histologically occur 2–4 weeks postreplantation (Figure 18.11).

In cases where mobility cannot be effectively controlled with suture splinting, semi-rigid orthodontic wires may be used. GlasSpan (GlasSpan, Exton, Pennsylvania) is a good alternative to orthodontic wires. When these splinting techniques are used, splints should be left in place for an extended period until reattachment can be confirmed (Figure 18.12).

18.1.9 Postop Instructions

Postop discomfort after replantation is usually less than with conventional apicoectomy. This is a result of a decreased amount of trauma during replantation and lack of an open wound. Patients should be instructed to avoid using the side where the replantation was performed. Routine pain medication such as

Figure 18.11 Suture splint on a tooth that was just replanted. (Courtesy of Dr Patricio Sumaza.)

Ibuprofen 600 mg is usually sufficient. Brushing and flossing should be avoided on the replanted tooth for a day or two, as well as its adjacent tooth. Chlorhexidine rinse is recommended to facilitate bacterial control of the region. Postop visits should be conducted at 2 weeks, 1 month, 3–6 months, 1 year, and beyond as desired. In the initial stage, if excess mobility of the tooth is observed, a splint should be placed or improved to facilitate reattachment of the tooth.

18.1.10 Cone Beam CT Scan

CBCT use has become a standard of care for endodontic microsurgery. For replantation procedures, it is debatable if a CBCT is always indicated. One example of an indication for its usage would be to determine the exact direction of curvature of the roots of a tooth. By determining, for example, that the apex severely curves buccally (not seen on a periapical film), the doctor can luxate the tooth buccally, therefore using that buccal curvature as an advantage to "slip" out the tooth without fracturing it, as opposed to luxating lingually, which would snap off a buccally curved tip (Figure 18.13).

18.1.11 Repairing Procedural Mishaps

Replantation can be implemented to help repair teeth with procedural errors, such as separated files that cannot be retrieved and adversely affect the healing, as well as overfills of gutta percha that cannot be retrieved conventionally and cause failure of the case (Figures 18.14, 18.15, and 18.16).

In summary, replantations are predictable, easy on the patient, and the best "implant" we can offer our patient. It should be in the surgical repertoire of every endodontist.

Figure 18.12 (a) Mandibular left second molar where an orthodontic wire was used to splint for 6 months (A-Splint) before stabilization was noted; (b) Glas Span kit, consisting of microbrush, etch/bond, glass tube containing pieces of hollow fiberglas rope, and flowable composite; (c) Glas Span fiberglas splint in place, connecting the maxillary left second molar that was just replanted with the distal portion of the occlusal surface of the first molar. (Courtesy of Dr Ameir Eltom.)

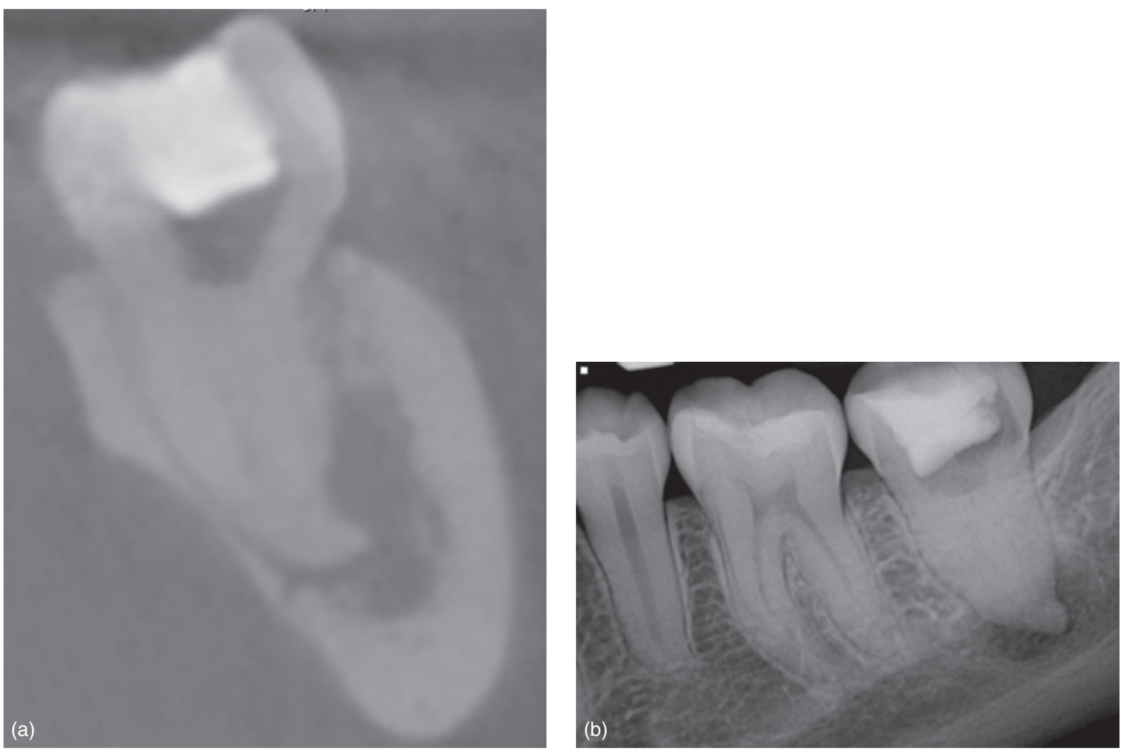

Figure 18.13 (a) CBCT slice showing severe buccal curvature of the mandibular left second molar; (b) periapical film of the same lower second molar. (Courtesy of Dr Martin Trope.)

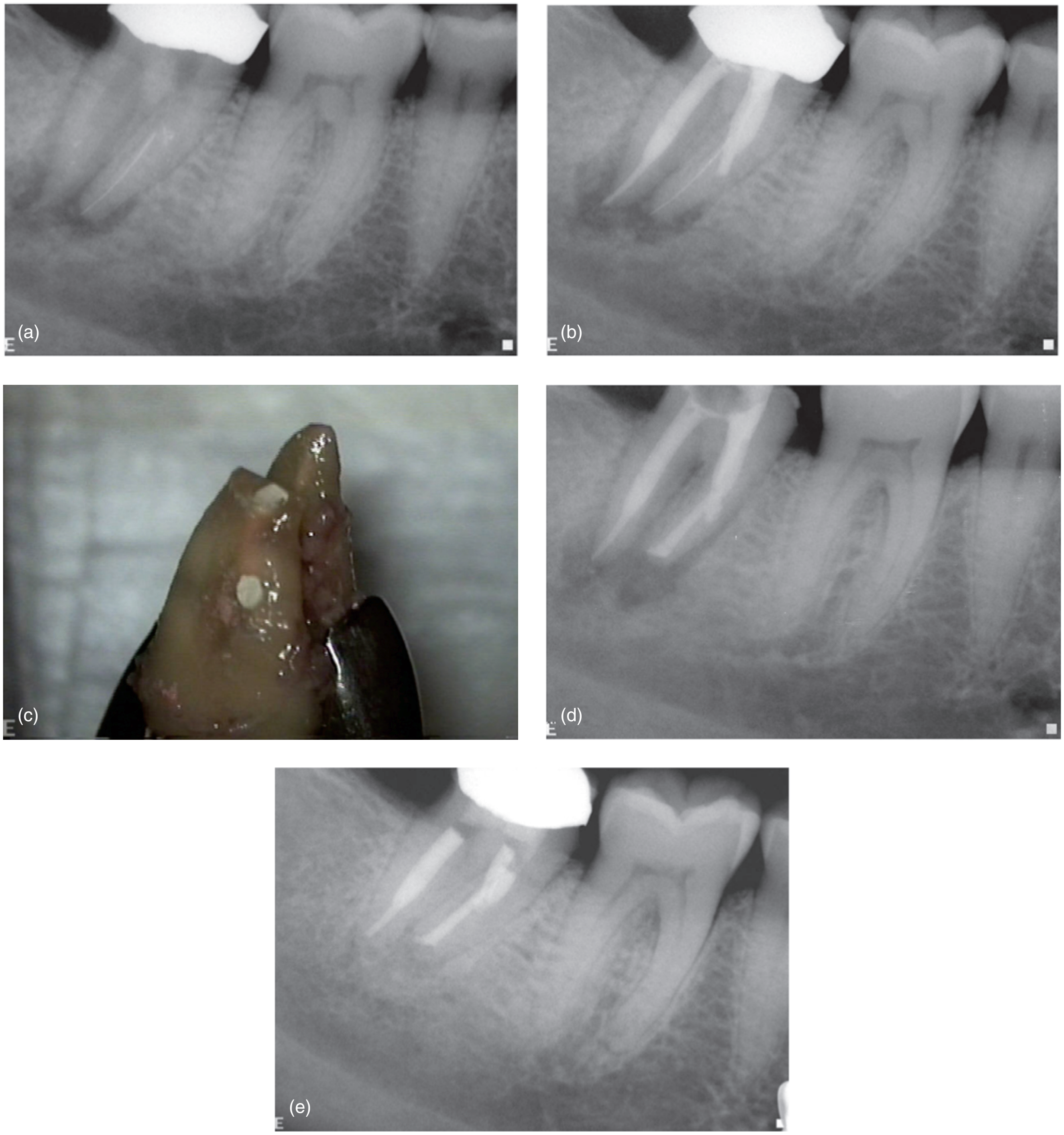

Figure 18.14 Mandibular right second molar with separated instrument and perforation in the mesial root, referred to endodontist. (a) Preoperative radiograph. (b) Postoperative conservative treatment. (c) Mesial root extraorally with apex and perforation site sealed with SuperEBA cement. (d) Postop radiograph. Note that after removal of the separated file extraorally, there was a large portion of the mesial canals unfilled, so they were retroinstrumented with NiTi rotary files and retrofilled with warm gutta percha, followed by immediate root end resection and preparation of root end as well as perforation with high speed 330 bur. They were then repaired with SuperEBA cement. (e) Four year follow-up showing complete healing and a new crown. (Courtesy of Dr Steve Leveson.)

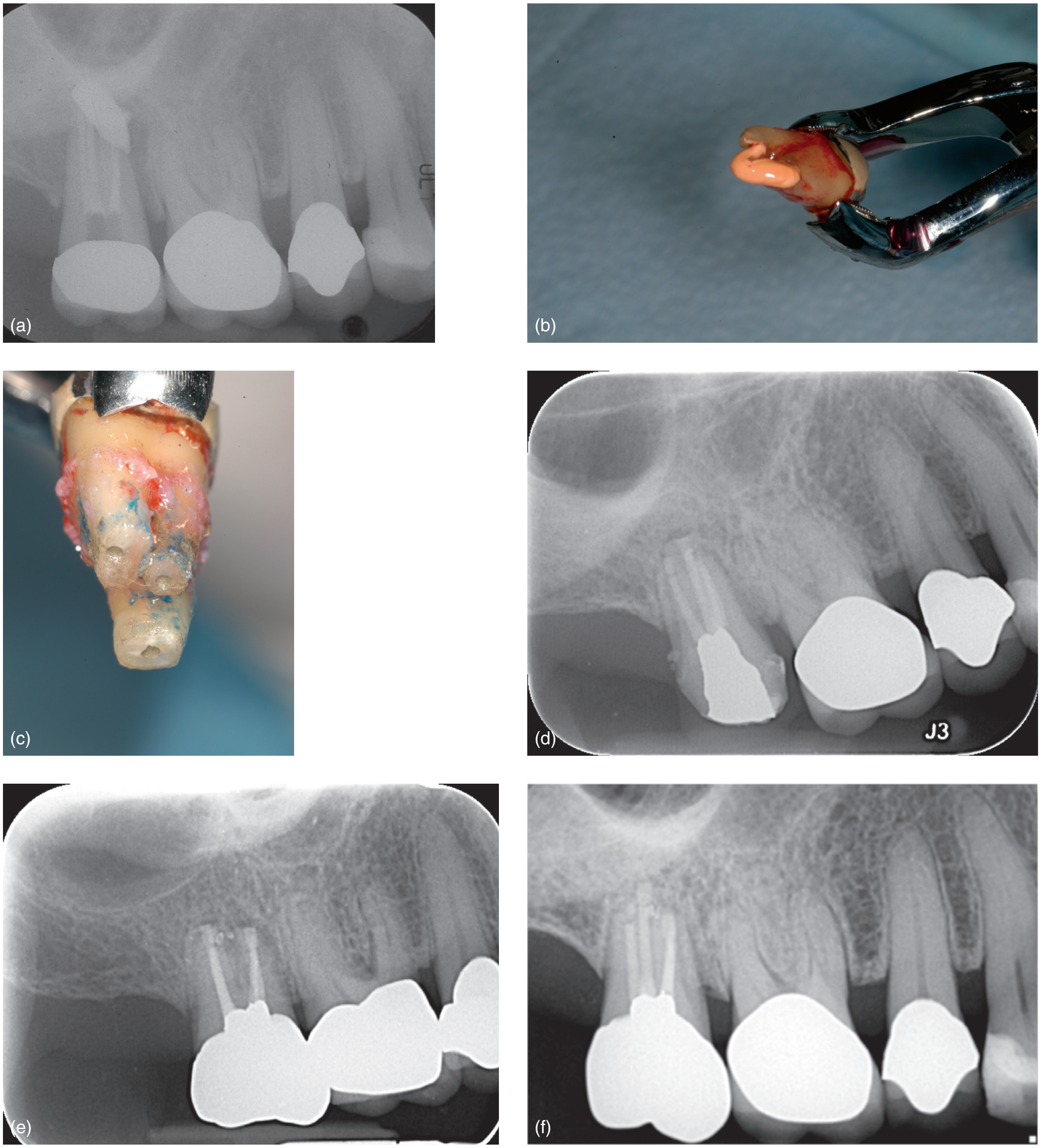

Figure 18.15 Maxillary right second molar with an overfill of gutta percha, encroaching on the sinus. Retrieval of the excess gutta percha would be impossible with conservative retreatment, and the location of the tooth precluded a surgical approach. (a) Preop radiograph; (b) excess gutta percha came out attached to the tooth; (c) all root ends prepared and filled with gray MTA; (d) postop radiograph; (e) 15 month follow-up showing complete healing; (f) 4 year follow-up. (Courtesy of Dr Mindo Lee.)

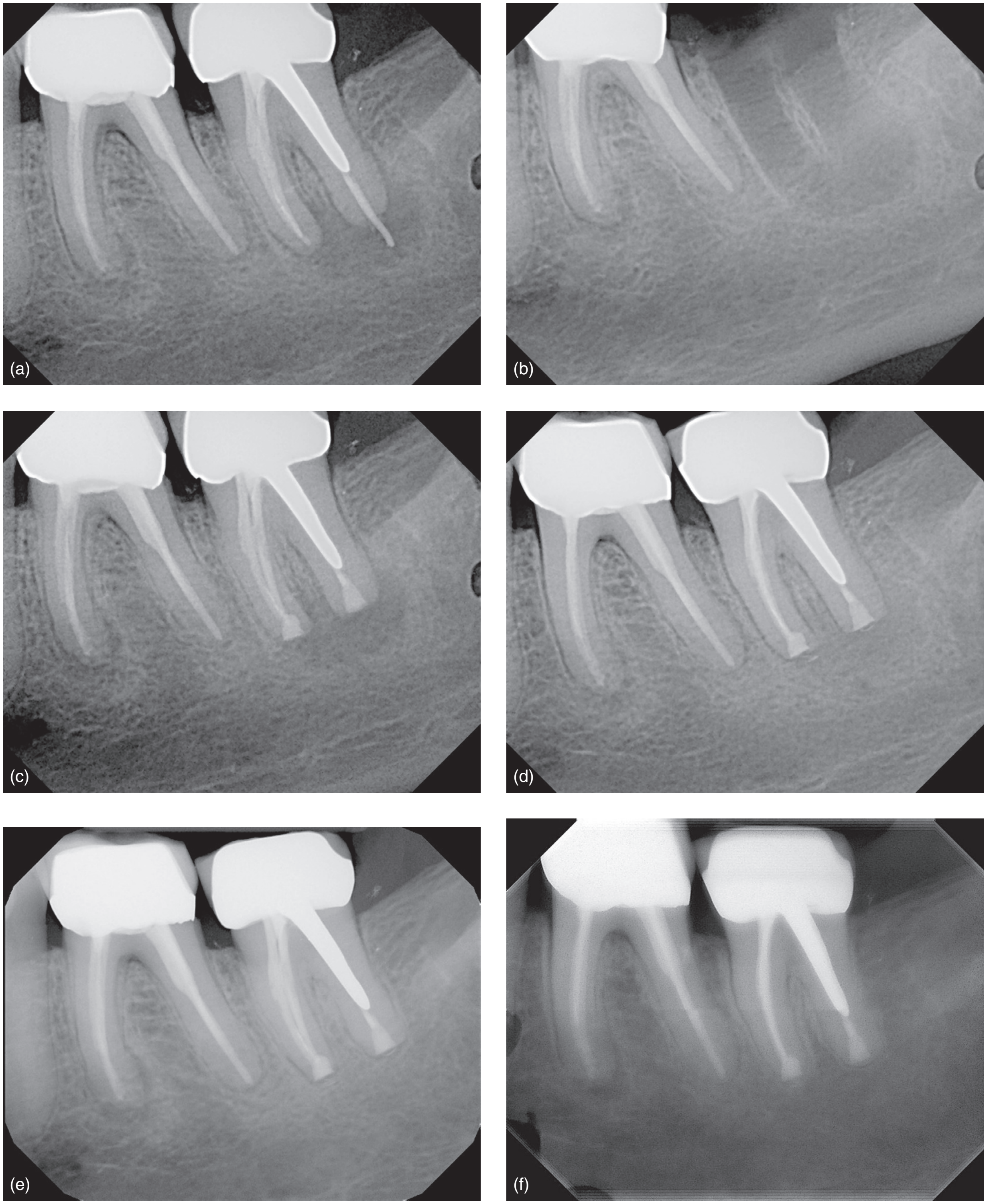

Figure 18.16 Mandibular left second molar was referred on a Friday afternoon as an emergency with the patient in severe pain and already on antibiotics, NSAIDS, and narcotics for several days without relief. Conservative retreatment with a large cast post/core would be time consuming and most likely cause destruction of the tooth. Even if post removal could be performed, the excess gutta percha would probably snap off the end of the tooth into the lesion. An "emergency" replantation was performed, and the patient was completely asymptomatic within 2 weeks. (a) Preop radiograph; (b) radiograph to show that the excess gutta percha came out with the tooth as well as intact interseptal bone, which will allow excellent stabilization upon replantation; (c) postop radiograph; (d) 5 week follow-up radiograph; (e) 1 year follow-up with complete healing; (f) 2 year follow-up (Courtesy of Dr Kenneth Lee.)

Suggested Readings

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Kawanami M, Sugaya T, Gama H. Periodontal healing after replantation of intentionally rotated teeth with healthy and denuded root surfaces. *Dental Trauma* 2001;17:127–133.

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19

Guided Tissue Regeneration in Endodontic Microsurgery

Garrett Guess and Samuel Kratchman

KEY CONCEPTS

- Grafting or membrane use does not appear to have any benefit for endodontic lesions confined to the apical area with no periodontal pathologic component based on current outcome studies.
- Membranes should be used in endodontic surgery when lesions are encountered where buccal and lingual cortical plates are missing to maximize the case outcome by encouraging regeneration of the apical bone. Combining a graft with a membrane is needed only when support of the membrane is necessary.
- Membranes plus grafts in apicomarginal and subcrestal defects have been shown to increase the amount of bone repair following treatment versus open flap debridement alone.
- High-level studies showing the long-term outcome of endodontic surgical cases being positively affected by GTR are not available, but there are clear benefits of grafting and membrane use from periodontal defect regeneration research that can benefit the overall long-term success.

Teeth that require endodontic microsurgery can present with pre-existing periodontal conditions that may detract from the short- or long-term healing potential. Performing endodontic surgery has the principal goal of not only maximizing the procedural outcome from an endodontic standpoint but also periodontally, by returning the site to its preoperative periodontal state despite bone removal to access the root end. Because endodontic microsurgery involves a process to stabilize the endodontic status of the tooth while accessing through the periodontal structures that affect the overall status of the tooth, guided tissue regenerative techniques have a place in the whole-tooth management of an endodontic surgical case. Guided tissue regenerative techniques involve the use of bone replacement grafting materials, cell-occlusive barriers or membranes, as well as bioactive host modulating agents used to maximize the body's healing potential to regenerate the body's lost tissues versus permitting them to repair.

There are three types of cases encountered when performing endodontic microsurgery where consideration should be made as to whether utilizing guided tissue regenerative materials will make an impact, as shown in Table 19.1.

Case Type 1: **Uncomplicated Osteotomy**
The uncomplicated osteotomy represent surgical cases that have only an isolated endodontic lesion; there is no periodontal defect. The majority of outcome studies in endodontic surgery are cases that are selected to have these isolated endodontic lesions, and in these studies there is no utilization of GTR materials. Studies on the outcome of endodontic microsurgery find success rates in the 93% range when no GTR techniques are utilized, indicating that in cases where an isolated endodontic lesion is present, there is no increase in outcome and no change in the favor of regeneration versus repair whether a graft or membrane or bioactive agent is utilized in conjunction with contemporary microsurgical techniques.

Case Type 2: **Complicated Osteotomy**
Complicated osteotomy cases represent those where an isolated endodontic lesion is present with no periodontal component, but the lesion size is considered large and/or the buccal and palatal/lingual plates of bone are resorbed (through and through) lesions. Animal studies as well as histologic evidence strongly support the use of a graft and membrane in complicated osteotomy cases.

Case Type 3: **Periodontal Involvement**
The final type involves cases where a defect of the supporting alveolar bone is present, such as a denuded root where no buccal plate is present

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Table 19.1 Types of cases encountered in endodontic microsurgery.

Case Type:	1. Uncomplicated	2. Complicated	3. Periodontally Involved
Pathology features:	Isolated endodontic lesion	Isolated endodontic lesion	Endo/Perio communication
	Normal probing	Through and through defects including sinus perforation	Loss of buccal plate, dehiscence, denuded root
	Intact bony support around the roots	Large lesion > 10 mm diameter	Furcal involvement
	Bone loss confined to the apical area		

initially or following degranulation or resection. The evidence indicates that a periodontally involved case benefits from the application of GTR in three ways: Facilitated healing, increase in success rate, and an improvement in the periodontal status of the tooth. Clot stabilization has been attributed to the benefit of GTR with regards to a facilitated healing process.

A collagen-based material is the most commonly used membrane material. Collagen has been shown to be advantageous over synthetic materials and can be derived from various parts of human cadavers or animals, most commonly from bovine or porcine sources. Collagen membranes, due to their inherent flexibility and adhesion properties can be easily adapted to the defects. They typically contain a compact layer that is placed in contact with the soft tissue preventing collapse and a more porous layer placed in contact with the bone, enabling integration of newly formed bone. Any membrane should extend approximately 2–3 mm beyond the margin of the defect. Currently on the market is a popular collagen-based membrane Bio-Gide (Geistlich Biomaterials, Princeton, NJ). Bio-Gide has a bilayer design with the smooth side marked "up" and a rough side that is positioned toward the defect. It has a high tensile strength and becomes adhesive when saturated with fluid. The typical way to place a membrane is to put it over the site and then with a saturated cotton pellet blot down the corners of the membrane (Figure 19.1). At this time, the membrane can still be positioned to the exact location one desires before saturating the membrane so it stays in place. One should try to keep the membrane submerged below the soft tissue before suturing. In the past, when materials like Gortex were used, if the membrane even peaked above the flap, it would get infected and need immediate removal. With the more biocompatible collagen membranes used today, it is still critical to keep them submerged, but will not necessarily cause failure if it were to slightly move above the incision line. Also, it is common practice to place a patient on an antibiotic after surgery, when bone grafting/guided tissue regeneration is used, in order to prevent post-operative infection and rejection of the grafting materials. There is a question that has been greatly researched and reported on as to whether bone grafting materials must always be combined with membranes or can one be used without the other? Regarding the resorbable collagen membranes, in order to maintain the barrier function for a longer period of time, the collagen can be cross-linked. A fast resorption rate is a concern when choosing a membrane. The critical time for epithelial proliferation is 14 days; therefore, the cells must be excluded from the surgical site for at least 14 days to prevent apical migration of epithelium. The cells needed for regeneration arrive at the wound site in approximately 3–4 weeks. Therefore, the space must be maintained for allowing selective cells to repopulate the site. We need at least 3–4 weeks of intact functioning of the membrane. That is why certain materials such as Collacote and Collatape (Zimmer Dental, Carlsbad, CA) may not be adequate membranes. Collacote is a bovine-based collagen material. It accelerates the wound healing process and stabilizes the blood clot. It protects the surgical site. It is inexpensive and easy to manipulate. The downside is that Collacote and Collatape fully absorb in 10–14 days.

To summarize a topic that frequently changes and on which research has been taking place for years, most likely the best material to fill a surgical site when there is no periodontal communication is the patient's own blood clot, and whether or not there is a benefit to placement of a resorbable membrane will depend on the size of the lesion, whether it is a through and through lesion, and if there is a communication between the sulcus and the lesion. Within endodontic lesions, one can classify based on the presence of a bony ridge or the absence of one. In many cases a sinus tract may exist, which could be in the sulcus, close to the gingival margin, or deep in the vestibule. It is imperative to always trace a sinus tract with gutta percha and take a radiograph. One can be fooled by the

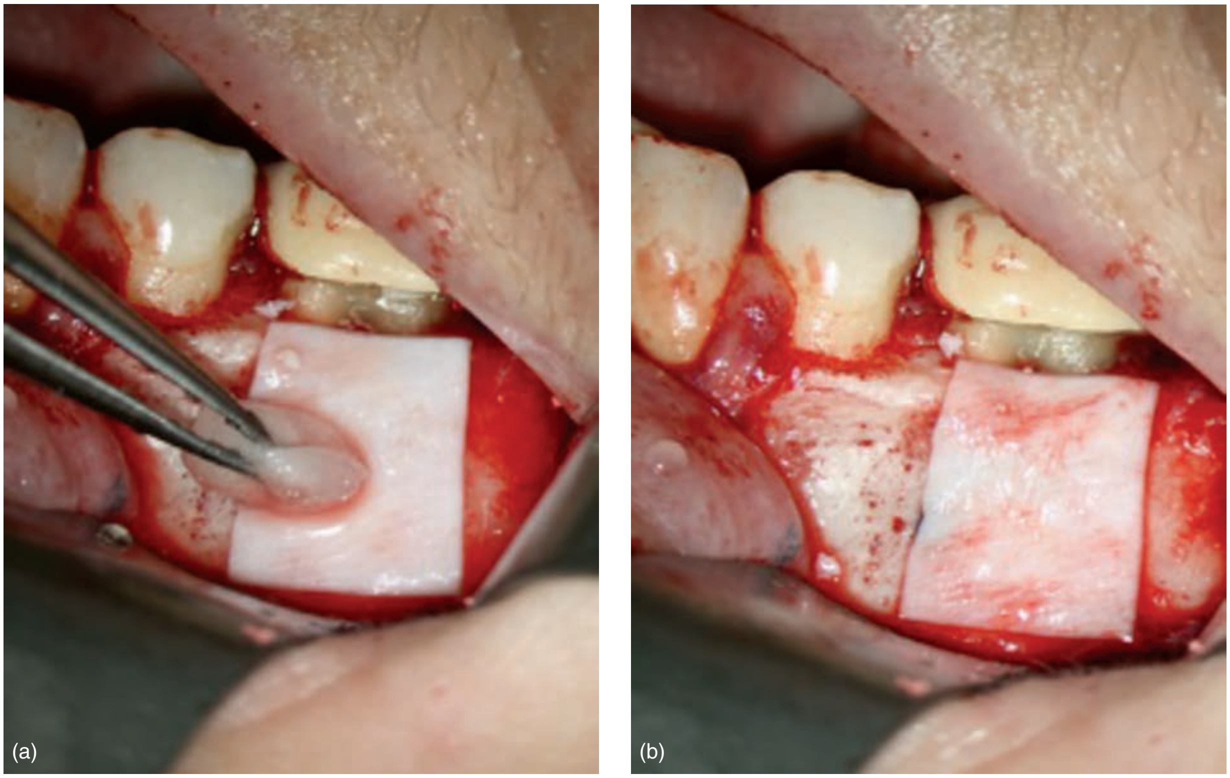

Figure 19.1 Membrane placement: (a) placing the membrane by patting down edges with a moist cotton pellet; (b) the membrane should extend 2–3 mm beyond the defect margins.

presence of a sinus tract located at the gingival margin, which is in actuality a true endodontic lesion. The differences were compared in the dog mandible between leaving a blood clot versus a resorbable membrane versus bone grafting material plus a membrane. It was found that the sites with membrane plus bone grafting material showed the greatest amount of bone regeneration, but the key factor appears to be the membrane and not the bone graft. Also, it is hard to extrapolate dog studies to human responses, considering one year in the life of a dog equals approximately seven human years. One thing for certain is that bone grafting materials are not fully resorbed, so histologically the new host bone incorporates the grafting materials, but also is encapsulated by fibrous connective tissue.

Since endodontic surgery involves leaving the natural tooth in place, we have different criteria from those who are trying to create a site for eventual implant placement. It is probably not critical if the healing at the end of an apex of a tooth treated surgically consists of bone, plus graft material, plus connective tissue, as long as the patient is asymptomatic and the tooth is functional; but would the success rate/survival rate of implants decrease if they are being placed in sites not containing much host bone? This refers not to a one year follow-up but rather 5–10 or even 20 year follow-ups.

The types of periapical lesions with guarded prognosis would be large lesions. The definition of "large" is debatable. Some say greater than 5 mm lesions are less likely to heal, while others consider 10 mm or greater to be the critical size that will require more time to heal. Even if the lesion is purely endodontic in origin, with no periodontal communication, most agree that once the lesion reaches 10 mm or greater, some type of grafting material and/or membrane is indicated. With lesions that are "through and through", meaning that the lesion extends from the buccal through the palatal or lingual bone, there is a decreased availability of progenitor cells to aid in healing from periosteum, endosteum, and bone marrow; therefore there is a much greater chance of connective tissue ingrowth. Such cases have approximately a 30% greater chance of healing with guided tissue regeneration, between 88% success with GTR, versus only 57% without GTR. To be able to treat these through and through lesions with the greatest chance of healing, one might have to consider the possibility of raising both a buccal and palatal flap, placing two membranes, and sandwiching in the bone grafting material (Figure 19.2). This may be difficult or even

Figure 19.2 History of trauma affecting maxillary left central and lateral incisors. Conservative endodontics performed but lesion persisted so buccal and palatal surgery treatment planned after CBCT confirmed through and through lesion. OraGraft freeze-dried human allograft (LifeNet Health, Virginia Beach, Virginia) and Ossix Plus (Orapharma, North Bridgewater, New Jersey) cross-linked collagen membrane placed. (a) Preop radiograph showing lesion surrounding maxillary left central and lateral incisors; (b) endodontic treatment completed on maxillary left central and lateral incisors; (c) slice from CBCT showing through and through lesion; (d) bone graft material mixed in dappen dish with sterile saline; (e) palatal membrane placed; (f) bone graft placed in buccal; (g) buccal membrane. (Courtesy of Dr Mina Saad.)

Figure 19.2 (*Continued*) (h) Oragraft mineralized ground cortical bone graft; (i) Ossix Plus membrane; (j) postop radiograph; (k) and (l) 2 angles 6 month follow-up; (m) and (n) 2 angles 4.5 year follow-up. (Courtesy of Dr Mina Saad.)

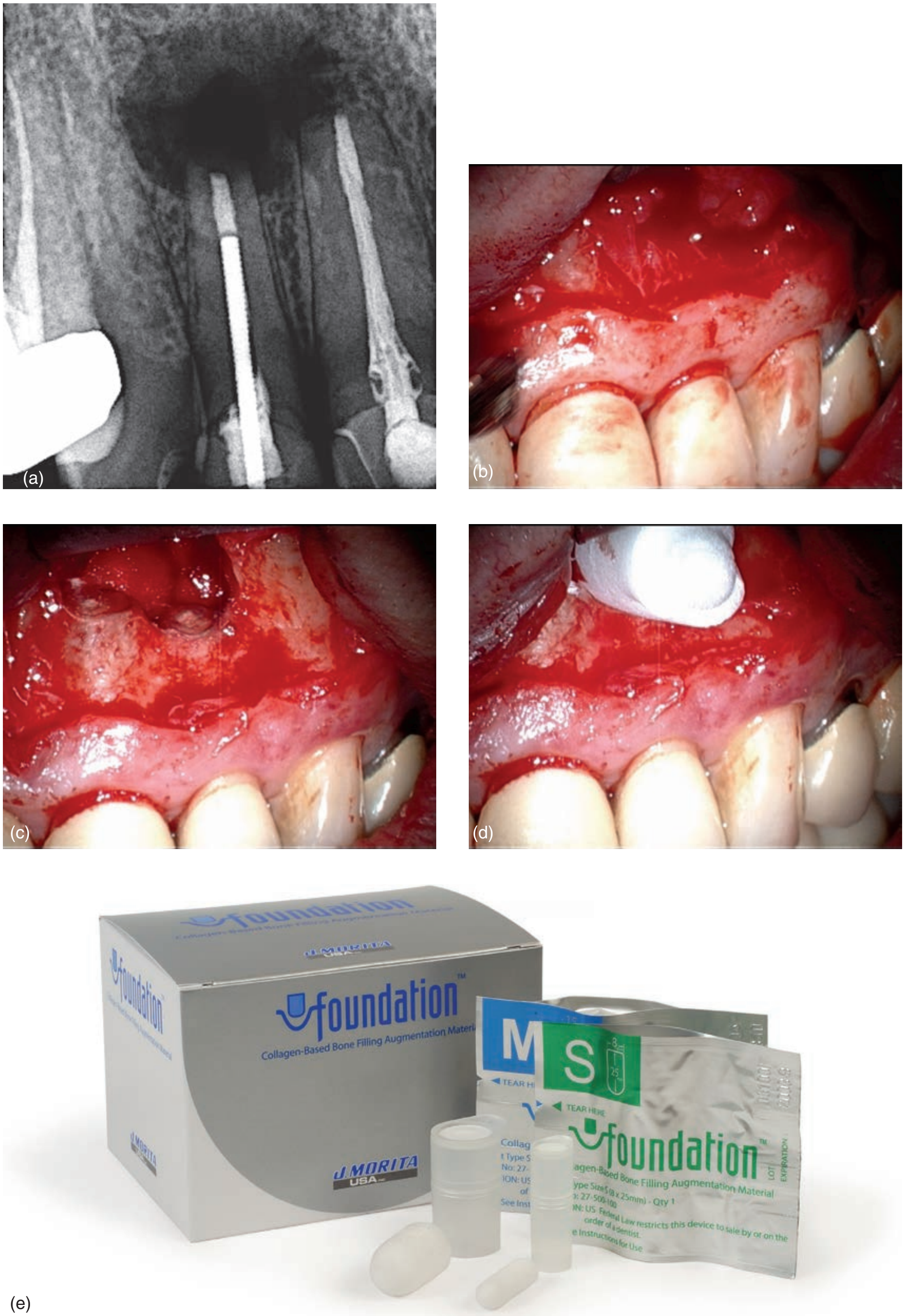

Figure 19.3 Failed apical surgery by oral surgeon on maxillary right lateral and central incisors. Treatment plan was extraction/bone graft/2 implants. Patient sought out a second opinion to try and save the teeth. (a) Preop radiograph showing large periapical lesion surrounding maxillary right lateral and central incisors; (b) incision raised and lesion is perforating facial bone; (c) Bioceramic root end fillings; (d) foundation graft material; (e) foundation graft material. (Figure 19.3d and e are courtesy of J. Morita USA, Inc.)

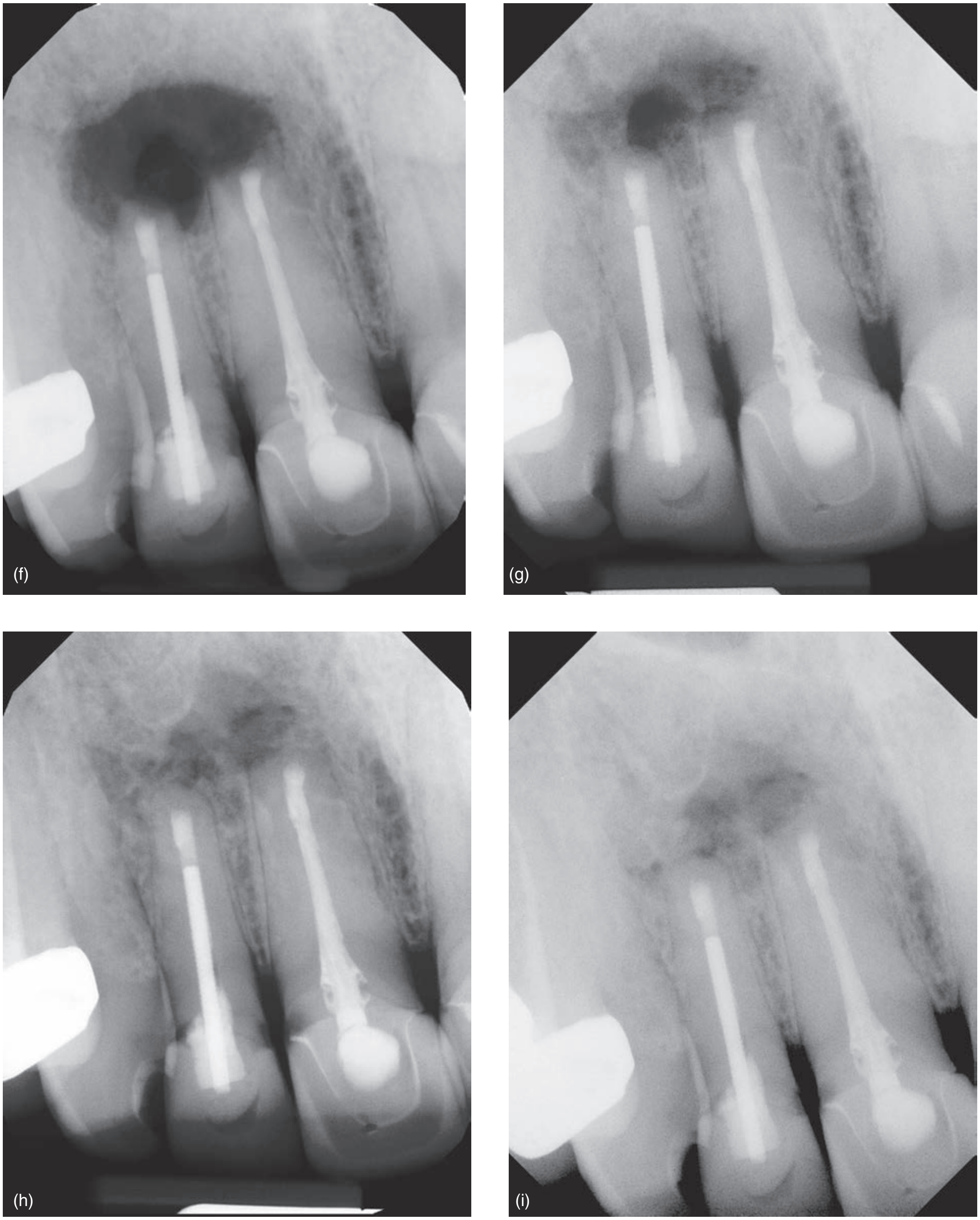

Figure 19.3 (*Continued*) (f) Postop second surgery; (g) 7 month follow-up; (h) 14 month follow-up; (i) 2 year follow-up.

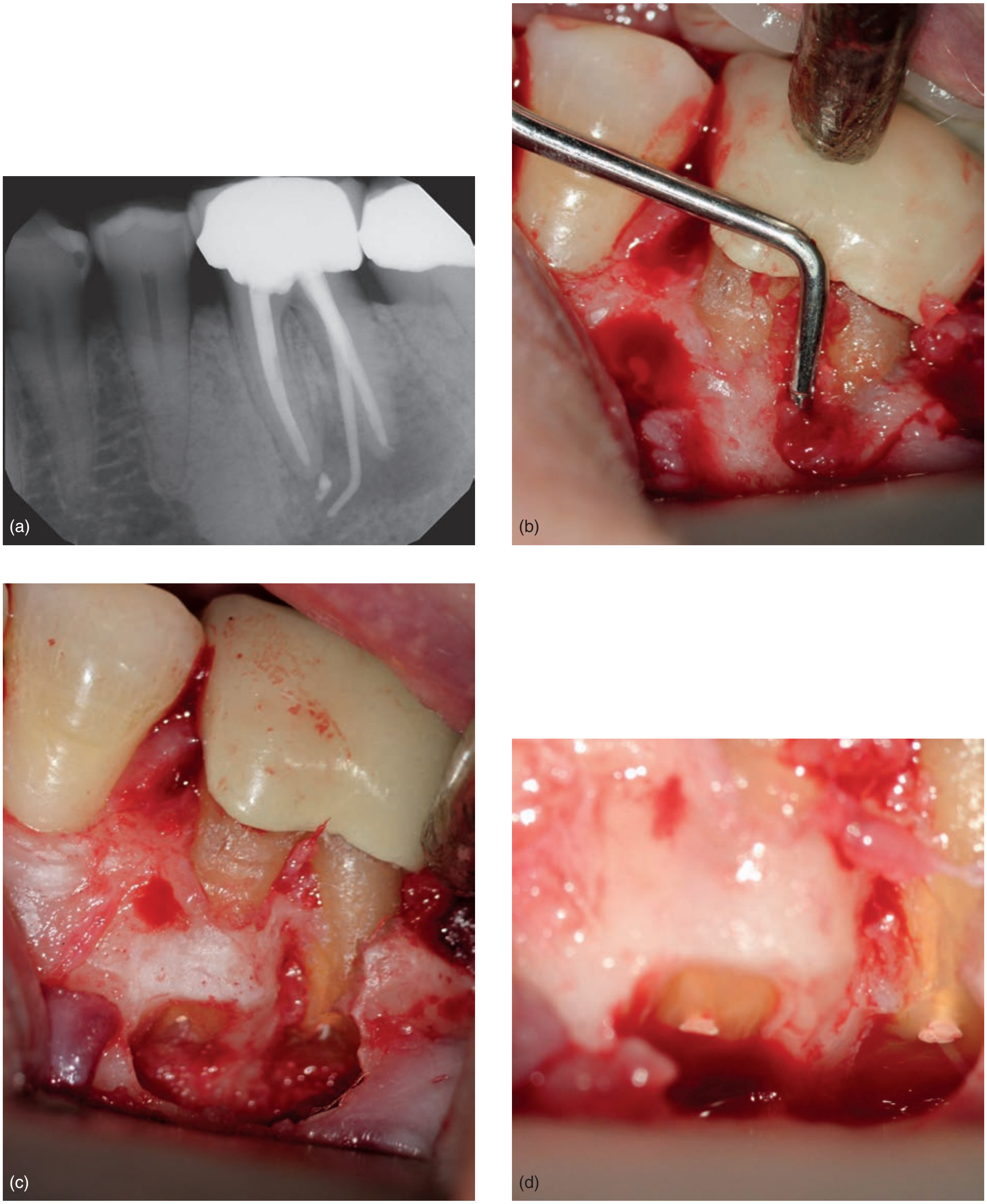

Figure 19.4 Failed non-surgical retreatment of mandibular left first molar with fistula tracing to periapical area and buccal probings in sulcus. Treatment plan was exploratory surgery due to possibility of a fractured root. (a) Preop radiograph mandibular left first molar with fistula tracing to apical lesion; (b) after incision, furca probing to apex noted; (c) complete fenestration of distal root and classic J-shaped lesion; (d) apicoectomies performed on mesial and distal roots.

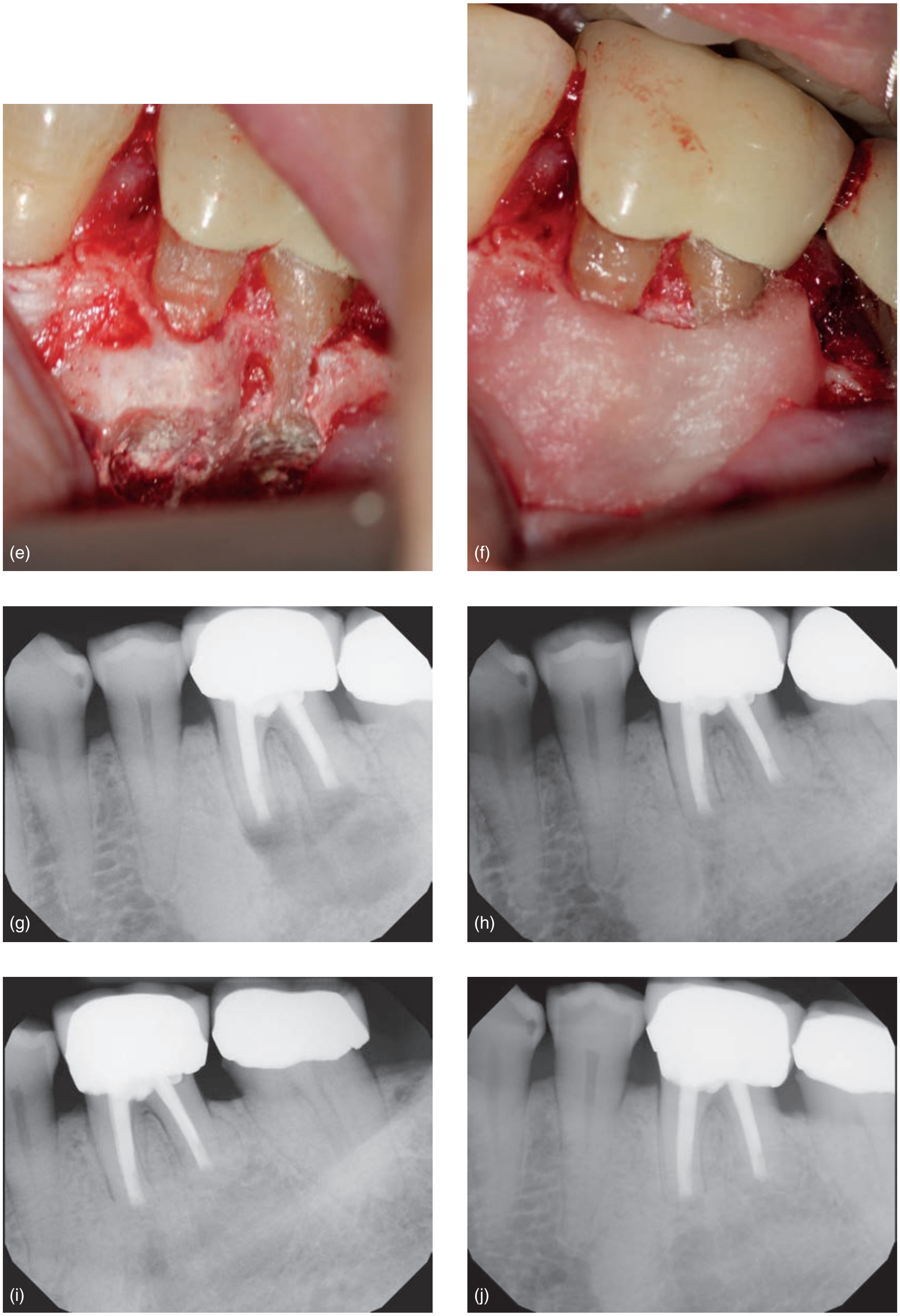

Figure 19.4 (*Continued*) (e) Bioceramic root end fillings; (f) foundation placed in crypt (not shown) and osteotomy covered by Collacote membrane; (g) postop radiograph; (h) 8 month follow-up; (i) 15 month follow-up; (j) 2.5 year follow-up.

impossible if the anatomy does not allow it, i.e., the palatal area of second molars or the lower posterior lingual areas. In such cases, the CBCT is necessary to determine the exact extent of the lingual/palatal lesion and whether there is a bony perforation on the lingual/palatal. When this occurs and access proves to be impossible, one can attempt to place a membrane behind the root from a buccal approach and tuck it in, followed by bone grafting material and a second membrane, keeping in mind that the palatal membrane is just acting as a barrier to prevent the grafting material from getting all over the site, acting like a piece of "bread" in a sandwich. In order to place a palatal membrane, a palatal flap must be raised, so that the membrane can cover the osteotomy site and extend 2–3 mm on to healthy bone around the surgical site. Another alternative treatment is an intentional replantation, which will be discussed in great detail in another chapter.

A current material being used, which shows excellent results is Foundation (J. Morita, Kyoto, Japan), a collagen-based bone augmentation material. It was originally designed to be used as a socket preservation for implant placement, where it promotes a faster growth of bone, allowing for implants to be placed in 8–12 weeks postextraction. Foundation is made from bovine atelocollagen (pepsin-solubilized) and its benefits for endodontic surgery are vast. It acts as both a graft and a membrane, it is inexpensive, and it is easy to place. Right before flap repositioning a "bullet" of Foundation is placed in the osteotomy site, and as you moisten it with saline, the material becomes gelatinous, allowing for easy manipulation and allowing it to not only fill the bony crypt but to cover the root surface as well. Another extremely important feature of Foundation is that it is radiolucent, allowing the practitioner to differentiate between healed bone at follow-up appointments, not wondering whether the radio-opaque findings are actually bone or remaining bone graft material (Figures 19.3 and 19.4).

When a periodontal defect is encountered while performing endodontic microsurgery, based on clinical studies in endodontics and many in the field of periodontics, and guided tissue regenerative materials are implemented, a histologic, radiographic, and clinical benefit is realized. The benefit of using a membrane plus a graft in cases with periodontal problems is the potential to provide a more stable long-term periodontal condition and more effectively retain the tooth due to regeneration of supportive bone versus healing with a soft tissue epithelial repair of the defect.

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20

Implants versus Endodontic Microsurgery

Frank Setzer and Syngcuk Kim

KEY CONCEPTS

- Understand the difference between success and survival.
- Demonstrate the outcomes for single implants and microsurgery.
- Impact on treatment planning.

20.1 Historical Perspective

For almost 100 years root end surgeries have been performed to save teeth from extraction when therapeutic approaches by primary secondary treatment were exhausted. During all these years, there has always been stiff opposition from parts of the dental community, ushering doubts about the effectiveness and the prognostic outcome of surgical endodontics. In the 1930s and 1940s, endodontic treatment per se was under scrutiny, and many teeth were needlessly sacrificed on the basis of the afterwards invalidated focal infection theory. The specialty organization of Endodontics was formed in 1943 in the United States and an increasing number of endodontic procedures was performed during the 1960s and 1970s, when new techniques were introduced. During these years, endodontic therapy, hand-in-hand with periodontal therapy, improved prosthodontic outcomes, and consistent long-term maintenance saved millions of teeth from removal and patients from having to resort to partial or full dentures. However, slowly but steadily, with the advent and widespread application of osseointegrating implants into dentistry, more teeth were being extracted. this time to be replaced by an implant fixture. The issue of treating a tooth endodontically with subsequent prosthodontic reconstruction versus extraction and implant placement has been hotly debated. In the last decade, a simplified approach of extraction and implant placement was common, but this did not always prove to be straightforward or ethical. In this context, endodontically treated teeth had been labeled as inferior to implants in regard to long-term stability and retention, and especially teeth requiring endodontic surgery were considered to be better suited for replacement than for therapy.

20.2 Benefits of Implants

Modern dental implants have added greatly to the restorative options available to the dental practitioner. Most contemporary systems are screw-type titanium implants that heal by osseointegration. Osseointegration is the direct apposition of vital bone on a titanium implant surface, facilitating immobile anchorage for restorative abutments. Early indications included the restoration of patients with fully or partially edentulous conditions.

Single-unit implants are often used to avoid the use of fixed partial dentures (FPDs), which require the removal of healthy tooth structure on the abutment teeth. Some studies showed inferior survival rates of FPDs in comparison to single-unit implants, in particular when abutment teeth had been endodontically treated.

20.3 Long-Term Prognosis of Dental Implants

Implant success and survival should be differentiated. This distinction is important, since, historically, implants were often reported as "successful", although mostly the mere presence of the implant in the mouth was recorded, which is in fact "survival". Sometimes, even "ailing" or "failing" implants were counted as successful units. This results from the lack of agreement to define success for dental implants. Some of the most

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

widely accepted criteria were put forward as Albrektsson's criteria in 1986, but revised by Smith and Zarb in 1989 and Buser *et al*. in 1991.

Besides clinical signs and symptoms, bone loss around the implant is the key criterion. To be regarded as *successful*, bone loss may range from a mere 0.2 mm per year after the first year of service according to Albrektsson's criteria (1986), up to complete peri-implant bone loss according Buser *et al*. (1991) as long as the implant fixture is retained. Yet, a systematic review and qualitative analysis of implant studies using implant systems by Straumann, Nobel BioCare, 3i, and Dentsply over a 20 year period found the majority of studies used survival criteria. A comparison between success versus survival rates described a cumulative survival rate of 92.2%, but a cumulative success rate of 83.4% for 1022 implants over 7 years of observation. It was demonstrated that implant "success" rates may be inflated by 6–10%, depending on whether implants were counted only after previously successful loading or immediately after placement. Smith and Zarb's modified Albrektsson's criteria (1989) recommended to disregard implants that failed prior to osseointegration or loading for an outcome analysis.

Nevertheless, according to the literature, outcome rates exceeding 95% were frequently reported, including an overall survival rate of 95.5% after 1 year of follow-up, as well as cumulative survival rates of 92% for two-stage implants over 15 years and 85% for one-stage implants over 10 years with the inclusion of early failures. More modern implants, in particular implants with rough, acid-etched or sand-blasted surfaces, have also demonstrated excellent survival rates of 97–98%.

Strict inclusion and exclusion criteria were used for implant trial participants, and thereby many "average" patients were excluded from implant outcome trials. Nevertheless, "average" patients are seen in a dental office on an everyday basis. In a normal population, specific habits or diseases are present that are known to have a negative impact on implant prognosis. This includes smoking, regular alcohol consumption, poor oral hygiene, Type IV bone, or other parafunctions like bruxism. In particular, the lateral forces exerted by bruxism were considered to be connected to early implant failures, as compared to vertical forces occurring when clenching. Data from such a highly selected patient pool may not represent true outcome values in the general population.

Moreover, most studies did not address related issues, such as the esthetic outcome, soft-tissue aspects, and patient satisfaction. For example, although an increase in surface roughness is regarded to give an excellent long-term outcome, there are still controversial debates as to whether an increased biofilm formation will make the implant more susceptible to peri-implantitis. If an implant suffers from acute or chronic peri-implantitis, it may have a great impact on the clinical reliance of the implant as well as on the patient's satisfaction with the implant restoration. Peri-implantitis has now been shown to be widespread. In a study published in 2016, peri-implantitis was present in 45% of all patients of a random implant patient sample. A meta-analysis on prevalence, extent, and severity of peri-implant diseases reported that 43% of implant units suffered from peri-implant mucositis and 22% from peri-implantitis, and highlighted the constant progression of the disease over time.

20.4 Implant Complications

Challenges for dental implant rehabilitations appear to be connected to the prosthetic restoration rather than the implant fixture itself. Whereas restorations on natural teeth have a good long-term prognosis, implant prosthodontic restorations have a lower life expectancy than the implant itself and are more prone to technical and biological complications. These complications may include the aforementioned peri-implantitis, bone loss exceeding 2 mm, as well as prosthetic or abutment screw loosening. Although higher survival rates and lower complication rates were reported in more recent clinical studies, the actual incidence rate of esthetic, biologic, and technical complications still remained high.

According to a study from the University of Minnesota, it also takes longer for a patient to adapt to a new implant restoration.

This applies particularly to esthetic restorations in the anterior maxilla. Satisfactory esthetics and gingival architecture are significantly more difficult to achieve with dental implants, particularly with situations where a thin scalloped periodontal biotype exists, a high smile line, or greater distances between interproximal contact points and the alveolar bone. Supraeruption of natural teeth adjacent to an implant may cause an esthetically unpleasant smile. No guarantee exists that an implant can stay with a patient for his or her lifetime. In fact, implants may eventually need replacement, which may cause traumatic bone due to the implant still being partially osseointegrated. Implants do not exceed the life expectancy of natural teeth at ten year observation points, including endodontically treated or periodontally compromised teeth.

A systematic review of the long-term survival of teeth versus implants, including only studies with a minimum of 15 years of follow-up, demonstrated that teeth outlasted dental implants in terms of longevity. The authors concluded that looking from a patient's lifetime perspective, especially in younger years, natural teeth should be retained if possible, knowing that reimplantations in previous implant locations are going to be even less successful. Thus, a new critical analysis has taken shape in periodontics and implant dentistry, with a renewed emphasis on saving teeth. Leaders in the field have criticized that patients were often recommended tooth extraction in the erroneous belief that dental implants had a better long-term prognosis than natural teeth. However, this has now been clearly rejected by various comparative studies, and the recognition of an overuse of implants and underuse of teeth for oral rehabilitation has taken place (Figure 20.1).

20.5 Long-Term Prognosis of Endodontically Treated Teeth with Root End Surgery

The long-term outcome of endodontically treated teeth should only be compared to implants on the basis of survival. A study on survival evaluated 1 462 936 teeth with primary endodontic treatment over a period of 8 years. Based on data from a health insurance company, 97.0% of these teeth were retained with the primary endodontic treatment still in place and 3.0% were extracted or received some form of surgical or non-surgical retreatment. Thus, after an additional retreatment procedure, the retention rate would be even higher. A similar investigation in Taiwan found that of 1 557 547 endodontically treated teeth 92.9% were still retained after 5 years. A meta-analysis initiated by the Academy of Osseointegration found no statistically significant differences between dental implants (95%) and endodontically treated teeth (94%) over a period of 6 years when the survival of restored single-unit dental implants and endodontically treated teeth were compared. The aforementioned matched pair long-term study performed at the University of Minnesota, comparing restored implants with restored endodontically treated teeth, in patients of similar health, age, and dental history, found an identical loss rate of 6.1% between the implant restorations and the natural teeth; however, the implant restorations required significantly more interventions to deal with complications directly related to the implant fixture or the restoration itself, than the tooth counterparts (Figure 20.2).

Surgical outcome has been mostly assessed by Rud's criteria (Rud *et al.*, 1972) or the slight modification by Molven's criteria (Molven *et al.*, 1987). As outlined in detail in other chapters, traditional root end surgery had little in common with modern endodontic microsurgery. Crude procedures included the use of a straight handpiece to bevel, resect, and prepare the root end at an inadequate angle and a retrograde filling with amalgam. The successful outcome of these procedures was 59.0%, but 93.5% for modern endodontic surgery. It is important to understand that an amalgamation of traditional and modern techniques for outcome evaluation will not reflect the actual outcome that can be achieved with modern methods. For example, another recent meta-analysis concluded that the survival of single implants was more favorable compared to that of teeth that had undergone microsurgery; however, the studies evaluated for microsurgery included the Retroplast technique, known to have a higher failure rate after 4–6 years.

In general, the outcome for modern endodontic microsurgery is excellent, raising the question for the limitations of tooth preservation. A good case selection is necessary for microsurgical success. The endodontic status of a tooth needs to be evaluated, including periapical pathosis, missed canals, perforations, etc. Whereas it has been suggested in the past that non-surgical and surgical retreatment were alternative procedures and non-surgical retreatment should always be preferred, this statement has to be reviewed carefully. If the original anatomy of the root canal system cannot be renegotiated by a non-surgical retreatment, the potential healing of existent apical periodontitis is only 40%. In these situations, a non-surgical retreatment may cause more damage, and a microsurgical procedure is preferred. Similarly, teeth where the disassembly of the existing restoration would lead to too much loss of tooth structure or a risk of fracture, surgical retreatment is the less invasive option. In particular, the remaining tooth structure is one of the decisive factors. To successfully reconstruct and permanently restore a tooth, the anatomical crown–root ratio must be evaluated, crown or root fractures ruled out, and 4–5 mm of supraosseous hard tissue structure will be needed, comprised of 3 mm biological width and 1–2 mm of ferrule. If the anatomical circumstances allow, crown lengthening or orthodontic extrusion can be performed to achieve these goals. Periodontal treatment should not be neglected, since historically it has proven to be highly successful. Teeth with moderate vertical bone loss, including teeth with furcation involvement, have

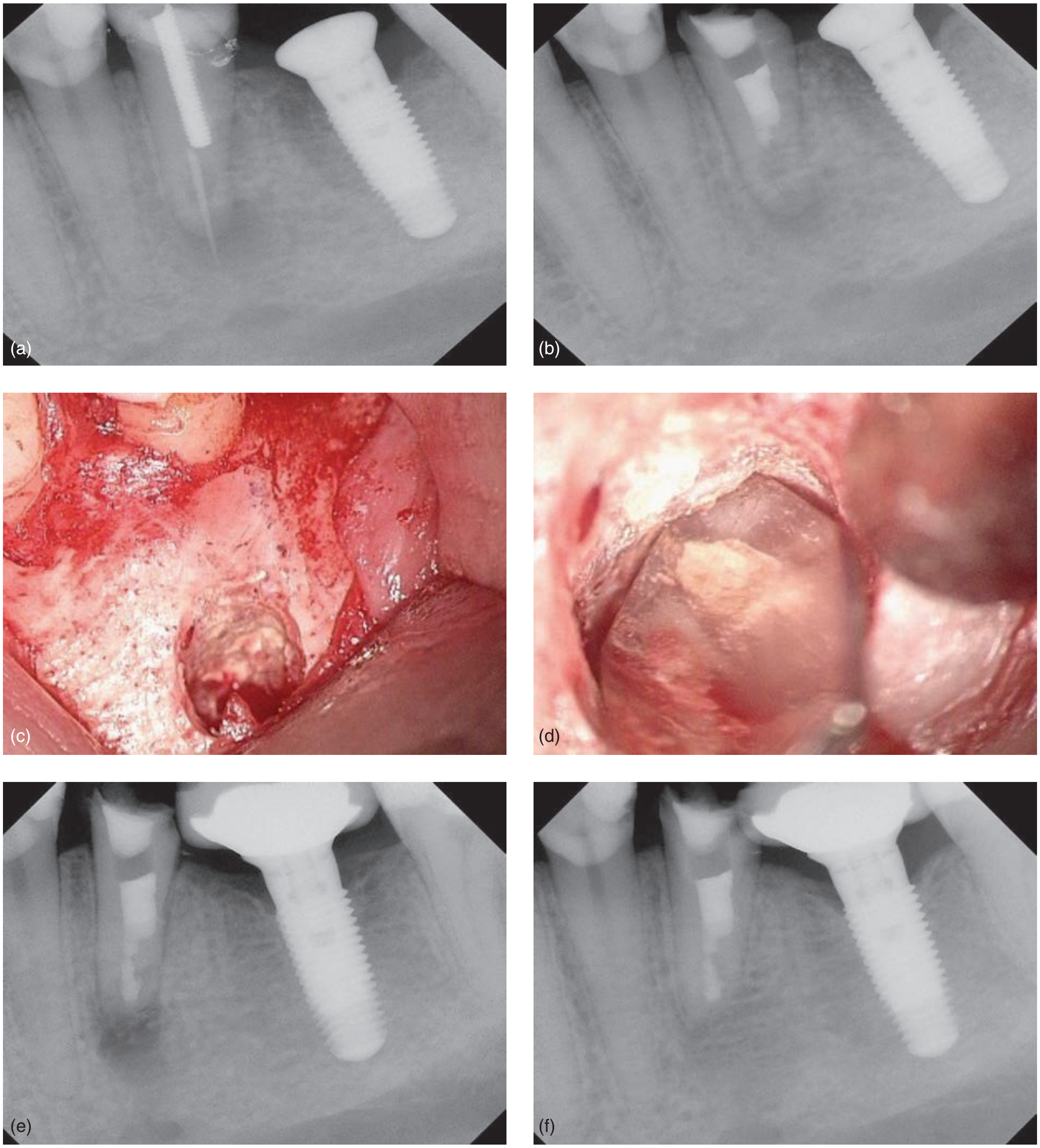

Figure 20.1 Second left mandibular premolar with insufficient previous root canal treatment, post, resorption, and temporary restoration next to dental implant in area of first mandibular molar. (a) Preoperative radiograph (note mesial bone defect on the unrestored implant fixture); (b) postoperative radiograph after non-surgical retreatment; (c) endodontic microsurgery: surgical treatment helps to avoid difficult implant placement; (d) root end filling in place; (e) postoperative radiograph after endodontic microsurgery (note the vertical step from the distal premolar bone level to the mesial implant bone level); (f) 1 year follow-up; periapical healing on premolar, bone level on implant re-established to first thread.

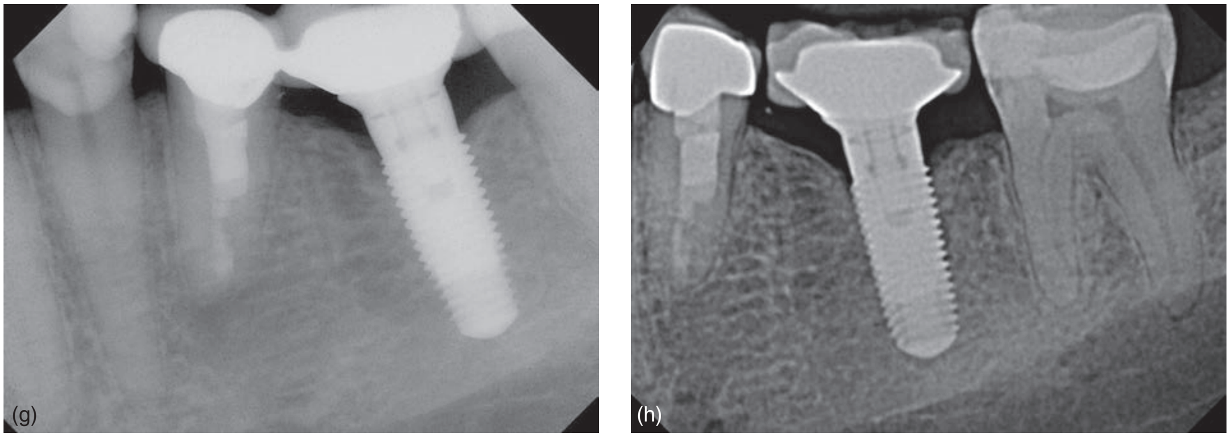

Figure 20.1 (*Continued*) (g) 3 year follow-up; initial peri-implantitis on implant unit; (h) 8 year follow-up; complete healing of premolar, progressing peri-implantitis distal of implant.

a favorable prognosis if the same criteria for periodontal therapy and long-term maintenance are applied. However, for planning endodontic microsurgery, if the tooth is periodontally compromised, and falls into classifications D, E, or F of the Kim/Kratchman criteria, the overall treatment plan has to be carefully assessed, to fulfill the patient's expectations and to also meet the financial abilities.

20.6 Conclusion

If a treatment plan is made correctly and the treatment is executed well, both implant therapy as well as restored teeth with a history of root end surgery have great outcomes and can serve the patient for many years. It must not be forgotten, however, that an extraction is irreversible, so the decision to remove

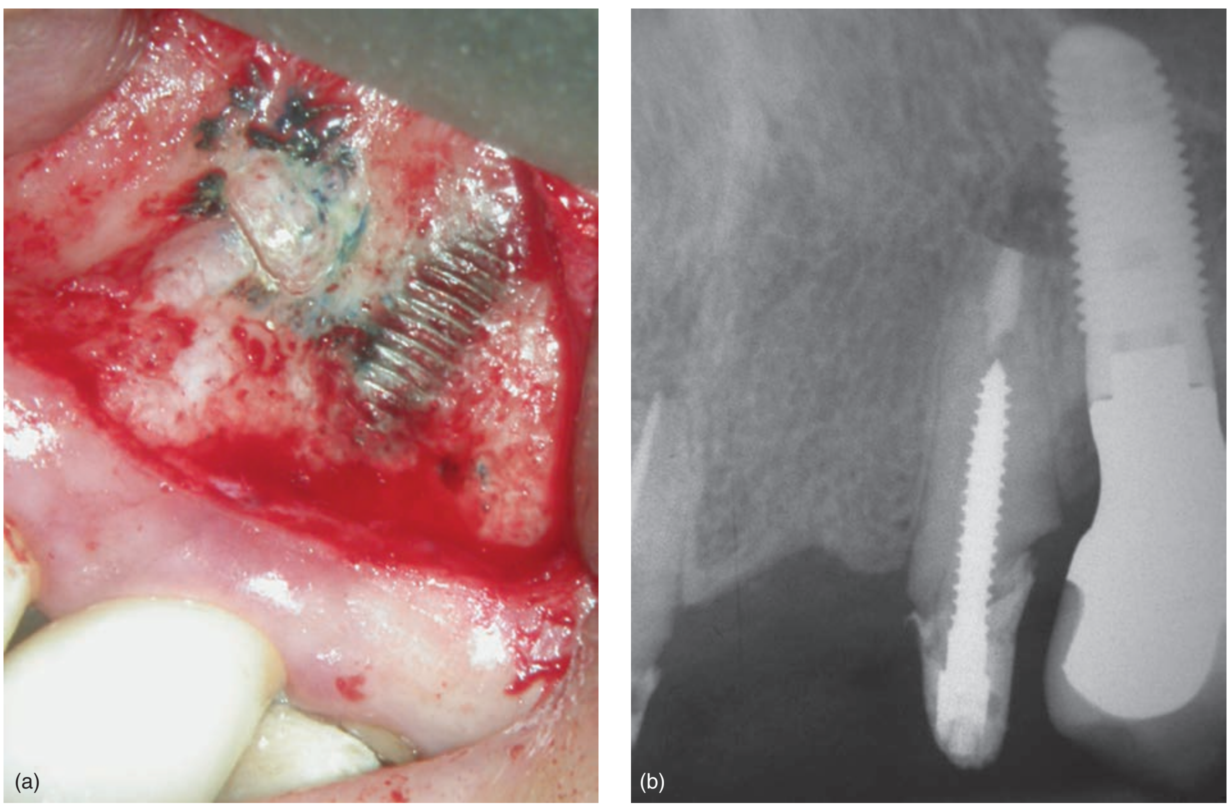

Figure 20.2 Second left maxillary premolar, with insufficient previous root canal treatment and post. Surgery initiated due to patient's constant pain upon palpation in area of the root tip. (a) Intraoperative clinical situation revealed exposed implant threads that were the original cause of pain to palpation. (b) Postoperative radiograph after endodontic microsurgery.

a tooth must be weighed carefully. There is no lifetime guarantee for an endodontically treated tooth, whether it has a history of non-surgical or surgical retreatment, nor for a dental implant. Both treating and restoring a tooth and placing an implant must be complementary treatment options. Suggestions to extract teeth with either apical periodontitis or that require surgical or non-surgical retreatment in order to place an implant does not reflect the current success rates for both non-surgical and microsurgical endodontics. Unfortunately, dentistry is becoming more influenced by market strategies and economic forces. A significantly lower rate of implant survival (73.0%) was demonstrated when inexperienced practitioners placed implants, in comparison to placement by implant specialists (95.5%). Clinical practice and the long-term benefits for the patients will suffer if treatments are rendered without proper clinical training and expertise. High-quality dentistry for both restored implants and restorations on natural teeth will be successful. For the endodontically treated tooth, regardless of whether it is initial treatment or retreatment, success includes proper build-ups and permanent restorations according to the accepted standards outlined above. Shortcuts and low-quality work will always lead to failure. Success/survival rates do not guarantee a favorable outcome due to an individual's clinical circumstances. Dentistry tries to follow suit with medicine by identifying the best clinical procedures through an evidence-based approach. Some of the questions, including whether to retain a natural tooth or to extract it and place an implant, may never be answered satisfactorily at a high level of evidence. The decision for a natural tooth or implant cannot be made based on outcome analysis, but given the tremendously successful changes in modern endodontic microsurgery, cases must be thoroughly examined to justify the extraction of a tooth that can be saved by surgical retreatment.

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21

Prognosis of Endodontic Microsurgery

Meetu Kohli and Euiseong Kim

KEY CONCEPTS

- Endodontic microsurgery has a predictable and significantly better outcome than that of traditional surgery.
- The evidence supports the fact that each step of the surgical procedure serves a purpose and influences the outcome.
- Long-term success of microsurgery is maintained without any significant reversal of healed sites over an increased observation period.
- The main factors that can influence the outcome is preoperative periodontal status of the tooth or the presence of a fracture.

Preservation of natural dentition is at the core of the evolution of endodontics and endodontic microsurgery.

Endodontic surgery was not widely accepted until a few years ago. It was considered an invasive procedure in a restricted surgical field, with a limited success rate. It is now a precisely and methodically conducted procedure with a predictable outcome, hence eliminating the assumptions inherent to traditional surgical approaches. In this chapter the prognostic literature on root end surgery will be deliberated upon.

Outcome studies need to be cautiously compared, as there are too many variables in treatment protocol and methodology. There is disparity in study design, sample sizes, inclusion and exclusion criteria, recall period, and lack of clinical and radiographic parameters for healing. Other factors that can further alter results are the amount and location of bone loss, the quality of previous root canal treatment or retreatment, coronal restoration, and most importantly the surgical materials and techniques. While discussing prognosis of endodontic surgery one has to be cognizant of the evolution of the technique and how it has influenced outcome. Few dental techniques have been substantially transformed, as has endodontic surgery. For many years, the state of the art was the traditional root end surgery (TRS) with surgical burs and amalgam as a root end filling. As the procedure evolved, contemporary root end surgery (CRS) incorporated the use of ultrasonic tips and more biocompatible filling materials such as intermediate restorative material (IRM), SuperEBA, mineral trioxide aggregate (MTA), Bioceramic materials, as well as microsurgical instruments. Endodontic microsurgery (EMS), however, is the most recent step in the evolution of periradicular surgery, applying not just modern ultrasonic preparation, filling materials, and microinstruments but also incorporating high-power magnification and illumination.

21.1 Best Available Evidence

Randomized controlled trials are seen as the gold standard to compare and contrast conclusively the difference in prognosis of two different techniques. However, as all the old published data suggests that the use of traditional techniques has a distinctly poorer outcome, designing such a study becomes unethical. Meta-analysis is a statistical procedure that integrates the results of several independent studies selected on the basis of strict inclusion–exclusion criteria. Pooled data from multiple studies increases the sample size and power of the study, making the results of statistical analysis less prone to error and more reliable. Hence a meticulous meta-analysis of the literature was undertaken by the authors to evaluate a large quantity of raw data extracted from the information published over time on root end surgery.

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

21.2 Parameters for Success: Clinical and Radiographic 2D

A concern when evaluating prognosis in endodontic surgery is the parameters used to define success or failure. In non-surgical treatment, healing takes place by eradicating the infectious source from the root canal system, allowing the body to repair and regenerate at the periapex. In surgery, the healing is that of an excisional wound as the anatomy is changed at the periapex. As the healing patterns are distinctly different in the two procedures, the application of common non-surgical endodontic success criteria such as the Periapical Index (PAI) is not appropriate.

In order to evaluate the outcome, the most succinct and comprehensive classification was first proposed by Rud *et al.* in 1972. This classification was based on 70 block biopsies done on human subjects. The samples were concurrently examined clinically, radiographically, and histologically. This classification was further appraised by Molven *et al.* in 1987 and 1996, in a long-term study, and was found to be consistent and reliable. Molven created a diagrammatic representation of the follow-up radiograph to help the observer evaluate an X-ray with a well-defined visual aid in order to reduce bias and observer variability (Figure 21.1). The radiographic classification consists of four groups. Success was defined as either group 1 (Figure 21.1a); complete healing or group 2 (Figure 21.1b); incomplete healing (scar tissue formation) and clinically by the absence of pain, swelling, percussion sensitivity, or sinus tract. Failure included group 3 (Figure 21.1c); uncertain healing (reduced lesion size) or group 4; and unsatisfactory healing (same or increase in lesion size), as determined by the radiograph. Clinical failure was defined as the presence of any of the symptoms mentioned above. Many studies tend to include group 3 (uncertain healing) (Figure 21.1d) with no clinical symptoms as healed cases or success, skewing the results for the positive. These teeth may be functional but are not truly successful.

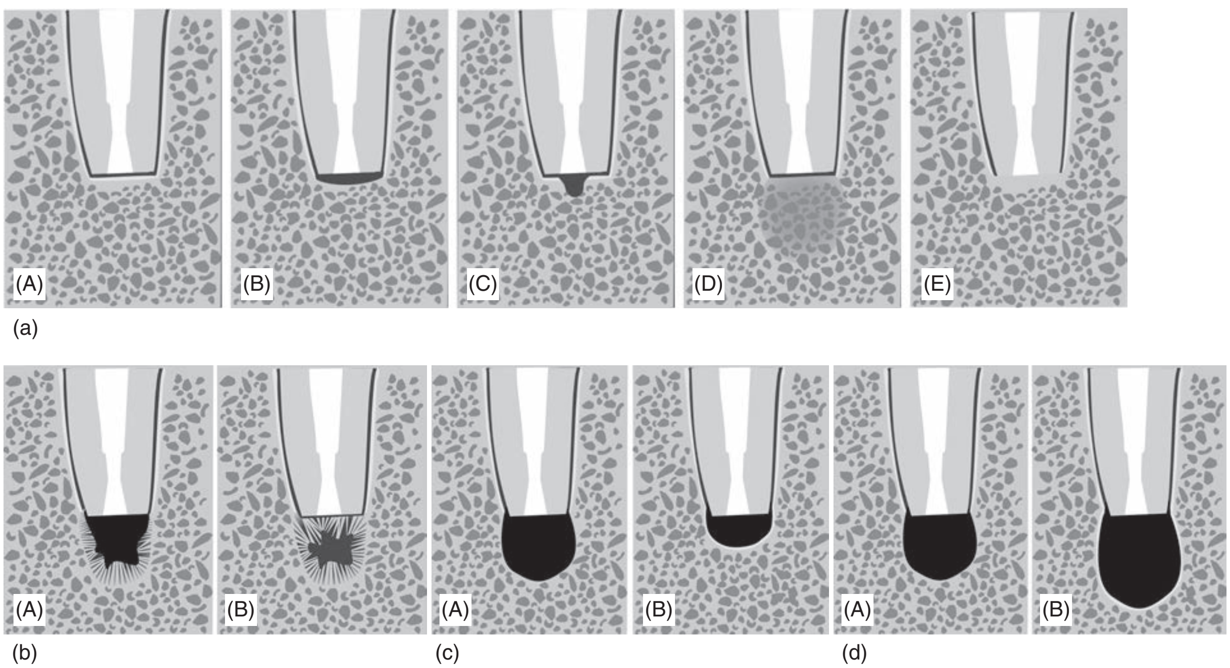

Figure 21.1 Modified pictures of Molven's radiographic classification of criteria for success. (a) Complete healing category. When the lamina dura is restored to original width (A). When the lamina dura is reconstituted but is less than two times the width along the resected root surface (B). When the lamina dura is widened along the root end filling material (C). Complete bone repair, but the density of bone in the surgical site is not the same as the surrounding bone (D). No discernible lamina dura or pdl at the resected root surface, suggesting ankylosis. (b) Incomplete healing category (scar tissue). The radiolucent area at follow-up has decreased but there is a dense radiolucency that is asymmetric to the apex and has a dense compact border often with a sun burst bone pattern (A). A dense radiolucent area not in continuity with the pdl within the surgical site (B). (c) Uncertain healing category. Here (A) represents the radiolucency as seen on an immediate postoperative radiograph and (B) represents the follow-up. The area has reduced significantly but is still larger than two times the original pdl space. (d) Unsatisfactory healing category where (A) represents the radiolucency as seen on an immediate postoperative radiograph and (B) represents the follow-up. The area has enlarged in size or remains the same.

Another important consideration is the follow-up time necessary for assessment. According to Molven (1996), postoperative healing-related changes mostly take place within the first year after surgery. At this point, the cases with complete or incomplete healing (scar formation) are regarded as a success while those with uncertain healing should be re-evaluated for 4 more years and then designated as a success or failure.

21.3 Parameters for Success: "Penn 3D Criteria" for Assessing Healing on CBCT

Periapical films are the most common method used to assess outcome of EMS. Rud and Molven's criteria, based on the correlation between clinical, histological, and radiographic findings of human subjects has been the most commonly utilized outcome criteria in surgical endodontics. The human study that was conducted to establish these criteria involved harvesting biopsy samples that included blocks of bone from the patients. However, in today's environment such a study design would be unethical. A more powerful tool in detecting periapaical radiolucencies is cone beam computed tomography (CBCT). It is more sensitive in detecting a radiolucent area and also allows us to view the lesion three-dimensionally. However, to corroborate the lesion seen on CBCT with a histological sample in humans, again presents the same problem of ethical constraints. However, as CBCT becomes the standard of care in endodontics, having a 3D criteria to define success versus failure is imperative.

Based on a randomized control trial assessing the success of MTA versus Bioceramic used as root end filling materials, the University of Pennsylvania Endodontic Department established the "Penn 3D Criteria" for assessing EMS outcome on CBCT. The criteria have been extrapolated from results of Chen *et al*. (2015). This microsurgical evaluation of MTA versus RRM putty (Brasseler, Savannah, Georgia) was conducted on a dog model. The surgical procedure was conducted after creating a periapical lesion similar to the clinical situation present in humans. The surgical procedure was carried out under magnification with microinstruments. The prognostic evaluation was done with PA, CBCT, Micro-CT and compared with histological samples after euthanizing the animals. The comprehensively obtained and statistically analyzed data from this study has recently been used to assess healing in patients on a 1 year CBCT scan by von Arx *et al*. (2010a, 2010b, 2016) on 61 roots treated microsurgically. Von Arx *et al*. found that the scoring criteria that was used in dogs was repeatable and reliable and applicable in a human subject. The three scoring criteria used to evaluate healing at the resected root surface, bone surrounding the resected root, and the healing of the cortical plate were combined to establish three categories of assessment as part of the "Penn 3D Criteria": complete healing, limited healing, and unsatisfactory healing. Each category has been described in Table 21.1. Just as with Molven's criteria for 2D evaluation, a diagrammatic representation of the follow-up CBCT was made to help the observer evaluate the images in conjunction with a visual aid in order to reduce bias and observer variability (Figure 21.2).

21.4 Reversal of Success

Reversal of success has often been debated. Del Fabbro *et al*. (2007) compared healing in non-surgical versus surgical retreatment. The conclusions were that a surgical retreat showed faster healing in the first

Table 21.1 Penn criteria for evaluating 3D scans of teeth following endodontic microsurgery.

Complete Healing	A. Reformation of periodontal space of normal width and lamina dura over the entire resected and unresected root surfaces B. Slight increase in width of apical periodontal space over the resected root surface, but less than twice the width of non-involved parts of the root C. Small defect in the lamina dura surrounding the root end filling D. Complete bone repair with discernible lamina dura; bone bordering the apical area does not have the same density as surrounding non-involved bone E. Complete bone repair. Hard tissue covering the resected root end surface completely. No apical periodontal space can be discerned
Limited Healing	A. The continuity of the cortical plate is interrupted by an area of lower density B. A low-density area remains asymmetrically located around the apex or has an angular connection with the periodontal space C. Bone has not fully formed in the area of the former access osteotomy D. The cortical plate is healed but bone has not fully formed in the site
Unsatisfactory Healing	The volume of the low-density area appears enlarged or unchanged

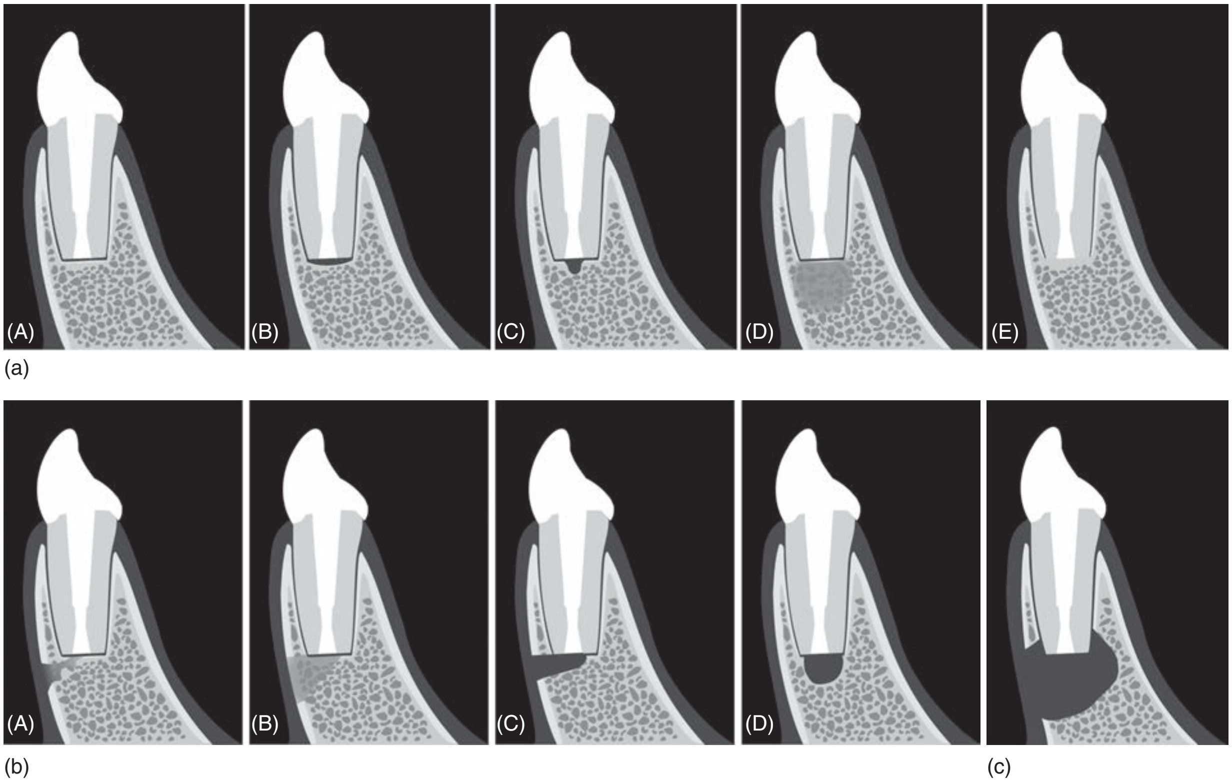

Figure 21.2 Penn 3D criteria for success. (a) Complete healing category. (A) Reformation of periodontal space of normal width and lamina dura over the entire resected and unresected root surfaces. (B) Slight increase in the width of apical periodontal space over the resected root surface, but less than twice the width of non-involved parts of the root. (C) Small defect in the lamina dura surrounding the root end filling. (D) Complete bone repair with discernible lamina dura; bone bordering the apical area does not have the same density as the surrounding non-involved bone. (E) Complete bone repair with hard tissue covering the resected root end surface completely. No apical periodontal space can be discerned. (b) Limited healing category. (A) The radiolucent area at follow-up has decreased significantly but the continuity of the cortical plate is interrupted by an area of lower density. (B) Bone repair in the surgical site but a low-density area remains asymmetrically located around the apex or has an angular connection with the periodontal space. (C) Significant bone repair has taken place but the bone has not fully formed in the area of the former access osteotomy. (D) The cortical plate has completely healed but there is a low-density area near the resected root surface.
(c) Unsatisfactory healing category. The volume of the low density area appears enlarged or unchanged.

year but, due to regression of successful cases over a longer follow-up period (4 years) and the slower healing in non-surgical cases catching up, the prognosis of the two procedures equalized over time. We agree that surgical cases probably show faster healing, but the reversal effect in surgery is unfounded. The two randomized trials that were evaluated in this meta-analysis do not use any means of magnification during surgery. They use burs for the root end preparation, glass ionomer cement or heated gutta percha as root end filling materials, and there is abundant data now to confirm that surgical procedures executed in the above manner have a decidedly lower success rate than EMS.

A recent publication by Song *et al.* in 2012, using microsurgical techniques, showed a high maintained success rate of 93.3% for more than 6 years. Only seven cases classified as healed with scar were considered to be failures over time. For the cases in the failure group, the causes of failure were analyzed during resurgery. Among the five cases that involved resurgery, one had a crack. The second case upon re-entry revealed an untreated lateral canal on the distal root surface. The last three cases showed leakage around the Super EBA root end filling. Excluding the case with the crack and the two unknown reasons for failure, cases with lateral canal and leakage around the filling material were believed to be the result of technical errors during surgery. All resurgerized cases except the tooth with the crack showed a successful outcome after resurgery. Therefore, carefully following the principles of microsurgical procedures could help reduce these failures.

Von Arx *et al.* (2016), in a five-year longitudinal evaluation of 191 cases previously evaluated at 1 year, reported that 11.3% of teeth (16/141) assessed as healed at 1 year regressed to unhealed at 5 years, though the technique used for surgery was not exclusively EMS. One-third of the cases were treated with none or minimal root end preparation and sealed with Retroplast, a dentine bonding resin material. In a previous study (2010) the author had compared the two techniques prospectively and found that EMS with MTA had a significantly higher success rate than that with Retroplast. As the root end management in the two techniques is different, the differences in treatment outcome cannot solely be attributed to just the root end filling material but the technique itself. Hence the reported reversal of success in this 5 year analysis should be assessed with caution.

It would be unrealistic to state that 100% of cases that heal at one year will stay healed for the lifetime of the patient. Factors that can lead to tooth loss include compromised restoration, fracture, periodontal disease, missed anatomy during inspection, inadequate depth of root end preparation or an ill-adapted root end filling. However, if the technique is followed meticulously, these errors can be kept to a minimum. Moreover, in an overall assessment, some of these negative outcomes are countered by successful healing of cases overtime that were designated as uncertain at the one year follow-up.

In conclusion, we believe that long-term success of microsurgery is well maintained over long observation periods, reversal of success notwithstanding.

21.5 Traditional Methods

The clinical success of traditional surgery, based on the absence of symptoms and on radiographic healing, ranged from 17% to 90%. A meticulous meta-analysis of the literature was undertaken for five languages by the authors. The result was presented in two parts. The first paper presented and compared weighted pooled success rates and relative risk ratios for traditional root end surgery (TRS) versus endodontic microsurgery (EMS). Twenty-one studies qualified (12 for TRS ($n = 925$) and 9 for EMS ($n = 699$)) according to the inclusion and exclusion criteria. Weighted pooled success rates calculated from extracted raw data showed a 59% positive outcome for TRS and 94% for EMS (Figure 21.3). This difference was statistically

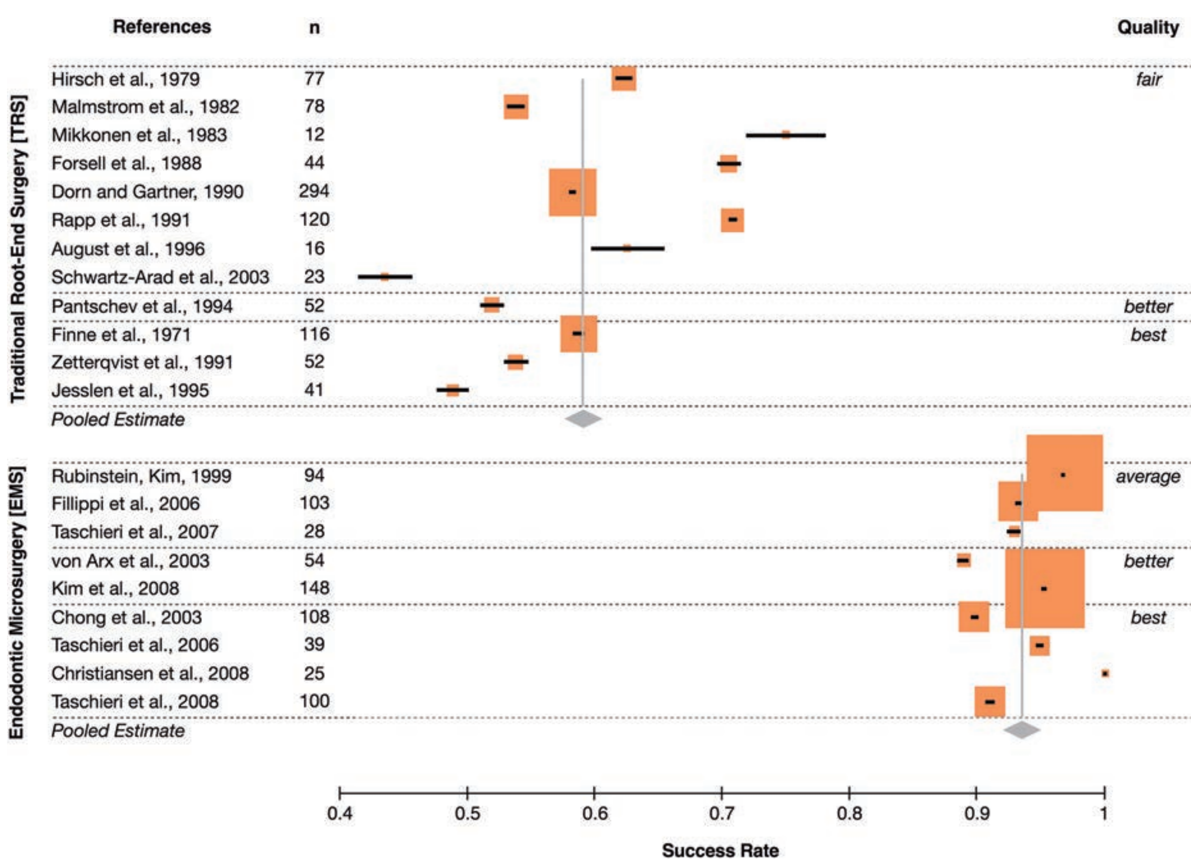

Figure 21.3 Forest plot of weighted pool success rates and individual study weights for groups TRS and EMS.

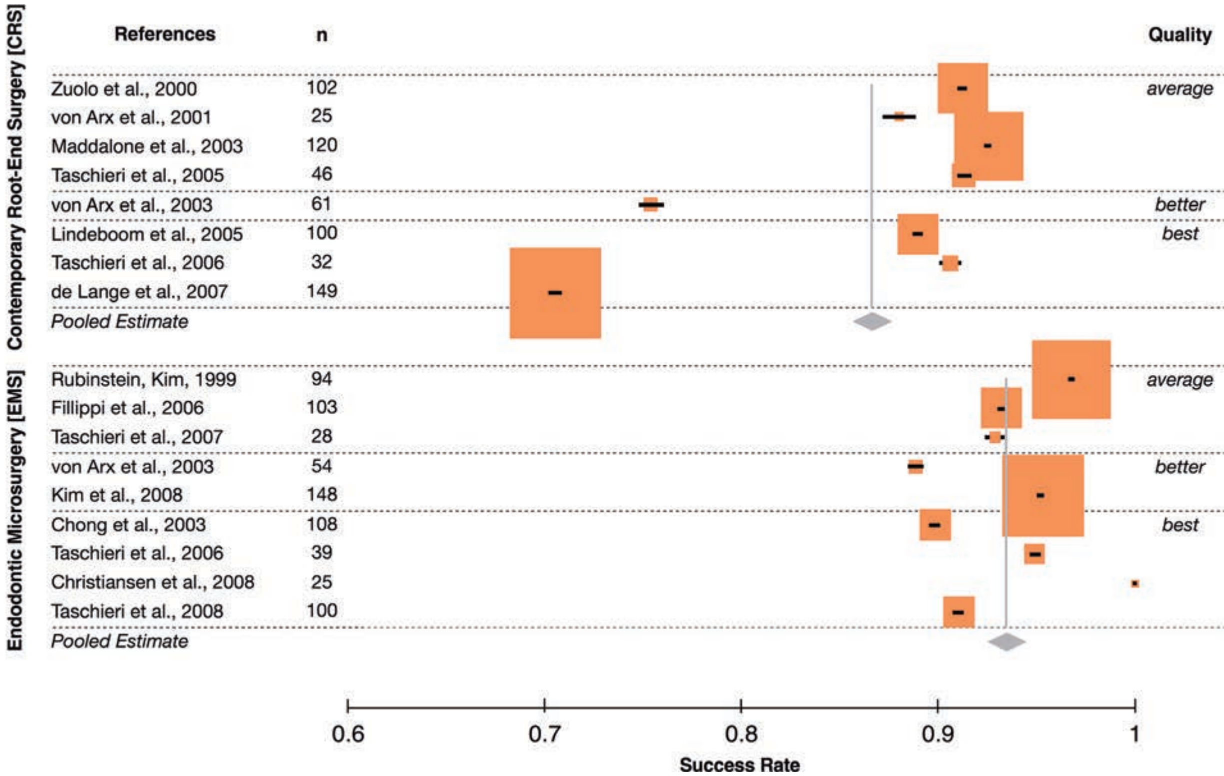

Figure 21.4 Forest plot of weighted pool success rates and individual study weights for groups CRS and EMS.

significant ($P < 0.0005$). The relative risk ratio showed that the probability of success for EMS was 1.58 times the probability of success for TRS. The use of TRS techniques should no longer be considered state of the art.

21.6 Modern Technique versus the Complete Microsurgical Approach

The use of magnification and illumination are an integral part of a microsurgical approach. As discussed, the protocol for endodontic microsurgery involves using mid- range magnification for the majority of the surgical procedure, including hemostasis, the removal of granulation tissue, the osteotomy, apicoectomy, root end preparation, and root end filling. High magnification should be used for the inspection and documentation of the resected root surface, the root end cavity preparation, and the root end filling, to observe fine anatomic details, such as accessory canals, isthmuses, fins, microfractures, or lateral canals. As these are a reservoir of microorganisms in a failing case, addressing them should be significant in determining the success of the case part two of the meta-analysis compared to contemporary non-microsurgical techniques (CRS) and EMS. Fourteen studies qualified according to the inclusion and exclusion criteria, 2 being represented in both groups (7 for CRS ($n = 610$) and 9 for EMS ($n = 699$)). Weighted pooled success rates calculated from extracted raw data showed an 88% positive outcome for CRS and 94% for EMS (Figure 21.4). This difference was statistically significant ($P < 0.0005$). The difference in probability of success between the groups was statistically significant for molars. No significant difference was found for the premolar or anterior group. From a clinical point of view, the increasing difficulty in anatomy and accessibility with molars compared to premolars and anterior teeth could be a logical explanation for a statistically significant difference between the use of microscope or endoscope versus the naked eye or loupes.

21.7 Root End Filling Materials

In conventional root end surgery, amalgam is used. Along with changes in technique, biofriendly materials such as IRM, SuperEBA, MTA, and Bioceramics have been introduced. It has been confirmed that these materials are better than amalgam. In two randomized clinical trials, which compared IRM and

MTA, high success rates were reported for both MTA and IRM (MTA: 92%, IRM: 86.7%) but without statistical difference. The superiority of MTA is due to its biocompatible properties. It has shown great results histologically in several animal models when placed in direct contact with tissue, but a major drawback of MTA is its handling properties, long setting time, and discoloration of the remaining tooth structure. In recent years, bioactive tricalcium silicate cements have been introduced, which show great promise in the published literature regarding biocompatibility, sealability, and favorable physical properties.

One root end filling material with a history in literature is Retroplast, a dentine bonding resin composite. In a direct comparison with MTA, Von Arx *et al.* in 2010a showed MTA success to be 91.3% and Retroplast 79.5%, respectively ($P = 0.003$). We do not consider placement of Retroplast as part of EMS.

21.8 Case Selection

Most endodontically treated teeth are rarely extracted because of endodontic reasons (8.6%), but primarily as a result of restorative (32.0%) or periodontal (59.4%) failures. Kim and Kratchman (2006) suggested a surgical classification A–F for proper case selection. In summary, classes A–C are characterized by being primarily endodontic lesions; classes D–F describe cases with associated periodontal involvement. In a comparison of surgical outcome of these classes, Kim *et al.* (2008) found a successful outcome of 95.2% for cases classified as A–C, which coincides with the success rates obtained in the meta-analysis on EMS. However, a success rate of 77.5% was found for classes D–F; the cases with endodontic–periodontal combined lesions was noted. Regenerative methods were employed in these cases. Further investigation is warranted in salvaging teeth with perioendo communication via microsurgical and regenerative techniques.

21.9 Resurgery

Most studies on the prognosis of resurgery report lower success rates than the first surgery, but most of these studies were before EMS was introduced. With the EMS-based technique, high success rates can be obtained even in resurgery, as supported by Song *et al.* (2011). Song observed a success rate of 92.9% in the 42 cases followed up for 2 years after the second surgical procedure. The most common cause of failure was no root end filling and incorrect root end preparation – either not along the long axis and/or insufficient depth (<3 mm). In conclusion, the failed cases usually represent the result of poor technique: the inability to control the anatomy at the apex and use of materials that fail to seal the microbial escape from the root canal system. Therefore, the use of high magnification and biocompatible materials such as Bioceramics can result in a high clinical success rate even in endodontic resurgery.

21.10 Summary

The success rates presented are undeniable evidence of the influence of the technical advances in surgical endodontics. It is up to the endodontic community to eliminate the variations in the technique that negatively influence the outcome. To achieve the high success rates the technique has to be strictly followed as each step serves a purpose in ensuring a successful outcome. Especially in times where salvageable teeth are being replaced by dental implants, it is an evidence-based certainty that teeth with lesions of endodontic origin can be treated with high success utilizing the triad of primary root canal therapy, nonsurgical *and* surgical retreatment. Surgical consideration is not a last uncertain effort to salvage the tooth but a viable, predictable, and highly successful treatment option.

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22

Positioning

Samuel Kratchman and Syngcuk Kim

KEY CONCEPTS

- Positioning of the doctor, the patient, the assistant, and the microscope are critical to an efficient microsurgery.
- Having to alter positions throughout the surgery will greatly increase the time of procedure as well as increase the difficulty.
- For maxillary teeth the patient's chin tilts downward and the microscope tilts away from the doctor.
- For mandibular teeth the patient's chin tilts upward and the microscope tilts towards the doctor.
- Gaining direct vision of any root without the need for a micromirror is critical for endodontic microsurgery.

22.1 Armamentarium

- Microscope
- Monitor
- Microsurgical instruments
- Two specialized pillows

Proper positioning is the key to any endodontic microsurgical procedure. This means proper positioning of the doctor, the assistant, the monitor, the patient, and the microscope. Without this, the surgical procedure will be longer than necessary, resulting in a longer and more painful recovery period for the patient. By understanding the concepts and with proper design of the operatory, the surgical procedure will be efficient and stress-free.

When thinking of the microscope, the first thing that comes to mind is magnification and illumination. These aspects are critical, but the microscope also allows for proper ergonomics of the doctor, preserving the back and neck of the practitioner, and therefore prolonging their career. The microscope allows one to sit upright and it is also recommended that the doctor's chair have proper arm rests, that allow the arms and elbows to rest comfortably and with only a slight bend (Figure 22.1).

The assistant is positioned with a direct view of the monitor, which, if the microscope has a video camera attached, allows the assistant to view the surgery live. This is critical as a well-trained assistant can assist off the monitor and therefore not having to bend into the patient's mouth as well as maintaining a good posture (Figure 22.2).

The monitor should never be in front of the doctor, because the doctor should be looking through the microscope, and it would be uncomfortable for the assistant to have to turn in order to see the monitor. Ideally, having two assistants for surgery will make the procedure more efficient. This allows one assistant to focus on retraction and suction, while the other assistant can pass the instruments and root end filling material.

The most important part of any endodontic procedure is patient comfort. This is true for surgery as well. Since the patient will be pivoting their chin depending on which arch is being worked on, it is critical to give the patient neck support with a pillow (Crescent Products, Rogers, Minnesota) (Figure 22.3).

When working on a maxillary or mandibular posterior tooth, the patient is instructed to rotate on to their side, as if in a sleeping position. This will allow the patient to remain comfortable throughout the procedure without unnecessary stress on their neck or back (Figure 22.4).

Another pillow is available when working on the posterior quadrants while the patient is lying on their side. This second pillow will give lower back support and prevent the patient from rolling back flat (Figure 22.5).

Microsurgery in Endodontics, First Edition. Syngcuk Kim and Samuel Kratchman.

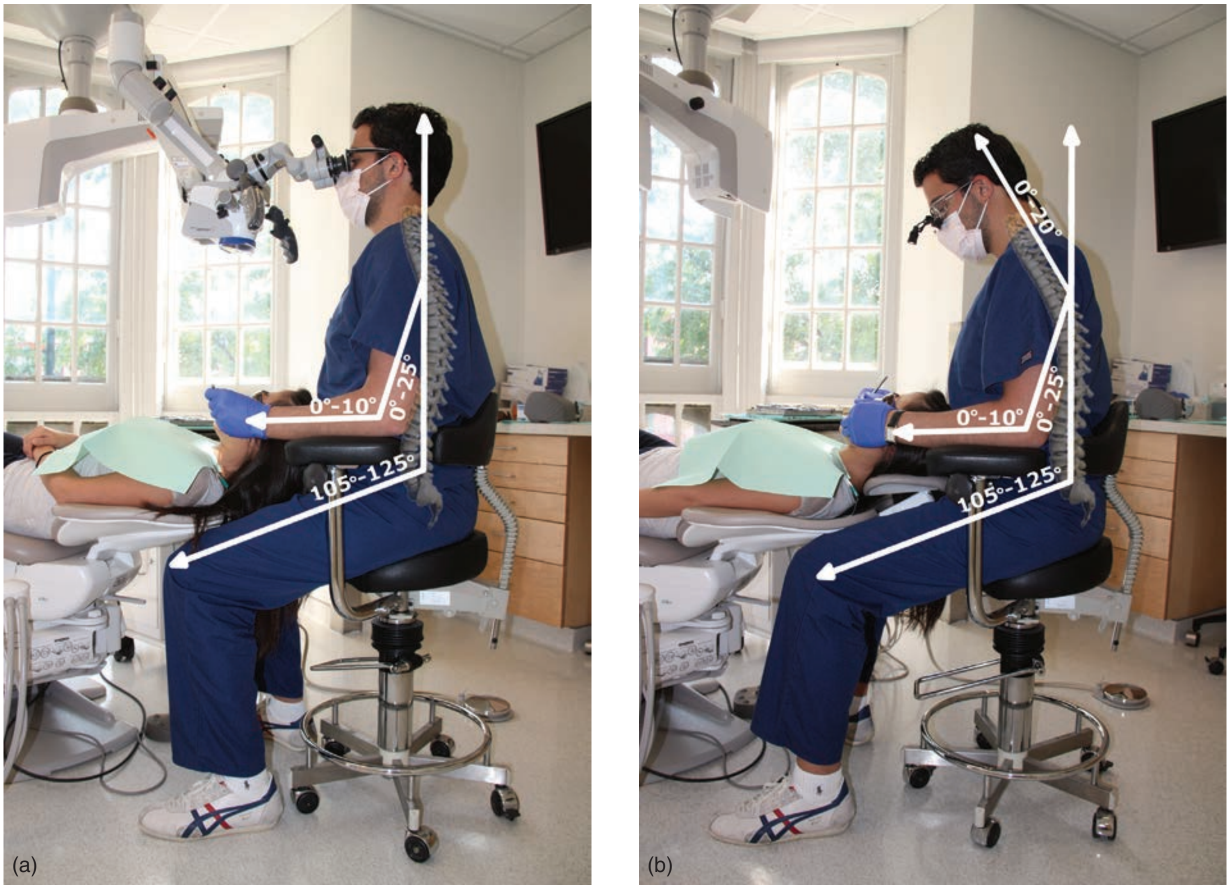

Figure 22.1 (a) Proper position of operator. (b) Improper position of operator, causing possible neck and back problems.

Figure 22.2 Surgical operatory with monitor in direct view of the assistant.

Figure 22.3 Neck pillow allowing patient to pivot chin for maxillary or mandibular teeth. (Thank you to Dr. Viola Hirsch for modelling.)

Regardless of the quadrant in the mouth being worked on, it is a necessity to maintain direct view of the root end being worked on. If there is dependence on the micromirror to see where the operator is working, this will slow down the procedure tremendously. Using the micromirror throughout the surgery would require a larger osteotomy to be able to fit the mirror together with a handpiece, as well as the constant need to stop and wipe the mirror due to water distorting the operator's view. The micromirror is designed for inspection only, whereas a direct view can be maintained of any root of any tooth, with proper patient/microscope positioning. For maxillary teeth, the patient's chin will pivot downwards, while the microscope tilts away from the patient (Figure 22.6).

When working on mandibular teeth the chin pivots up and the microscope tilts toward the doctor (Figure 22.7).

When the microscope and tooth are perpendicular, this will not allow for complete view of the entire root apex, necessitating the constant use of a micromirror (Figure 22.8).

Figure 22.4 Proper position of patient when working in maxillary or mandibular posterior quadrants.

Figure 22.5 Larger pillow for additional back support.

Figure 22.6 Position of microscope and patient to achieve a direct view of the maxillary anterior tooth.

Figure 22.7 Position of microscope and patient to achieve a direct view of the mandibular posterior tooth.

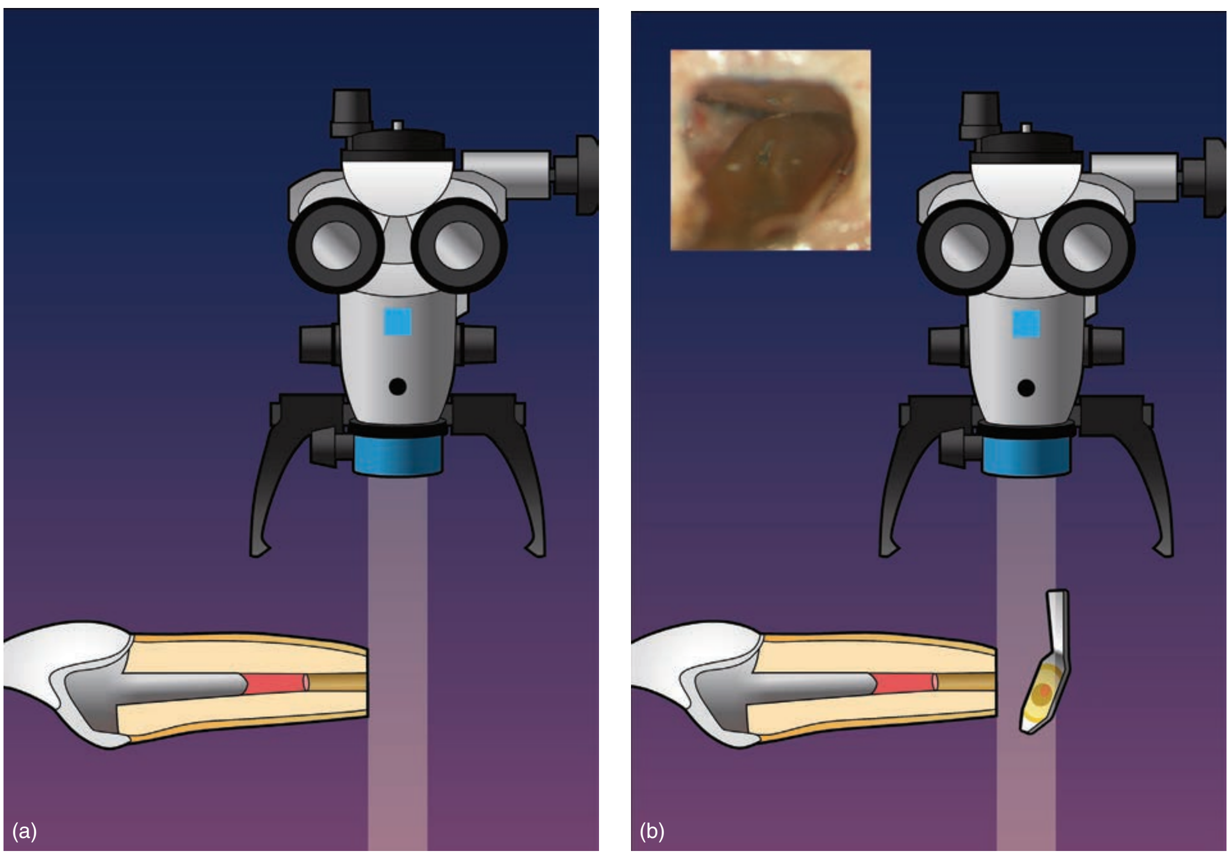

Figure 22.8 (a) Incorrect position requiring an indirect view of the apex. (b) The need for a micromirror to visualize the root apex.

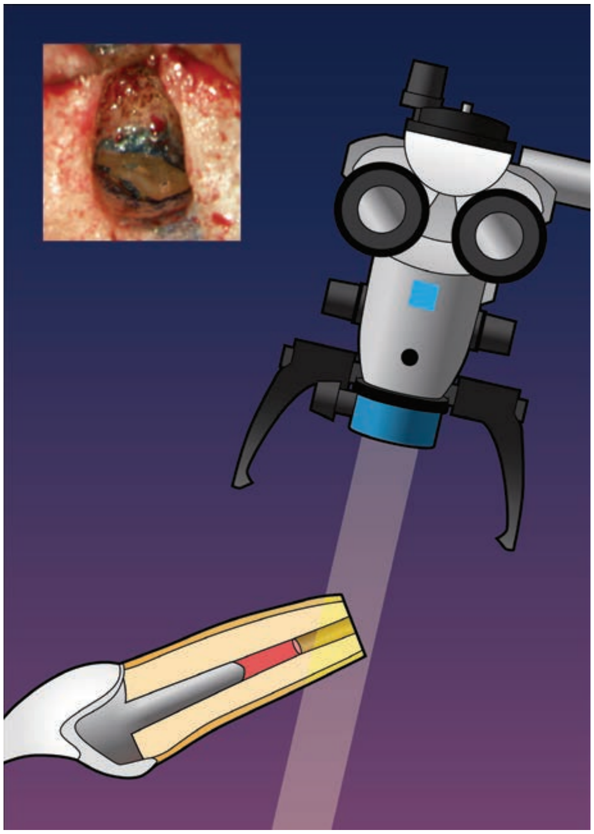

Figure 22.9 Correct position allowing a direct view of the entire apex.

When the microscope is inclined properly and the patient's head is tilted properly, then a complete view of the resected root surface can be achieved, without the need to bevel the root excessively, removing unnecessary root structure (Figure 22.9).

If all these directions are followed, every surgery procedure can be completed in a timely manner, which makes the recovery much quicker for the patient. Without proper positioning, the operator will end up spending more time adjusting the patient and the microscope, therefore prolonging the entire procedure as well as making surgery much more stressful than it needs to be.

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