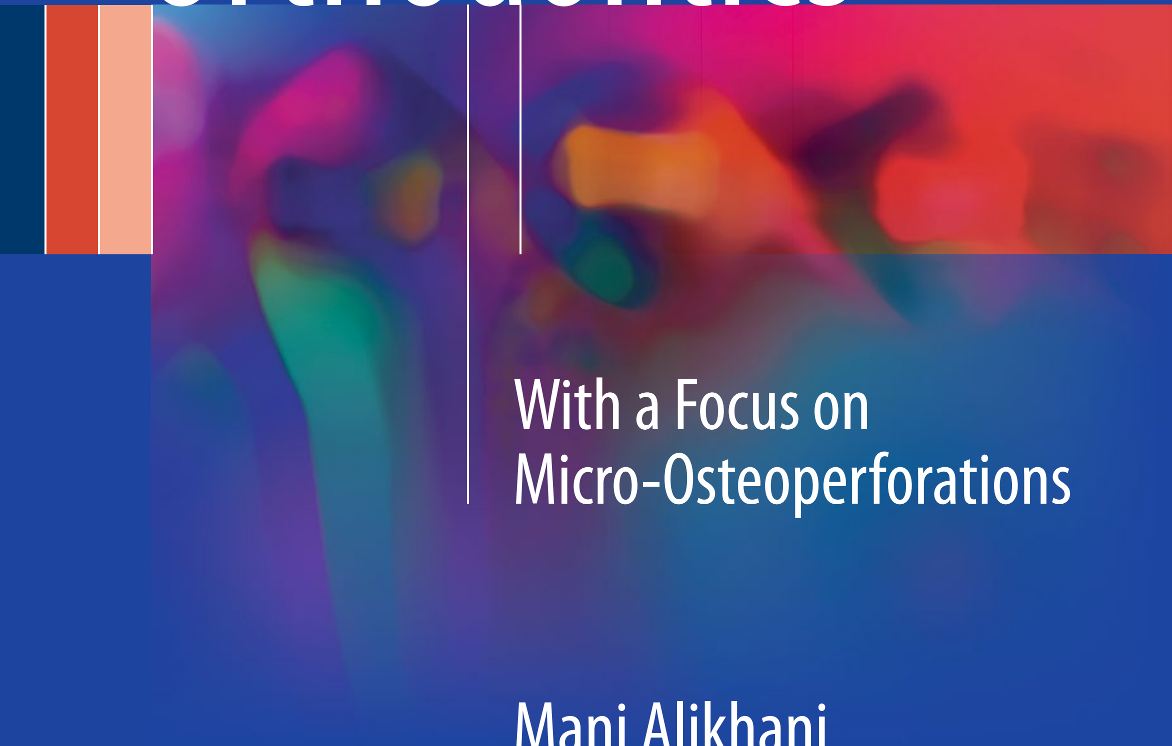
Clinical Guide to Accelerated Orthodontics



With a Focus on Micro-Osteoperforations

Mani Alikhani
Editor

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Preface

As scientists and orthodontists investigating tooth movement, I would be telling an incomplete story in this book if I did not introduce our readers to another movement – the CTOR Movement.

Several years ago, alongside a team of like-minded individuals, I started the Consortium for Translational Orthodontic Research (CTOR, www.orthodonticscientist.org), a center dedicated to translating bench and animal research into improved and innovative orthodontic therapies. This approach of performing basic science research that addresses specific clinical problems is the keystone of the CTOR Movement. Micro-osteoperforation (MOP) treatment, and the catabolic and anabolic effects described in this book, is the first successful result of this targeted research effort.

Since MOP treatment was patented, the CTOR Movement gained momentum, as CTOR researchers are busy developing new orthodontic treatment approaches. In fact, CTOR now has 7 patents for innovations that will revolutionize orthodontic and craniofacial orthopedic treatment. These include products and methods to enhance alveolar bone healing and maintenance, expand the boundaries of craniofacial and orthopedic corrections, and automated fully adjustable braces.

The CTOR Movement cannot survive without continued involvement of passionate clinician-scientists, each of whom is equal parts highly skilled orthodontist and highly skilled researcher. Motivated clinicians who strive to improve the profession of orthodontics but feel that their research skills are not up to the task are welcome to enroll in the CTOR Fellowship Program. Here, fellows find a welcoming environment where they learn to integrate their passion for clinical orthodontics with their imaginations and newly acquired research skills to become a unique clinician-scientist ready to tackle challenging problems in our profession. CTOR Fellowship graduates fit well in a number of roles, as evidenced by their careers as clinicians, educators, and leaders in their countries.

Another aspect of the CTOR Movement is CTOR's numerous collaborators at universities around the world. These richly rewarding collaborations bring clinicians and scientists together with CTOR scientists to develop, perform, and test methods and device prototypes in orthodontics and craniofacial orthopedics clinical trials. This aspect of the CTOR Movement is further enhanced through the numerous industrial partnerships that CTOR nurtures. These partnerships not only expand the range of CTOR-driven research and development, but they also allow CTOR to establish partnerships and consulting relations with a variety of orthodontics and biomedical manufacturing companies. This greatly improves the efficiency of getting our research ideas from concept to market.

The CTOR Movement represents a novel approach to translational research, which emphasizes research aimed specifically at real-life clinical problems that orthodontists face in their practices. In its short existence, CTOR has been a driving force for innovation in orthodontics, rooted on solid biological principles, advancing new theories for tooth movement and craniofacial growth, changing the way orthodontists will practice in this century. We believe the future of orthodontics is here and CTOR will be shaping it one invention at a time.

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Conflict of Interest

The original work on the effect of micro-osteoperforations on tooth movement resulted in a patent filled by New York University in which two of the editors/authors are named as inventors: Mani Alikhani and Cristina Teixeira.

The authors declare no further potential conflicts of interest with respect to the authorship and/or publication of this book.

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Biphasic Theory and the Biology of Tooth Movement

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1.1 Introduction

Teeth move through alveolar bone through naturally occurring drift or in response to orthodontic forces. Orthodontists want to optimize this movement while reducing potential risk factors. Orthodontic researchers have taken on this clinical challenge by uncovering the biological phenomena associated with tooth movement.

There is a general consensus that the major biological events that permit orthodontic tooth movement are bone resorption to remove alveolar bone in the path of movement followed by bone formation to maintain the integrity of alveolar bone. The rates of bone resorption and tooth movement are directly proportional, while the rate of bone formation determines treatment success. In broader terms, orthodontic tooth movement can be divided into two phases: bone resorption occurs during the catabolic phase, and bone formation occurs during the anabolic phase.

While we generally agree on the overall cellular and histological events necessary for orthodontic movement, the detailed mechanisms mediating these events are not completely understood. How do orthodontic forces activate bone resorption and formation? Do orthodontic forces directly or indirectly induce tooth movement? Does the periodontal ligament (PDL) influence the rate of tooth movement? To address these questions, we will begin by examining how bone cells function.

1.2 Bone Cells and Their Role in the Biology of Tooth Movement

Three types of bone cells play a significant role in the biology of tooth movement: osteoblasts, osteocytes, and osteoclasts. Osteoblasts are mononuclear cells found along bone surfaces. They are derived from mesenchymal stem cells in the bone marrow and synthesize collagenous and non-collagenous proteins that comprise the organic bone matrix, known as osteoid. Inactive osteoblasts, particularly in the adult skeleton, are called bone-lining cells. These cells are quiescent until growth factors or other anabolic stimuli induce their proliferation and differentiation into cuboidal osteoblasts. Osteoblasts are the main cells participating in the anabolic phase of orthodontic tooth movement with a limited role during the catabolic phase.

Osteocytes are mature osteoblasts immobilized in lacunae within the bone matrix. Notable for exquisitely fine processes that traverse the mineralized matrix in tunnels called canaliculi, osteocytes make contact with each other and with osteoblasts residing on the bone surface. As the most numerous cell type in the bone, the osteocyte's intricate three-dimensional intercellular network serves as the key mechanosensor for recognizing mechanical load and signaling osteoclasts and osteoblasts to reshape bone to fit the mechanical demand.

The mechanism by which mechanical stimulation activates osteocytes is not clear. Bone loading under physiologic condition results in strain, or deformation, in the bone matrix and the osteocyte lacunae and canaliculi. Some investigators suggest that it is the strain magnitude in the matrix, rather than in the lacunae or canaliculi, that triggers bone remodeling [1]. Conversely, others argue that load is not the major osteogenic trigger. They posit instead that load by-products, including strain rate [2], strain distribution [3], or fluid flow [4], are the primary remodeling initiators. While this controversy remains under active investigation, there is consensus that osteocytes detect mechanical stimulation via fluid shear stress resulting from increased fluid flow in the lacuno-canalicular system and electrical strain potentials. These responses to mechanical load activate osteocytes to secrete key factors, such as prostaglandins, nitric oxide, or insulin-like growth factors (IGFs), which then activate osteoclasts and osteoblasts in a tightly synchronized biological phenomenon called bone remodeling.

While it is clear that osteocytes are critical for normal bone remodeling, the precise role they play in the biology of tooth movement is unclear. They may play a role in the catabolic phase of movement by activating osteoclasts. However, it is more probable that they play a role in the anabolic phase by coordinating osteoblast activation.

Osteoclasts are the bone cells carrying out the critical job of resorbing bone during orthodontic tooth movement. Unlike osteoblasts and osteocytes, osteoclasts are specialized monocyte/macrophage family members, notable for forming through fusion of numerous monocytic precursors to create giant multinucleated cells. Terminal differentiation in this lineage is characterized by the acquisition of mature phenotypic markers, such as the calcitonin receptor and tartrate-resistant acid phosphatase (TRAP), and the appearance of a ruffled border rich in proton pumps that acidify the bone surface to which the cells are attached, resulting in resorption pits.

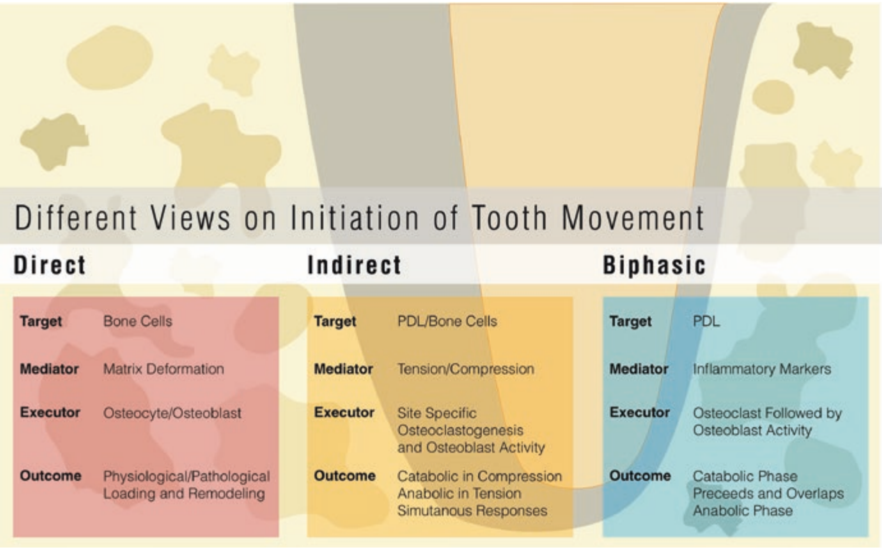
Osteoclasts control the rate of bone resorption during orthodontic treatment and, therefore, the rate of tooth movement. However, osteoclasts do not function independently. In fact, they require signals from several other cell types for their maturation, activation, and ability to perform targeted, site-specific bone resorption. The consequences of unregulated osteoclast activation would be catastrophic as bone resorption would proceed unchecked producing weakened bone and fractures. Consequently, osteoclasts cannot be direct targets of orthodontic forces. Instead, the upstream events that control osteoclast formation and activation must be the main targets. What these upstream events are remains controversial; but they can be foundations for developing new theories in the biology of tooth movement. We have compiled the scientific evidence to support a new *Biphasic Theory of Tooth Movement*.

1.3 Catabolic Phase of Orthodontic Tooth Movement

1.3.1 Theories on Initiation of Tooth Movement

Orthodontic forces produce different types of movement depending on the magnitudes of forces and couples applied to the teeth. Each type of tooth movement causes a specific stress distribution across the PDL and alveolar bone. It is widely accepted that areas experiencing the highest compression stresses undergo the highest levels of osteoclastic bone resorption. Many theories have been proposed to explain the initial events leading to osteoclast activation in these compression sites. In general, these theories split into two camps: one proposes that bone cells (especially osteocytes) are the direct target of orthodontic forces (*Direct View*), while the other proposes that the PDL is the key target of orthodontic treatment (*Indirect View*) (Fig. 1.1). Importantly, there is agreement in both theories that osteoclasts are the cells that resorb bone and, therefore, are the cells that control the rate of tooth movement.

Based on research involving stress responses in weight-bearing bone, the Direct View proponents claim that there are two mechanisms by which direct loading may activate osteocytes. First, when mechanical stimulation is at physiologic levels, osteocytes "measure" the different components of mechanical stimulation (such as matrix deformation) and direct the bone remodeling machinery by triggering osteoclasts to remove weakened old bone and rebuild new load-tolerant bone by activating osteoblasts. By this mechanism, orthodontic tooth movement is considered a physiologic adaptation to mechanical stimulation induced by orthodontic forces. Second, higher (pathologic) mechanical loads produce microfractures in the matrix, which are detected by osteocytes, resulting in increased bone remodeling at the



Different Views on Initiation of Tooth Movement

	Direct	Indirect	Biphasic
Target	Bone Cells	PDL/Bone Cells	PDL
Mediator	Matrix Deformation	Tension/Compression	Inflammatory Markers
Executor	Osteocyte/Osteoblast	Site Specific Osteoclastogenesis and Osteoblast Activity	Osteoclast Followed by Osteoblast Activity
Outcome	Physiological/Pathological Loading and Remodeling	Catabolic in Compression Anabolic in Tension Simutanous Responses	Catabolic Phase Preceeds and Overlaps Anabolic Phase

Fig. 1.1 Theories on initiation of tooth movement. Histological studies have supported classical theories on the biological mechanism responsible for tooth movement. This schematic summarizes the main differences among currently accepted theories that can be described in terms of targets, mediators, executers, and outcomes. The Direct and Indirect views have different targets for the initial orthodontic force. However, they assume that catabolic and anabolic responses in bone are independent, simultaneous, and geographically limited to areas exposed to compression and tension stresses, respectively. The Biphasic Theory incorporates the latest evidence on the biology of tooth movement and proposes an initial phase of catabolism in response to trauma and inflammation, which in turn activates an anabolic phase. Geographically, these catabolic and anabolic responses can overlap due to extensive coupling of osteoclast and osteoblast activation

damaged site. By this mechanism, orthodontic tooth movement is considered a response to trauma caused by orthodontic forces.

While the osteocyte-driven bone remodeling response to physiologic or pathologic levels of forces is supported by data derived from studies of weight-bearing bones, applying this theory of bone remodeling in response to orthodontic forces is questionable. Experiments in long bones and alveolar bone demonstrate that at physiologic levels, osteocytes do not recognize static forces [5, 6]. This argues against considering orthodontic tooth movement as a physiologic adaptation to mechanical stimulation, since orthodontic forces are mostly static rather than intermittent, as long bones would experience. Further rejecting that idea, forces applied to dental implants used as anchorage during orthodontic treatment do not induce movement of the implant.

Can orthodontic forces stimulate tooth movement by inducing microfractures in the bone? While microfractures occur in response to orthodontic forces [7], the possibility that this is the main mechanism triggering tooth movement is low because orthodontic force cannot move an ankylosed tooth. Moreover, the relationship between force magnitude and tooth movement is not linear, and soon after applying orthodontic force, the bone remodeling rate reaches a saturation point. If microfractures are the trigger for tooth movement, higher forces should continually increase the rate of movement, without ever reaching a saturation point [8]. It should be emphasized that while application of high-magnitude forces (at the pathologic level) may damage the bone around an implant significantly to the point of implant failure, high-magnitude forces do not move the implant in bone. Taken together with the fact that low-magnitude forces (at the physiologic level) are applied during clinical orthodontics, these data strongly suggest that microfractures are not the trigger for orthodontic tooth movement.

Supporters of the Indirect View of tooth movement propose that the PDL is the primary target of orthodontic forces. Consider the impossibility of moving an ankylosed tooth, which lacks a PDL. Based on this proposal, different orthodontic forces produce characteristic compression and tension patterns within the PDL, and these patterns are time dependent. For example, if a compressive force is applied for only a few seconds (i.e., it is intermittent), fluids filling PDL spaces prevent quick displacement of the tooth because the fluids are incompressible. However, if a compressive force is sustained (i.e., it is static, as in orthodontic treatment), fluids are squeezed out of the PDL, providing space for tooth displacement in the socket and further PDL compression. The immediate result of this displacement is blood vessel constriction in the compression site, resulting in decreased blood flow and nutrient and oxygen levels (hypoxia) in the compression site. Depending on the magnitude of pressure and blood flow impairment, some of the cells undergo apoptosis, while other cells die nonspecifically, resulting in necrosis that is identified histologically as the cell-free zone. Apoptotic or necrotic changes are not limited to PDL cells, and osteoblasts and osteocytes in adjacent alveolar bone may also die in response to orthodontic forces.

The physiologic and pathological responses to orthodontic force may have different outcomes, but initially both responses produce an aseptic, acute inflammatory

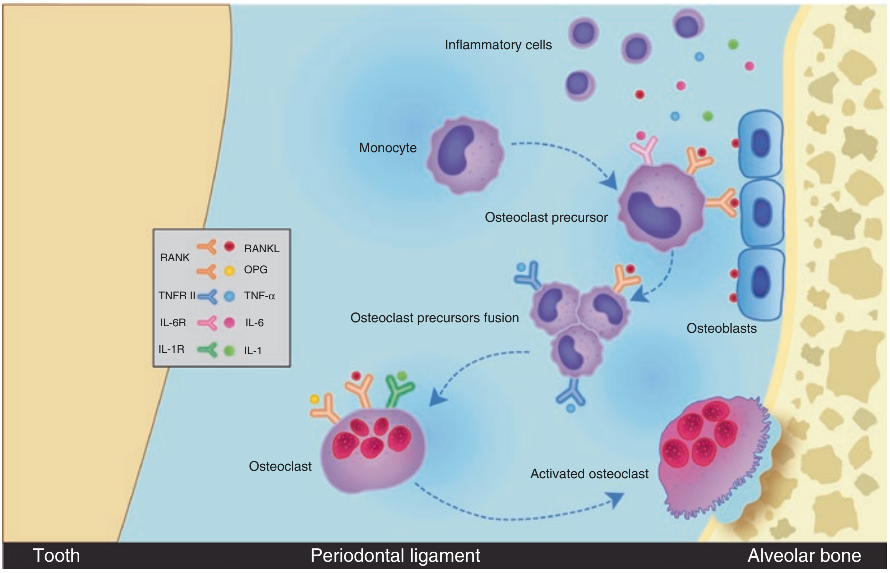


Fig. 1.2 Cytokines regulate osteoclastogenesis. Cytokines are important mediators of osteoclastogenesis that perform varied roles throughout the differentiation of monocyte-macrophage precursors into mature osteoclasts. Inflammatory cells (which migrate from the bloodstream into the PDL in response to orthodontic forces) and local cells (such as osteoblasts) express receptor activator of nuclear factor κB ligand (RANKL), which then binds to its receptor (RANK) on the surface of osteoclast precursors (such as monocytes). RANK-RANKL binding initiates adhesion of these cells to each other to form multinucleated osteoclasts. While some of these cytokines induce osteoclast precursors to differentiate into osteoclasts (RANKL, TNF-α), others directly stimulate osteoclast activation (RANKL, IL-1). Additionally, local cells can also downregulate osteoclastogenesis by producing a RANKL decoy receptor, osteoprotegerin (OPG)

response with the early release of chemokines from local cells (Fig. 1.2). Chemokines are small proteins released from local cells that attract distant cells to the area by facilitating expression of adhesion molecules in blood vessels and stimulating recruitment of inflammatory and precursor cells from the microvasculature into the extravascular space. Given their strong biological influence on localized cellular activity, it is important to discuss chemokines in the context of the biology of tooth movement and to demonstrate their role in our Biphasic Theory of Tooth Movement.

1.3.2 Initial Aseptic Inflammatory Response

Chemokines released early in orthodontic tooth movement are critical for triggering bone resorption. Monocyte chemoattractant protein-1 (MCP-1/CCL2) recruits monocytes from the bloodstream to enter the surrounding tissue where they become tissue macrophages or, importantly to us, osteoclasts [9]. Similarly, CCL3 and [10] and CCL5 (RANTES) [11] released during orthodontic tooth movement lead to osteoclast recruitment and activation.

Shortly after applying orthodontic forces, a broad spectrum of mediators is released from inflammatory and local cells. These inflammatory mediators are cytokines, extracellular proteins that induce both pro- and anti-inflammatory processes. Pro-inflammatory cytokines help to amplify or maintain inflammation and bone resorption. The primary pro-inflammatory cytokines released during orthodontic tooth movement are IL-1α, IL-1β, TNF-α, and IL-6 [12]. Importantly, cytokines are also anti-inflammatory, thereby preventing runaway inflammation. Inflammatory cells, such as macrophages, and local cells, such as osteoblasts, fibroblasts, and endothelial cells, release this cocktail of inflammatory regulators.

Two other classes of inflammatory mediators that are released during orthodontic tooth movement deserve special mention. First are the prostaglandins (PGs), which are derived from arachidonic acid metabolism and can mediate virtually every step of inflammation such as vasodilation, increase vascular permeability, and cellular adhesion. During orthodontic tooth movement, PGs are produced directly (by local cells or by inflammatory cells in response to mechanical stimulation) or indirectly (by cytokines). For example, TNF-α potently stimulates PGE_2 formation [13]. PGs act locally where they are generated, and then they spontaneously decay or are enzymatically destroyed [14, 15]. Second are the neuropeptides that participate in many stages of inflammation due to orthodontic forces. Neuropeptides are small proteins, such as substance P, that transmit pain signals, regulate vessel tone, and modulate vascular permeability [16].

The importance of all of these inflammatory markers when discussing orthodontic tooth movement is highlighted by their role in osteoclastogenesis. Remember, osteoclast activation is the first and rate-limiting step in orthodontic tooth movement. Without the chemokines and inflammatory cytokines to trigger osteoclast formation and activation, we could not move teeth. Thus, let us now turn our attention to the mechanisms by which inflammatory mediators influence this critical step in orthodontic treatment.

1.3.3 Inflammatory Mediators Governing Osteoclastogenesis

As previously discussed, osteoclasts are multinucleated giant cells derived from hematopoietic stem cells in the monocyte-macrophage lineage. Functionally, osteoclasts are highly specialized to resorb bone. After recruitment to the compression sites, monocyte-macrophage precursors begin to differentiate into osteoclasts. Cells responding to orthodontic forces secrete cytokines into the extracellular environment, which then bind to their receptors on the precursor cells to trigger osteoclastogenesis and activation. For example, TNF-α and IL-1 bind to their receptors, TNFRII [17] and IL-1R [18], respectively, and directly stimulate osteoclast formation from precursor cells and osteoclast activation (Fig. 1.2). Additionally, IL-1 and IL-6 [19] indirectly stimulate local cells or inflammatory cells to express macrophage colony-stimulating factor (M-CSF) and receptor activator of nuclear factor κB ligand (RANKL), which then induce cell-to-cell interactions through their respective receptors, c-Fms and RANK, on the osteoclast precursor surface (Fig. 1.2).

RANKL is a potent osteoclast activator; thus, it is not surprising that other inflammatory mediators enhance osteoclast formation through enhancing RANKL expression. PGs, especially PGE_2, released by stromal cells, have been studied extensively for their role in mediating orthodontic tooth movement [20]. As mentioned before, local cells produce PGs directly in response to orthodontic forces or indirectly as downstream targets of cytokines, such as TNF-α. As would be expected of such a potent inflammatory mediator, the RANK-RANKL pathway is tightly regulated. Local cells normally downregulate RANK-RANKL-induced osteoclastogenesis by producing a RANKL decoy receptor, osteoprotegerin (OPG) [21]. Therefore, OPG levels in compression sites must decrease to enable tooth movement.

1.3.4 Cytokine Inhibition and Tooth Movement

The importance of cytokines in controlling the rate of tooth movement can be appreciated from studies that block their effects. Injecting IL-1 receptor antagonist or TNF-α receptor antagonist (sTNF-α-RI) results in a 50% reduction in tooth velocity [22–25]. Similarly, tooth movement in TNF type II receptor-deficient mice is reduced compared to wild-type mice [26]. Animals deficient in chemokine receptor 2 (a receptor for chemokine ligand 2) or chemokine ligand 3 show a significant reduction in orthodontic tooth movement and the number of osteoclasts [27]. Likewise, nonsteroidal anti-inflammatory drugs (NSAIDs) inhibit PG synthesis, which then reduces the rate of tooth movement [28, 29]. Inhibiting other derivatives of arachidonic acid, such as leukotrienes, also significantly decreases the rate of tooth movement [30].

1.3.5 Saturation of the Biological Response

Taken together, the studies on inflammation strongly support the conclusion that inflammatory markers play a critical role in orthodontic tooth movement by controlling the rate of osteoclast formation and, therefore, bone resorption. It logically follows that increasing the magnitude of orthodontic forces would trigger a cascade of increased inflammatory marker expression and osteoclastogenesis resulting in faster tooth movement. Surprisingly, a major controversy among researchers studying the biology of tooth movement revolves around the relation between force magnitude and the rate of tooth movement. Some studies show that higher forces do not increase the rate of tooth movement [31, 32], while others argue the opposite [33]. This incongruity is explained by inappropriately equating the distance teeth move with the rate at which teeth move for any given magnitude of force. Although tooth movement is indeed the desired result of the biological response to force, it does not precisely measure the relation between force magnitude and the biological response that regulates the rate of tooth movement.

Many factors affect the amount of tooth movement independent of the force magnitude. These factors can be intrinsic, such as differences in root shape and alveolar bone density, or they may be extrinsic, such as occlusal forces, chewing habits, or limitation of the orthodontic appliance's mechanical design. These variables are difficult to accurately assess in humans due to the need for a large group of subjects with similar anatomical features, age, gender, and type of malocclusion. While these limitations are easier to control in animal models, depending on the study duration, measuring tooth movement as the sole representative of the effect of force magnitude can still produce conflicting results because the biological response varies throughout the stages of tooth movement. Different investigators may capture different stages of this biological response and make erroneous conclusions that do not represent the complete process.

Because of biological and experimental design limitations mentioned above, it is logical to study the biological response to different force magnitudes in rats that share a similar genetic background and use molecular and cellular changes, rather than the magnitude of tooth movement, as the outcome measurements in studies on effect of force on the rate of tooth movement. Using this approach, recent studies demonstrate that increasing the magnitude of orthodontic force increases inflammatory marker levels, osteoclast recruitment and formation, alveolar bone resorption, and the rate of tooth movement. Unexpectedly, these studies revealed that there is a force level above which we cannot stimulate the biological responses any further [34]. Thus, the cytokine release that orthodontic forces can produce has an upper limit, and consequently the osteoclast activity initiated by orthodontic forces has a saturation point (Fig. 1.3). While the saturation point can vary with the type of tooth movement, patient anatomy, bone density, and duration of treatment, the range of this variation is limited, and therefore, the rate of tooth movement is usually predictable. While increasing the force magnitude does not overcome this limitation, any methodology that can increase the osteoclast numbers in the area could be the answer to enhancing this biological response.

1.4 Anabolic Phase of Orthodontic Tooth Movement

1.4.1 Osteoblast Activation

The catabolic phase of tooth movement that we just discussed is followed by an anabolic phase that allows the bone to keep its new morphological relation with adjacent structures. Importantly, the anabolic phase must involve both the trabecular and cortical bone. However, the molecular events that initiate the anabolic phase are not clear.

Alveolar bone on the side opposite to the direction of tooth movement is exposed to tensile stresses. Similar to osteoclast activation on the compression side, osteoblast activation on the tension side cannot be denied. But why are osteoblasts activated on the tension side? Some have suggested that osteoblast activation in these

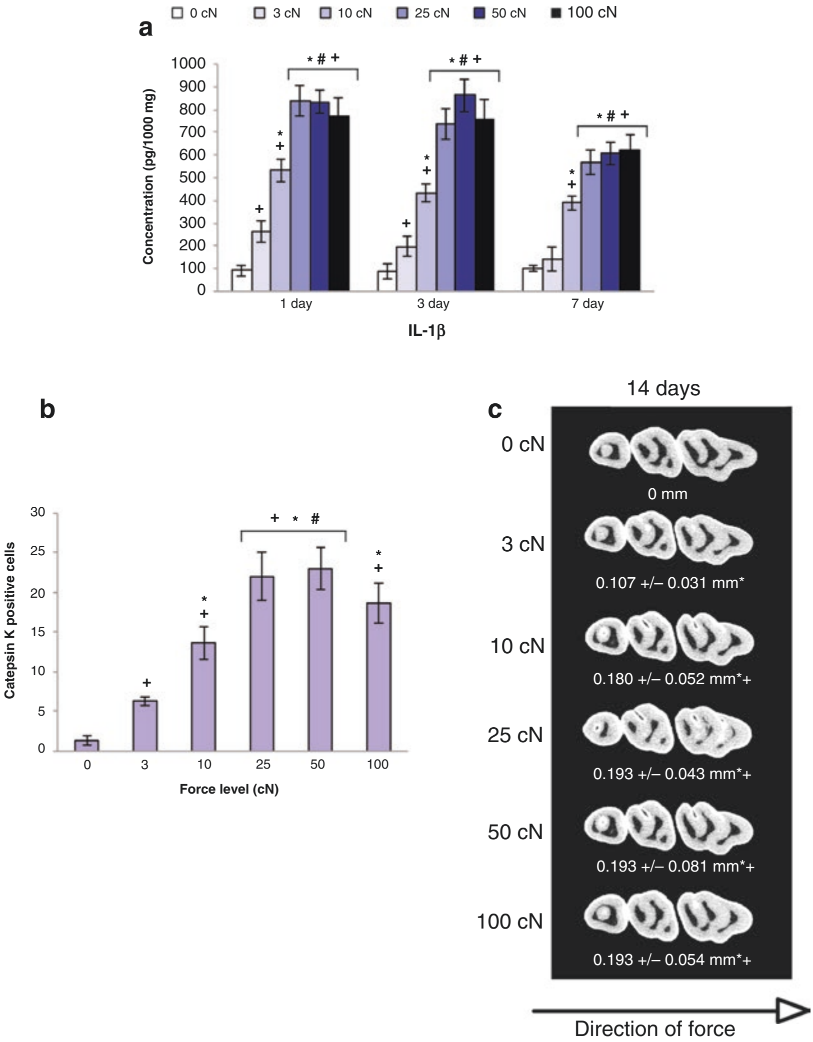


Fig. 1.3 Saturation of biological response with increased orthodontic forces. The upper right maxillary molar of rats was exposed to different magnitude of forces (0 to 100 cN), and the hemimaxilla was collected for analyses at different time points. (**a**) IL-1 β was evaluated by enzyme-linked immunosorbent-based assay after 1, 3, and 7 days of force applications. Data expressed as the mean ± SEM of concentration in picograms per 100 mg of tissue. (+ Significantly different from 0 cN at same time point; * significantly different from 3 cN at same time point; # significantly different from 10 cN at same time point.) (**b**) Mean numbers of osteoclasts in the PDL and adjacent alveolar bone of mesiopalatal root of maxillary molar 7 days after application of force. Osteoclasts were identified as cathepsin K-positive cells in immunohistochemical stained sections (brown cells) from different force groups. Each value represents the mean ± SEM of five animals (+ significantly different from 0 cN; * significantly different from 3 cN; # significantly different from 10 cN). (**c**) Micro-CT images of right maxillary molars of control and different experimental groups 14 days after application of force. Each value represents the mean ± SEM of the average distance between first and second molar measured at height of contour in five animals (* significantly different from 0 cN; + significantly different from 3 cN)

areas is simply a response to tensile stresses. However, many observations discredit this view. While some in vitro experiments demonstrate osteoblasts activation in response to tensile forces [35], these experiments have not been supported by in vivo studies. Experiments in long bones and alveolar bone demonstrate that at physiologic levels, osteoblast activation requires intermittent loads of specific frequency and acceleration [6, 36, 37]. Therefore, application of static tensile forces such as orthodontic forces would not be able to explain bone formation on the tension side. Furthermore, it has been shown that static tensile forces on long bones cause bone resorption and not formation [38]. Interestingly, tensile forces that are applied with high frequency and acceleration are osteogenic, similar to compression forces [5, 39]. Thus, other factors must explain the anabolic phase of orthodontic tooth movement. The Biphasic Theory of Tooth Movement was developed to address these inconsistencies.

1.5 Biphasic Theory of Tooth Movement

As we have just detailed, the biological phenomenon of tooth movement results from tightly coupled and choreographed responses of osteocytes, osteoclasts, and osteoblasts to orthodontic forces. Specifically, evidence points to the conversion of orthodontic forces into temporally sequenced catabolism followed by anabolism in alveolar bone. Taken together, the data on tooth movement led us to developed the Biphasic Theory of Tooth Movement to not only more fully explain the biological consequences of orthodontic treatment but to also guide researchers to develop accelerated, efficacious, and safe orthodontic treatments.

1.5.1 Biology of Tooth Movement: Rethinking the Existing Data

The classic theory of the biology of tooth movement has three main pillars:

1. Compression activates osteoclastogenesis and osteoclast activation, while tension activates osteoblasts; therefore, osteoclasts should populate compression sites, and osteoblasts should populate tension sites.
2. The catabolic and anabolic responses occur independently of each other in the PDL, on opposite sides of the tooth.
3. Although independent, the catabolic and anabolic phases occur simultaneously, since both compression and tension occur simultaneously.

While these principles are still the foundation of current thinking, they are only partially true. Histologic sections at early time points of force application demonstrate activation of osteoclasts on both compression and tension sites, suggesting that both compressive and tensile forces can traumatize the PDL (Fig. 1.4a). It also demonstrates unequivocally that osteoclastogenesis is not limited to the compression side. This can clearly be observed in uCT scans of alveolar bone around

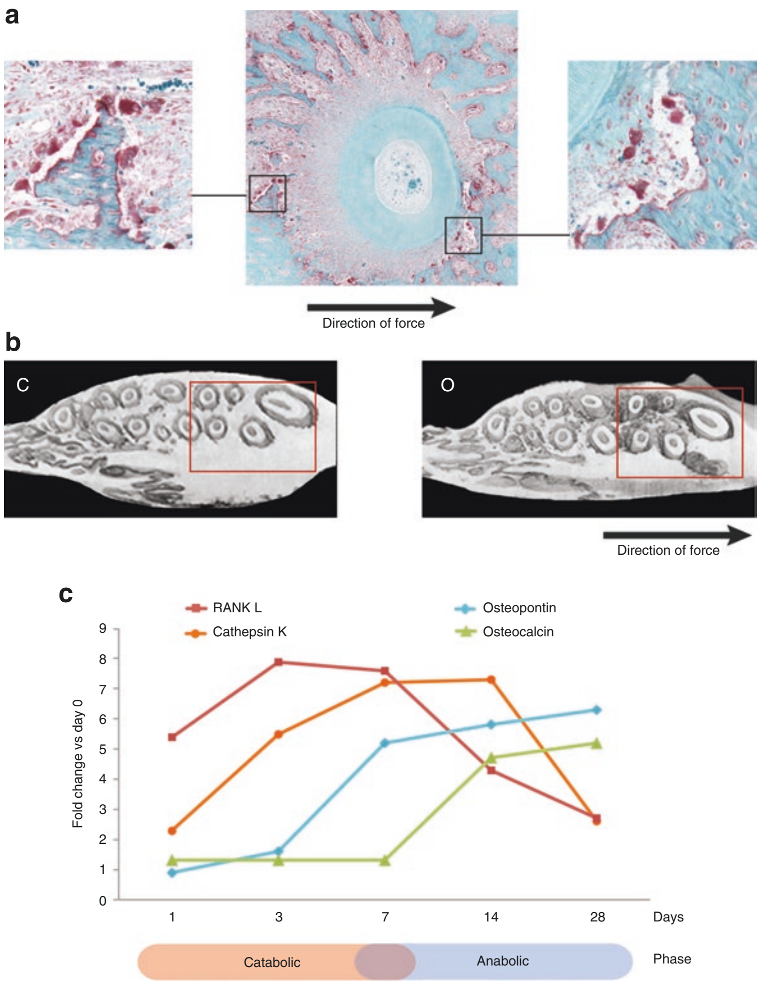


Fig. 1.4 Evidence supports the Biphasic Theory of Tooth Movement. Rat hemimaxilla was collected at different time points after application of force (25 cN) to mesialize the first molar. Control animals did not receive any force. (**a**) Immunohistochemical staining for tartrate-resistant acid phosphatase 3 days after force application. Axial section shows osteoclasts identified positive red cells in both the tension and compression side of the moving root. (**b**) Micro-CT images of right maxillary molars of control (*C*) and orthodontic force (*O*) animals, 14 days after application of force, show significant osteopenia surrounding the moving first molar (*red rectangular area*). (**c–e**) Reverse transcription polymerase chain reaction analysis of osteoclast (RANKL and cathepsin K) and osteoblast (osteocalcin and osteopontin) markers in the hemimaxilla of rats at different time points after force activation. Data is presented as fold increase in expression in response to orthodontic force compared to day 0 and as mean ± SEM of three experiments. (**c**) The onset of significant differences in RANKL and cathepsin K was observed at day 3 and for osteopontin and osteocalcin at day 7 and day 14, respectively, supporting a catabolic phase preceding and anabolic phase during tooth movement. (**d**, **e**) Reverse transcription polymerase chain reaction analysis of rat maxillae where molars were moved in the absence (ortho) or presence (ortho + AI) of anti-inflammatory drugs, added to the drinking water (* significantly different from ortho group)

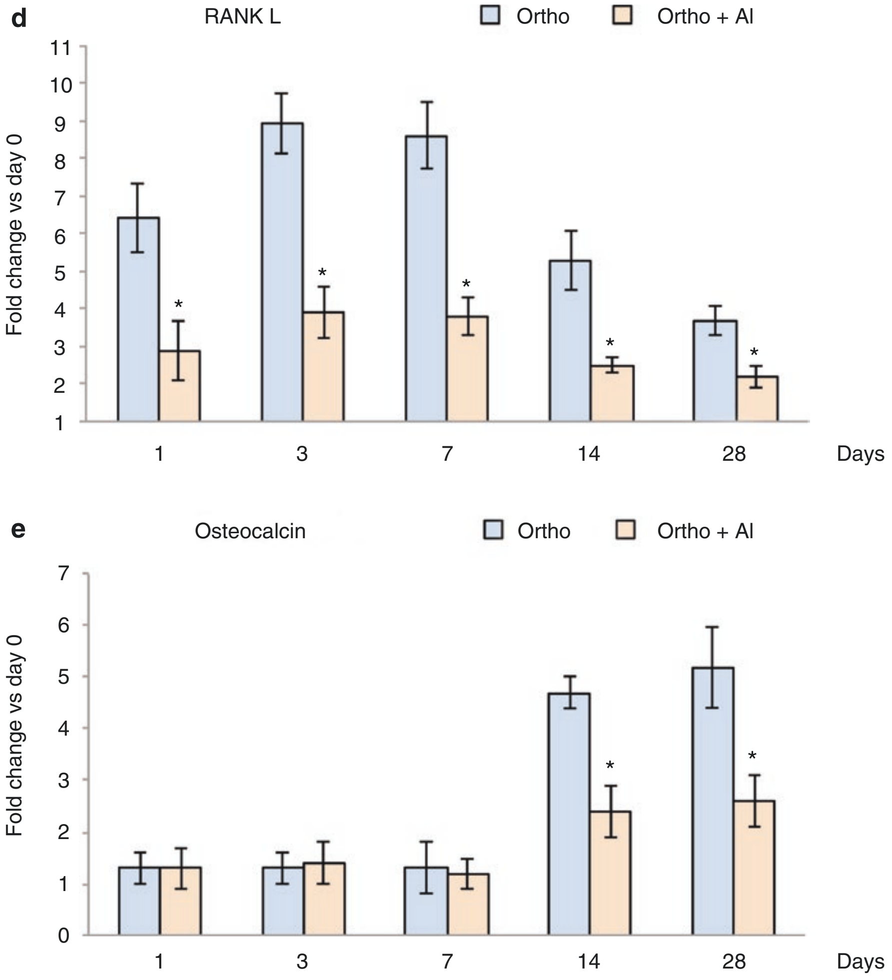


Fig. 1.4 (continued)

moving teeth, which demonstrate increased radiolucency all around the tooth and not only on the compression side (Fig. 1.4b).

It is also illogical to assume a strict geographical distribution of bone resorption and formation based on compression and tension. If tension produced only bone formation without any resorption, then the trailing, tension-bearing alveolar bone would become measurably (in fact, ridiculously) thicker following tooth movement. Likewise, if compression only produced bone resorption, then there would be complete resorption of alveolar bone at the leading, compression-bearing region of the socket. In fact, neither of these occurs, which means that both catabolic and anabolic responses occur in the alveolus around the entire tooth – regardless of the type of force that is actually experienced at a specific site – ensuring that the alveolus remains intact throughout orthodontic treatment.

While both the catabolic and anabolic phases occur at all points around the tooth, they do not occur simultaneously. There is a measurable delay in the anabolic phase following the catabolic phase, as demonstrated by the high expression of osteoclasts markers at early stage of tooth movement and high expression of osteogenic markers toward later stages of tooth movement (Fig. 1.4c). If the anabolic phase results directly from tensile stress, then one would expect osteoblast activation and the expression of bone formation and resorption markers to occur simultaneously, without any delay. Furthermore, when anti-inflammatory medication is given (with a subsequent decrease in osteoclastogenesis), osteogenic activity decreases significantly as measured by decreased osteogenic marker expression (Fig. 1.4d, e).

Based on these observations, it logically follows that the biologic response during tooth movement comprises two clearly separated phases that are not site specific. Indeed, contrary to the three pillars supporting the current concept of orthodontic tooth movement, *both* compression and tension stresses cause damage to the PDL, which simultaneously stimulate a perimeter of osteoclastogenesis (Fig. 1.5b). The tooth will move in the direction of the orthodontic force into the space created by osteoclast activity, and with that movement, the perimeter of osteoclastogenesis drifts in the direction of the force. This phase is followed by an anabolic phase, where osteoblasts are activated to replace the destroyed bone, creating a perimeter of osteogenesis (Fig. 1.5c). The osteoclastogenesis perimeter is a prerequisite for the activation of the osteogenic perimeter. It is important to note that in considering our proposal that there is a strict temporal relationship between the osteoclastogenesis and osteogenic phases, histological sections would appear to contradict our conclusion by demonstrating that the two phases are independent events. Remember, histological sections are deceiving because they are static representations that cannot depict a dynamic phenomenon. Instead, the data on osteoresorptive and osteogenic markers clearly support the temporal relationship that we propose.

In the Biphasic Theory of Tooth Movement, osteoclasts play an important role in the activation of osteoblasts. This agrees with numerous studies that suggest osteoclasts are principle osteoblast regulators [40]. In healthy individuals, osteoclast activation is tightly coupled to osteoblast activation. This effect can occur through different pathways: (1) osteoclasts release paracrine factors that directly recruit and activate osteoblasts; (2) osteoclasts activate osteoblasts through direct cell-cell interaction; (3) bone resorption by osteoclasts exposes bone matrix proteins that then indirectly attract and activate osteoblasts (Fig. 1.6). While these pathways differ fundamentally, they do share an important feature. In each case, osteoclast activity precedes osteoblast activity. This directionality is seen any time osteoclasts are activated – not just during orthodontic tooth movement – and is best visualized by the remodeling cone where the head of the cone is occupied by osteoclasts and the tail of the cone is filled with osteoblasts. By harnessing this repeatable and

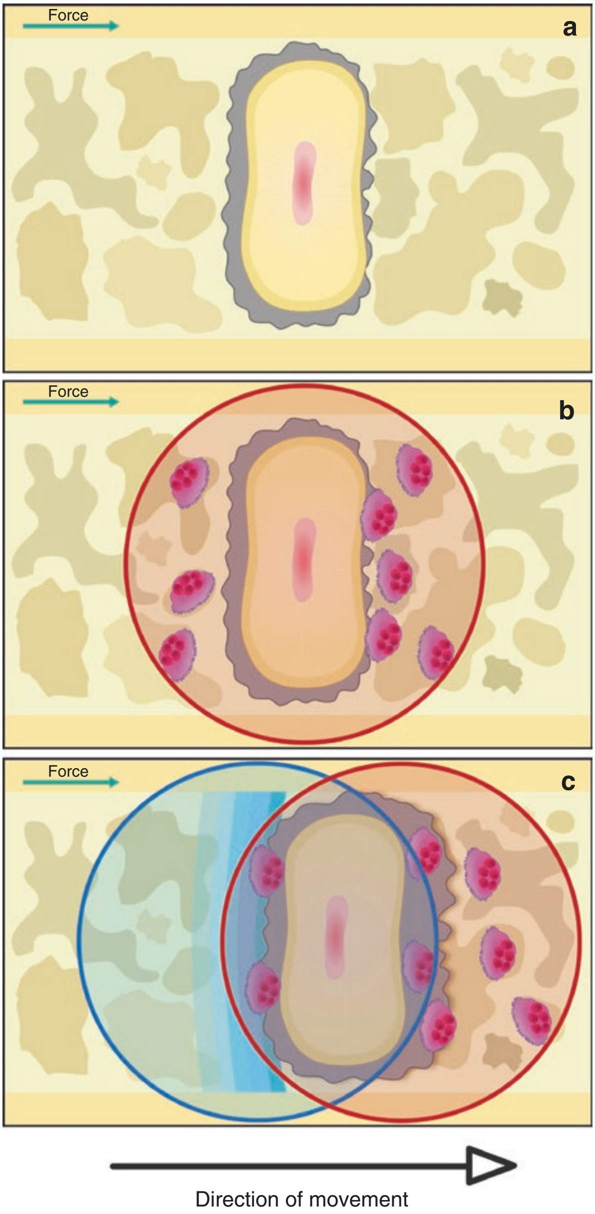


Fig. 1.5 Schematic of Biphasic Theory of Tooth Movement. The biologic response during tooth movement comprises two clearly separated phases. After application of an orthodontic force (**a**), both the compression and tensile stresses generated by displacement of the tooth cause damage to the PDL, stimulating a perimeter of osteoclastogenesis (**b**). Once the tooth moves in the direction of the orthodontic force into the space created by osteoclast activity, a perimeter of osteogenesis is created in roughly in the same area of the alveolar bone where the catabolic response took place (**c**). As a result, the tooth moves in the direction of the force

predictable sequential process, we can increase the anabolic effect of orthodontics in both trabecular and cortical bone. This phenomenon and the concept of a biphasic unit will be discussed in detail in Chap. 5.

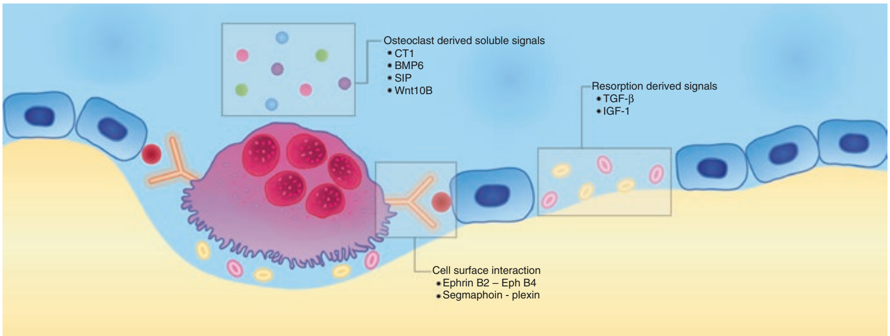


Fig. 1.6 Coupling of osteoclast activity with osteoblast activity. The coupling of the catabolic response (osteoclast activity) with the anabolic response (osteoblast activity) during orthodontic tooth movement can occur through different pathways: osteoclast-derived signals working in a paracrine fashion (such as BMP6 or Wnt10B), direct cell-cell interaction (such as ephrin B2-Eph B4), and growth factors released from the matrix during bone resorption (such as TGF-β and IGF-1)

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Different Methods of Accelerating Tooth Movement

2

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2.1 Introduction

The increased demand for fast orthodontic treatment, especially by adult patients, has lead researchers in the field to focus on accelerated tooth movement with the aim of reducing treatment duration while maintaining treatment efficiency. The approach that researchers select to accelerate the rate of movement depends on their interpretation of the data on the biology of tooth movement. A researcher who chooses to amplify body reactions to orthodontic forces may either try to increase the release of cytokines (if they believe inflammatory responses of the PDL and bone are the key factor in controlling the rate of tooth movement) or optimize the mechanical stimulation (if they believe orthodontic tooth movement is a direct physiologic response to mechanical stimulation). Other researchers may choose not to mimic the body's response to orthodontic forces but instead to artificially increasing the number of osteoclasts. These approaches include local or systemic induction of different chemical factors or application of physical stimuli that can increase the number of osteoclasts independent of orthodontic forces. It should be emphasized that, in spite of some disagreement about the initial trigger that start the cascade of events leading to bone resorption and tooth movement, all theories agree that osteoclast activation is the main rate-controlling factor in orthodontic tooth movement.

2.2 Stimulating the Artificial Pathway to Increase the Rate of Tooth Movement

2.2.1 Chemical Agents

If bone resorption is the key factor in controlling the rate of tooth movement, application of any agent that increases the rate of bone turnover should increase the rate of tooth movement. With this in mind, the effect of application of parathyroid hormone (PTH), thyroxin, relaxin, vitamin D3, corticosteroids, and osteocalcin in the rate of tooth movement has been examined.

2.2.1.1 Parathyroid Hormone (PTH)

PTH is naturally secreted by the parathyroid glands and causes an increase in the concentration of calcium in the blood by stimulating bone resorption. Since tooth movement depends on the resorption of bone in the direction of movement, there have been studies that aimed to accelerate tooth movement by increasing the PTH levels. While these studies have shown positive results and have succeeded in accelerating tooth movement in animal models, the increase in the rate of tooth movement by exogenous PTH appeared to occur in a dose-dependent manner, by either systemic infusion [1] or local delivery every other day in a slow-release formulation [2]. It should be noticed that although continuous elevation of PTH leads to bone resorption, intermittent short elevations of the hormone level can be anabolic for the bone [3] which may be related to the biphasic effect, which will be explained in more detail in Chap. 5.

2.2.1.2 Other Hormones

Another agent that may increase the rate of tooth movement is the thyroid hormone (thyroxin). Thyroxin affects intestinal calcium absorption; thus, it is indirectly involved in bone turnover and induction of osteoporosis. It has been shown that exogenous thyroxin can increase the rate of tooth movement [4] which can be related to increase in bone resorption.

Recently, the hormone relaxin has been used in rats to increase the rate of tooth movement. Relaxin is capable of reducing the organization level of connective tissues, facilitating rapid separation between adjoining bones. Unfortunately, no significant increase in the rate of tooth movement was observed in these studies [5].

In addition, other factors such as calcitonin or estrogens that can prevent bone resorption have also been reported to decrease the rate of tooth movement [6].

2.2.1.3 Vitamin D3

Vitamin D3 (1,25-dihydroxycholecalciferol) is another factor that can affect the rate of bone remodeling, and therefore, the effect on the rate of tooth movement has been studied. Vitamin D3 regulates calcium and phosphate serum levels by promoting their intestinal absorption and reabsorption in the kidneys. Furthermore, it promotes bone deposition and inhibits PTH release. Based on these mechanisms, one would expect that vitamin D3 should decrease the rate of tooth movement. To the contrary, it has been shown that vitamin D3 can increase the rate of tooth movement if injected locally [7, 8]. This effect can be related to the effect of vitamin D3 on increasing the expression of RANKL by local cells and therefore activation of osteoclasts [9].

2.2.1.4 Osteocalcin and Corticosteroids

Local injection of osteocalcin, a bone matrix component, in a rat model of tooth movement, caused rapid movement due to attraction of numerous osteoclasts into the area [10].

Corticosteroid effects on tooth movement have also been studied. While the anti-inflammatory effect of corticosteroids can decrease the rate of tooth movement, in the presence of cytokines such as IL-6, they may stimulate osteoclastogenesis and cause osteoporosis [11]. The effect of corticosteroids on tooth movement can vary based on the dosage and whether they are administered before the expression of cytokines (induction period) or after their presence. Therefore, while some studies demonstrate an increase in rate of tooth movement [12], others did not report any changes [13, 14].

2.2.1.5 Limitations

The application of chemicals to accelerate tooth movement suffers from many problems. First, all the chemical factors have systemic effects that raise questions about their safety during clinical application. Second, the majority of the factors have a short half-life; therefore, multiple applications of the chemical are required, which is not practical in clinic orthodontics. Furthermore, the administration of a factor in a manner that allows an even distribution along the alveolar bone surface in the compression site is still a challenge. Uneven distribution can change the pattern of resorption and therefore the biomechanics of tooth movement.

2.2.2 Physical Stimulation

2.2.2.1 Mechanical Stimulation

One methodology that has been proposed to increase the rate of tooth movement is the application of high-frequency low-magnitude forces (vibration) to teeth being moved by orthodontic forces. The main assumption in this hypothesis is that the bone is a direct target of orthodontic forces, and therefore by optimizing mechanical stimulation, it is possible to increase the rate of tooth movement. While this stimulation under certain conditions can be effective, the premises supporting the development of this technique are not correct. As we discussed before, the assumption that tooth movement is the result of direct response of bone cells to mechanical stimulation is incorrect, which means that optimizing the mechanical stimulation based on bone cell activity, especially osteocytes, is not a correct approach. Based on this biological principle, application of vibration and orthodontic forces will never be able to move an ankylosed tooth. In addition, all studies in long bone and alveolar bone [15] demonstrate osteogenic effects of vibration with increases in bone density without any resorptive effect, which logically should delay, rather than accelerate, the rate of tooth movement.

While there is little evidence that supports the effect of vibration on the rate of tooth movement [16], it is possible that application of high-frequency low-magnitude forces during orthodontic movement stimulates a pathway far different from its direct effect on bone. If that is true, the frequency dependence of the stimulant is questionable, and literature in this field should not be used to justify applying vibration during tooth movement.

2.2.2.2 Heat, Light, Electric Currents, and Magnetic Fields and Laser

Early studies on the application of heat and light during orthodontic tooth movement [17] have demonstrated faster tooth movement. Similarly, animals exposed to longer hours of light also show an increase in the rate of tooth movement [18]. However, the magnitude of this acceleration was either small or could be explained more by systemic effect of the stimulant and not necessarily local effects.

Minute electric currents have been suggested to increase the rate of tooth movement. Some studies did not report any changes in the rate of tooth movement [19], while others report significant increase [20]. Similarly, studies on static magnetic fields produce inconsistent results on the rate of tooth movement with some showing an increase [21] and others demonstrating no change in the rate of tooth movement [22].

Based on the piezoelectric theory, some researchers suggest using a pulsed electromagnetic field to accelerate tooth movement [23]. Indeed, animals that received this type of stimulation during orthodontic tooth movement demonstrate increased tooth movement [24]. However, the mechanism of action that mediates this effect is not clear, and inflammation and osteoclast activation were not studied.

2.2.2.3 Low-Level Laser Therapy

Recently more attention has been given to possible effect of low-level laser therapy (LLLT) on the rate of tooth movement. LLLT is a treatment that uses low-level lasers or light-emitting diodes to alter cellular function. LLLT is controversial in mainstream medicine with ongoing research to determine whether there is a demonstrable effect. Also disputed are the dose, wavelength, timing, pulsing, and duration [25]. The effects of LLLT appear to be limited to a specified set of wavelengths [26], and administering LLLT below a dose range does not appear to be effective [27].

In general the mechanism of action of LLLT is not clear and sometimes opposite to what is required for orthodontic tooth movement. For example, LLLT may reduce pain related to inflammation by dose-dependently lowering levels of PGE_2, IL-1, and TNF-α, decreasing the influx of inflammatory cells such as neutrophils, oxidative stress, and edema [28]. Due to anti-inflammatory and osteogenic effects of LLLT [29], application of LLLT to increase the rate of tooth movement is controversial. While some studies demonstrate increased rates of tooth movement [30], other studies did not see any effect [31]. The anti-inflammatory effect of LLLT should delay the tooth movement, while the proliferative effect may help increase the number of osteoblasts. On the other hand, some studies show an increase in number of osteoclasts during LLLT application with orthodontic tooth movement [32], which cannot be explained by a proliferative effect of lasers since osteoclasts arise from precursor cells and not proliferation of mature osteoclasts, as some have suggested. Further studies in this subject are clearly necessary.

2.2.2.4 Limitations

Unfortunately, applying any of these physical stimuli to increase the rate of tooth movement currently suffers from a lack of evidence, unknown mechanism of action, and general impracticality. In addition, the magnitude of the increase in the rate of tooth movement is not significantly high to also be clinically relevant and justify their application in the daily orthodontic practice. Despite these shortcomings, this field has great potential for growth an innovation, when based on solid biological principles.

2.3 Stimulating the Natural Pathway to Increase the Rate of Tooth Movement

As discussed in Chap. 1, orthodontic forces induce an aseptic inflammatory response [33, 34] during which many cytokines and chemokines are activated and play a significant role in osteoclastogenesis. It is logical to assume that increasing the activity of these factors should significantly increase the rate of tooth movement. One way of stimulating a higher level of cytokine and chemokine release in the area of tooth movement is inducing trauma to the area. Different approaches described in the literature that induce varying degrees of trauma have shown to affect the rate of tooth movement. These approaches include corticotomies, piezoincisions, and micro-osteoperforations. The success of these interventions can be attributed to the role of inflammation and osteoclastogenesis in tooth movement. Although similar in the biological pathways activated, these approaches differ in the extent of trauma to the tissues, invasiveness, and consequently have different complications, pain, and discomfort associated with them. Most importantly, not all these procedures are easy to use or conveniently repeatable, allowing the orthodontist to integrate its accelerating effect into the biomechanical design and anchorage requirements of each patient's treatment.

2.3.1 Corticotomy

The more invasive and traumatic technique is corticotomy. This technique proposes exposing the alveolar bone by reflecting an extensive gingival tissue flap followed by numerous deep cuts and perforations into the cortical and trabecular bone in between the dental roots [35] performed with a rotary high-speed tool. This procedure generates a massive inflammatory response as a result of significant bone trauma. Therefore, it is not surprising to learn that corticotomies have been shown to accelerate tooth movement in rat animal models [36]. The expected levels of cytokine activation are the highest of all the other techniques of similar category, which may be of benefit in cases of mild to moderate crowding where only simple leveling and aligning mechanics are required. This can be achieved with light wires when no complex mechanics is needed. While clinical cases have been reported in support of this technique, it is worth to note that even though the initial biological response may be favorable, significant complications are associated with this technique:

1. Its aggressive and invasive nature makes it difficult for the patient to accept repeated application at different stages of treatment.
2. It is the least economical option for both patient and clinician.
3. It is a time-consuming procedure that requires the longest recovery time.
4. Due to the aggressive nature of this procedure, it is very difficult to incorporate it at the different stages of treatment, where the target of movement may change. Therefore, it is not useful during routine orthodontic treatment, since different teeth at different stages of treatment need to be moved.
5. If not used wisely can jeopardize anchorage.
6. The catabolic effect produced by this method is massive and may be beyond what is needed at the stage of its application. This is considered unnecessary

trauma to sound bone and surrounding structures. Further details on the needs and application of catabolic effect of trauma-based stimulation during orthodontic treatment will be discussed in Chap. 4.

7. The anabolic effect that follows will be as massive as the catabolic effect which in turn promotes bone formation which can interfere with tooth movement during consequent stages of treatment. This will be explained in further details in Chap. 5

2.3.2 Piezoincision

A less invasive approach than corticotomies proposes the use of a vertical incision in the soft tissue mesial and distal to the tooth to be moved and the use of a piezoelectric blade to create linear incisions in the bone along the soft tissue openings created by a scalpel. Depending on the number and location of the piezoincisions, this procedure could result in considerable trauma and resulting inflammation. Recent animal studies have shown extensive and significant decrease in alveolar bone volume around the dental root and increased osteoclastic activity when orthodontic forces were applied in conjunction with piezoincisions, but tooth movement was not evaluated [37].

Just like corticotomy, this procedure requires the intervention of another specialist other than the orthodontist such as a periodontist or oral surgeon, with additional cost to the patient and a deterrent to the repeated application which would be necessary after the inflammation subsides, for continuous accelerated movement. Due to these reasons, piezoincisions are not practical in the daily orthodontic practice for patients and for clinicians.

2.3.3 Micro-osteoperforations: An Innovative, Less Invasive, More Efficient Approach

A third approach was developed by investigating the minimal trauma to the bone required to elicit an inflammatory response capable of overcoming the biological saturation point of orthodontic forces, and therefore, accelerate tooth movement without compromising the supporting alveolar bone [38]. The proposed procedure consists of small and shallow osteoperforations that can safely be placed on the surface of the buccal or lingual cortical plates by the treating orthodontist, with minor side effects and limited pain or discomfort. This procedure does not require a soft tissue flap or any additional incision. In both animal and human studies, application of few shallow osteoperforations in the proximity of the moving tooth resulted in a significant increase in inflammation, osteoclast activation, bone remodeling, and tooth movement as discussed in details in the next chapter.

2.4 Clinical Evidence for Accelerated Tooth Movement

Now that we reviewed the current accelerated tooth movement techniques from the scientific support and mechanism of action, we can also look at proposed methodologies from the perspective of a patient. For an orthodontic patient, it is important to understand how invasive the proposed adjunct procedure is, how effective it is, what are the complications, and cost. And if the procedure requires the service of another healthcare provider with additional cost and time commitment, that also needs to be consider in the patient's decision.

There are not many randomized clinical trials on the use of the interventions described above. Indeed, considering the high interest in these procedures, the level of evidence is variable, mostly low to moderate. When the Cochrane Collaboration's tool [39] for risk of bias is used to grade randomized or quasi-randomized controlled clinical trials published between 2010 and 2015 (Tables 2.1 and 2.2) on the different nonchemical techniques to accelerate tooth movement, several potential sources of bias were found, and only 5 out of 18 studies scored a low risk of bias indicative of high-quality studies as summarized below.

2.4.1 Level of Clinical Evidence

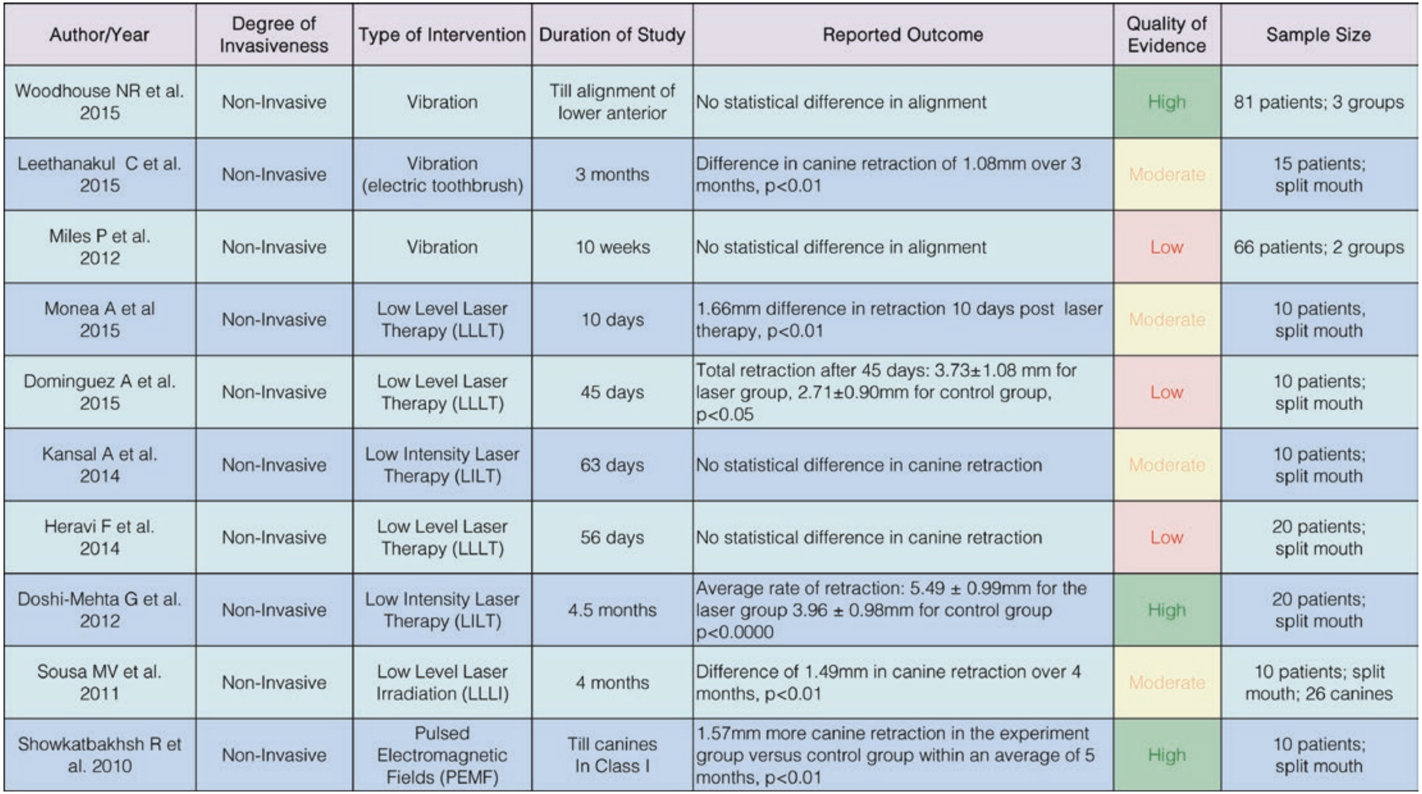
Tables 2.1 and 2.2 summarize the level of evidence for clinical studies on accelerated tooth movement techniques. Studies were divided according to the invasiveness of the procedure as invasive, moderately invasive, minimally invasive, or noninvasive. Invasiveness may be one of the most important decision factors for orthodontic patients considering available methods to reduce treatment duration. There is low to moderate level of evidence supporting the use of corticotomies in accelerating tooth movement [40–44] and moderate-quality evidence and high-quality evidence that piezoincision [45] and micro-osteoperforations [46] accelerate the rate of tooth movement, respectively. There is overall moderate-quality evidence that vibration [47–49] may not have any effect on the rate of tooth alignment, but it may increase the rate of canine retraction. There is high-quality evidence that pulsed electromagnetic fields have the ability to increase the rate of tooth movement; however, the results are modest and are only represented by one study. There is low- to high-quality evidence that low-level laser therapy has the ability to modestly increase the rate of tooth movement, but at least two studies showed no effect [30, 50]. However, the frequencies and wavelengths of the lasers used are not standardized across the studies, and it is uncertain if this has any impact on the effectiveness of the intervention.

While animal tooth movement studies continue to dissect the mechanism and biology supporting some of these approaches, new randomized controlled clinical trials are needed to establish the effectiveness of some of these procedures.

Table 2.1 Summary of clinical evidence from invasive to minimally invasive accelerated tooth movement procedures

Author/Year	Degree of Invasiveness	Type of Intervention	Duration of Study	Reported Outcome	Quality of Evidence	Sample Size
Khanna R et al. 2014	Invasive	Periodontal Distraction Modified Corticotomy	3 months	Mean difference at end of experiment of canine retraction is 0.23mm, $p<0.01$	Low	25 patients; split mouth
Sakthi SV et al. 2014	Invasive	Corticotomy	4 months	Average rate of space closure: 1.8 mm/mo in the mx and 1.57 mm/mo in the md for in experimental group; 1.02 mm/mo in the mx and 0.87mm/mo in the md in the control group, $p<0.05$	Low	40 patients; control & experimental groups
Bhattacharya P et al. 2014	Invasive	Corticotomy	Till canines in Class I	Average of 130.5 days for experimental vs 234.1 days for control, $p<0.01$	Low	20 patients; randomized into control & corticotomy groups
Al-Naoum F et al. 2014	Invasive	Corticotomy	12 weeks	Differences of up to 0.53mm a week in retraction, $p<0.01$	Low	30 patients; split mouth
Shoreibah EA et al. 2012	Invasive	Modified Corticotomy	Till alignment of lower anterior	Reported 31.5 week difference in treatment time and statistically significance, no p-value given nor other statistics provided	Low	20 patients; randomized into control & corticotomy groups
Aboul-Ela SM et al. 2010	Invasive	Corticotomy	4 months	Difference in canine retraction of 1.14mm in the first month but decreasing to 0.04mm in the fourth month, $p<0.01$	Low	13 patients; split mouth
Aksakalli S et al. 2015	Moderately Invasive	Piezocision	Till canines in Class I	Average time for canine retraction in experiment group is 3.54mths vs 5.59mths in control group, $p<0.05$	Moderate	10 patients; split mouth
Alikhani M et al. 2013	Minimally Invasive	Micro-osteoperforations	28 days	Rate of canine retraction increased 2.3 fold, $p<0.05$	High	20 patients; experimental & control groups

Table 2.2 Summary of clinical evidence for non-invasive accelerated tooth movement procedures



Author/Year	Degree of Invasiveness	Type of Intervention	Duration of Study	Reported Outcome	Quality of Evidence	Sample Size
Woodhouse NR et al. 2015	Non-Invasive	Vibration	Till alignment of lower anterior	No statistical difference in alignment	High	81 patients; 3 groups
Leethanakul C et al. 2015	Non-Invasive	Vibration (electric toothbrush)	3 months	Difference in canine retraction of 1.08mm over 3 months, $p<0.01$	Moderate	15 patients; split mouth
Miles P et al. 2012	Non-Invasive	Vibration	10 weeks	No statistical difference in alignment	Low	66 patients; 2 groups
Monea A et al 2015	Non-Invasive	Low Level Laser Therapy (LLLT)	10 days	1.66mm difference in retraction 10 days post laser therapy, $p<0.01$	Moderate	10 patients, split mouth
Dominguez A et al. 2015	Non-Invasive	Low Level Laser Therapy (LLLT)	45 days	Total retraction after 45 days: 3.73 ± 1.08 mm for laser group, 2.71 ± 0.90mm for control group, $p<0.05$	Low	10 patients; split mouth
Kansal A et al. 2014	Non-Invasive	Low Intensity Laser Therapy (LILT)	63 days	No statistical difference in canine retraction	Moderate	10 patients; split mouth
Heravi F et al. 2014	Non-Invasive	Low Level Laser Therapy (LLLT)	56 days	No statistical difference in canine retraction	Low	20 patients; split mouth
Doshi-Mehta G et al. 2012	Non-Invasive	Low Intensity Laser Therapy (LILT)	4.5 months	Average rate of retraction: 5.49 ± 0.99mm for the laser group 3.96 ± 0.98mm for control group $p<0.0000$	High	20 patients; split mouth
Sousa MV et al. 2011	Non-Invasive	Low Level Laser Irradiation (LLLI)	4 months	Difference of 1.49mm in canine retraction over 4 months, $p<0.01$	Moderate	10 patients; split mouth; 26 canines
Showkatbakhsh R et al. 2010	Non-Invasive	Pulsed Electromagnetic Fields (PEMF)	Till canines In Class I	1.57mm more canine retraction in the experiment group versus control group within an average of 5 months, $p<0.01$	High	10 patients; split mouth

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Introduction to Micro-osteoperforations

3

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3.1 Overcoming Saturation of the Biological Response

One of the main challenges in orthodontics today is the desire to decrease treatment time without compromising treatment outcome. To address this challenge, we need to understand the three variables that can control the duration of treatment. First, there are practitioner-dependent factors, such as proper diagnosis and treatment planning, mechanotherapy, selection of appliances, and delivery of treatment in a timely fashion. Second, we have patient-dependent factors, such as maintaining appointments, good oral hygiene, integrity of the appliances, and following the practitioner's instructions. The third factor is regulated by the individual's biology and to a certain degree under the control of the practitioner.

Recent studies demonstrate that increasing the magnitude of orthodontic force increases the biological response resulting in increased inflammation, osteoclast recruitment, formation and activation, alveolar bone resorption, and increased rate of tooth movement. As discussed in Chap. 1, these studies also revealed that there is a force level above which we cannot stimulate the biological responses any further [1]. We called this phenomenon "saturation of the biological response" since at this force level stimulation of cytokine release and osteoclast activity has reached its peak or saturation point. While increasing the force magnitude will not overcome this limitation, any methodology that can increase the osteoclast numbers in the area could be the answer to enhancing this biological response and accelerating orthodontic tooth movement.

3.2 Simpler and Safer Approach

In Chap. 2 we discussed different methods of accelerating tooth movement by stimulating the biological response to orthodontic forces. The major shortcoming of many of these methods is the complexity of the response to orthodontic forces. While inflammation plays a critical role, this response is a multifactorial phenomenon with many up-regulated and down-regulated factors. Logically, an effective and safer approach will always be to stimulate the body to amplify its natural inflammatory pathways.

Animal and clinical studies conducted by CTOR, the Center for Translational Orthodontic Research, supports a simple and safe approach to overcome the saturation of the biological response. This method introduces controlled microtrauma without affecting the integrity and architecture of hard and soft tissues, to stimulate the expression of inflammatory markers, which can, in synergy with orthodontic forces, amplify the bone response beyond its saturation point. CTOR group first examined this hypothesis using an animal model of tooth movement before completing the human clinical trials. Since the objective of this translational research was establishing a therapeutic modality, the practicality and versatility of the technique was the focus of these studies. Results of this translational effort are presented in this chapter.

3.3 From Rats to Humans

3.3.1 Animal Study

Thirty-six adult male Sprague-Dawley rats were divided into three groups. In the experimental group (MOP), animals received a spring connecting the first maxillary molar to the incisors to apply a force to move the first maxillary molar mesially and three shallow micro-osteoperforations in the cortical bone 5 mm mesial to the first maxillary molar (Fig. 3.1a). In the sham group (O), animals received the exact same force without the micro-osteoperforations. In the control group (C), animals received passive springs without any force application. All animals were anesthetized and springs exerting a force of 25 cN were placed between the first maxillary molar and incisors as described by Alikhani et al. [2]. For microcomputed tomography (CT) analysis, hemimaxillae were scanned using Scanco micro-CT to evaluate changes in bone density. For histological analysis and immunohistochemistry studies, the hemimaxillae were collected, fixed in 10% phosphate buffered formalin, decalcified, and embedded in paraffin blocks that were sectioned at 5-μm thickness. Hematoxylin and eosin staining was used to evaluate cell and tissue morphology and areas of bone resorption. Tartrate-resistant acid phosphatase (TRAP) immunostaining was used to locate and quantify osteoclast numbers and activity. For fluorescent microscopy, hemimaxillae were collected and embedded in polymethyl methacrylate. Blocks were sectioned with 7-μm thickness and viewed under fluorescent microscopy to evaluate bone formation and mineral deposition. Cytokine gene expression was evaluated by reverse transcription-polymerase chain reaction analysis. The hemimaxillae were collected and immediately frozen in liquid nitrogen for mRNA extraction and analysis. All methods are described in detail in Teixeira et al. [3].

3.3.2 Human Clinical Trial

A randomized, single-center, single-blinded study was approved by the institutional review board of New York University. Participants were recruited from the patient pool that sought comprehensive orthodontic treatment at the department of orthodontics at New York University College of Dentistry. Twenty patients were randomly divided into control and experimental groups. Patients' ages ranged from 19.5 to 33.1, with a mean age of 24.7 years for the control group and 26.8 for the experimental group. The control group consisted of three men and seven women whereas five men and five women participated in the experimental group. All participants had similar malocclusions; for inclusion criteria, refer to Alikhani et al. 2013 [2]. Both groups received similar treatment until the initiation of canine retraction. At that time, the experimental group received three micro-osteoperforations (MOP) between the canine and the second premolar on one side only, while the contralateral side served as additional control (CL) (Fig. 3.2a). The control group

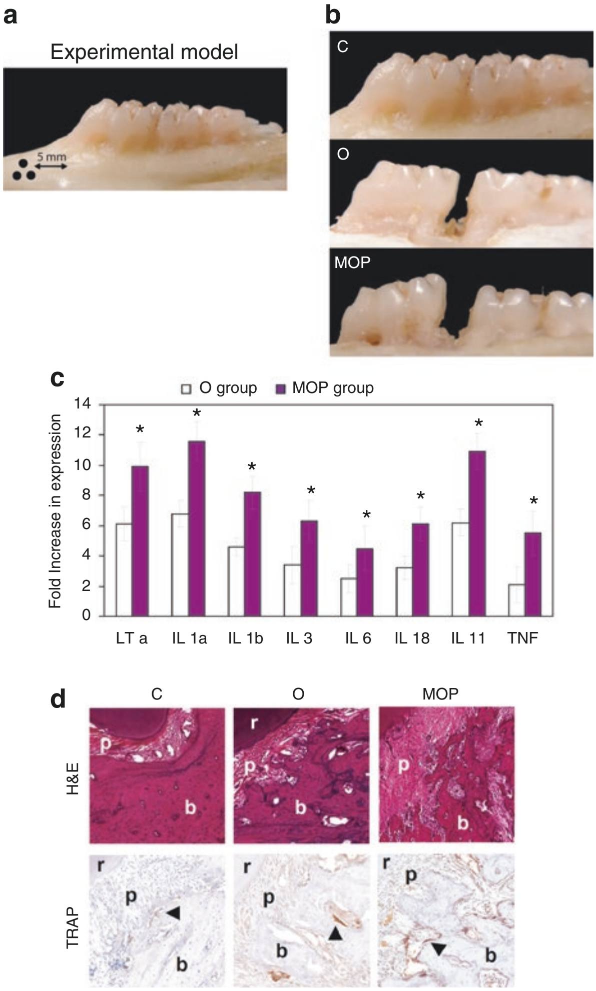


Fig. 3.1 Micro-osteoperforations accelerate tooth movement in rats. (**a**) Rat hemimaxilla showing the location of three MOPs placed 5 mm mesial to the first molar. (**b**) Comparison of the magnitude of tooth movement after 28 days of orthodontic force application (*C* control, *O* orthodontic force only, *MOP* orthodontic force + micro-osteoperforations). MOP shows greater magnitude of movement. (**c**) Reverse transcription-polymerase chain reaction analysis of cytokine gene expression. Data is presented as fold increase in cytokine expression in the O and MOP groups in comparison with C group. Data shown is mean ± SEM of three experiments. (**d**) Histological sections stained with hematoxylin and eosin (*top panels*) show increase of periodontal space (*p*) thickness around the mesiopalatal root (*r*) of the first molar and increase in bone (*b*) resorption both in the O and MOP groups. Immunohistochemical staining (*bottom panels*) shows an increase in osteoclast activity represented by the increased number of tartrate-resistant acid phosphatase-positive osteoclasts (*arrowhead*) in both the O and MOP groups

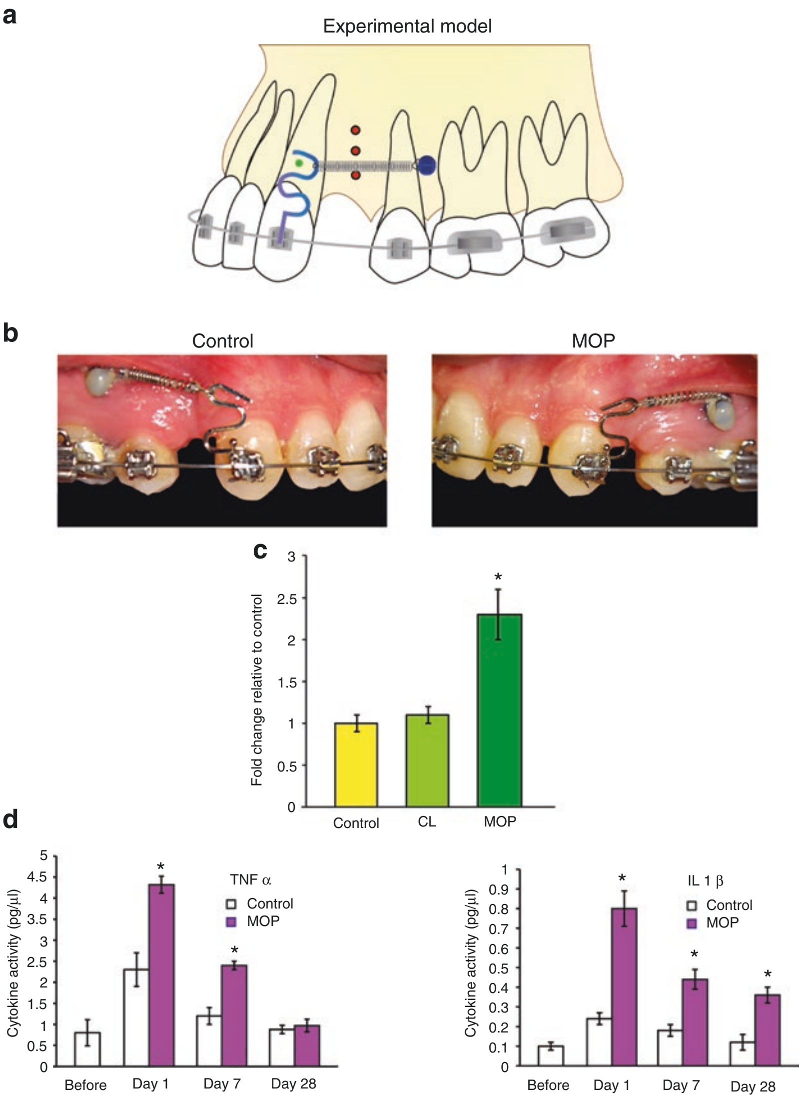


Fig. 3.2 Micro-osteoperforations accelerate canine retraction in a human clinical study. (**a**) Diagram showing the orthodontic setup during canine retraction. A power arm extending from the vertical slot of the canine bracket to the level of the center of resistance (CR, *green circle*) is connected to a temporary anchorage device (*blue circle*), placed between the second premolar and the first molar at the level of the CR of the canine, by a NiTi coil that exerts a continuous force of 50 cN. Three MOPs (*red circles*) were placed between the canine and the second premolar prior to retraction. (**b**) After 28 days of force application, the canine retraction is significantly greater in the MOP group than in the O group (orthodontic force alone). (**c**) Canine retraction in MOP group increased by 2.3-fold after 28 days of retraction in comparison with the C group and the contralateral side of the experimental group. (**d**) Expression of inflammatory marker in the gingival crevicular fluid—as measured by enzyme-linked immunosorbent-based assay before retraction and 24 h, 7 days, and 28 days after force application—shows significantly higher levels in the MOP group than in the C group. Data is presented as pg/uL. *Significantly higher than control ($p < .05$)

(C) did not receive MOP on either side. Clinical examination after 24 h of placing the MOP in the experimental group showed no signs or symptoms of trauma. Canine retraction was accomplished using a calibrated 100-g nickel titanium closing spring that connected the canine via a custom-made power arm extending from the vertical slot of the canine bracket to the level of the center of resistance, to a temporary anchorage device that was placed between the second premolar and the first molar. The evaluation of the rate of canine retraction was achieved through dental cast analysis from impressions taken immediately before the initiation of canine retraction and 28 days after the retraction. The distance between the canine and the lateral incisors was measured at three points: incisal, middle, and cervical thirds of the crown using a digital caliper with an accuracy of 0.01 mm. The inflammatory response was evaluated by studying the cytokine level in the gingival crevicular fluid (GCF). Samples were collected from the distobuccal crevices of the canine before treatment, immediately before canine retraction, and at every subsequent visit. Patient pain and discomfort were assessed by using a numerical scale. Patients were asked to choose a number from 0 to 10—0 meaning "no pain" and 10 meaning "worst possible pain"—on the day of appliance placement, the day of canine retraction, and 24 h, 7 days, and 28 days after retraction. For method details, refer to Alikhani et al. [2].

3.3.3 Surprising Similarities

In the rat study, application of micro-osteoperforations significantly increased tooth movement by twofold ($p < .05$) in the MOP group in comparison with the O group (Fig. 3.1b). At the molecular level, the expression of cytokines/cytokine receptors increased significantly 24 h after force application in the MOP and O groups in comparison with the C group (Fig. 3.1c). In addition, 21 cytokines were significantly higher ($p < .05$) in the MOP group than the O group. Histological analysis revealed increased alveolar bone resorption in both the MOP and O groups when compared to the C group. However, the MOP group showed a significantly greater rate of alveolar bone resorption than noted in the O group and a subsequent increase in PDL thickness (Fig. 3.1d). Immunohistochemical staining of TRAP-positive osteoclasts (Fig. 3.1d) revealed a threefold increase in the number of osteoclasts in the MOP group in comparison with the O group.

Using a canine retraction model in humans, we were able to mirror the results of our animal study. In our clinical trial, 28 days after initiation of canine retraction, we observed a significant increase in the space between the canine and lateral incisor in the MOP group when compared to both C group and CL side, where movement was diminutive (Fig. 3.2b). Dental cast measurements showed a 2.3-fold increase in canine retraction in comparison with both C group and CL side ($p < .05$) (Fig. 3.2c). Protein analysis of the GCF showed an increase in cytokine expression after 24 h of force application when compared to the pre-retraction levels for the same patients. However, in the MOP group, cytokines were significantly higher than in the C group ($p < .05$) (Fig. 3.2d). After 28 days, all cytokine levels were decreased back to pre-retraction levels with the exception of interleukin-1 beta (IL-1β). In the experimental group, IL-1β was still significantly higher (5.0 and 3.6-fold, respectively) than their levels before retraction (Fig. 3.2d).

3.3.4 Studies Summary

CTOR animal studies have shown that introducing small holes in alveolar bone (MOPs) during orthodontic tooth movement can significantly stimulate the expression of inflammatory markers. This was accompanied by a significant increase in the number of osteoclasts and bone resorption (Fig. 3.3) as anticipated Teixeira et al. [3]. We observed that the increase in bone remodeling was not limited to the area of the moving tooth, but extended to the tissues surrounding the adjacent teeth (data not shown). The increase in the number of osteoclasts, and therefore increase in bone resorption and osteoporosity in response to bone perforations, may explain the increase in the rate and magnitude of tooth movement observed in this study, thereby suggesting that the perforations do not need to be close to the tooth to be moved to accelerate the rate of tooth movement.

The results of our human clinical trial were surprisingly similar to the rat study. Canine retraction in the presence of MOPs resulted in twice as much distalization as the one observed with the orthodontic forces alone. This increase in tooth movement was accompanied by an increase in the level of inflammatory markers.

3.3.5 Safety and Patient Comfort

To investigate safety and comfort of the procedure we recorded pain and discomfort levels using a numerical rating scale from 1 to 10. We also collect information about possible complications throughout the duration of the study, such as bleeding, infection, or need for analgesic medication. Patients that underwent canine retraction in the presence or absence of micro-osteoperforations reported an increase in discomfort levels when compared to pre-retraction levels (Table 3.1). However, no significant difference was noted between the MOP and the C group (orthodontic force alone group). Moreover, after the placement of the MOPs, patients reported only moderate discomfort that was bearable and did not require any medication (Table 3.1). These results suggest that MOPs do not cause any additional pain or discomfort beyond that induced by orthodontic forces alone. Furthermore, no complications for this minimally invasive procedure were reported during the study.

3.4 Advantages of Micro-osteoperforations

When compared to other surgical approaches to accelerate tooth movement, it is obvious that MOPs offer a number of advantages. This procedure is minimally invasive and flapless and can safely be performed by the orthodontist. Corticotomy

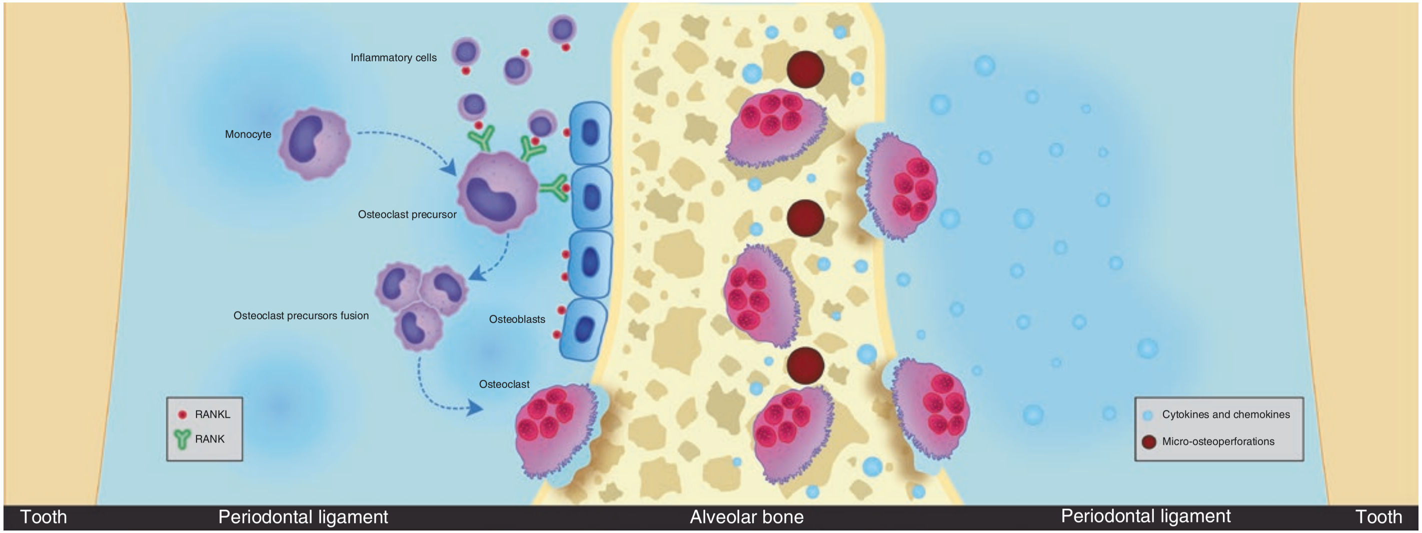
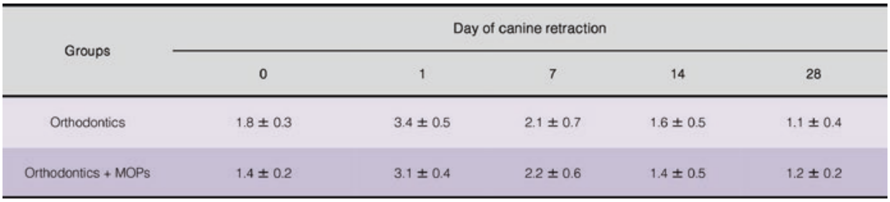


Fig. 3.3 Schematic of the effect of cytokines and micro-osteoperforations on osteoclastogenesis and bone resorption. (*Left side*) Inflammatory cells that migrate to the periodontal ligaments from the bloodstream in response to orthodontic forces, as well as local cells such as osteoblasts, express nuclear factor κB ligand (RANKL) that binds to the receptor (RANK) on the surface of osteoclast precursor cells such as monocytes. This binding initiates the adhesion of these cells to each other to form osteoclasts that start the bone resorption. (*Right side*) Adding micro-osteoperforations increases the expression of inflammatory cytokines and chemokines, which will, in turn, increase the recruitment of osteoclasts and therefore the rate of bone resorption

Table 3.1 Pain and discomfort for control (ortho) and experimental (ortho+MOPs) groups using a numerical rating scale (NRS)



Groups	Day of canine retraction				
	0	1	7	14	28
Orthodontics	1.8 ± 0.3	3.4 ± 0.5	2.1 ± 0.7	1.6 ± 0.5	1.1 ± 0.4
Orthodontics + MOPs	1.4 ± 0.2	3.1 ± 0.4	2.2 ± 0.6	1.4 ± 0.5	1.2 ± 0.2

or piezoincision procedures, on the other hand, require either the reflection of a full-thickness flap to expose the buccal and lingual alveolar bone or soft tissue incisions, followed by interdental cuts through the cortical bone. Recently, a modification of this technique has been introduced where, after selective decortication in the form of lines and points, a resorbable bone graft is placed over the surgical site. The effect of this technique has been incorrectly attributed to the shape of the cuts made into the bone (block concept) and to the bone grafts [4–9]. As previously discussed in Chap. 1, the rate of tooth movement is controlled by osteoclast recruitment and activation. Therefore, regardless of the shape or the extent of the cut, bone resorption will not occur unless osteoclasts are activated. This means that, similar to micro-osteoperforations, the effectiveness of corticotomy or piezoincision can be related to the activation of cytokines that are released in response to the trauma induced during the cuts. The release of cytokines is expected to be significantly higher in corticotomy and piezoincision in comparison with micro-osteoperforations due to the more invasive nature of these procedures and the extensive trauma to the bone. Unfortunately, similar to micro-osteoperforations, the increased level of cytokines will not be sustained for a long period of time with these procedures and will eventually return to normal levels. Therefore, repeating these procedures to maintain the desired level of cytokine activity requires significant cost and time commitment for the patient due to the need for the services of another specialist, periodontist, or oral surgeon.

As we will demonstrate in the following chapters, MOPs offer a practical and minimally invasive procedure that can be repeated as needed by the orthodontist. MOPs can be incorporated into daily mechanics, at different stages of treatment, and selectively placed in the areas where tooth movement is desired.

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Catabolic Effects of MOPs at Different Treatment Stages

4

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Contents

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4.1 Introduction

In the previous chapters, we have reviewed the mechanism through which MOPs can activate osteoclasts and enhance bone resorption. While this procedure clearly can increase the rate of tooth movement, if not planned and incorporated properly into the treatment plan, it may not necessarily decrease the total duration of treatment. Thus, excellent orthodontic outcomes are not based on random tooth movements, regardless of how fast we can move a tooth, but rather they depend upon precise movements in exact directions.

Orthodontic treatment has many stages, and each stage has two main components: target teeth that should be moved and anchor teeth that should not be moved. While in one stage of treatment, some teeth act as anchor units, in another stage of treatment, the same teeth may become the target units. Therefore, enhancing the biological response around all the teeth, simultaneously without proper planning, is most likely unnecessary or even counterproductive. It should be emphasized that the principles of physics and mechanics are not affected by the rate of tooth movement. While MOPs can accelerate the rate of tooth movement, for every movement in the desired direction, there is still a side effect movement that should be controlled. Therefore, treatment duration is not determined by how fast we move teeth but how wisely we plan each stage of treatment and take advantage of biology and physics to maximize our efficiency in achieving the goals of that stage.

4.2 Goals for MOPs During Orthodontic Treatment

With the proper mechanical design, the incorporation of the catabolic effects of MOPs in each stage of treatment has the following goals:

1. Accelerate the movement of target teeth
2. Facilitate the desired type of tooth movement

3. Development of biological anchorage
4. Decrease the possibility of root resorption

4.2.1 Accelerate the Movement of Target Teeth

The most common use of MOPs is to accelerate tooth movement. For this application, MOPs should be applied close to the target tooth only at the time when that target tooth is ready to be moved. If MOPs are applied too early around a tooth that is not mechanically ready to be moved (e.g., prior to having sufficient space), the bone will have enough time to progress from the catabolic stage to the anabolic stage (as discussed in Chap. 5), not only will this not accelerate tooth movement, it will cause a delay and may even decrease the rate of movement.

To accelerate the rate of movement, MOPs should be applied mostly in the direction of movement. However, the catabolic effects of MOPs are not limited to the point of application and can spread into the adjacent bone. This provides some leeway when attempting to find an adequate location for MOPs application. Factors that may affect the location for MOPs application include visibility, accessibility, magnitude of crowding, and root proximity. For patient comfort, accessibility, and visibility, MOPs are best applied on the mesiobuccal, distobuccal, or on both sides of the target tooth's root (Fig. 4.1). Since increasing the number of MOPs has a positive effect on the rate of tooth movement [1], in cases where the tooth adjacent to the target tooth is missing, it is wise to apply MOPs on the edentulous alveolar ridge in addition to mesiobuccal and distobuccal sites (Fig. 4.2). In some patients, thick lingual/palatal cortical bone can slow down the movement. To accelerate the rate of movement in these patients, MOPs can also be applied to the lingual/palatal cortical plate (Fig. 4.3). Regardless of the location, human clinical trials results suggest that MOPs should be reapplied at least every other month until proper movement has been achieved.

4.2.2 Facilitate the Desired Type of Tooth Movement

The catabolic effects of MOPs not only affect the rate of tooth movement; they also affect the type of tooth movement. The type of tooth movement depends on the relation between the force and the center of resistance of the tooth, which is determined by the surrounding bone. In denser bone, the center of resistance moves apically, which increases the distance between the point of force application (on the crown) and the center of resistance (on the root). Therefore, producing a desired bodily tooth movement requires a larger couple, to cancel the unwanted moments that results from orthodontic forces. However, when the bone density is low, the center of resistance moves occlusally toward the alveolar crest, which decreases the distance between the orthodontic force and the center of resistance, thereby reducing the couple required to overcome the unwanted moments (lower couple to force ratio (Mc/F)) (Fig. 4.4). Thus, MOPs can help achieve the desired type of tooth movement by biologically changing the position of the center of resistance to a more

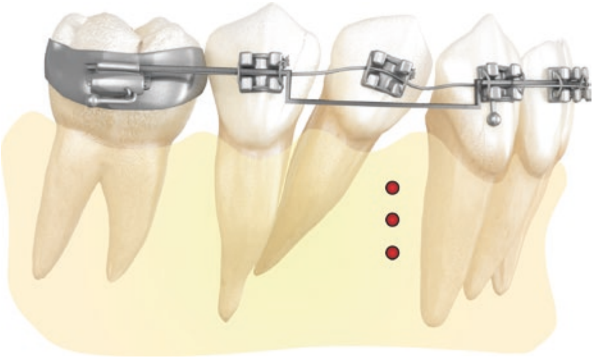


Fig. 4.1 MOPs accelerate target tooth movement. MOPs (*red circles*) should be applied only around the target tooth to accelerate its rate of movement. When possible MOPs should be applied on both distal and mesial sides of the root to be moved

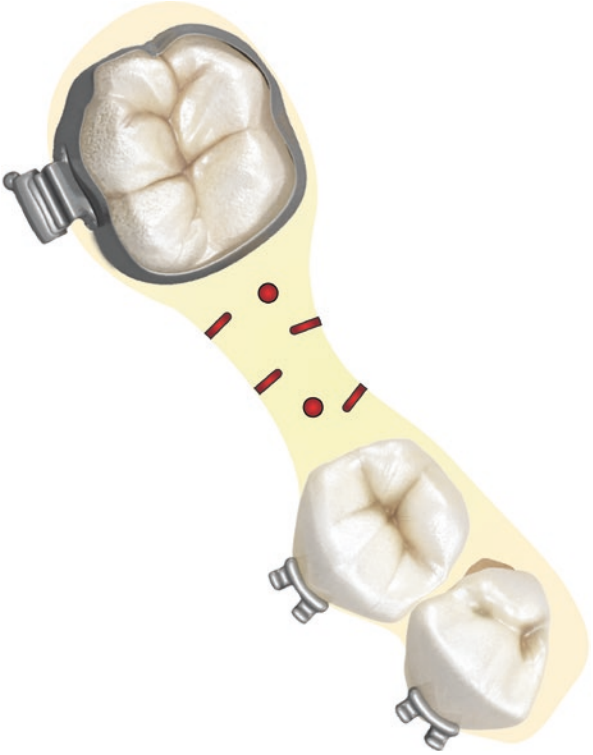


Fig. 4.2 Application of MOPs on residual alveolar ridge. When the target tooth is located adjacent to an extraction space, application of MOPs on the residual edentulous area of alveolar bone can increase the rate of movement significantly

Fig. 4.3 Buccolingual application of MOPs. Application of MOPs on both lingual and buccal cortical plates, in patients where the palatal alveolar bone resist the movement not only overcomes the obstacle but can also accelerate the rate of tooth movement

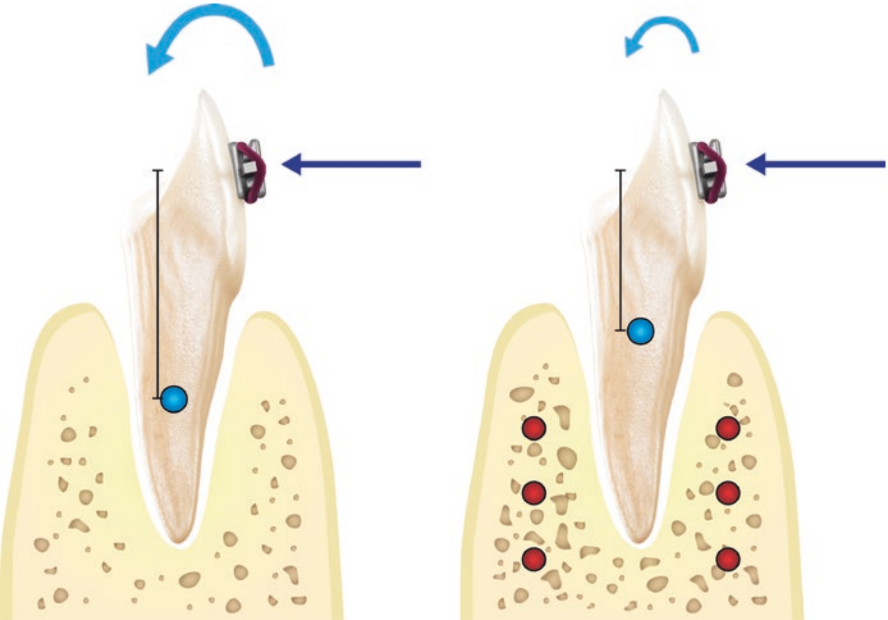


Fig. 4.4 MOPs can change location of center of resistance. MOPs reduces the density of alveolar bone, and as a result the center of resistance of a tooth (*blue circle*) moves occlusally, decreasing the moment generated by force application to the crown (*curved blue arrow*)

favorable location, therefore facilitating difficult movements such as bodily movement. This is clinically very important, especially in cases of severe bone resorption of edentulous area where a dense cortical plate prevents bodily movement and causes severe tipping.

4.2.3 Development of Biological Anchorage

During protraction or retraction of one tooth or a segment of teeth, the main concern in current mechanotherapy is how to minimize the movement of anchor teeth. The most common approach focuses on decreasing the rate of movement of the anchor tooth or teeth by increasing the size of the anchor unit. This approach is based on the assumption that the larger the anchorage mass, the slower or smaller the movement will be. This can be achieved by connecting the anchor teeth together through a transpalatal arch (TPA) or Nance appliance, adding second molars, interarch elastics, and other similar approaches designed to oppose a large number of anchor teeth against a smaller number of target teeth. While this is a good approach, similar results can be achieved by increasing the rate of movement of the target unit. By increasing the speed of target teeth movement through decreasing surrounding bone density, while preserving the bone density around the anchor unit, it is possible to add a biological component to the anchorage preparation (Fig. 4.5).

With this understanding of anchor and target teeth, we can now easily define the area for application of MOPs. For example, for canine retraction or anterior teeth retraction, MOPs should be applied adjacent to the canine or anterior teeth. Conversely, to increase anterior anchorage during posterior protraction, MOPs should be applied around the posterior teeth. This biological approach, of increasing anchorage through MOPs application, is much safer and easier to use than other approaches to achieve biological anchorage, such as torqueing molar roots toward the cortical plate. Moving the roots of a tooth toward the cortical bone not only produces questionable advantages from the point of anchorage, it also can be dangerous and may promote root resorption. However, MOPs application around target teeth does not require any changes in root angulation of anchor teeth, and, therefore, it lowers stresses on the roots. In addition, MOPs also decrease the stress level around target teeth significantly, which in turn reduces the possibility of root resorption, as discussed below.

4.2.4 Decrease the Possibility of Root Resorption

In patients with very dense alveolar bone, any tooth movement may result in significant root resorption. This is especially more likely in those movements that produce concentrated stress on a small area of the root, such as the apex. This can occur during intrusion or torqueing. However, even during movements that distribute stress over larger areas of root, if dense bone prevents quick bone clearance by osteoclasts along the path of movement, these osteoclasts will stay in area for a long

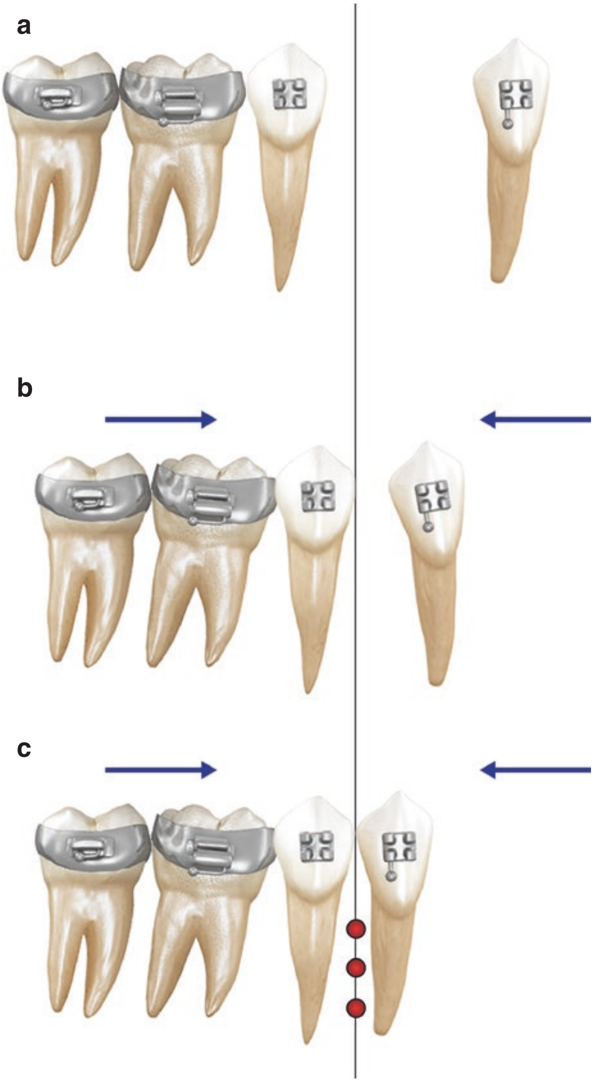


Fig. 4.5 MOPs can function as biological anchorage. By changing the density of alveolar bone surrounding the moving teeth, MOPs can change anchorage requirements. (**a**) Position of canine and posterior teeth before canine retraction. (**b**) Position of canine and posterior teeth during retraction, showing posterior teeth moved mesially while canine moved distally. (**c**) Position of canine and posterior teeth during retraction after application of MOPs (*red circles*). Posterior teeth moved mesially similar to (**b**) but the canine retraction increased. The increased distance traveled by the canine during retraction was not accompanied by additional movement of anchor teeth, and it was accomplished by biological anchorage

time, which allows them to attack the alveolar bone and adjacent roots (Fig. 4.6). By applying MOPs, it is possible to increase the number of osteoclasts significantly along the path of movement compared to non-MOPs treatment, which increases the rate of bone resorption and tooth movement. Therefore, osteoclasts will not linger in one area long enough to attack the root(s) of the target tooth which rapidly move through the MOPs site (Fig. 4.7).

It is reasonable to ask why are roots around MOPs sites not at a greater risk for resorption given that MOPs application recruits significantly more osteoclasts to an area? It is important to understand that it is the duration that osteoclasts are present at the site rather than the number of osteoclasts that significantly impacts root

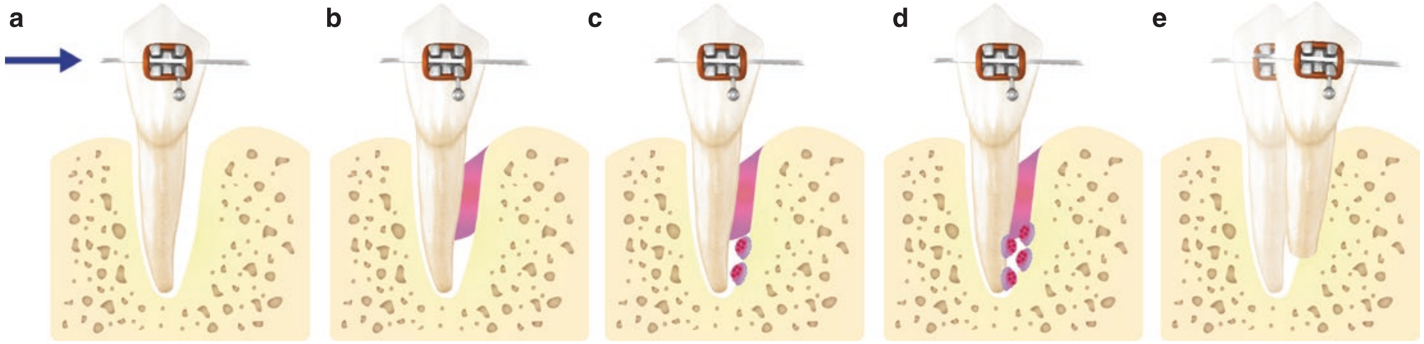


Fig. 4.6 Root resorption during movement through dense alveolar bone. In the presence of dense alveolar bone, osteoclasts will linger in the area for longer periods of time which gives them the opportunity to attack both bone and adjacent root. (**a**) Schematic of tooth before application of force, (**b**) necrotic area in response to orthodontic force application (*pink area*), (**c**) appearance of osteoclasts in the area (*red cells*), (**d**) prolonged presence of osteoclasts in the area due to dense alveolar bone, (**e**) delayed tooth movement and resorption of adjacent root

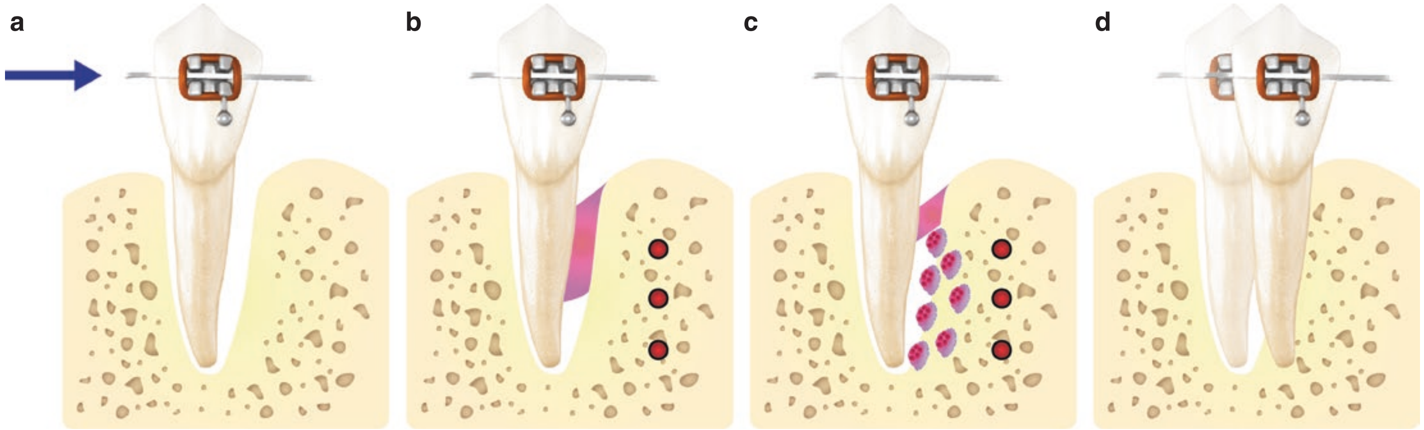


Fig. 4.7 MOPs can prevent root resorption during movement through dense alveolar bone. Application of MOPs stimulates recruitment and activation of greater number of osteoclasts from both PDL and bone side, which shortens the duration of necrosis, and of their presence in the area. (**a**) Schematic of tooth before application of force, (**b**) necrosis (*pink area*) after force application in the presence of MOPs, (**c**) large number of osteoclasts (*red cells*) recruited into the area clear the necrosis faster, (**d**) tooth movement accomplished without root resorption

resorption. If a relatively small number of active osteoclasts stay in an area long enough, they can stabilize themselves on any mineralized tissue, which puts both alveolar bone and root surfaces at risk for resorption.

Delay in movement depends on the extent of the cell free zone (necrosis) produced in response to orthodontic forces, while the rate of mineralized tissue clearance depends on osteoclasts activity. Increasing the magnitude of orthodontic forces not only does not increase the rate of tooth movement, as saturation of the biological response is attained (Chap. 1), it also increases the possibility of root resorption by producing large areas of cell-free zones that may not clear quickly. This is especially true in adults where increase in bone density increases the possibility of creating large necrotic areas. In addition, since the number of osteoclasts is limited (will reach saturation point), rate of clearance is low which allows the cells to stay in the area for a longer time. Treatment with MOPs in adults can recruit a large number of osteoclasts that have less time to attach to the root and cause root resorption. Thus, MOPs are indicated when an adult patient is missing permanent teeth and the clinician plans to close the space by moving the adjacent teeth a large distance, quickly, with the proper type of tooth movement and with less possibility of root resorption.

In children, the possibility of root resorption is lower than in adults since bone density is low and alveolar bone is very cellular with significant blood supply. Due to this natural difference, it is more difficult to produce large areas of necrosis in the PDL of children, and if any area of necrosis develops, it will clear quickly. Therefore, MOPs in children to prevent root resorption are not necessary.

4.3 Stages of Treatment

Orthodontics has five stages of treatment, although not all stages are necessary in all patients:

1. Pre-alignment stage: Appliances (such as a palatal expander) or sectional braces (such as those needed for segmental intrusion/extrusion) are placed to address major skeletal or segmental problems within the dental arches before full fixed appliances are used.
2. Leveling and aligning stage: This stage has two components:
    - (a) Early stage: The majority of teeth that require minor tooth movements are leveled and aligned without engaging teeth that need special attention (such as a severely tilted molar, impacted tooth, blocked-out tooth, or severely rotated tooth).
    - (b) Late stage: Leveling and aligning of all teeth including difficult teeth are addressed.
3. Post-alignment stage: Major retraction or protraction of a tooth or a segment of teeth are accomplished.
4. Finishing stage: Detailing the final tooth position in each dental arch is completed, and the patient is prepared for debonding.
5. Retention stage: Appliances are removed and retainers are delivered.

MOPs can be used wisely during all stages of treatment to decrease the total duration of treatment.

4.4 MOPs During Pre-alignment Stage

For adult patients with significant transverse or vertical problems, it is sometimes necessary to complete a short stage of pre-alignment treatment before starting the full fixed appliances set up. In these cases, bonding full fixed appliances will slow down the treatment and prevent the clinician from localizing potential side effects to one or two areas where they can easily be controlled. The mechanics in the pre-alignment stage is based on a *determined system* (where forces and moment can be correctly predicted) vs. a full fixed appliance set up, which is considered an *undetermined system* (moments and forces changes with time and it is difficult to predict their presence and their side effects). MOPs in combination with precise mechanics can significantly decrease treatment duration by preventing unnecessary movements. The common challenges in the pre-alignment stage where MOPs can be useful include but are not limited to the following treatment objectives:

4.4.1 Intrusion of Anterior Teeth in Adults

One of the more prominent challenges during intrusion treatment of adult patients is the possibility of root resorption due to the relatively high density of adult alveolar bone and high stress area around the apex of the intruded teeth. While application of lighter intrusive forces is one possible way to decrease prolonged necrosis around the roots, this approach alone cannot change the properties of the bone around the apex, and while it can reduce the magnitude of root resorption, it cannot prevent it. In addition, it can prolong the treatment duration. MOPs application in combination with light forces effectively reduces local bone density temporarily and encourages circulation and migration of inflammatory cells into the area. The release of inflammatory markers and the activation of osteoclasts that follows help enhance bone resorption and, therefore, decrease the possibility of prolonged necrosis and consequently root resorption while decreasing the duration of treatment. Therefore, during intrusion in adult patients, we recommend light forces in combination with MOPs (Fig. 4.8).

4.4.2 Intrusion of Posterior Teeth in Adult

Intruding one or several posterior teeth is a common challenge in adult orthodontic treatment that can be addressed in the pre-alignment stage. These problems usually occur in adults who lose posterior vertical height following extraction of non-restorable posterior teeth that leaves large edentulous areas. In these cases, not only

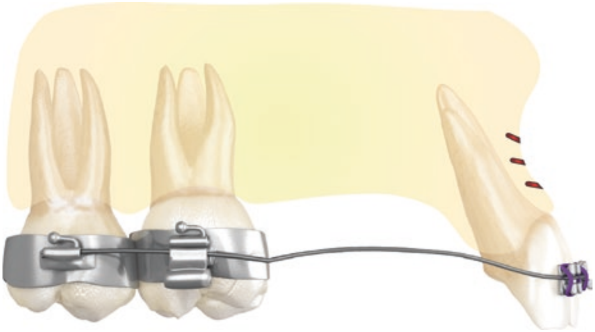


Fig. 4.8 Application of MOPs during intrusion. Application of MOPs with sectional mechanics during intrusion of anterior teeth in adults not only can decrease the duration of treatment, it can also reduce the incidence of root resorption. MOPs (*red rods*) are applied between the roots of anterior teeth

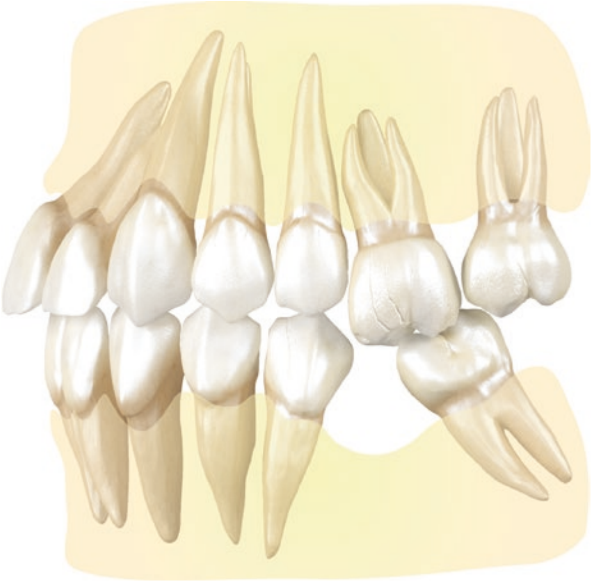


Fig. 4.9 Effect of tooth extraction on occlusion and adjacent teeth position. Unrestored extraction space usually is accompanied with extrusion of opposing tooth and tilting of adjacent teeth into the space which make any prosthetic replacement difficult and compromised

do adjacent teeth tip toward the extraction space, but the opposing teeth will also have the tendency to extrude, which makes orthodontic space closure or prosthetic restoration (with an implant or a bridge) practically impossible (Fig. 4.9). Treatment in such cases includes correction of the inclination of adjacent teeth and the intrusion of opposing teeth. If a clinician decides to intrude the opposing tooth or segment of teeth using a TAD, intrusion can be done as part of the pre-alignment stage. However, if the clinician decides to use classic intrusion mechanics, they should postpone intrusion until later, when the majority of teeth can function as anchorage and are stabilized with rigid wires. Application of intrusion forces on posterior segments can cause root resorption since high levels of stress can build around the root apexes. To decrease bone density and increase the rate of movement, application of MOPs in the vicinity of the root is recommended. However, if TADs are part of treatment, MOPs should not be applied too close to the TADs, to avoid

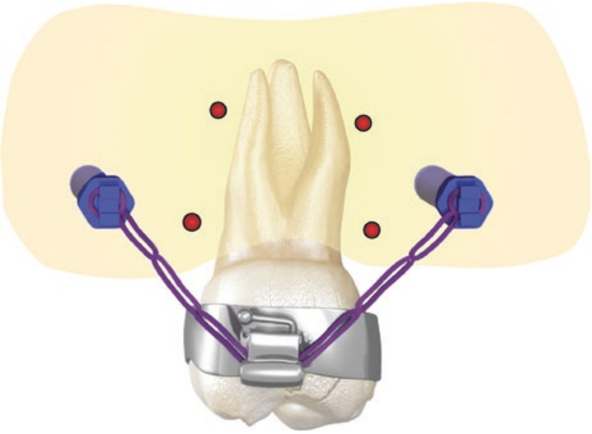


Fig. 4.10 Efficient single tooth intrusion mechanics with MOPs and TADs. MOPs can accelerate intrusion of an over-erupted posterior tooth using TADs as anchorage. In this case, it is recommended not to apply MOPs (*red circles*) very close to the TADs so their stability is not compromised

compromising the stability of the TADs (Fig. 4.10). Similar to the intrusion of anterior teeth, application of MOPs in these cases can reduce the duration of treatment while decreasing the possibility of root resorption.

4.4.3 Expansion in Adults

Expansion usually is accomplished at an early stage of treatment during the pre-alignment stage and most often in children prior to fusion of the midpalatal suture. Since skeletal changes in adults are slow, dental-alveolar movement is an important part of transverse correction in adults. Due to the reduced capacity for transverse expansion in adults, two concerns are raised:

1. Do slow skeletal changes and dense alveolar bone cause significant dental tipping? We will discuss this concern in the context of the catabolic effects of MOPs below.
2. Does alveolar bone follow transverse tooth movement or does transverse tooth movement cause dehiscence in alveolar bone? This concern will be addressed in the next chapter where the anabolic effects of MOPs are discussed.

Dental tipping during expansion can increase the risk of dehiscence, especially in the alveolar crest, and also can worsen the occlusion, especially in open bites cases (Fig. 4.11). While this is a real concern in adults, MOPs can help control these side effects.

Tipping in response to transverse forces has two causes. One cause is the distance between the force and the center of resistance of maxilla, which causes the hemimaxillae to tip along with the teeth that are housed in the hemimaxillae (Fig. 4.11a). This is one of the sources of tipping that is observed in children, where there are less dental changes than skeletal changes. In adults, similar tilting can occur

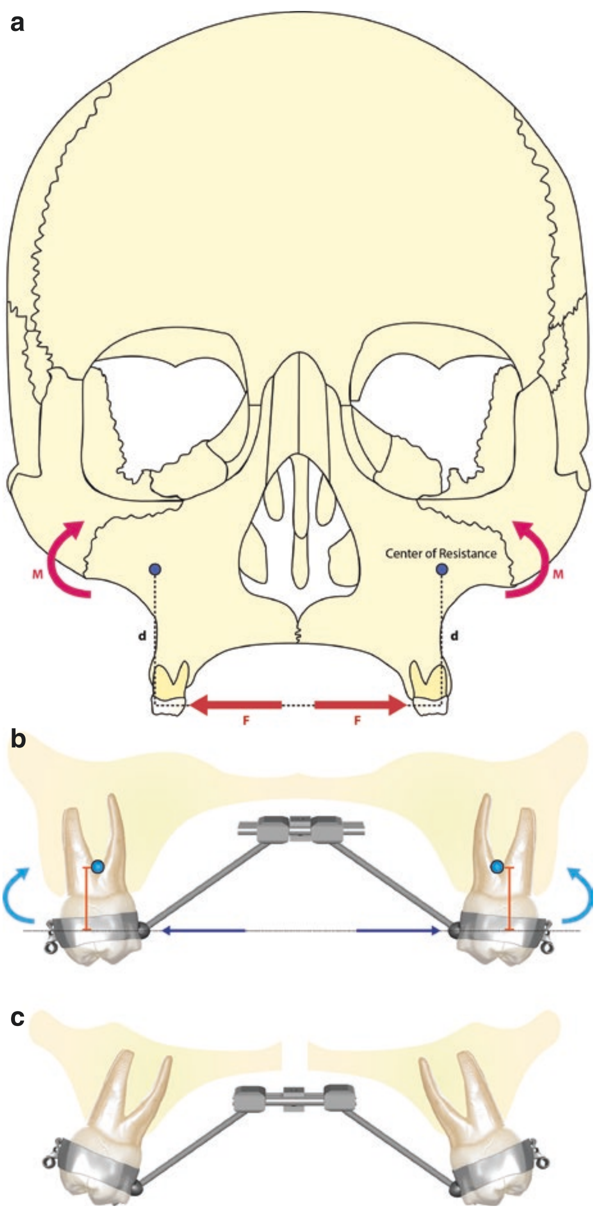


Fig. 4.11 Tipping during adult expansion. Tilting during expansion has two components: skeletal and dental. (**a**) Skeletal tipping is the result of the distance between force application and the center of resistance of maxilla, causing tilting of hemi-maxilla and the dentition together. Dental tipping that is due to the distance between force application and center of resistance of posterior teeth (**b**), which can worsen the open bite and can cause dehiscence in crest of alveolar bone (**c**)

especially if transverse forces are directly applied to the skeleton, for example, through the use of TADs. MOPs application cannot decrease this tipping. The second cause of tipping is due to the distance between the force application and the centers of resistance of teeth (Fig. 4.11b). This can be a concern especially in appliances that are attached to posterior teeth because forces are delivered directly to the

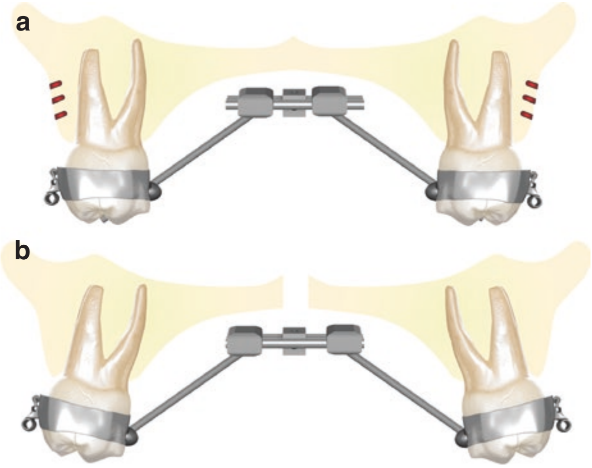


Fig. 4.12 Catabolic effects of MOPs during expansion. Catabolic effects of MOPs (**a**) during adult expansion decreases the alveolar bone density temporarily and allows more (**b**) favorable posterior tooth movement with less tilting. This procedure encourages the anabolic effects of MOPs in combination with slow expansion

teeth (Fig. 4.11c). While the opposite moments that are produced by the molar bands of the expander will resist this tipping, they are not large enough to prevent it. Applying MOPs in adult buccal segments during expansion changes the alveolar bone density around the teeth and therefore helps move the center of resistance to a more favorable position, where the possibility of tipping decreases significantly even in severe open bite cases (Fig. 4.12). Therefore, clinicians can control the possible side effects by biologically preparing the alveolar bone and mechanically minimizing the side effects.

Another concern in adult maxillary expansion is the possibility of root resorption due to the relatively high density of adult cortical bone. In children, fast skeletal adaptation and less dense alveolar bone significantly reduce the possibility of root resorption during palatal expansion. By adding MOPs to expansion treatment in adults, alveolar bone density decreases temporarily, which reduces the possibility of root resorption due to the transient activation of a larger number of osteoclasts in the area, as previously discussed.

In addition, during maxillary expansion in adults, there is the possibility of transferring the stress to the cranial base, which can have severe side effects. To achieve skeletal changes, many clinicians apply high forces especially through TADs with the objective of “breaking” the suture. However, the major resistance to expansion in adults is not in the midpalatal suture, and high forces can easily be transferred to the cranial base, which can be very dangerous, especially if they are delivered fast. Fractures of the sphenoid bone with severe complications such and blindness have been reported.

The fact that MOPs facilitate favorable dentoalveolar changes, it eliminates the need for significant skeletal changes during adult expansion and offer the possibility of using light forces in adults to achieve the desired results. Lighter forces delivered at longer intervals will prevent generating high stress areas close to the cranial base. Similarly, applying intermittent, rather than continuous, force is more desirable, since it allows the body to adapt and repair.

In conclusion, during adult expansion, the forces should be light and the rate of movement slow. In this case, the catabolic effects of MOPs in adults are used not to accelerate the rate of tooth movement, but to improve the quality of tooth movement and to control the side effects.

4.4.4 Asymmetrical Expansion

Another problem that can be addressed during the pre-alignment stage is asymmetric expansion. The majority of transverse problems in adults or teens are related to symmetrical constriction that causes a functional shift of the mandible to one side during closure, which can create the illusion of an asymmetric problem. In these cases, providing proper expansion automatically corrects the shift and apparent asymmetry. However, there are cases with a true asymmetric arch form. A major problem in treatment of these cases is that all orthodontic forces produce equal and opposite forces, which have the tendency to produce reciprocal movements that equally will affect the side that does not need any correction. To prevent reciprocal movement, clinicians usually apply additional resistance to the anchor side, for example, by increasing the number of teeth in anchor unit versus the target teeth unit on the opposite side (Fig. 4.13a). Clinicians can also address asymmetries by adding additional forces unilaterally to the target side, for example, by adding unilateral cross elastics only on target teeth (Fig. 4.13b). While these approaches can help, they are associated with their own side effects. For example, when using unilateral elastics, unilateral vertical forces will appear that can significantly affect the cant of the occlusal plane.

By applying MOPs to one side of an asymmetric jaw, it is possible to increase the movement of target teeth against anchor teeth and encourage the desired unilateral movement (Fig. 4.14). Combining this technique of increasing the speed of movement of target teeth with any anchorage method that decreases the movement of anchor teeth can significantly improve the chance of correcting unilateral constriction without side effects on the non-constricted side.

4.5 MOPs During the Leveling and Aligning Stage

Leveling and aligning does not necessarily involve movement of all teeth simultaneously. While the majority of teeth only require minor movement for correct alignment other teeth, such a severely tilted teeth, a teeth blocked out of the arch, or a severely rotated tooth, may need special attention later, once the space has been created for its correction or the other teeth can be engaged in a rigid wire and can serve as anchor. MOPs can be very useful at both the early and late alignment stages as discussed below.

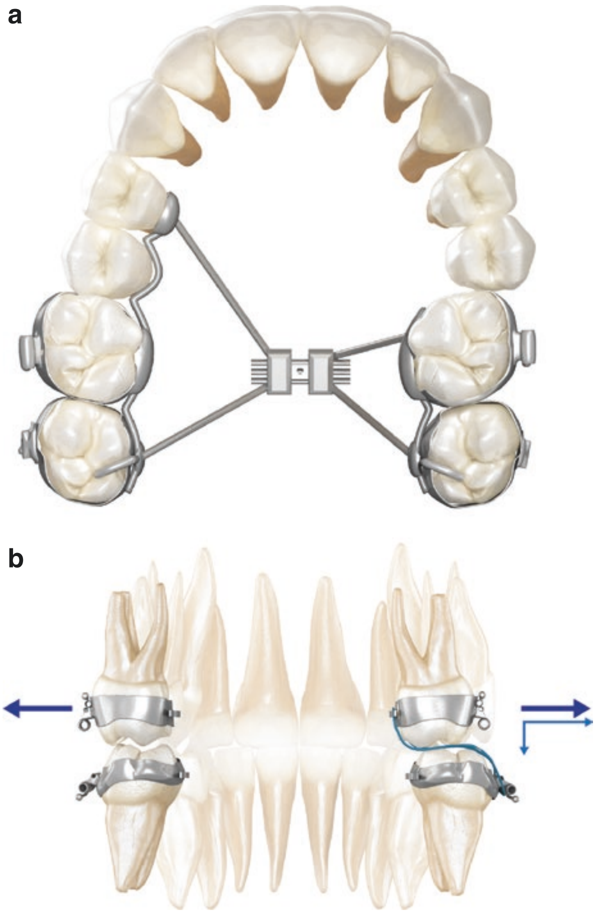


Fig. 4.13 Correction of true asymmetry by classic mechanics. A true asymmetrical dental arch can be addressed by opposing few target teeth against many anchor teeth (**a**). In these situations, even though both sides will receive equal and opposite forces, the magnitude of movement of anchor unit is limited due to size difference. (**b**) Similarly movement of target teeth vs. anchor teeth can be encouraged by using unilateral forces such as rubber bands

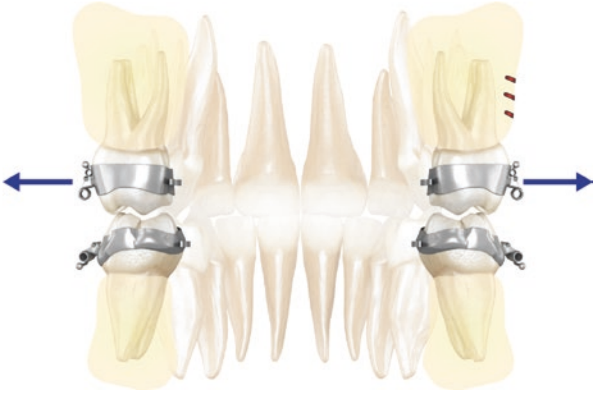


Fig. 4.14 Application of MOPs for asymmetrical expansion: Unilateral application of MOPs in the buccal cortical plate along posterior teeth to be moved can encourage unilateral expansion using principles of biological anchorage

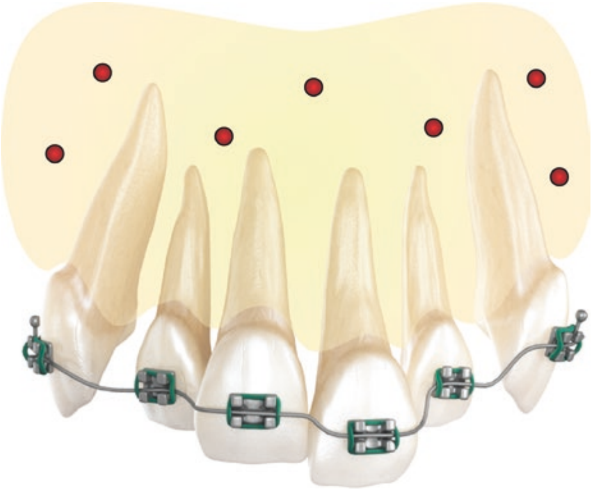


Fig. 4.15 Application of MOPs at the early stage of leveling and aligning. MOPs can be applied in association with flexible wires for faster result during early stage of leveling and aligning for correction of simple crowding (MOPs are shown as *red dots*)

4.5.1 Early Alignment Stage

4.5.1.1 Simple Crowding

As discussed previously in this chapter, the purpose of the early stage of alignment is to level and align the majority of teeth that do not have any complex issue such as severe tipping, ectopic eruption, impaction, severe intrusion, severe extrusion, severe rotation, or teeth that require significant root movement. As long as there is enough space for leveling and aligning, any minor discrepancy in the first, second, and third order would be addressed as part of this early stage of treatment. In that case, a combination of flexible wires and MOPs can quickly resolve mild to moderate crowding. This is specifically important for patients that require rapid results due to social demands or an upcoming special occasion, in which case the anterior teeth can be rapidly aligned (Fig. 4.15).

Based on Newton's Third Law of Motion, when one tooth receives a force, the adjacent teeth will receive an equal and opposite force. For small movements of target teeth, equal and opposite movement of anchor teeth may be acceptable. However, for larger movements, the opposite movement of anchor teeth may become a significant unwanted side effect that should be controlled. In these cases, it is better to biomechanically stabilize the anchor teeth with rigid wires and by limiting MOPs application only around target teeth, to increase the rate of movement of these teeth without increasing the rate of movement of anchor teeth. As a general rule, MOPs at the early stage of alignment should be very selective and limited to target teeth.

MOPs around a tooth without enough space for alignment should be postponed until anchor teeth are stabilized with rigid wire and enough space has been created for movement of the target tooth. Premature MOPs application around a crowded tooth that is not ready to move does not decrease the treatment duration. If a

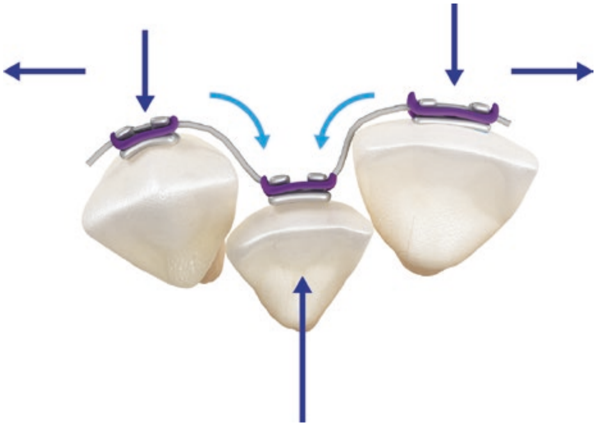


Fig. 4.16 Premature and inefficient application of MOPs. Premature use of flexible wires and MOPs to move a tooth blocked out of the arch without creating adequate space and securing the anchor teeth not only will not decrease the duration of treatment, but also it can increase the possibility of root resorption and exposure of the anchor teeth to unnecessary movements (forces in *navy blue*, moments in *light blue*)

clinician applies MOPs prematurely, without applying any force on the target tooth, bone metabolism will gradually change from the catabolic phase to anabolic phase, which can actually prolong orthodontic treatment. While it might seem logical that including a severely malpositioned tooth in a flexible wire in the presence of MOPs would increase the probability of generating the desired forces and moments to align all the teeth, this assumption is incorrect. Simple mechanics is not necessarily the correct approach, and sometimes it can prolong the treatment significantly even in the presence of MOPs. In the above example, adding a tooth with a complex problem to a flexible wire produces an undetermined system, which has side effects that would not be obvious to the clinician eyes (Fig. 4.16). These mechanics can significantly affect the adjacent teeth and temporarily push them into misalignment. These back and forth movements are unnecessarily harmful to roots and will significantly delay treatment. While MOPs will optimize the biology of tooth movement, poor mechanical design will significantly delay the treatment.

Remember that MOPs do not change the physical and mechanical laws governing orthodontic tooth movement and that shortening treatment time is only possible by combining an optimized mechanical design with the MOPs-enhanced biological response. At the end of the early stage of alignment, the majority of teeth should be leveled, aligned and ready to receive a more rigid wire to function as anchor units to correct other complex tooth problems.

4.5.1.2 Changing the Arch Form

When planning to gain space by increasing the arch perimeter, MOPs should be applied only in the area where arch expansion is required. By selective MOPs

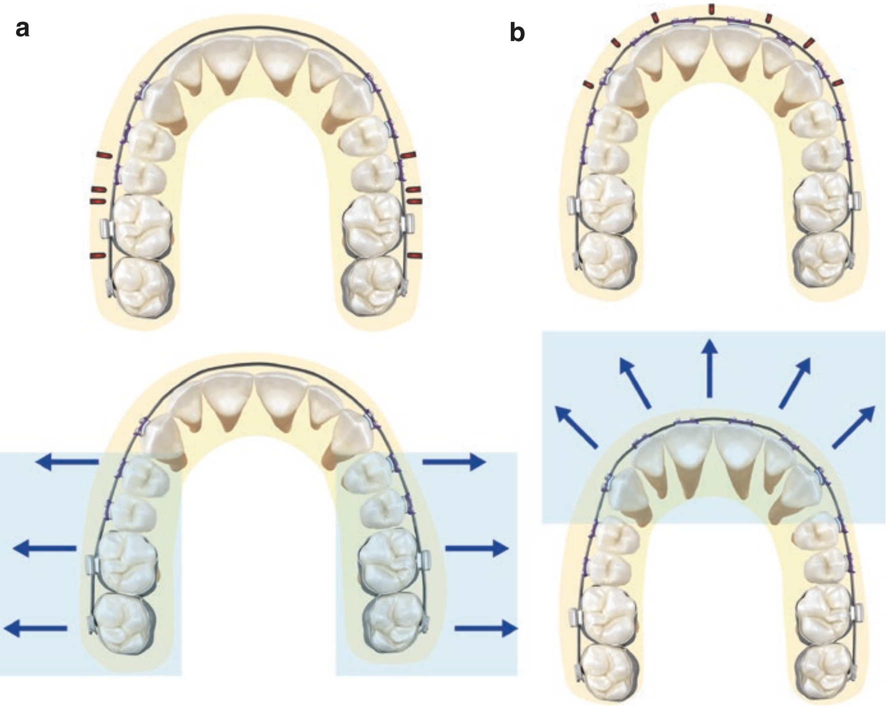


Fig. 4.17 Application of MOPs to change the shape of the arch. MOPS can facilitate changes in arch form both posteriorly and anteriorly. (**a**) To change the shape of the dental arch from narrow to a more square shape, it is wise to not include the anterior teeth in the arch wire and stimulate posterior expansion by applying MOPs on both right and left buccal plates. (**b**) To change the form of dental arch from square to more ovoid shape, MOPs should be applied around anterior teeth to favor bone changes in the anterior area, while the posterior segments maintain their shape

application in different arch segments, it is possible to change the rate of expansion in those areas and therefore change the general shape of the arch. If space is needed mostly by increasing the dental arch perimeter transversely, MOPs should be done on the posterior segment (Fig. 4.17a). In these cases, it is wise not to engage the anterior teeth to prevent their proclination. An expanded flexible arch wire can provide the required force to increase arch perimeter posteriorly. In more severe cases, this should be accomplished with a palatal expander. Alternatively, if the arch perimeter requires anterior expansion, MOPs should be localized around the anterior teeth (Fig. 4.17b). In these cases, an expanded flexible arch wire still produces transverse forces posteriorly; but, since the anterior segment moves faster than the posterior segment, the shape of arch will change more anteriorly than posteriorly. After the desired changes have been achieved, the shape of arch will be secured by rigid wires.

4.5.2 Late Alignment Stage

MOPs are very useful during the late stages of leveling and aligning when the majority of teeth are aligned and have been secured as an anchor unit by rigid wires. This unit now can resist the side effect forces and moments that are produced when attempting to move severely misaligned teeth. In general, treatment of severely misaligned teeth requires three steps: first, space is created by mesiodistal movement of adjacent teeth on rigid wires; second, proper bends in rigid wires preserve the space; and, third, misaligned teeth are engaged into flexible wires to move into the newly created space.

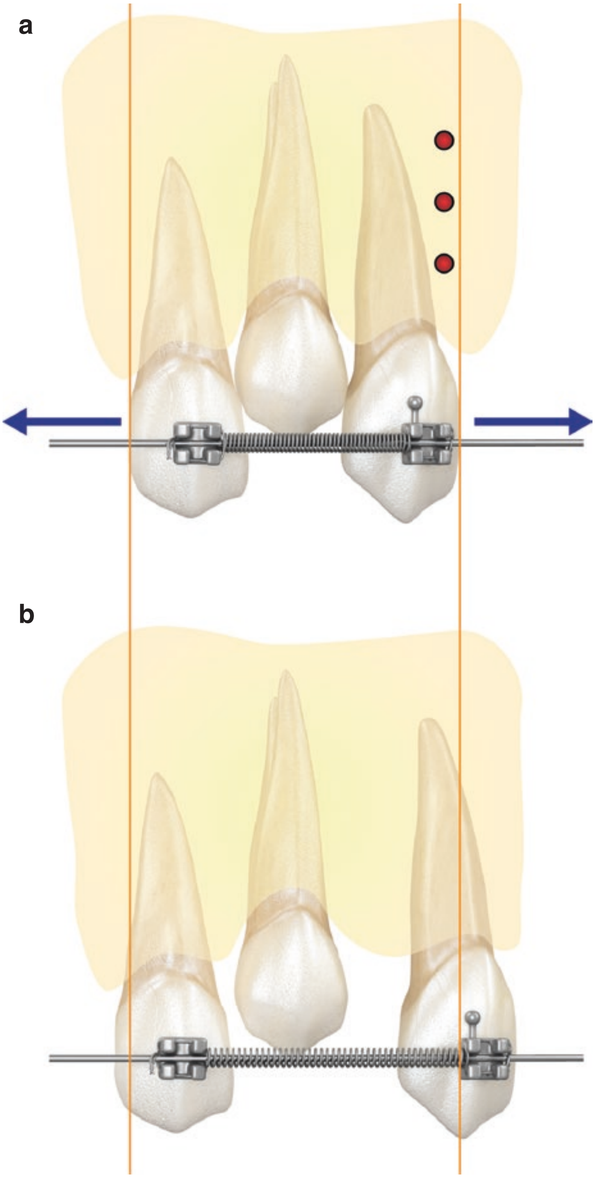
4.5.2.1 Blocked-Out Teeth

If one or more teeth are blocked out of the arch lingually or buccally, and there is not enough space for their alignment, it is best to apply MOPs around adjacent teeth to facilitate their mesial and distal movement to create the needed space for the blocked tooth or teeth. By selective MOPs application at this stage, we can stimulate space opening in one side more than the other (Fig. 4.18). After preparing adequate space, MOPs can then be applied around the blocked-out tooth, and, while maintaining the created space with a rigid wire, a flexible overlay wire can be used to produce the desired movement (Fig. 4.19a). A similar system can also be applied for the guided eruption of an impacted tooth. While eruptive force is applied to the impacted tooth with a spring, rubber band, or overlay wire, MOPs can be applied along the eruption path to facilitate the tooth movement (Fig. 4.19b).

4.5.2.2 Molar Uprighting

When molar uprighting is needed, there is usually excess space on the mesial side due to a lost tooth. In this situation, two different mechanical pathways can be taken: (1) uprighting with closure of space, which will require significant root movement, and (2) uprighting with space opening, which mostly consists of controlled-tipping with distalization (Fig. 4.20). If root movement is the main objective of treatment, the uprighting spring should move the center of rotation occlusally to the distal marginal ridge of the tooth to prevent any distal crown movement (Fig. 4.21a). During this movement, one of the main concerns is the high stress level on the root that can cause significant resorption, especially in the presence of dense alveolar bone. By preparing the bone in the direction of root movement, it is possible to not only achieve the final position faster but also safely with less possibility of resorption (Fig. 4.21b). To facilitate root movement and prevent crown movement, MOPs should be applied only on the mesial bone, leaving the distal alveolar crest intact to resist crown distalization. To maximize the catabolic effects of MOPs in these cases, MOPS application to the ridge is recommended whenever possible. It should be emphasized that these mechanics alone will close some of the mesial space and any additional attempt to close the space should be avoided until uprighting is complete. Attempts to close the space before uprighting

Fig. 4.18 Application of MOPs during space development. By creative application of MOPs in just one side, for example, mesial of a canine (**a**), it is possible to increase space opening in one direction and not the other (**b**)



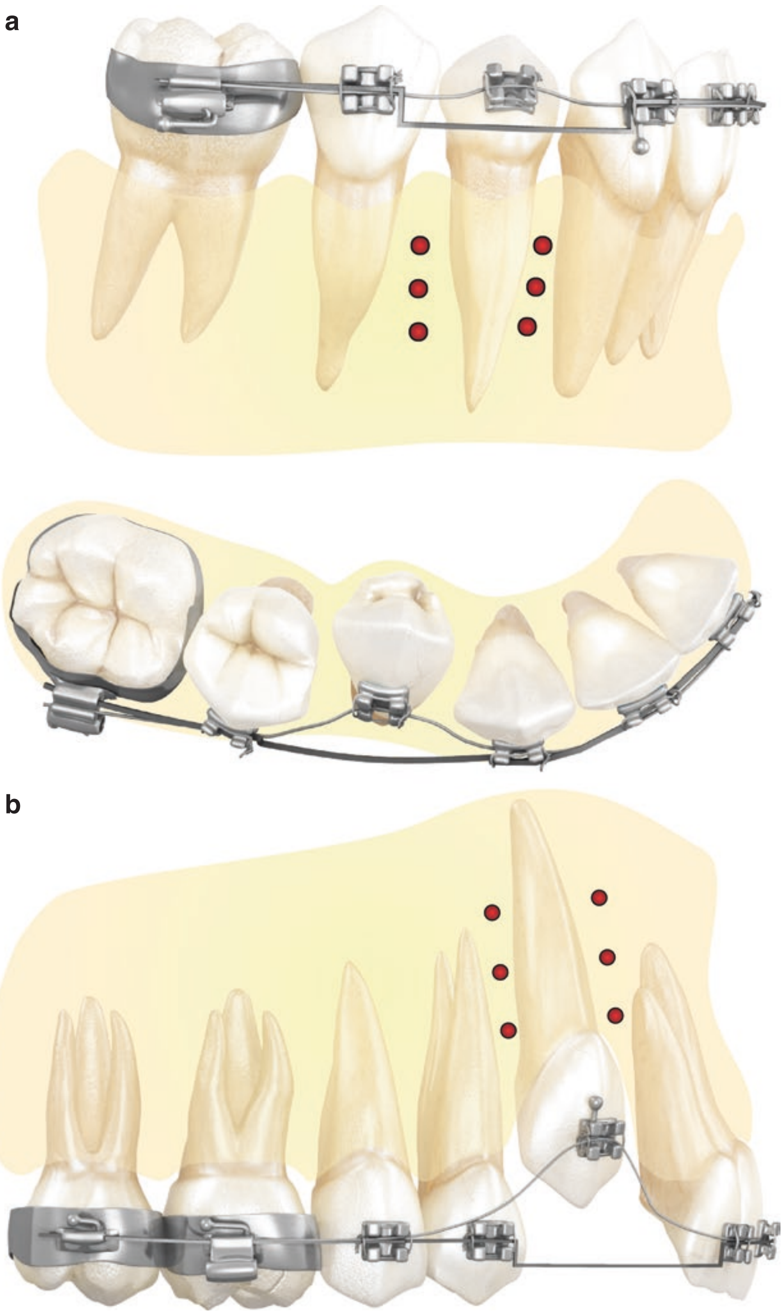


Fig. 4.19 Application of MOPs during late-stage of leveling and aligning. In the late stages of leveling and aligning (**a**) after preparation of space, anchor teeth can be secured with rigid wire bent to stop them from moving and target tooth will move faster with application of MOPs and using an overlay wire (**b**). Using similar mechanics, MOPs can facilitate eruption of impacted tooth, using an overlay wire and the aligned teeth as anchorage when engaged in a steel arch wire

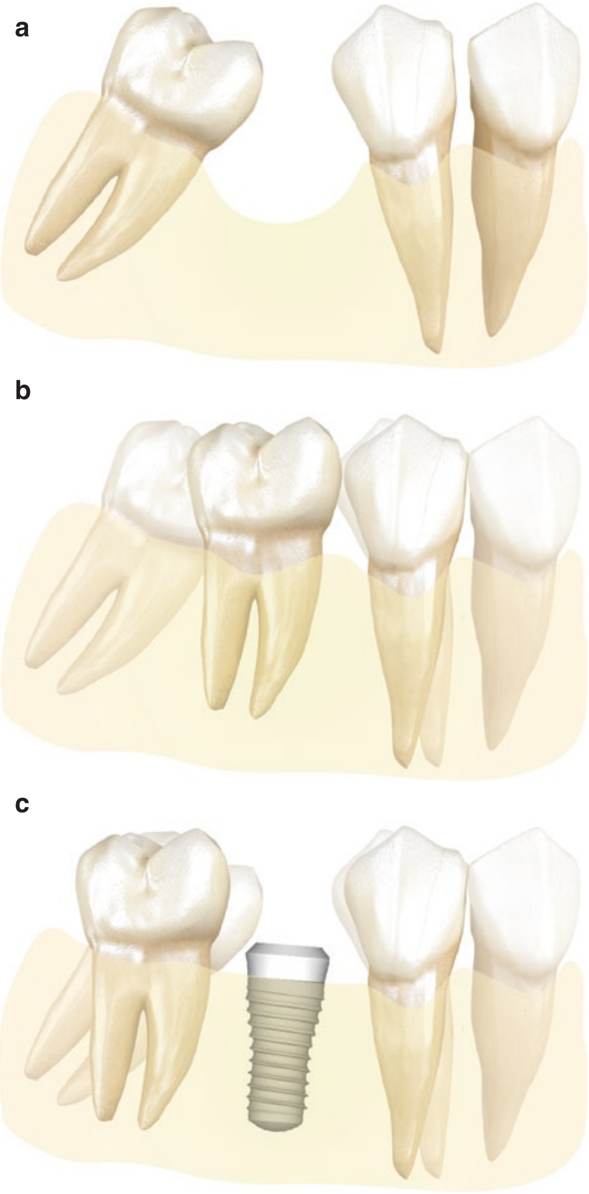


Fig. 4.20 Molar uprighting options. When one of the posterior teeth has been extracted, adjacent molar will tilt toward extraction space (**a**). Treatment for these patients may include either (**b**) uprighting of the molar and closure of space or (**c**) opening of the space and placement of an implant (**b**)

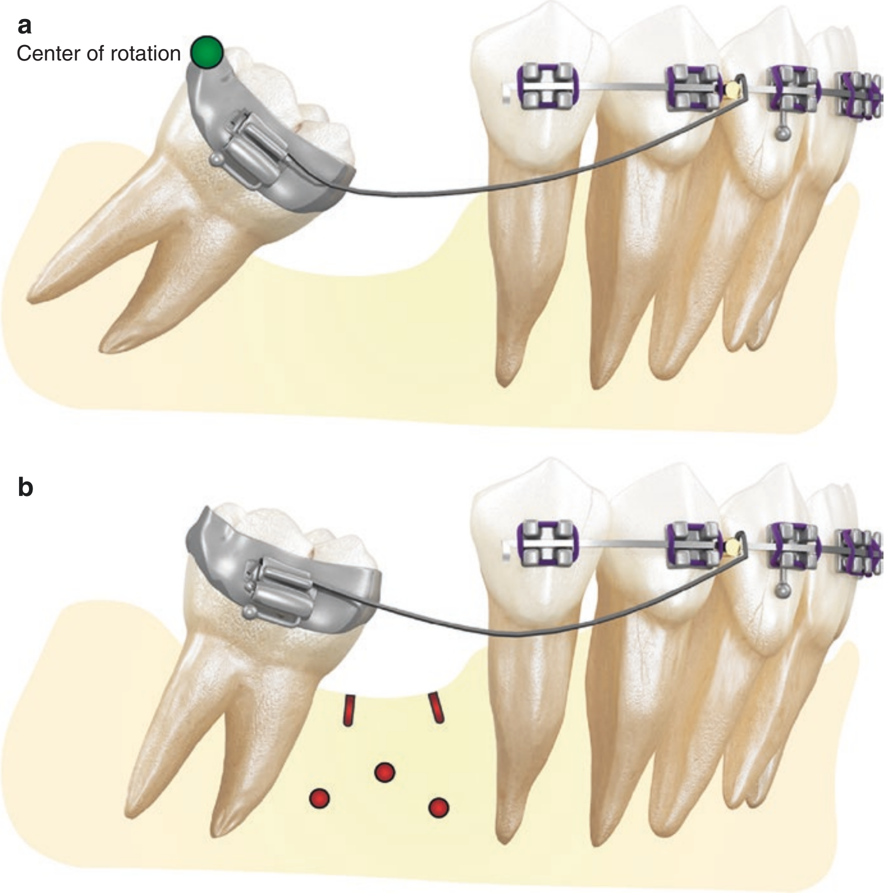


Fig. 4.21 MOPs application during molar uprighting in combination with space closure. Root movement is essential if uprighting the molar is accompanied with closure of space. In these cases, distal movement of crown should be prevented, and mesial movement of root should be encouraged mechanically and biologically. (**a**) This approach will put the center of rotation of movement on the distal marginal ridge of the molar. (**b**) In addition, root movement can be encouraged biologically by application of MOPs mesial of the molar

is complete will produce large moments that counter the moments produced by the uprighting spring and delay the treatment.

In cases that require molar uprighting with distal crown movement, the center of rotation of the movement should move toward the apex of the distal roots (Fig. 4.22a). The main challenge in these cases is the alveolar crest distal to the tilted tooth, which is usually dense and resists any movement. The dense alveolar bone often causes resorption on the distal aspect of a molar close to the alveolar crest. By applying MOPs to the alveolar crest distal to the crown, it is easier to upright the molar and significantly decrease the risk of resorption (Fig. 4.22b).

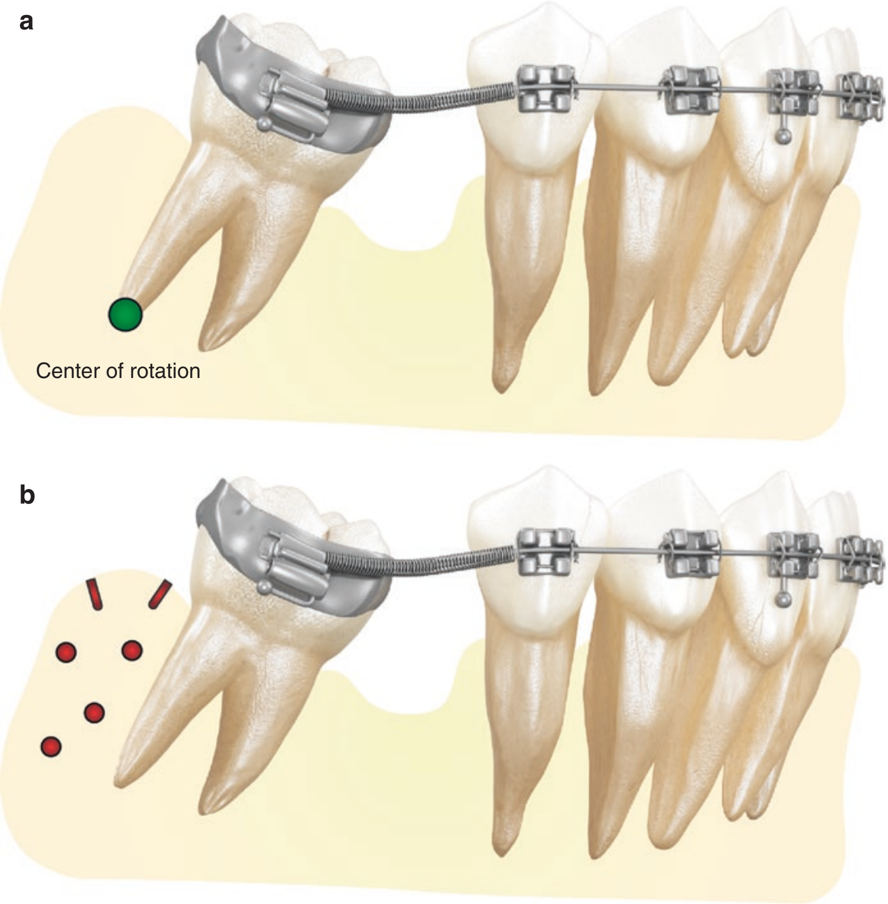


Fig. 4.22 MOPs application during molar uprighting in combination with distal crown movement. The clinician may choose to upright the molar with distal crown movement. (**a**) In this case, the center of rotation of the molar should move to the apex of distal root. (**b**) To facilitate distal crown movement, MOPs should be applied in the area distal to the tooth, in the crest of alveolar bone where dense cortical bone can prevent uprighting

4.5.2.3 Severe Rotations

One of the main challenges in orthodontics is correction of severe rotations. This correction, similar to treating blocked-out teeth, has three stages: (1) creating the space, (2) preserving the space, and (3) correcting the rotation. While MOPs application closer to the adjacent teeth can help create space, MOPs around a severely rotated tooth should be applied only at the time that space has been made available and the clinician is ready to apply the de-rotating couple (Fig. 4.23a). For a severely rotated tooth that resists correction, applying MOPs on both the buccal and lingual plates, especially along the direction of the couple, is highly recommended (Fig. 4.23b). However, for the majority of cases, MOPs placed buccally will provide sufficient biological stimulation.

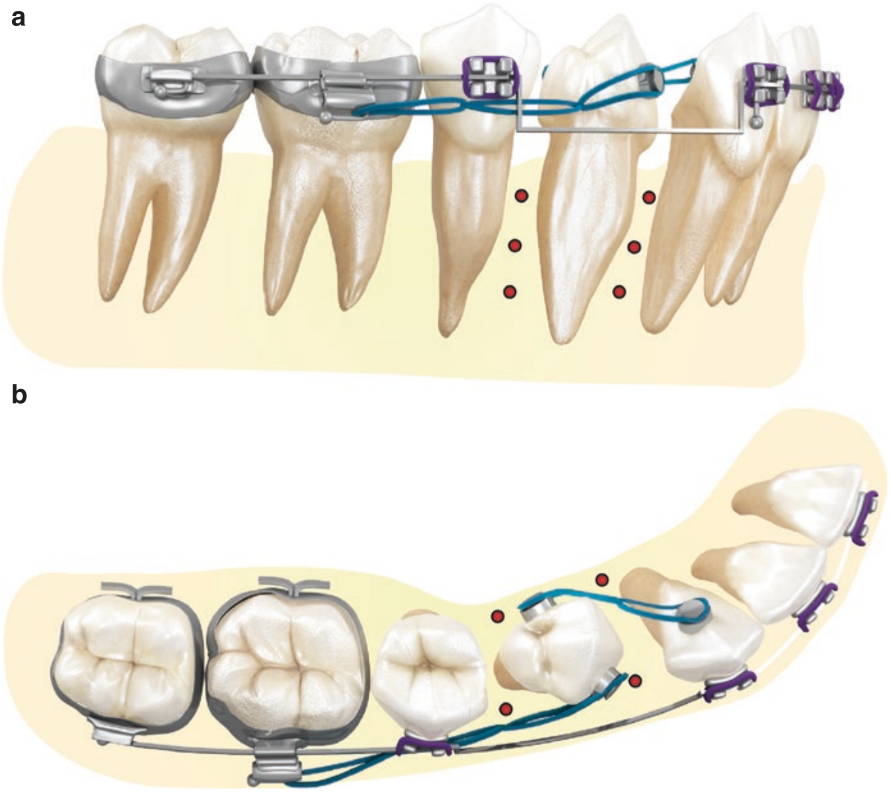


Fig. 4.23 Application of MOPs for correction of severe rotations. After the anchor teeth are secured in a stabilizing wire, (**a**) application of MOPs can significantly facilitate correction of rotation of a target tooth. (**b**) While in the majority of cases buccal MOPs are sufficient, application of lingual MOPs can significantly accelerate the treatment

4.6 MOPs During the Post-alignment Stage

MOPs also are very useful in the post-alignment stage, where the rigid working wire has been engaged in all the brackets, and it is time to move a single tooth or segment of teeth mesiodistally. Without MOPs, this stage in adults may take a very long time to complete, depending on the amount of movement required and the bone quality. Combining MOPs with a very well-designed mechanics – where proper force and moment are applied to prevent uncontrolled tipping – can accelerate tooth movement significantly and subsequently decrease the overall treatment time. The most common applications of MOPs in this stage are:

A. Canine retraction
B. Anterior teeth retraction
C. Posterior teeth protraction
D. Posterior teeth distalization

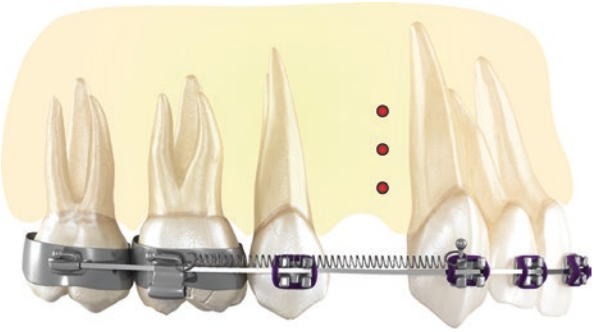


Fig. 4.24 Application of MOPs during canine retraction in post-alignment stage. In post-alignment stage, 2–3 months after extraction of first premolars, MOPs can be applied distal to canines and repeated every other month until canine retraction is over to accelerate its movement significantly

4.6.1 Canine Retraction

For cases requiring premolar extractions, space closure can be achieved by retracting the anterior teeth after retracting the canines, or en masse retraction where all six anterior teeth are retracted simultaneously. In both situations, if a patient requires maximum anchorage, MOPs application can simultaneously help accelerate the retraction and provide maximum anchorage. Interestingly, the extractions themselves serve as the best source of inflammatory cytokines thereby delaying the need for MOPs until 2–3 months following extraction. In these cases, MOPs can be applied in the extraction space just distal to the canines (Fig. 4.24). To maintain the quality of bone around the anchor teeth, no MOPs should be applied around the posterior teeth.

In cases of severe crowding, when extraction of first premolars is required at the beginning of treatment, canine retraction should be done at least partially in the pre-alignment stage, before any bracket has been placed on the anterior teeth. This movement provides enough space for aligning the anterior teeth without increasing the risk of proclination. Sectional mechanics usually are the most efficient mechanics in this scenario (Fig. 4.25). By combining the biomechanical effects of v-bends and MOPs, it is possible to produce maximum anchorage for canine retraction without the need for TADs.

4.6.2 Anterior Teeth Retraction

During anterior teeth retraction, MOPs should be applied around all four anterior teeth, if the canines are already retracted (Fig. 4.26) or six anterior teeth if the canines are not distalized yet. When space closure is planned by reciprocal movement of anterior and posterior segments, and maximum anchorage is not necessary, MOPs should be applied around both anterior and posterior teeth.

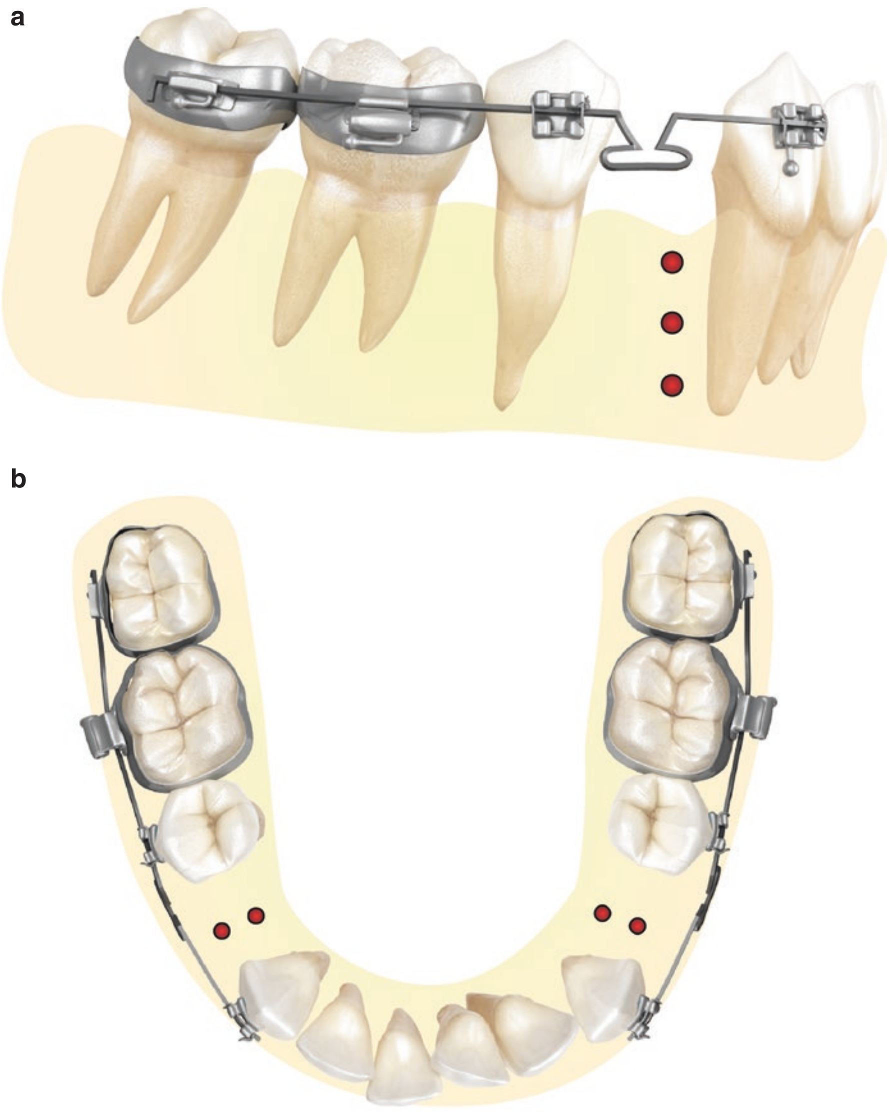


Fig. 4.25 Application of MOPs during canine retraction in pre-alignment stage. In cases with severe crowding, (**a**) early extraction of first premolar and preliminary retraction of canines are necessary to provide enough space for alignment of anterior teeth. (**b**) In this stage, application of MOPs with sectional mechanics, 2–3 months after extractions, is very effective

MOPs around the lower anterior teeth can significantly help in dental correction of class III patients. Alveolar bone in the lower anterior teeth is surrounded by dense cortical bone that can significantly delay tooth movement, contributing to root resorption and anchorage loss. In addition, due to the alveolar bone density, the centers of resistance of the lower anterior teeth are located more apically which

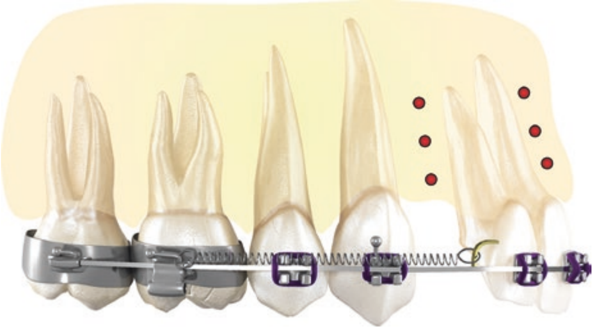


Fig. 4.26 Application of MOPs during retraction of anterior teeth. In post-alignment stage, after canine retraction, MOPs can be used to accelerate the rate of retraction of remaining anterior teeth. With this objective, MOPs can be applied distal to laterals and between centrals and laterals

significantly decreases the ability to produce bodily movement. It is very common in these patients to find severely retroclined lower anterior teeth with apexes that are pushed toward the buccal cortical plate (uncontrolled tipping). MOPs can be very useful to prevent root resorption and to improve the moment-to-force ratio (Mc/F). While the catabolic effects of MOPs in these patients can be significant, the anabolic effects of MOPs may be even more crucial to stimulate cortical drifting, as discussed in Chap. 5. Due to the importance of the anabolic effects of MOPs in class III patients corrections, it may be more helpful to apply MOPs on both buccal and lingual plates. If anabolic effects of MOPs are required, light forces should be applied, and accelerated tooth movement should not be the focus of treatment.

MOPs application around the upper anterior teeth also helps greatly in correcting class II patients with excessive overjet. In these patient, poorly designed mechanics may cause unnecessarily retroclination of the upper anterior teeth. This possibility increases significantly in adults with dense alveolar bone. Deficient of torque in turn can prolong the finishing stage and increase possibility of root resorption. With MOPs and well-thought mechanics, it is possible to keep proper angulation of anterior teeth during treatment.

4.6.3 Posterior Teeth Protraction

Another major application of MOPs is protraction of posterior teeth especially in the maxilla of class III patients. In these conditions, anterior teeth cannot provide sufficient anchorage, and any retraction of upper anterior teeth may worsen the occlusion and create a negative overjet. While TADs can significantly help build strong mechanical anchorage, applying MOPs posteriorly can cause less resistance during protraction and, therefore, enhance the relative anterior biological anchorage (Fig. 4.27).

Application of MOPs for protraction of posterior teeth is very useful in teens who are missing a permanent posterior tooth, such as second premolar, and plan to replace the missing tooth by protracting molars. In these cases, after extraction of primary molars, MOPs are applied locally around the first molar area (Fig. 4.28) to facilitate protraction with less demand on the anterior anchor unit and also to decrease the risk

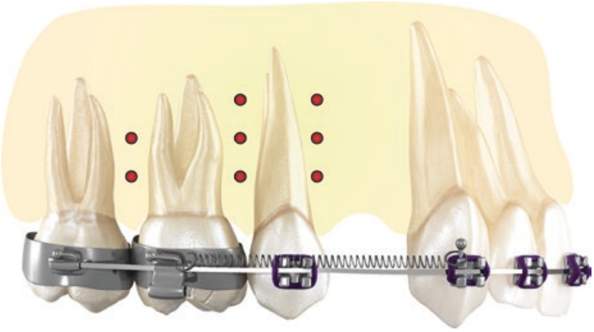
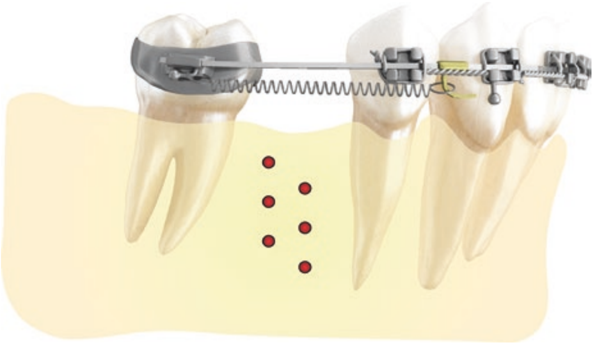


Fig. 4.27 Application of MOPs during protraction of posterior teeth. Anterior teeth cannot function as a strong anchorage unit for protraction of posterior teeth. While applying TAD may help build proper anchorage, application of MOPs around posterior teeth can stimulate biological anchorage. In this case, protraction of posterior teeth results in shorter exposure of anterior teeth to stress, which may decrease the need for TADs in borderline cases

Fig. 4.28 Application of MOPs for replacement of missing posterior tooth in teens. For many teens with missing permanent 2nd premolars, it is possible to extract the primary molar and close the space by predictable protraction of first molar with the help of localized application of MOPs



of root resorption. It should be emphasized that fewer sessions of MOPs applications are required in younger patients because of their lower alveolar bone density. To decrease the stress on the anterior anchorage unit during protraction of first molars, it is better to take advantage of the eruptive force of the second molars and, as much as possible, allow the second molars to naturally migrate mesially.

In cases where the majority of the posterior teeth are present, it is wiser to protract one at a time using the teeth distal to the target tooth as anchorage, to decrease stress on the anterior teeth. In these cases, MOPs should be applied only around the tooth that is moving and not the posterior teeth that function as anchorage (Fig. 4.29). As posterior teeth are moving forward one by one, the area of catabolic activity should be maintained by frequent MOPs application.

While MOPs significantly help anchorage preparation by decreasing the resistance of bone in the path of tooth movement, there is increased chance for anchorage loss if the distance a tooth has to move is large. Therefore, in cases where the tooth needs to be moved for large distances, maximum anchorage is necessary, and increasing anchorage by other methods is strongly recommended.

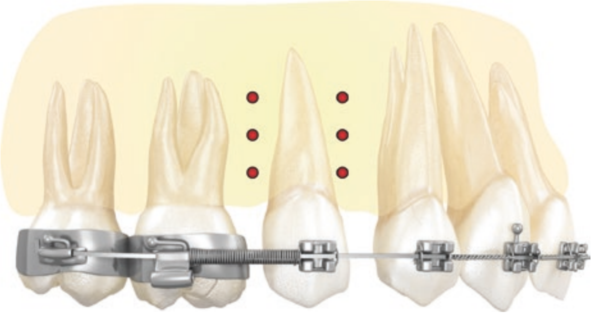


Fig. 4.29 Application of MOPs for replacement of missing tooth in adult. In adult patients with a missing tooth, application of MOPs in the area allows the gradual protraction of the posterior teeth. The teeth distal can temporarily function as anchorage to decrease stress on anterior teeth

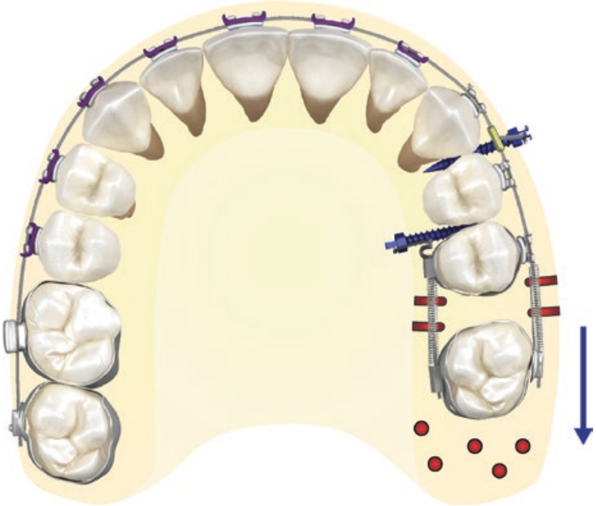


Fig. 4.30 Application of MOPs for distlization of posterior teeth. In patients that require distalization of posterior teeth, application of MOPs on the distal cortical bone can significantly facilitate distal movement. Combination of TADs and MOPs can be used when significant distalization is required

4.6.4 Posterior Teeth Distalization

Distalization of posterior teeth can be challenging due to the significant resistance of the cortical bone against distal movement and the movement of the anterior anchor segment forward that can worsen the occlusion. MOPs can help overcome both challenges. Application of MOPs in the distal alveolar bone can decrease bone resistance in the path of distalizaiton, while enhancing biological anchorage and decreasing the stress on the anterior segments. However, for cases that require significant distalization, combination of TADs and MOPs is recommended (Fig. 4.30).

4.7 Finishing Stage

There is no need for MOPs during the majority of the finishing stage, as only small detailing of the occlusion remains. However, two conditions may benefit from MOPs application: (1) when there is a small residual space that resists closing and (2) when significant root movement is necessary for paralleling of roots in an extraction space or correction of torque.

4.7.1 Closure of Residual Space

In some patients, after closing the majority of space in the post-alignment stage, some resistance will appear in closing a small residual space, or space reopens during the finishing stage. This mostly occurs due to thick buccal or lingual alveolar bone that does not allow complete movement or if space closure was achieved mostly by tooth tipping. In these cases, MOPs application in the buccal, and sometimes lingual cortical, plate can significantly help in closing the remaining space by removing any residual resistance from surrounding bone. In addition, due to facilitating root movement, MOPs allow last-minute corrections of uncontrolled tipping by facilitating the proper type of tooth movement in the presence of proper mechanics.

However, by using MOPs in the earlier stages of treatment, the majority of tooth movement should have been optimized during treatment, and there should not be any major movement needed during the finishing stage.

4.7.2 Correct Root Angulation

Application of improper mechanics during the post-alignment stage and during retraction of upper or lower anterior teeth may change the angulation of the anterior teeth. Insufficient moment-to-force ratio (Mc/F) may cause significant tipping of anterior teeth (loss of torque), which can compromise the occlusion and esthetics. Similarly, root angulation in the posterior segment during space closure may have changed due to the side effects of mechanics, which needs to be addressed during the finishing stage. Therefore, after the post-alignment stage, a panoramic radiograph is recommended to evaluate the root position. Also, evaluation of the patient's smile and profile can help the clinician to determine if the upper or lower teeth have been retroclined significantly and if they require correction of torque.

Combination of MOPs and proper mechanics in the post-alignment stage could significantly avoid these problems during the finishing stage. However, when faced with these issues, the clinician can use MOPs to facilitate the required root movement, reduce the stress on the roots of anterior teeth and anchor teeth, and finish the treatment. By applying MOPs, it is possible to decrease the bone resistance in the path of movement of the roots and make corrections in a short period of time (Fig. 4.31). During this stage, the main objective should be maintaining the crown position that has been established after the post-alignment stage and focus mostly on root movement.

4.8 Retention Stage

One of the main challenges in orthodontics is relapse after treatment is completed. Studies on the value of MOPs in reducing relapse are very limited, but clinical experience suggests a value for MOPs in this process. MOPs can contribute to the final stability of the treatment by the following:

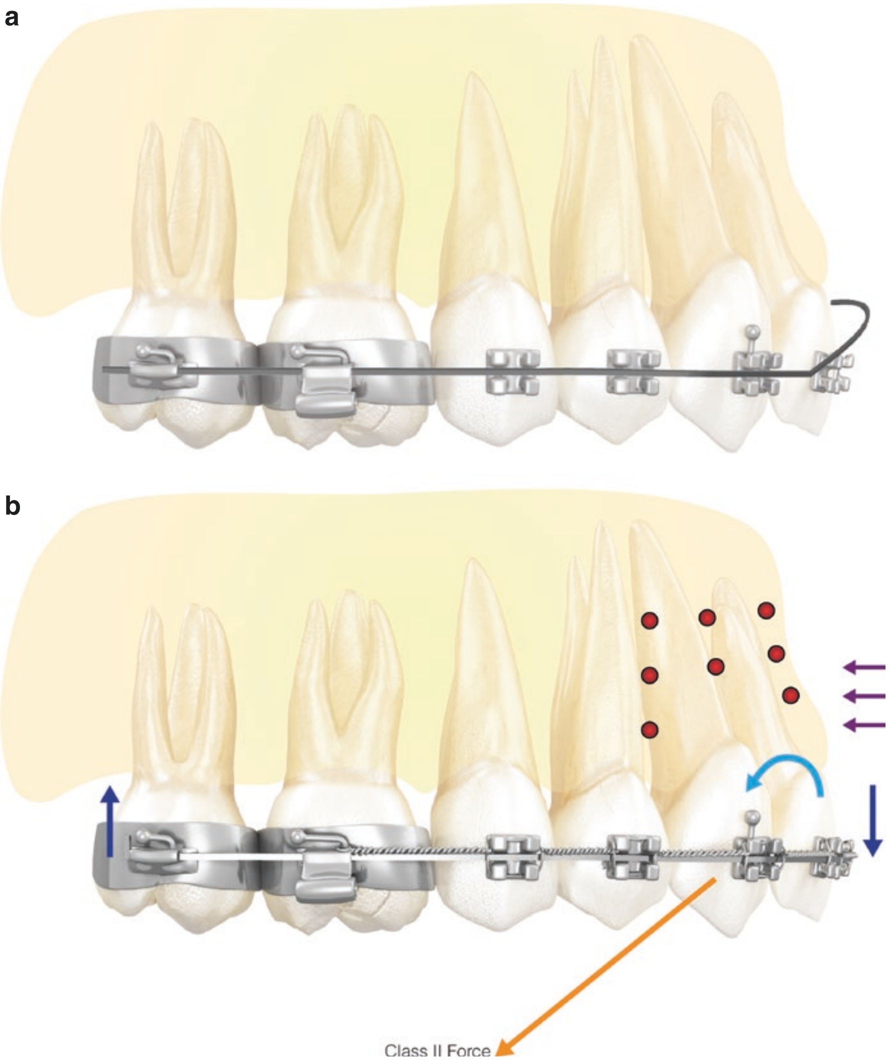


Fig. 4.31 Application of MOPs for correction of torque. In conditions of severely retroclined anterior teeth (**a**), the combination of proper mechanics that produce adequate anterior couple and (**b**) MOPs around anterior teeth can facilitate root movement without significant stress on the roots or anchor teeth (*blue arrow* shows moment, *short arrows* show forces, *yellow arrow* represents class II inter-arch force application)

1. MOPs during correction of severe crowding promotes more extensive remodeling around the roots with new attachment between periodontal fibers and newly made bone reestablished. This can prevent the possibility of stretched fibers that carry memory to relapse.
2. MOPs allows proper tooth movement (bodily movement versus tipping) resulting in improved treatment outcomes with teeth placed in a more stable uprighted

position. Paralleling of the roots, achieving proper overbite and overjet, correction of toque, uprighting of inappropriate inclination, and extensive movement of teeth to establish proper occlusion while preserving root integrity all contribute to the final stability.
3. The anabolic effect of MOPs also helps produce more stable results by encouraging the movement of the bone with the tooth, avoiding dehiscences and root exposure.

Another obvious application of MOPs during retention is when a patient develops minor relapse due to improper or insufficient retainer wear. In these cases, if the patient refuses retreatment with fixed appliances, it is possible to reestablish proper alignment and occlusion in a short period of time by combining MOPs with a simple removable appliance or clear aligners.

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Anabolic Effects of MOPs: Cortical Drifting

5

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5.1 Introduction

In the previous chapter, we have extensively discussed the catabolic effect of Micro-osteoperforations (MOPs) that is characterized by the release of inflammatory markers in response to minor trauma to the bone, which in turn activate osteoclasts and stimulate bone resorption. However, the catabolic response is not the only effect of MOPs. In fact, osteoclasts will be replaced by osteoblasts to initiate a repair phase that restores the structure of resorbed bone. This phase is known as the anabolic phase.

While catabolic phase of MOPs has many clinical applications as discussed previously, the anabolic phase of MOPs can significantly expand the orthodontic corrections and should be incorporated in treatment planning. It is important to note that anabolic effect of MOPs automatically appears subsequent to the catabolic effects, regardless of the clinician intention. Whenever a clinician applies MOPs to accelerate tooth movement, enhance biological anchorage, decrease root resorption, or move teeth through a long distance, osteoblast activity is a positive effect that inevitably follows osteoclast activation and helps keep the integrity of alveolar bone. Often clinicians are not aware of these beneficial features of MOPs and therefore may not utilize them properly. However, there are many clinical situations where the catabolic effect of MOPs may not be required, but a clinician utilizes MOPs to activate its anabolic effect. The purpose of this chapter is to train the clinician on how to incorporate anabolic effects of MOPs in orthodontic treatment planning when additional bone formation is needed. Anabolic effects of MOPs will expand the envelope of tooth movement into areas that were previously considered impossible. The gradual bone formation in the absence of any skeletal cut, flap, or graft can expand the opportunity of nonsurgical correction for many moderate and severe skeletal problems.

To better understand this unique property of MOPs, we will take a closer look at the biological principles supporting the biphasic unit.

5.2 Biphasic Unit: The Base of Natural Adaptation of the Skeleton

The basic unit of formation of the skeleton in the craniofacial area is defined by osteoclast removing the old bone structure and guiding the osteoblasts to establish a new structure. Since the activity of this unit occurs in two consecutive phases of bone resorption (catabolic phase) followed by bone formation (anabolic phase), this unit is called biphasic unit. Based on this theory, osteoclasts play a significant role in sculpturing the craniofacial skeleton including the alveolar bone. In this process, osteoclasts function as polar cells, and the direction of bone formation is dictated by osteoclast direction of resorption. This directionality can simply be observed in the natural bone remodeling cone, formed in the skeleton to remove the old bone and replace it with the new bone. In the cone, osteoclasts act as the frontline and determine the path of osteoblast activity (Fig. 5.1). This unit, therefore, plays a

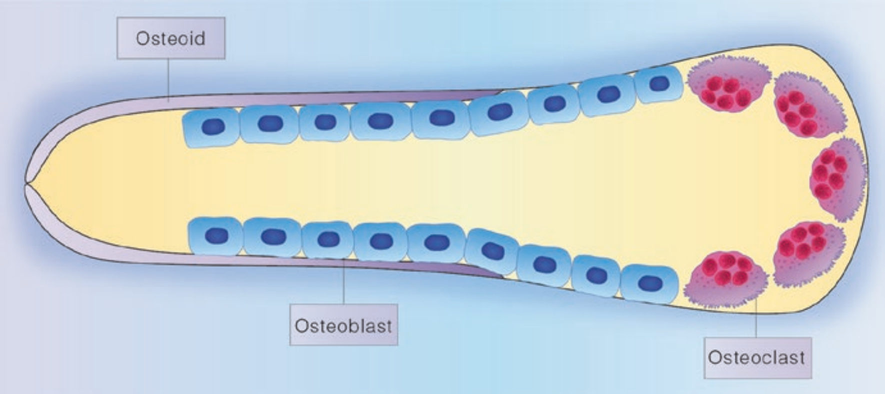


Fig. 5.1 Schematic of a remodeling cone. Remodeling cones play a significant role in renewing the skeleton in response to natural demands. Osteoclast activity removes the bone in the front, while osteoblast rebuilds the bone in the back of the cone. This is an example of a biphasic unit with two consecutive phases of bone resorption (catabolic phase) followed by bone formation (anabolic phase), occurring in a particular direction

significant role in the growth of craniofacial area that occurs naturally in response to demands of the soft tissue. Under the activity of this unit, cortical bone can drift in the direction of growth to accommodate the growth of soft tissue, a process called cortical drifting.

The function of the biphasic unit depends on the communication between osteoclasts and osteoblasts. As discussed in Chap. 1, the coupling between osteoclast activity and osteoblast activity can occur through three different pathways, the release of paracrine factors by osteoclasts, direct cell-cell interaction, and the release of bone matrix proteins as the result of osteoclast resorption activity (Fig. 6 of Chap. 1). While these pathways differ fundamentally, they do share an important feature. In each case, osteoclast activity precedes osteoblast activity.

The activity of biphasic unit is not limited to the periods of growth and development in children and adolescents but occurs throughout life as we age, to a limited degree. For example, natural cortical drifting can be observed in adults after tooth extraction. The tooth in the opposing arch will extrude toward the extraction space along with the cortical bone surrounding it (Fig. 5.2). Similarly, cortical drifting can occur under pathological conditions such as during the slow growth of a cyst or tumor (Fig. 5.3). In these scenarios, while osteoclasts create space for the tumor or cyst by resorbing bone, they stimulate bone formation causing the expansion of alveolar bone by drifting the surrounding cortical bone to an outer perimeter. Interestingly, in conditions of acute growth of a cyst or tumor, while significant amounts of osteoclasts are activated, the progression of disease can be faster than the repair process. Therefore, osteoblasts do not have enough time to make the new bone, and instead of expansion of alveolar bone, perforation of cortical plate will occur. This observation also emphasizes the importance of slow treatment when new bone formation is required, to allow osteoblasts to fabricate the new bone.

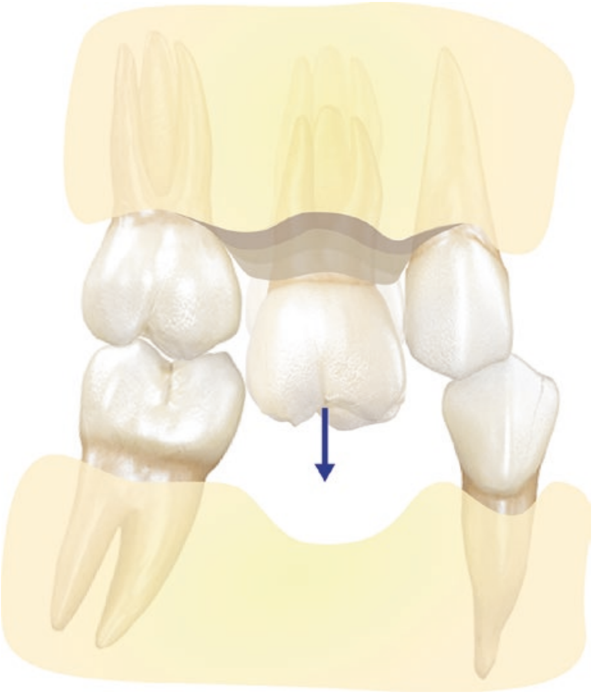


Fig. 5.2 Cortical drifting during tooth eruption. During natural eruption of a tooth, slow cortical drifting is the mechanism that maintains the bone-tooth relationship (*blue arrow* shows direction of tooth eruption)

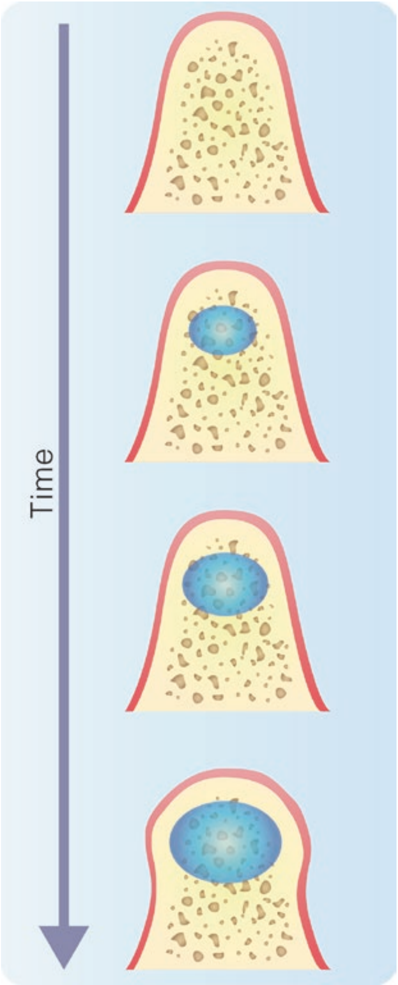
While osteoclasts are activated before osteoblasts, after the initial stage of catabolic events, osteoclasts move to a new position, and active osteoblasts replace the bone resorbed by osteoclasts. Therefore, during cortical drifting there will be a period of time when osteoclasts and osteoblasts work simultaneously in adjacent locations. After the stimulant for osteoclasts activation has been removed, the catabolic phase will end and only osteoblasts remain in the area to finish the job.

Due to role of time in this process, the dynamics of the biphasic unit can be missed by investigators that study the skeleton in “snap shots” of time which capture the bone only at the catabolic or anabolic phase. Without looking at the skeleton as a dynamic environment, they may rush into the conclusion that osteoclast and osteoblast activities are not coordinated, but they are separate and isolated phenomena, which is far from reality.

5.3 Application of MOPs for Cortical Drifting

Soft tissue demands trigger physiologic and pathological activation of the biphasic unit in the skeleton to allow its adaptation to these changes. Similarly, application of MOPs can artificially stimulate the biphasic unit which not only helps to recruit

Fig. 5.3 Cortical drifting in response to pathology. In response to a slow growing cyst or tumor (*top to bottom images*), cortical drifting accommodates the expanding pathology (*shown as the blue circle*). This phenomenon will not occur if the rate of growth of the pathology is faster than cortical drifting



the osteoclasts to the area of interest to remove the old bone but also activates the osteoblasts to reshape the alveolar bone based on the clinician's desire. This property of MOPs can be used in two main clinical scenarios:

5.3.1 To Expand the Boundaries of Existing Alveolar Bone

One of the main challenges when treating adult orthodontic patients is the thickness of the buccal and lingual cortical plates of alveolar bone. These cortical plates are considered the natural boundaries for tooth movement. It has been assumed that any attempt to move a tooth beyond these boundaries may cause areas of significant root exposure (dehiscence) due to the lack of coordinated movement of the bone with the tooth. This limitation has a tremendous effect on clinical decisions such as extraction vs. non-extraction or surgical vs. nonsurgical treatment plans. The belief on this natural limitation, when treating a significant skeletal problem that requires tooth movement beyond the boundaries of the cortical plate, leads orthodontists to suggest orthognathic surgery as the only option to avoid alveolar bone dehiscence.

For severe skeletal problems, orthognathic surgery may still be the best solution; however, for many severe to moderate problems, MOPs offer a conservative approach for dental and skeletal corrections. Shallow perforation on the surface of buccal or lingual cortical plate can stimulate the biphasic unit, resulting in bone formation on the surface of the plate. The combination of these shallow perforations with orthodontic tooth movement can drift the cortical plate in the direction of tooth movement.

This phenomenon in combination with slow tooth movement can help the development of the bony skeleton while maintaining the integrity of the alveolar bone around the moving tooth or teeth. Due to this anabolic effect of MOPs, it is now possible to expand the boundaries or envelope of tooth movement. This has great impact in two areas of treatment, palatal expansion in adults and retraction of lower anterior teeth in class III patients. Both scenarios will be discussed in more detail later on this chapter. Due to these skeletal changes, the effects of MOPs can be considered orthopedic.

5.3.2 To Stimulate Bone Formation in the Area of Bone Loss

One of the challenges of orthodontic treatment is moving teeth in areas where of significant bone loss, such as the residual alveolar ridge of an old extraction (Fig. 5.4). These areas can also develop due to traumatic extraction (Fig. 5.5) or lack of development of alveolar bone around an ankylosed tooth. MOPs in the area not only facilitate movement of teeth but also stimulate bone formation which helps keep the integrity of alveolar bone around the tooth moving into the defective area. It must be noted that bone grafting or placement of an implant is not always a realistic option. The anabolic effects of MOPs allow the clinicians to offer closing the space by tooth movement as a viable option. With the use of MOPs, this is no longer considered a big challenge in orthodontics.

5.4 Incorporating Anabolic Effects of MOPs in Orthodontic

5.4.1 General Considerations

The stage of treatment and the patient needs will determine whether a clinician needs to delay or stimulate anabolic effects of MOPs.

When bone formation is needed, the anabolic effect is the main objective for applying MOPs and should be promoted and not delayed. In these cases, the anabolic phase should be stimulated either ahead of tooth movement or at least

Fig. 5.4 Deficient alveolar ridge in old extraction space. Extraction is accompanied with severe bone resorption in both vertical and horizontal direction. The remaining bone in the area usually is a dense cortical bone. Orthodontic movement of a tooth into these spaces is considered a challenge plagued with many complications

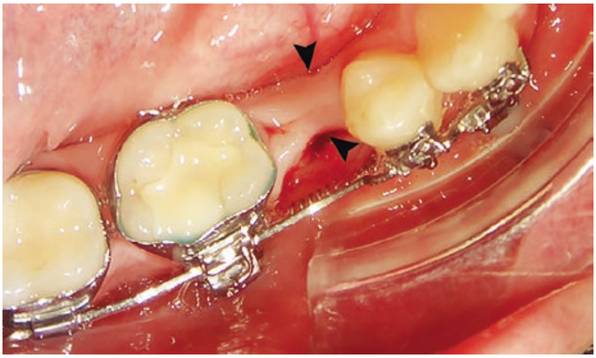


Fig. 5.5 Clinical representation of bone loss due to traumatic extraction. The alveolar ridge in the area of traumatic extraction presents severe bone loss (*black arrow heads*). This is a perfect example of indicated MOPs – induced anabolic response

simultaneously with the movement. In adult expansion, for example, the safe drift of the bone with teeth buccally is very important for maintaining alveolar bone integrity. Cortical drifting of the buccal cortical plate in these cases can help transform a surgical case into a nonsurgical case. In this situation, while application of deep MOPs may help in changing the bone density to facilitate movement, application of multiple shallow MOPs on the cortical bone can stimulate cortical drifting, allowing the bone to move with the teeth.

Since maintaining the new bone requires mechanical stimulation, it is advisable to stimulate bone formation at the same time of tooth movement. Without mechanical function, the bone formation is temporary and will disappear shortly after, similar to any bone without the function. This phenomenon can be seen after extractions, where alveolar bone resorbs in a short period of time.

It must be noted that if a clinician increases the intervals between MOPs applications, the anabolic effects that automatically follow the catabolic phase will generate the new bone. However, if the catabolic effect was the main target of applying

MOPs, these prolonged intervals may undermine this purpose and therefore be counterproductive. In these cases, a clinician should delay the anabolic effects of MOPs by frequent application of deep micro-osteoperforations to keep the active osteoclasts in the target area longer and prolong the catabolic response.

5.4.2 Common Clinical Applications

5.4.2.1 Cortical Drift During Adult Expansion

Alveolar cortical bone sets the physical and physiological limits of orthodontic tooth movement. In the majority of orthodontic treatment plans, it is unnecessary to cross this boundary. A tooth can be moved in trabecular bone between labial and lingual cortical plates and in a sagittal direction easily and safely. But what happens if we plan to move a tooth against the labial or lingual cortical plates?

This is a critical question, and orthodontists face a conundrum when they have a borderline extraction case, where expansion would provide the space needed to unravel the crowding but the alveolar boundary conditions are not healthy enough to tolerate the expansion. Therefore, it would be of great value for orthodontists to manipulate these boundary conditions by increasing bone formation on the surface of the cortical plate.

As mentioned previously, the main concern in adult expansion is the possibility that the alveolar cortical bone will not follow the tooth movement, and the tooth moves out of the cortical plate. In children, due to wider palatal suture, it is possible to produce a significant skeletal movement with less reliance on dentoalveolar movement during expansion. However, in adults, due to the narrower and more interdigitated sutures, the application of expansion forces can produce limited skeletal changes and mostly cause dentoalveolar changes.

While the majority of expansions in children have a large skeletal component, dentoalveolar changes are also induced but are safer in children. Alveolar bone in children is wider (due to hosting both primary and permanent teeth) and more cellular with larger trabecular areas and less dense cortical bone. These conditions do not exist in adults where alveolar bone gradually changes with the increase of age to become narrower, less cellular, less trabecular accompanied by a significant increase in the density of cortical bone.

Due to these limitations, remodeling of alveolar bone should be the main goal in adult expansion. As long as alveolar bone in adults can move with the teeth, the final result of expansion cannot be differentiated from sutural expansion. To achieve this goal, both catabolic and anabolic effects of MOPs are required. Catabolic effects of MOPs temporally decrease the density of alveolar bone to facilitate a more desirable movement of teeth (bodily) in alveolar bone and decrease the possibility of root resorption. On the other hand, the anabolic effect of MOPs stimulates osteoblast activity in the periosteal surface of the buccal cortical plate allowing cortical drifting (Fig. 5.6). Therefore, two types of MOPs should be applied during adult expansion: to decrease density of alveolar bone, deeper but fewer MOPs are recommended, while to stimulate periosteal activity, multiple but shallower MOPs are

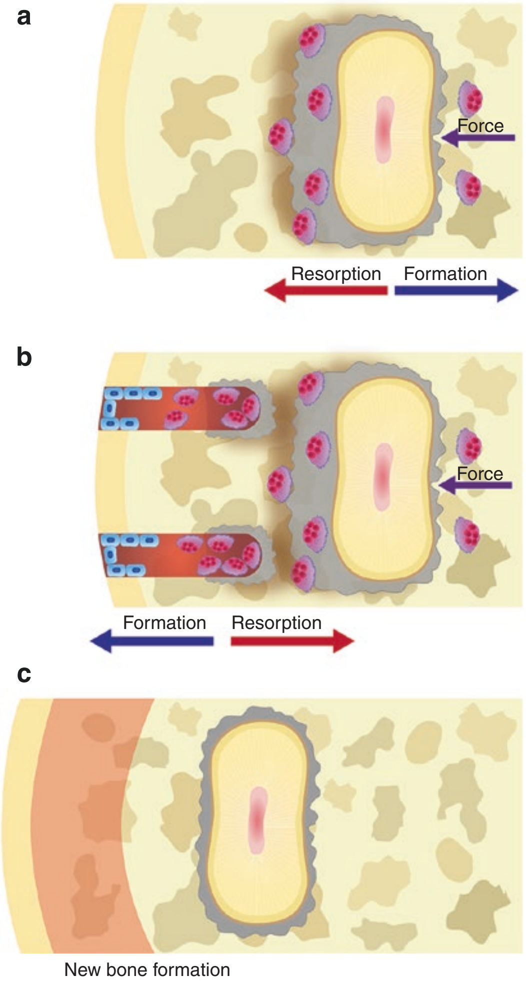


Fig. 5.6 Cortical drifting during expansion in response to MOPs. During expansion and as a result of transverse forces, the biphasic unit is activated (**a**) resulting in a wave a bone resorption (*red arrow*) followed by bone formation (*blue arrow*). (**b**) Application of short perforations during expansion can activate osteoclasts on the surface which in turn activate the osteoblasts stimulating a remodeling cone or second biphasic, resulting in cortical drifting on the surface. (**c**) This cortical drifting couples bone movement with tooth movement during expansion

recommended (Fig. 5.7). Since the majority of bone formation is required around middle to occlusal part of cortical plate, shallow MOPs should direct toward those areas, while deep MOPs can be directed toward more apical part of alveolar bone to facilitate root movement. However, it is preferred to limit the points of application of MOP whether shallow or deep to attached gingiva and to target other areas by changing the angle of the perforation tip to reach different areas of the bone to be targeted. This will allow for easier penetration as well as better healing and patient comfort.

While few deep perforations can stimulate catabolic effects of MOPs, multiple shallow perforations are required to stimulate bone formation evenly on buccal cortical plate (Fig. 5.8). In the maxilla, the alveolar bone in the apical part is wider in nature; therefore, the application of deep MOPs to stimulate the catabolic effects on the palatal wall is not necessary, and buccal application of both types of MOPs is

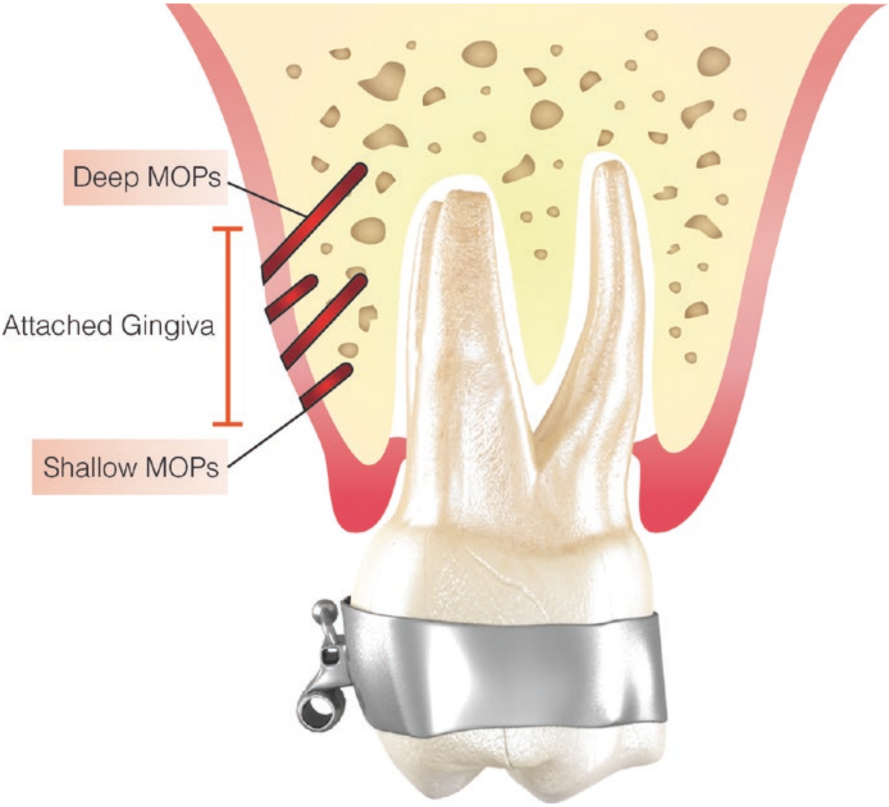


Fig. 5.7 Shallow MOPs in attached gingiva stimulate cortical drifting. While long perforations can stimulate catabolic effects deep inside trabecular bone that facilitate tooth movement, multiple shallow perforations are enough to stimulate cortical drifting

adequate. In addition, both types of perforations can be applied either prior to force delivery (few weeks before activation of expander) or simultaneously with activation of expander.

It should be emphasized that to achieve proper bone formation, the force delivery should be very gradual (opening of expander every 2 days) in coordination with osteoblast activation. In this case, as expansion forces gradually activate osteoclasts in the force direction, short MOPs activate osteoclasts and osteoblasts at surface to produce cortical drifting (Fig. 5.6).

5.4.2.2 Retraction or Protraction of Anterior Teeth

Cortical bone is not only a limitation in transverse movement but can also be a boundary for the movement of anterior teeth in the sagittal direction. This boundary can dictate the clinician's decision between surgical and nonsurgical treatment especially for skeletal class II and III patients. Similar to expansion, any movement of anterior teeth toward the cortical bone will not only impose a risk of root resorption but also may cause the teeth to move out of bone resulting in dehiscence or

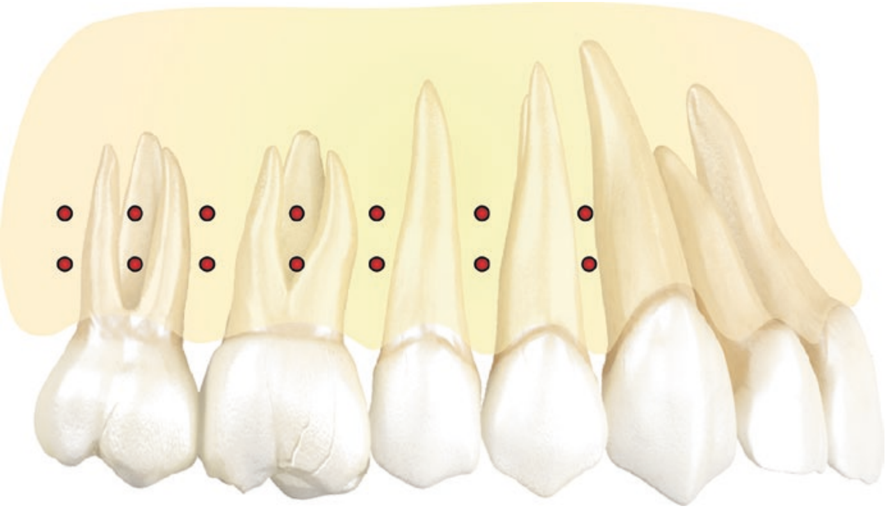


Fig. 5.8 Stimulating anabolic effects at the periosteal surface. Multiple shallow perforations spread over the area of interest have an anabolic effect over the periosteal surface. These shallow perforations will activate osteoclast and consequently osteoblasts (biphasic unit) and at the same time cause subperiosteal bleeding resulting in robust bone formation

fenestration. Due to the high density of cortical bone, it is very common for even the best designed mechanics to cause uncontrolled tipping with roots of upper or lower anterior teeth pressed toward the labial cortical bone and the occlusal part of the root pushed toward the alveolar crest of the lingual plate. Sound mechanics with high M/F ratio if combined with catabolic effect of MOPs (to decrease bone density) will increase the possibility of healthy movement and decrease the possibility of root resorption.

To take advantage of this property of MOPs, deep MOPs should be applied in the labial plate, while shallow MOPs should be applied in middle to occlusal portion of lingual plate to stimulate periosteal activity in the direction of movement (Fig. 5.9). In cases of severe class III skeletal problems, when lower first premolars have been extracted and significant retraction of canines is required, it is better to delay placement of brackets on lower anterior teeth while retraction is in progress and, instead, encourage natural cortical drift of anterior teeth by MOPs. MOPs will facilitate the natural distal drifting of lower anterior teeth in the absence of any orthodontic force. This natural dental and skeletal drift can significantly reduce the possibility of any side effects on lower anterior teeth roots and alveolar bone. Similar principals can be applied to sever class II and maxillary anterior teeth.

5.4.2.3 Tooth Movement Through Deficient Alveolar Ridges

A Challenge with Many Complications

During mesiodistal movement of teeth, appropriately directed forces rarely place any tooth in danger of breaching the physical limit set by the cortical bone. The only time sagittal movement can jeopardize the cortical bone integrity is when the

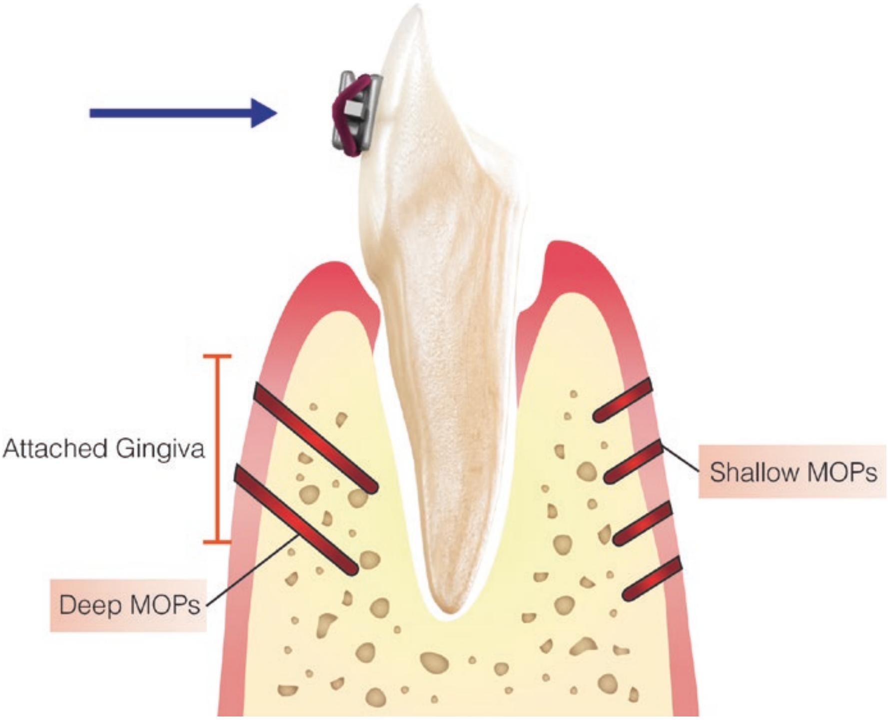


Fig. 5.9 Application of MOPs to stimulate anabolic effects in class III patients. In class III patients, requiring significant retraction of lower anterior teeth, short perforation of lingual plate of lower anterior alveolar bone can stimulate cortical drifting in the direction of movement. These should be applied in addition to long perforation on the buccal cortical plate which facilitate tooth movement

tooth is moved into severely resorbed areas of alveolar bone (e.g., old extraction areas) or when a wider tooth such as molar is moved mesially for a significant distance into a narrower area of the arch such as a small premolar site. These areas usually are occupied with dense cortical bone that is short in height and narrow in width.

Moving a tooth to close these spaces is very challenging, can cause root resorption, and usually results in tilting of the crown into the edentulous space, without significant root movement (Fig. 5.10). Root fenestration can be observed in both buccal and lingual plates and recession of alveolar bone may occur. In addition, the slow rate of tooth movement often discourages clinicians and patients from attempting any closure of large extraction spaces. Clinicians often refer the patient for implant placement, which may not be achieved easily either due to the severe bone resorption and insufficient alveolar bone width. In some of these cases, placing a bridge may be difficult to justify, especially if adjacent teeth are sound and healthy.

Fig. 5.10 Orthodontic tooth movement into a deficient ridge. Dense cortical bone in the area of a deficient ridge can resist movement and cause tooth tipping and root resorption. In addition, the lack of stimulation of osteoblasts while limiting the magnitude of cortical drifting can result in alveolar bone loss and root exposure

Can Alveolar Ridge Augmentation Before Tooth Movement Solve the Problem?

When a clinician decides to close a large space, would grafting of the resorbed bone ahead of movement be beneficial? While grafting for implant placement can clearly be beneficial [1], the advantages of grafting a resorbed alveolar ridge prior to tooth movement are controversial. First, since these areas are already resorbed, stabilizing the graft in the area is not a simple task. Due to this lack of stability, movement of the tooth should be delayed until bone formation has occurred which may take 2–12 months. During this time, bone formation will contribute to increasing bone density and therefore may further delay the tooth movement and add to the possibility of root resorption since it takes longer for osteoclasts to remove the dense bone. Second, there is a general consensus that grafting is more successful in adding to horizontal width of alveolar ridge and not in vertical height [2]. While from an implant point of view increasing the width of the bone could allow usage of wider implant and can significantly improve stability, from an orthodontic point of view, the most important factor is the height of alveolar bone. Third, grafting is a very technique-sensitive approach, and depending on the method used for application of the membrane and its stability, grafts may show up to 50% resorption [3, 4]. Considering all these factors collectively, the benefit of grafting of edentulous bone for orthodontic purposes is questionable.

When alveolar ridge augmentation has been accomplished by distraction osteogenesis, the new bone may have enough height and can function as a scaffold to maintain bone integrity after the tooth movement. Additionally, the new bone is not dense enough to affect the catabolic stage of movement. This may seem a beneficial treatment option for severe resorption. However, due to the complexity of the procedure, practicality of this procedure is under question and is not justifiable for everyday cases.

MOPs and Cortical Drift as a Simple and Efficient Solution

If the orthodontist is planning to close these spaces, MOPs can facilitate the process through two mechanisms: through osteoclast activation that decreases the bone density making it possible to move teeth without significant delay, root resorption, or tipping (Fig. 5.11) and through osteoblast activation that rebuilds and maintains the integrity of the alveolar bone (biphasic unit). In these cases, MOPs should be applied not only on the buccal plate but also on the bony ridge and, if possible, the lingual cortical bone (Fig. 5.12). MOPs should be repeated every month or at least every other month until all the space is closed. It should be emphasized that osteoblast migration in the presence of trabecular bone is fast, while cortical drifting is a slow process. Therefore, in these cases, combining MOPs with slow tooth movement is key to success.

Role of PDL During Cortical Drifting

Application of MOPs couples catabolism-dependent tooth movement with anabolism-dependent bone formation that restores the bone height and width in the previously edentulous site. It is important to note that the final height and width of the bone in the extraction space after tooth movement mostly follow the height and width of alveolar bone surrounding teeth that move into the space, rather than the preexisting height or width of alveolar bone in the extraction site (Fig. 5.13). This is due to the role of PDL in dictating the final geometry of alveolar bone.

Clinicians should differentiate between permanent alveolar bone loss that is irreversible and reversible geometrical changes of alveolar bone, due to tooth position such as excessive tilting of a tooth. As the inclination of a tooth changes in response to orthodontic forces, the geometry of alveolar bone will change due to the presence of PDL, and as long as PDL is intact, this geometry can be altered by reversing the movement. Therefore, during the movement of a tooth into an extraction space, if the tooth tilts, the contour of alveolar bone will take the form of a pocket. This pocket is not real (pseudo-pocket), and during the uprighting stage, the contour of alveolar bone will be corrected as long as the PDL is intact (Fig. 5.14).

The significance of PDL is best manifested during orthodontic movement when moving a tooth with existing bone loss and recession into an extraction space (e.g., due to periodontal disease). This bone loss will remain with the tooth, and even if

Fig. 5.11 Application of MOPs during tooth movement into a deficient ridge. Application of long perforations can stimulate catabolic effects that will decrease the side effects caused by dense cortical bone in area of residual ridge, while shallow perforations stimulate cortical drifting to ensure bone integrity around the tooth during movement

the bone in the extraction area has more favorable height and width, the bone loss around the tooth will remain the same as prior to the movement and will not improve in neither height nor width even with MOP application (Fig. 5.15). In other words, the anabolic effect of MOPs cannot restore the bone around a tooth with preexisting bone or attachment loss.

Bone Grafting After Tooth Movement

Is there a benefit to grafting the tooth with loss of attachment before it is moved orthodontically? If the moving tooth has bone loss, and the area of bone loss is reconstructed by any type of graft, but the attachment between the tooth and new bone through the PDL is not established, the new bone is not sustainable and will not drift with the tooth during orthodontic tooth movement. As mentioned earlier, for the bone to be able to drift with the moving tooth, it needs to be connected to the tooth through PDL. Therefore, if bone grafting is necessary to restore the bony

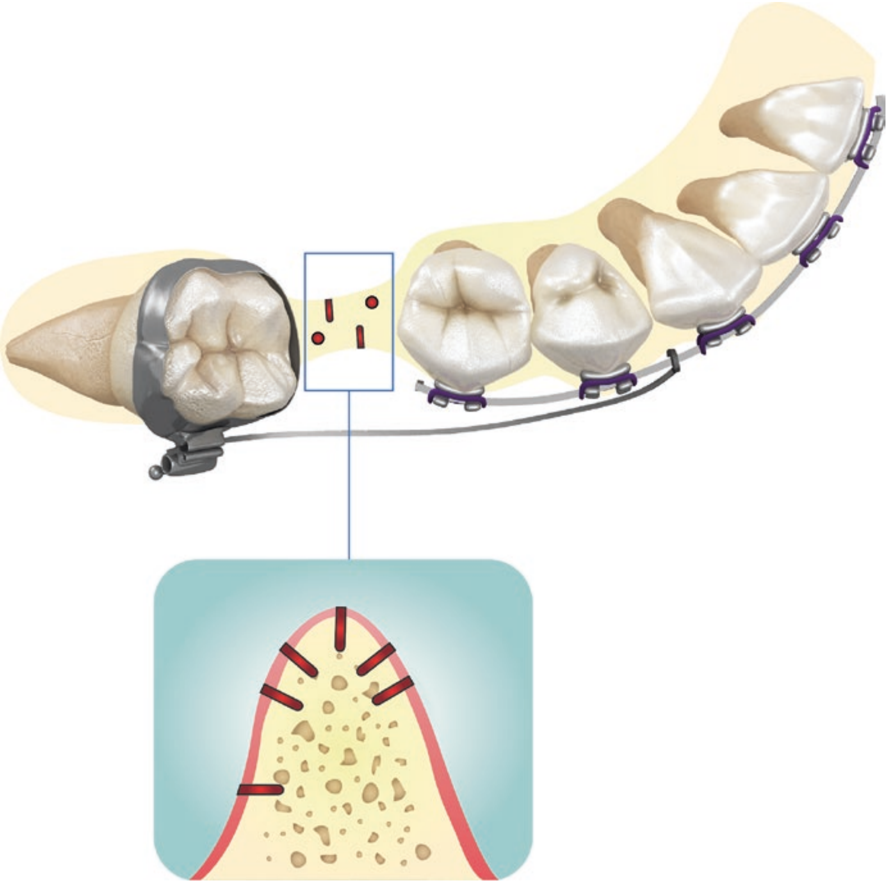


Fig. 5.12 Application of MOPs on the deficient alveolar ridge. In the presence of an old extraction site, the application of MOPs on both the buccal cortical plate and over the residual ridge that is covered by dense cortical bone and when possible also in the lingual cortical plate

Fig. 5.13 Effect of MOPs in the height of alveolar bone. While application of MOPs activates cortical drifting into the residual ridge of an extraction site, the final height of alveolar bone is dictated by height of alveolar bone before movement. This is clearly seen in these “before and after” radiographs of a first molar extraction site. MOPs cannot increase the height of alveolar bone during space closure movement

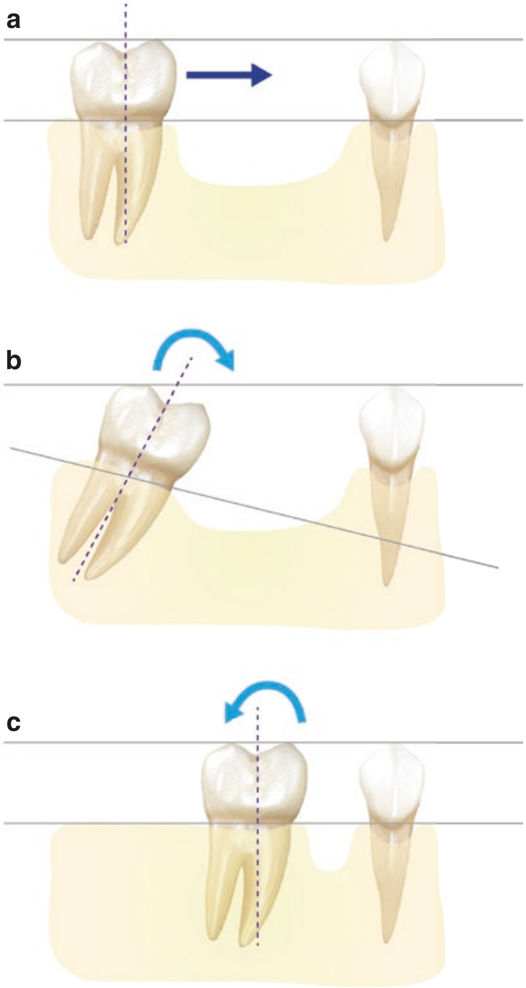


Fig. 5.14 Reversible changes in alveolar bone geometry. While alveolar bone loss due to periodontal disease is not reversible, change in architecture of the bone due to changes in angulation of a tooth is reversible and should not be confused with bone loss. (**a**) Before movement of the tooth into extraction space. (**b**) Tilting of the tooth during movement and change in the architecture of supporting bone. (**c**) Reversal of changes in bone architecture by uprighting the tooth. These changes do not cause bone loss

defects around the moving tooth, it is better to delay the procedure until all orthodontic tooth movements have been completed.

5.4.2.4 Cortical Drift When the Maxillary Sinus Is Close to the Alveolar Ridge

In the maxilla, long-term extraction spaces can be accompanied with severe bone resorption and complicated by the proximity of the maxillary sinus to the alveolar ridge. To move a tooth through the dense cortical bone surrounded by the oral cavity on one side and the sinus on the other side (Fig. 5.16a) takes a significant amount of time and requires additional procedures. The expectation of very slow tooth movement may encourage the clinician to apply higher forces which increases the magnitude of the moment on the tooth and therefore encourages more tipping, with no effect on the rate of tooth movement. In addition, these conditions present an additional challenge since movement of the tooth through the sinus needs be accompanied by significant bone formation.

Fig. 5.15 Clinical effect of MOPs on the height of residual ridge. Application of MOPs allows movement of the tooth into an area of bone loss – with dense alveolar bone – without root resorption or severe tilting. However, even in the presence of MOPs, the final height of alveolar bone is dictated by original height of alveolar bone that surrounds the moving tooth

In these situations, applying MOPs will increase the number of osteoclasts in the area, increase the resorption rate of the dense cortical bone, and accelerate tooth movement. This change in bone density also affects the center of resistance of the tooth, which biomechanically helps root movement through alveolar cortical bone adjacent to the sinus. These are all benefits of the catabolic response to MOPs; however, in these cases the anabolic and not the catabolic effects of MOPs should be the focus of treatment, and light forces should be applied. In addition, since application of deep MOPs may penetrate the sinus, shallow but multiple MOPs should be applied in the path of tooth movement (Fig. 5.16b). The activation of the biphasic unit by MOPs stimulates the osteoblasts to actively lay down the new bone creating a path for tooth movement without roots moving into the sinus (Fig. 5.16c) and maintaining the integrity of alveolar bone.

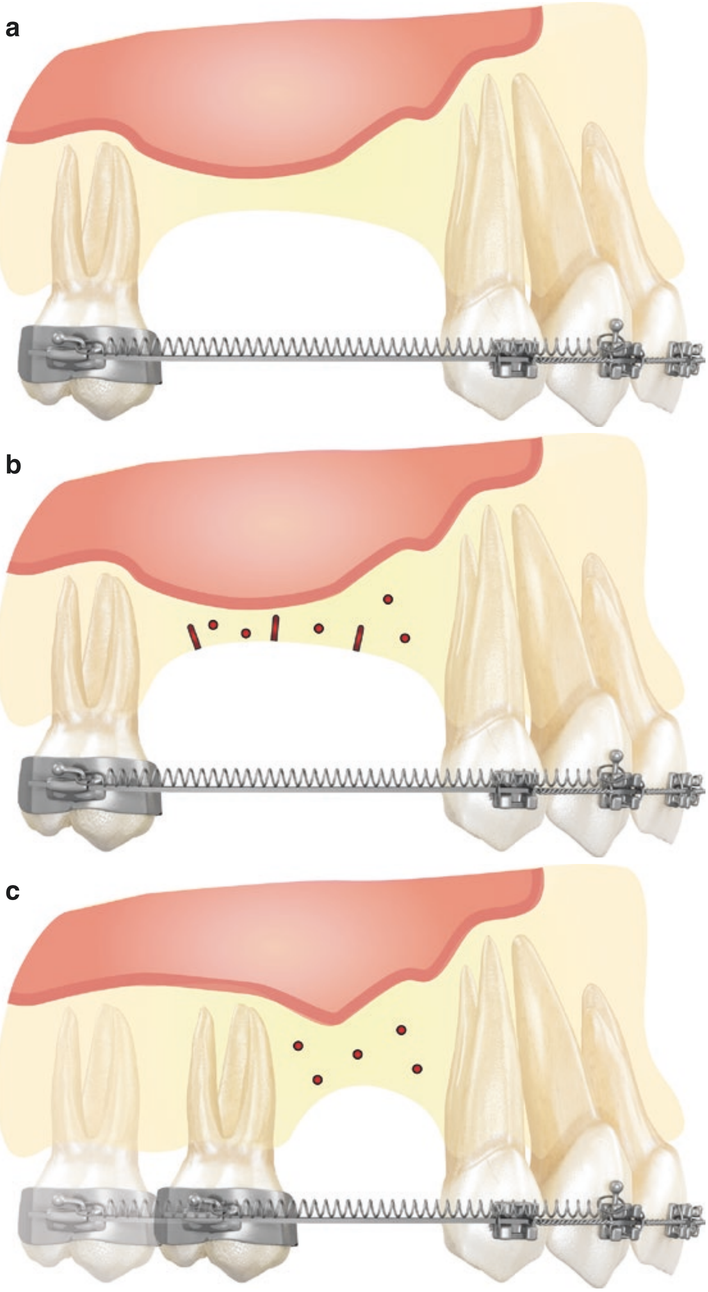


Fig. 5.16 Anabolic effect of MOPs during tooth movement in proximity of maxillary sinus. (**a**) Extraction space in posterior area of upper jaw is usually accompanied by proximity of the sinus. (**b**) Application of MOPs activates both catabolic and anabolic responses that facilitate movement and at the same time stimulate bone formation. (**c**) Movement of posterior teeth into the area of extraction and gradual bone formation "pushes" the sinus back

Similar to the discussion on space closure, the magnitude of bone formation is dictated by magnitude of the bone surrounding the tooth that is moving to the extraction space, and if this bone is not adequate (due to loss of attachment) at the end of treatment, the clinician should not expect higher level of the bone at the alveolar ridge.

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Step-by-Step Guide for Performing Micro-osteoperforations

6

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6.1 Introduction

In this chapter we will review the clinical protocol for applying micro-osteoperforations (MOPs) in daily clinical practice. This is a clinical guide for step-by-step delivery of MOPs based on clinician judgment. Additionally, the tools that have been developed to facilitate MOP delivery are introduced.

6.2 When to Apply MOPs

As it was discussed in previous chapters, MOPs stimulate catabolic effects in the bone that removes the old bone surrounding the target tooth. This phase is then followed by anabolic effect that facilitates the formation of the new bone around the tooth. Catabolic and anabolic effects occur sequentially regardless of when and where we apply the MOPs. However, if the time of MOP application is planned properly, then each phase can have significant clinical benefits.

Catabolic effects induced by MOPs can be beneficial in numerous clinical situations, such as accelerating the rate of tooth movement, facilitating bodily tooth movement, facilitating root movement during molar uprighting or torque correction, allowing movement through large distances and movement through dense resorbed ridges, mediating symmetrical and asymmetrical expansion in adults, enhancing biological anchorage, and reducing the risk of root resorption (Table 6.1).

Anabolic effects of MOPs can be used for expanding the envelope of corrections through cortical drift. This phenomenon will help the bone follow tooth movement during expansion in adults, during retraction of lower anterior teeth for class III correction in teens and adults, and help maintain bone integrity during tooth movement in regions with thin cortical bone such as residual alveolar ridge (Table 6.1).

Due to these seemingly opposite effects of MOPs, timing of application is crucial. Premature application of MOPs may allow enough time for bone metabolism to shift from catabolic to anabolic, preventing the clinician from taking advantage of the catabolic phase. Thus, the clinician must apply MOPs only when the patient is biomechanically ready. For example, is there sufficient space to unravel tooth crowding? Is the arch leveled and ready for bodily tooth movement? Is the expander in place and ready for activation? Are anchor teeth secured in rigid wires to support the movement? Has treatment progressed to the stage of intrusion, torque correction, or molar uprighting?

Assuming that the time for MOP application has been properly selected (for review, please refer to Chaps. 4 and 5), we are outlining below steps I through VI for the MOP procedure.

6.3 Step I: Update Medical and Dental History

Similar to any minor surgical procedure, MOP application should start with a medical evaluation of the patient. Even though MOP is a minor procedure, it is always wise to make sure the patient does not have allergies to any components of local

Table 6.1 Clinical applications of the catabolic and anabolic effects of MOPs.

Objectives	Clinical Applications	Effect
Accelerating Tooth Movement	Different stages of adult treatment	Catabolic
Facilitating Root Movement Bodily Movement	Uprighting/Intrusion/Extrusion Root Torque/Closure of large space	Catabolic
Movement into Deficient Alveolar Bone	Closure of old extraction space	Catabolic
Differential Anchorage	Reducing bone density around moving teeth while preserving anchorage unit	Catabolic
Decreased Possibility of Root Resorption	Reducing bone density and duration of exposure to osteoclasts	Catabolic
Restoring Deficient Alveolar Ridge Sinus Remodeling	Tooth movement and cortical drift	Catabolic + Anabolic
Expansion in Adults Asymmetrical Expansion	Cortical drift and bodily movement of buccal segment(s)	Catabolic + Anabolic
Retraction and Protraction Beyond Cortical Boundary	Cortical drift and bodily movement for dental compensation past original plate	Catabolic + Anabolic

anesthetics. If the patient is allergic to lidocaine, another local anesthetic such as prilocaine should be selected.

If the patient, for any reason, requires systemic strong anti-inflammatory medication(s), it is better to postpone the MOP treatment and even orthodontic treatment in general, to a stage that the patient does not require these medications or can be maintained in milder anti-inflammatory medication. MOPs in these patients can be beneficial since it can stimulate local release of inflammatory markers without significant systemic effects.

A physician should be consulted for any medical procedure that can compromise the patient, even for minor surgical treatment, including MOPs (Table 6.2). For patients that require antibiotic prophylaxis, proper medication should be taken before or after the required procedure.

Severe consumption of tobacco or excessive alcohol, or any other condition such as uncontrolled diabetes that can affect bone and gum healing, contraindicate MOPs application.

6.4 Step II: Informed Consent

Patient informed consent should be obtained prior to performing MOPs. MOP is a safe procedure, but the consent form should include possible side effects that can be associated with any minor surgical procedure such as simple extractions. A sample of the consent form can be found in Fig. 6.1.

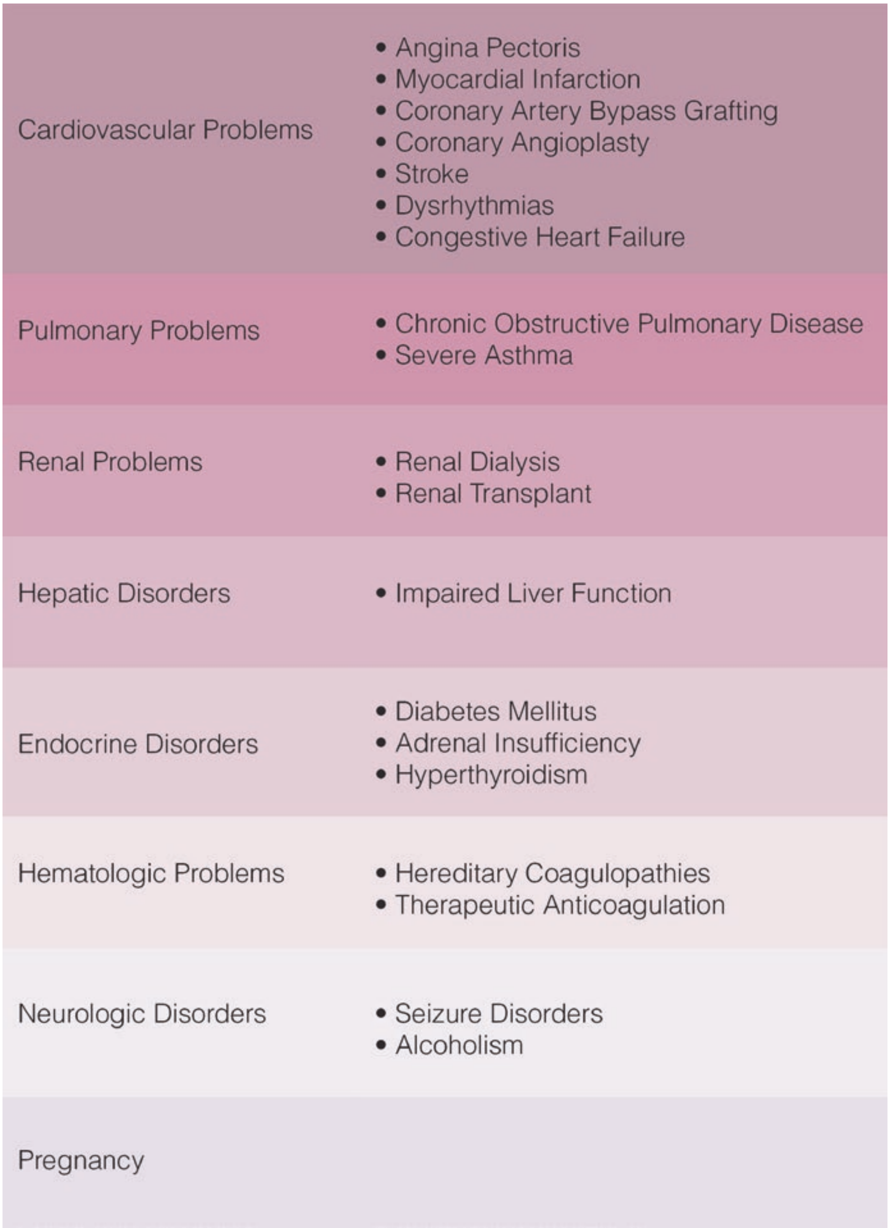
6.5 Step III: Patient Evaluation

Before initiating the MOP procedure, you have to make a decision regarding the location, number, and depth of the MOPs. These parameters will vary according to anatomy, the stage of treatment, and the particular clinical indication for MOPs in your patient.

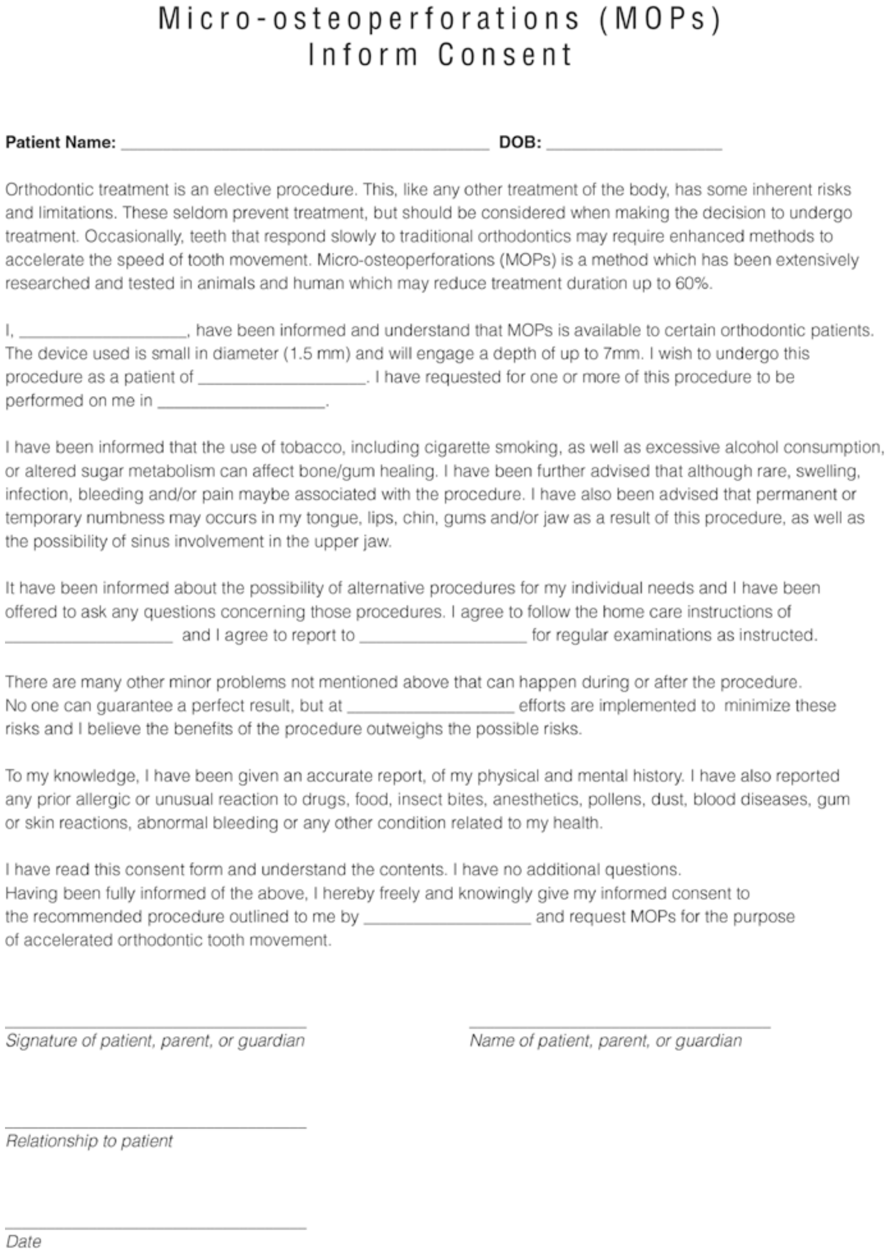
An intraoral exam of the area of interest should be performed to determine the length and thickness of attached gingiva, health of periodontium, closeness of frenum, distance between teeth and their inclination, and finally accessibility of the area of interest for performing MOPs.

A panoramic radiograph can help to determine the quality of the bone, location of the sinus, proximity of the inferior alveolar nerves, distance between the roots, and length of the roots and should be obtained just prior to MOP application. All other radiographs taken within 6 months prior to MOP treatment are sufficient and need not be retaken. Cone beam computed tomography (CBCT) has become a more popular way for taking initial records and can be used instead of a panoramic radiograph. CBCT is a useful tool to give a general idea of the three-dimensional image and shape of the alveolar bone. However, studies have shown that these scans do not

Table 6.2 Medical conditions that may contraindicate the use of MOPs and / or may require medical clearence before the procedure.



Cardiovascular Problems	• Angina Pectoris • Myocardial Infarction • Coronary Artery Bypass Grafting • Coronary Angioplasty • Stroke • Dysrhythmias • Congestive Heart Failure
Pulmonary Problems	• Chronic Obstructive Pulmonary Disease • Severe Asthma
Renal Problems	• Renal Dialysis • Renal Transplant
Hepatic Disorders	• Impaired Liver Function
Endocrine Disorders	• Diabetes Mellitus • Adrenal Insufficiency • Hyperthyroidism
Hematologic Problems	• Hereditary Coagulopathies • Therapeutic Anticoagulation
Neurologic Disorders	• Seizure Disorders • Alcoholism
Pregnancy	



Micro-osteoperforations (MOPs)
Inform Consent

Patient Name: ______________________ **DOB:** ____________

Orthodontic treatment is an elective procedure. This, like any other treatment of the body, has some inherent risks and limitations. These seldom prevent treatment, but should be considered when making the decision to undergo treatment. Occasionally, teeth that respond slowly to traditional orthodontics may require enhanced methods to accelerate the speed of tooth movement. Micro-osteoperforations (MOPs) is a method which has been extensively researched and tested in animals and human which may reduce treatment duration up to 60%.

I, ____________, have been informed and understand that MOPs is available to certain orthodontic patients. The device used is small in diameter (1.5 mm) and will engage a depth of up to 7mm. I wish to undergo this procedure as a patient of ____________. I have requested for one or more of this procedure to be performed on me in ____________.

I have been informed that the use of tobacco, including cigarette smoking, as well as excessive alcohol consumption, or altered sugar metabolism can affect bone/gum healing. I have been further advised that although rare, swelling, infection, bleeding and/or pain maybe associated with the procedure. I have also been advised that permanent or temporary numbness may occurs in my tongue, lips, chin, gums and/or jaw as a result of this procedure, as well as the possibility of sinus involvement in the upper jaw.

It have been informed about the possibility of alternative procedures for my individual needs and I have been offered to ask any questions concerning those procedures. I agree to follow the home care instructions of ____________ and I agree to report to ____________ for regular examinations as instructed.

There are many other minor problems not mentioned above that can happen during or after the procedure. No one can guarantee a perfect result, but at ____________ efforts are implemented to minimize these risks and I believe the benefits of the procedure outweighs the possible risks.

To my knowledge, I have been given an accurate report, of my physical and mental history. I have also reported any prior allergic or unusual reaction to drugs, food, insect bites, anesthetics, pollens, dust, blood diseases, gum or skin reactions, abnormal bleeding or any other condition related to my health.

I have read this consent form and understand the contents. I have no additional questions. Having been fully informed of the above, I hereby freely and knowingly give my informed consent to the recommended procedure outlined to me by ____________ and request MOPs for the purpose of accelerated orthodontic tooth movement.

____
Signature of patient, parent, or guardian

____
Name of patient, parent, or guardian

____
Relationship to patient

____
Date

Fig. 6.1 Sample of consent form for application of MOPs produce an accurate representation of the alveolar bone due to many factors such as voxel size, impact of software used, and presence and absence of soft tissue. Furthermore, CBCT has been reported to overestimate alveolar bone loss by a margin of 1 mm which is significant for such a small narrow structure [1, 2]. If CBCT scans have already been obtained as part of the patient initial records, these scans can be used, preferably the constructed panoramic radiograph as a reference to the planning of MOP; otherwise, a panoramic radiograph is sufficient.

6.6 Location

Important questions arise when we decide on the location for MOP application: What is the target area where MOPs should be applied? How high along the root should the MOPs be positioned? Should MOPs be applied mesial or distal to the tooth? Do we apply MOPs on the buccal or lingual plate, or on both? Answers to these questions are determined by the purpose of application of MOPs.

Area of Application The area of application depends on the clinical indication for MOPs. To take maximum advantage of the catabolic effects of MOPs, they should be close to the target teeth and far from anchor teeth. Therefore, the MOPs for catabolic effects are more localized (Fig. 6.2). For catabolic purposes since deep perforations are applied, these perforations are done usually in the buccal surface between the roots, on alveolar ridge (in case of extraction), or rarely in the lingual surface between the roots.

The area of application can play a significant role in the direction of movement. There are two clinical scenarios that arise. If the mechanical design provides precise force application in a certain direction, the location of MOPs is not important. In these cases, MOPs should be applied around the target tooth to encourage more bone

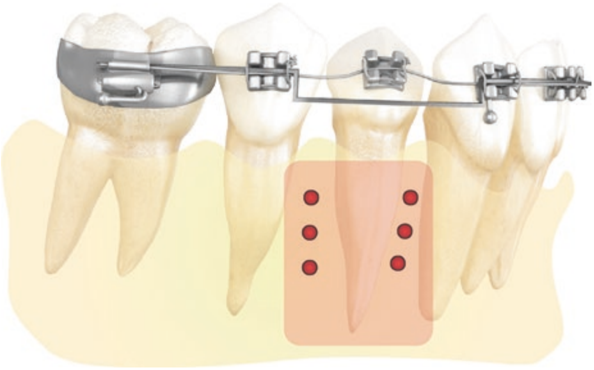


Fig. 6.2 Area of application of MOPs for catabolic stimulation.To harness the catabolic effects of MOPs perforations are located mesial and distal of the target tooth in the area of attached gingiva.

remodeling (Fig. 6.3a). On the other hand, it is possible to encourage movement in the desired direction by focusing the MOP application in one direction, compensating for mechanical shortcomings in guiding precise movement (Fig. 6.3b).

For anabolic effect of MOPs, it is preferable to cover more surface area if possible. Therefore, the area of application of MOPs for anabolic effects is more spread out (Fig. 6.4). To accomplish this, application of shallow perforations may apply not only between the teeth but also on the surface of the bone that covers the roots.

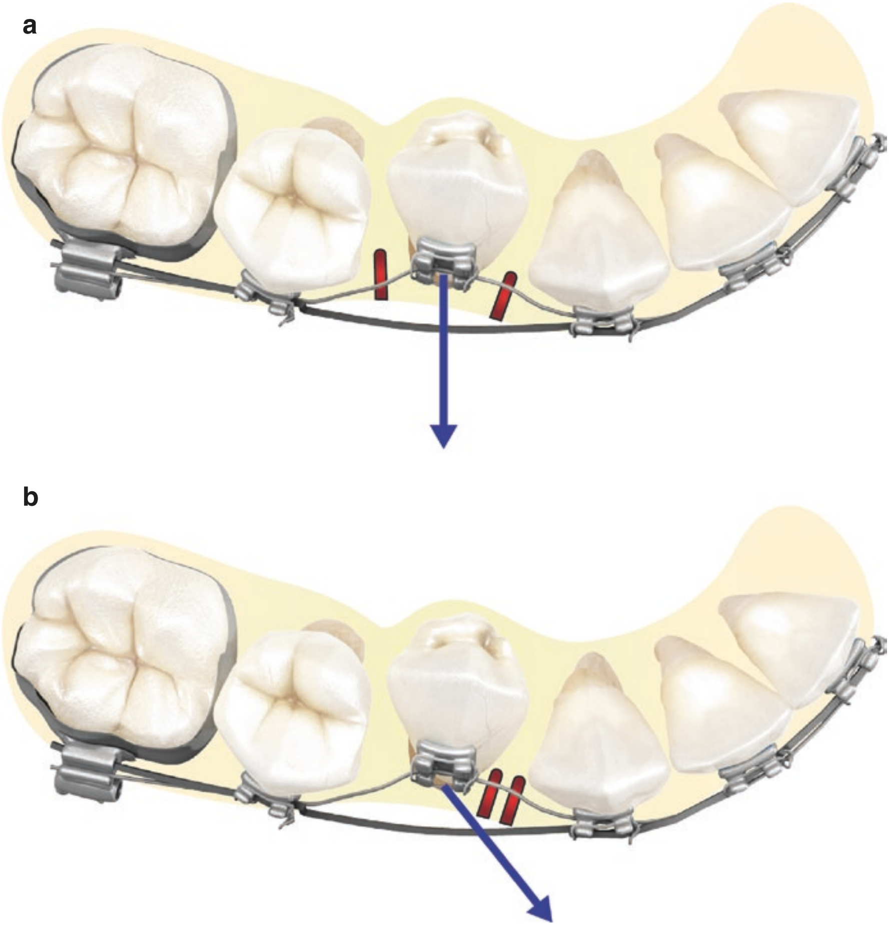


Fig. 6.3 Strategic application of MOPs based on desired direction of movement. In some set ups, such as the use of an overlay wire, the direction of movement is dictated by the wire and is difficult to control by the clinician. MOPs can be applied around the target tooth for buccal movement in the direction of blue arrow **(a)**. However, application of unilateral MOPs facilitates displacement in one particular direction (shown by blue arrow) and allow the clinician to have better control on the direction of movement **(b)**

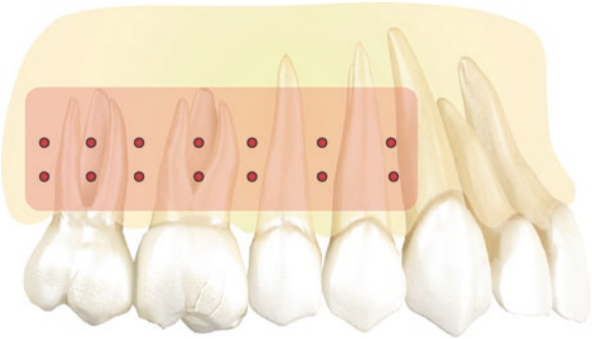


Fig. 6.4 Area of application of MOPs for anabolic stimulation. Multiple shallow perforations are spread over the area of interest to induce an anabolic effect over a large periosteal surface.

Height The superior and inferior limits of MOPs are best determined in relation to the muccogingival junction (MGJ). For patient comfort, MOPs should be placed within the attached gingiva to 1 mm apical to the MGJ (Fig. 6.5 a and b). This creates the least soft tissue interference during the procedure, minimizes postoperative discomfort, and maximizes healing. However, in conditions when a resistance toward root movement is observed, placing MOPs more apically will be beneficial. If you chose to place MOPs in a more apical location (e.g., for intrusion or torque correction), it may be helpful to angle the device apically, so that while MOPs are applied through attached gingiva, you still have access to more apical tissues (Fig. 6.6). Gripping the bone in this direction is difficult, and clinician should redirect the appliance if the tool tip slides along the cortical plate. If MOP application through attached gingiva is not possible, application through mobile mucosa can be considered. Stretching the soft tissues by proper lip and cheek retraction will help to prevent ulceration.

Mesiodistal Position For deep perforations (catabolic effects), the roots determine the mesiodistal limits of MOP position. Always keep the root location and angulation in mind while performing MOPs by referring to the patient's radiographs. In combination with visualization and palpation of the bone, the clinician can determine the root location and thus the ideal location for MOP placement. As a general rule, MOPs should be applied mesial and distal to the root of the tooth to be moved. Tools for MOP application have been designed so they will not penetrate roots. In case the tip of the MOP device approximates the roots, the patient will immediately react due to hypersensitivity. In addition, the appliance cannot penetrate further into the root, and simple withdrawal of the appliance and change the direction of application will solve the problem.

For shallow perforations (anabolic effects), MOPs can be applied on any point of the area of interest, and since their purpose is to produce periosteal stimulation, they are shallow and possibility of touching the root is very minimum.

Buccal/Lingual Placement MOPs can be applied in both buccal and lingual cortical plates. However, due to accessibility issues, direct vision, and thin mucosa that covers the lingual cortical plate of the mandible, the buccal cortical plate is the most favorable place for anterior mandibular MOP placement. Nonetheless, when the lingual

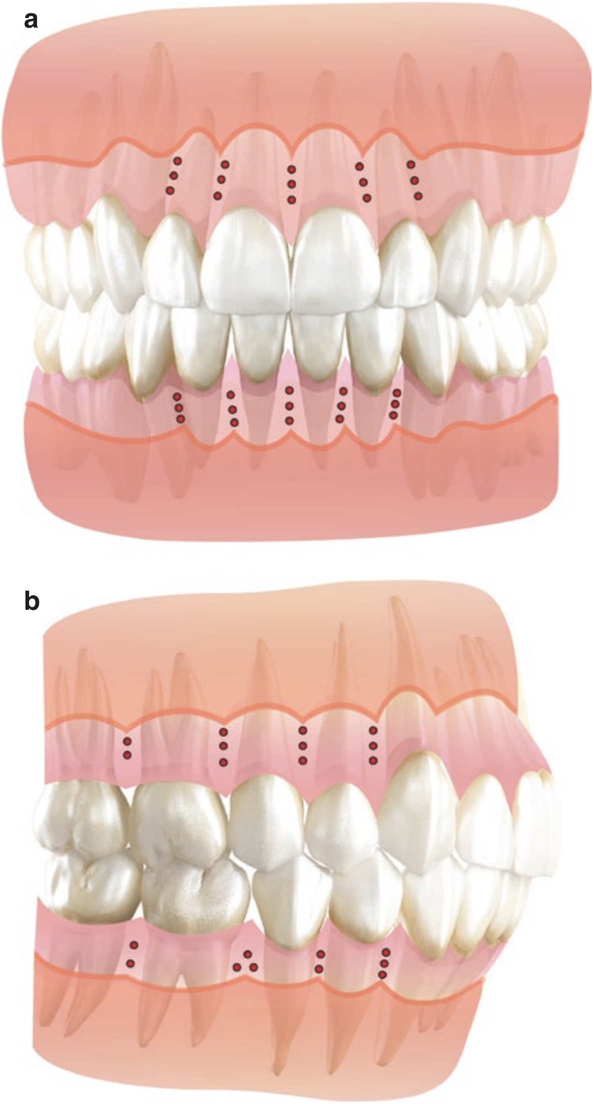


Fig. 6.5 Application of MOPs in the buccal cortical plate. Height of application of MOPs should be limited to attached gingiva for patient comfort. (**a**) Height of application of MOPs around anterior teeth, (**b**) application of MOPs around posterior teeth may have different distribution and number as determined by root proximity, accessibility, and width of attached gingiva

cortical plate affects the movement of the tooth, or when anabolic effects of MOPs in the lingual cortical plate are required, MOPs should be applied in the lingual plate. For this application contra-angle appliances are preferable (Fig. 6.7).

In cases of residual ridges, especially where bone resorption significantly decreases the width and height of alveolar bone, in addition to buccal and lingual cortical plate, MPO application on top of the ridge is advisable. It should be

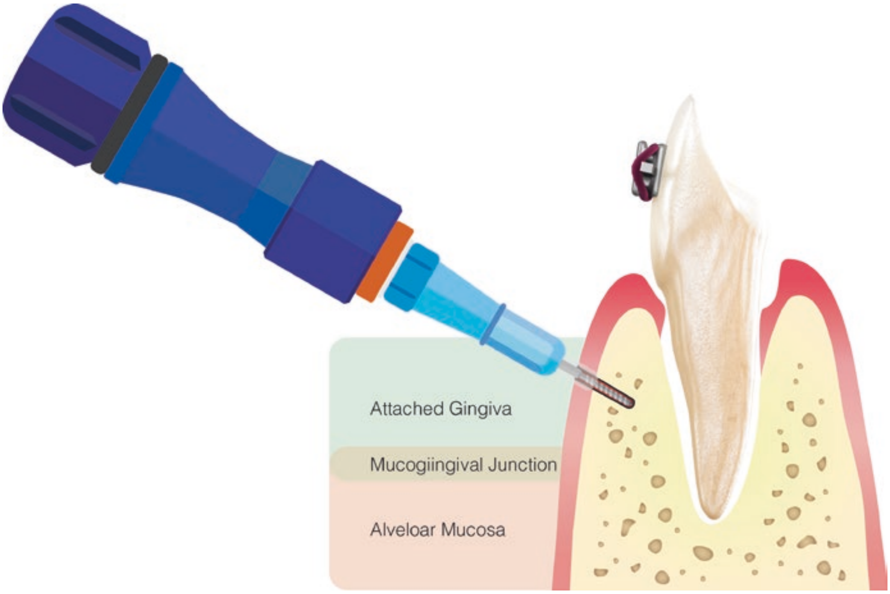


Fig. 6.6 Application of MOPs to favor root movement. To access the apical portion of the root when the attached gingiva is narrow it is possible to angulate the MOP device so that the origin of perforation will start from attached gingiva while the perforation is done closer to the root of the tooth

emphasized that due to bone resorption, vital anatomical features such as nerve or salivary glands may be more exposed to trauma; thus, the clinician should examine the area properly before applying MOPs.

Number and Depth of MOPs MOPs increase the inflammatory response and thus turnover of the bone. It has been shown by increasing the magnitude of trauma that the magnitude of the inflammatory response increases. Therefore, MOPs can stimulate larger inflammatory responses in two ways: (1) by increasing the number of perforations and (2) by increasing the depth of penetration. Studies have shown that increasing the number of MOPs increases the rate of tooth movement. However, given the limited area of the recipient sites between the dental roots, 2–4 perforations per site are ideal. In areas where applying the higher number of MOPs is not possible, increasing perforation depth can compensate for the smaller number of perforations.

For catabolic purposes, *deep MOP* with penetration depths of 3–7 mm into the bone is recommended. However, the clinician needs to consider the thickness of soft tissue and cortical plate when deciding how deep to perforate the cortical plate (Fig. 6.8).

In patients with very thick cortical bone, the initial MOPs should be shallow to prevent excessive discomfort for the patient. This stimulation will start the catabolic stage,

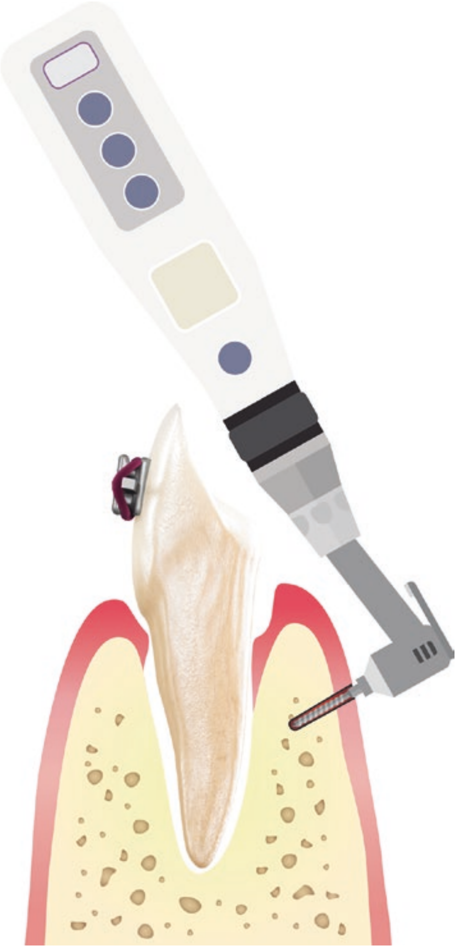


Fig. 6.7 Contra-angle devices (manual or rotary) for access to the lingual cortical plates and the posterior buccal cortical surfaces. They also facilitate perforation of thick bone that may resist the use of hand held devices.

which decreases bone density. Due to changes in bone density, the perforation depth can increase in subsequent applications without significant discomfort for the patient.

If an anabolic effect of MOPs is the main goal of treatment, deep penetration is not necessary, and *shallow MOPs* with 1–2 mm perforation depth are sufficient.

In conditions that both catabolic and anabolic effects of MOPs are required, a combination of few deep perforations (for catabolic effects) with multiple shallow perforations (for cortical drifting) will stimulate both process.

6.7 Step IV: MOP Tools and Setup

Before initiating the procedure, make sure you have all your tools available and accessible. MOPs are very simple and quick to perform. If you are ready, patients will perceive it as a simple minimally invasive adjunct procedure that can be

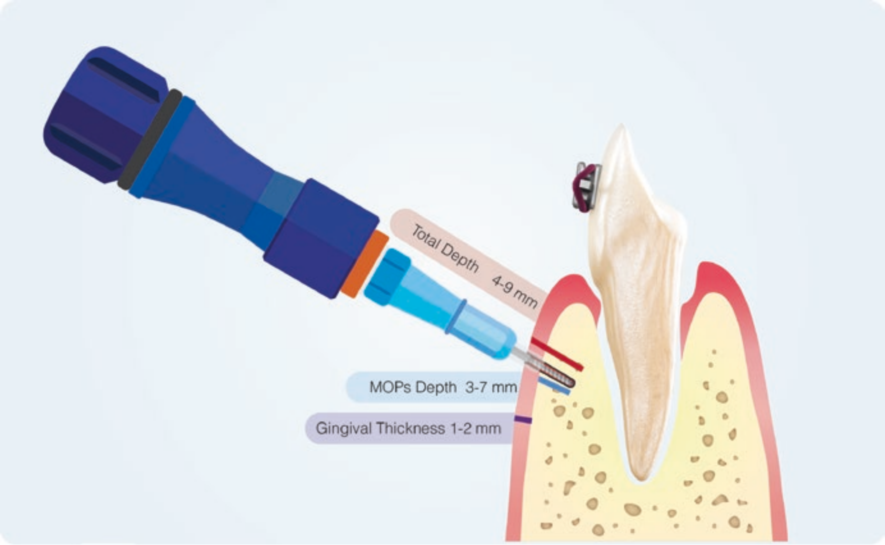


Fig. 6.8 Depth of perforation for catabolic effect should account for the total of thickness of soft tissue (1-2 mm) and thickness of bone (3-7 mm) to perforate into the trabecular bone if possible. These may require angulation of tool to avoid dental roots.

performed seamlessly in a short period of time. Here is a list of tools needed to perform MOPs (Fig. 6.9):

1. MOPs tool
2. Chlorhexidine oral rinse solution (optional)
3. Gauze/cotton rolls
4. Cheek retractor (optional)
5. Topical and local anesthesia
6. Carpule syringe and needle gauge
7. College plier and mouth mirror
8. Periodontal probe
9. Suction and water syringe

Orthodontists may choose to have the patient rinse their mouth with 15 ml (1 tablespoon) undiluted chlorhexidine oral solution (chlorhexidine gluconate – Peridex) or any other mouth wash for 30 seconds before MOP application to reduce microbial-related inflammation in the gingiva.

PROPEL Inc. has developed a tool to facilitate the application of MOPs (www.propelorthodontics.com). This tool allows the clinician to set a particular length for the cutting tip allowing a safe and predictable procedure according to their clinical assessment of each patient periodontal support thickness (Fig. 6.10a). Tools are available in both manual and slow-speed handpiece attachment, in case dense cortical bone does not allow proper penetration (Fig. 6.10b). For the

Fig. 6.9 Tray of tools and materials required to perform MOPs. Majority of components of this tray is already available in any orthodontic practice and MOP devices are the only additional components needed

majority of cases, straight tools that allow access to the buccal cortical plate with direct vision are sufficient. However, to access the mandibular lingual plate or buccal cortical plate close to the second molar, a contra-angle tool may be more suitable.

6.8 Step V: MOP Procedure

1. Ask the patient to rinse their mouth with 15 ml of chlorhexidine oral solution for 30 seconds.
2. Determine the area of interest where you want to perform MOPs. In some areas, such as anterior teeth, using a lip/cheek retractor can help provide clear access to the area of MOP application.
3. Wipe the area with a wet gauze or cotton roll to eliminate the excess saliva and dry the area.
4. Apply the topical anesthesia on the area planned for anesthetic injection and leave the topical for 1–2 min.
5. Start local infiltration with fine needle tip. For MOPs local infiltration is the only method of injection that you require in both maxilla and mandible. Nerve blocks

Fig. 6.10 MOP tools developed by Propel Orthodontics: (**a**) manual adjustable tool; the length of MOPs can be set before the procedure so the clinician can control the depth of perforation based on patient need**.** (**b**) For patient with thick cortical bone or for access to difficult area, this tool for comfort of the clinician is available in both manual and rotary format

are never necessary since teeth are not the target of treatment and the procedure is not painful. Also slight patient awareness during the procedure will allow the clinician to know if they get too close to the roots. The most common local anesthetic drug is lidocaine (xylocaine) 2% with 1:100,000 epinephrine. In case of allergy to lidocaine, prilocaine 4% with 1: 200,000 epinephrine (4% Citanest Forte) or mepivacaine 2% with 1:20,000 levonordefrin (2% Polocaine) can be used. The amount of anesthesia for one location is about one fourth carpule or less. For the majority of procedures, the maximum local anesthesia per visit does not exceed two carpules. Wait a few minutes after the injection and use a probe or explorer to check if the area is sufficiently anesthetized. By anesthetizing only the gingival tissue and periosteum in the area of interest, the nociceptive and proprioceptive feedbacks from the roots are maintained to provide the clinician with biologic feedback regarding the root or nerve proximity.

6. Set up sterile MOP tool with a disposable tip set to the appropriate length, and gently perforate the cortical plate in the area of interest with a light stable rotation movement. Remove the tool gently by rotating in the opposite direction after perforation reaches the set depth (Fig. 6.11).
7. During MOP application slight bleeding is expected. This is normal and can be stopped using wet gauze/cotton to press on the MOP site.
8. Evaluate the area before dismissing the patient to make sure that the bleeding has stopped. It is advisable that MOPs are applied at the end of the session, so the patient can leave afterward. However, in cases where a fixed orthodontic appliance may affect accessibility, MOPs should be applied after the wire is removed and the patient is sent for brushing and rinse.

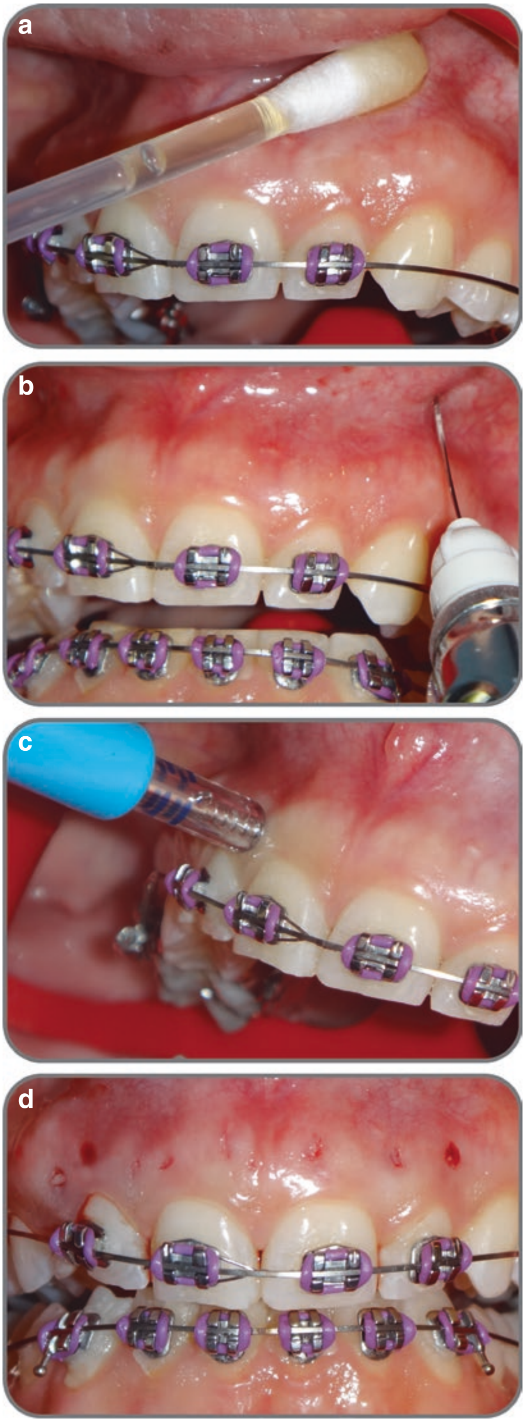
6.9 Step VI: MOP Postoperative Care

As observed in human clinical trials, patients report low levels of pain after the MOP procedure (Chap. 3). Patients that received MOPs reported the same discomfort as patients that only received orthodontic force without MOPs. However, the clinician should inform the patient about the possibility of feeling slight discomfort after MOPs. Because individual responses may vary, advise the patient in case of discomfort to take pain medication, such as acetaminophen. However, no anti-inflammatory medication (such as NSAIDs) should be prescribed. This is very important, as NSAIDs inhibit the inflammatory effect of MOPs, thereby rendering the procedure ineffective.

The use of chlorhexidine is not necessary postoperatively, but in case of poor oral hygiene or in patients with compromised health, chlorhexidine rinses are recommended. In most patients, regular mouth washes or salt water rinses are sufficient to keep the area clean. Patients do not need to change their brushing and flossing habits in the area where MOPs have been applied.

No major complications such as excessive bleeding, infection, or symptomatic root damage are expected. However, the clinician should be careful and use good

Fig. 6.11 Step-by-step performance of MOPs in the anterior area: (**a**) application of topical anesthetic, (**b**) application of local anesthetic, (**c**) application of MOPs, (**d**) attached gingiva right after application of MOPs



clinical judgment when selecting location and depth of perforations to avoid exposing the patient to unnecessary MOPs.

Please note that MOP tools are disposable and cannot be reused. Any reusage of the tool can add to the possibility of infection.

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Planning MOPs in Your Daily Practice

7

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7.1 Introduction

While thoughtful application of MOPs can significantly reduce the treatment duration, improper usage of MOPs can only expose patients to unnecessary local anesthetics and the discomfort of procedure. In this chapter, we review factors that help clinicians make a correct decision in the application of MOPs. In addition, we review treatment planning examples for the most common clinical applications of MOPs.

7.2 Frequency of Application of MOPs

Depending on the indication, the frequency of application of MOPs can be different. For catabolic effects, 3–5 repetitions of deep MOPs are enough. For anabolic effects, stimulation of bone formation by shallow perforations should continue until movement is completed or forces have been stopped. In both cases, it is wise to use MOPs either every session or every other session which is the equivalent of every 28–56 days.

As it was discussed previously, MOPs should be applied at each stage only around target teeth, and for patient comfort, it is better to limit the number of points of applications in each session. For example, for patients with expansion appliances, it is better to apply MOPs on both quadrants of the upper jaw and postpone application of MOPs in the lower jaw until required maxillary expansion has been achieved.

7.3 Reactivation of Orthodontic Forces and MOPs

The role of MOPs is to decrease bone density in the path of movement by activation of osteoclasts. However, osteoclasts are also activated by orthodontic forces. Any reactivation of orthodontic forces can stimulate cytokine release and further activation of osteoclasts. Therefore, while MOPs can cause a peak in the activation of osteoclasts, shorter intervals of reactivation of orthodontic appliances will prolong the effect of MOPs by preventing the drop in the level of cytokines. In the cases the clinician plans to apply MOPs to accelerate the rate of tooth movement, we recommend seeing the patient more often to reactivate the appliances and forces. This approach will decrease the need for frequent application of MOPs while the rate of tooth movement will increase.

7.4 Relation Between Force Magnitude and MOPs

Previously we have shown that there is a point of saturation of the biological response after which it is not possible to increase the rate of tooth movement unless another stimulant such as MOPs is introduced. However, by repeating MOPs, the bone density gradually decreases which means the saturation point will gradually increase which will allow application of higher magnitude of forces. The denser the bone, the lower the saturation point and therefore the less tolerance for higher forces. In other words, while high forces were not able to increase the rate of tooth movement, after few applications of MOPs, the same forces will be able to increase the biological response and the rate of tooth movement. While at the beginning of treatment lighter force is recommended, if MOPs are applied, a gradual increase in force magnitude in combination with MOPs will increase the rate of tooth movement beyond the original saturation point. Under the same principle, it is common for the clinician to observe that when incorporating MOPs into treatment, patients are less sensitive to higher forces and tolerate frequent reactivation of appliances.

7.5 Incorporating MOPs in Orthodontic Treatment

7.5.1 Treatment Plan for Patients with Crowding

Many adult patients chose limited treatment for alignment of anterior teeth in a short period of time. In patients where alignment can be accomplished by proclination of anterior teeth without the need to create space, a combination of localized MOPs and application of flexible wires will provide a fast result. In the example in Fig. 7.1, patient #1, the majority of the occlusal problems are localized in the anterior region of the arches and can easily be corrected by proclination of upper anterior teeth. Since posterior teeth do not require any movement, MOPs should not be applied around posterior teeth (Fig. 7.1).

Alternatively, if a patient requires space development before correction of crowding, application of MOPs should be postponed until the space has been created, and rigid wires can be used to secure the space. This additional step can add to the treatment duration, but as mentioned before, proper mechanics decreases the overall treatment time. In the following example, patient #2 requires anterior arch development to create enough space to avoid excessive lower anterior teeth proclination. Therefore, the lower left central incisor was not moved until the space was available for its alignment. MOPs are then combined with an overlay wire to bring the tooth into the arch (Fig. 7.2). In these two cases, if the clinician insists on combining MOP application and flexible wires from the beginning, they may eventually

Initial

Final (6 months later)

Fig. 7.1 Patient #1 required proclination of upper anterior teeth that was achieved by simple progress into rectangular archwires. Localized MOPs around upper anterior teeth facilitated movement and allowed correction in a short period of time

Initial

Final (8 months later)

Fig. 7.2 Patient #2 requires development of both upper and lower arches to create enough space to allow alignment of anterior teeth. Application of MOPs around the blocked lower left central incisor and simple progress of archwires would not shorten the treatment time. In this case, first MOPs were applied during development of lower arches, and when enough space was created for the lower incisor, MOPs were applied around this tooth to accelerate its movement

align the teeth, but due to poor mechanics, the treatment time, direction of movement, and side effects will be unpredictable.

7.5.2 Treatment Plan to Upright the Roots

For patients with ectopic eruption, or loss of the permanent tooth, root movement is critical. Patient #3 is a teenager that due to the ectopic eruption of the second molar requires significant root uprighting. Extraction of the second molar will force the patient to wear a retainer for a long time to prevent supra-eruption of the opposing

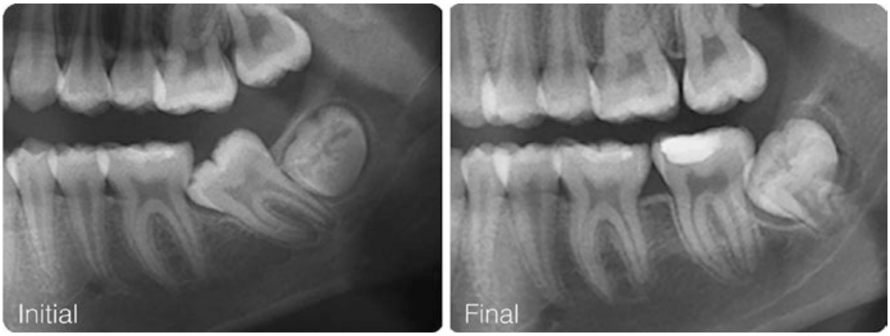


Fig. 7.3 Patient #3 required uprighting of the second molar that due to ectopic eruption was locked distal to the first molar, with only part of the distal cusp exposed in the oral cavity. With proper mechanics and application of MOPs, uprighting by root movement was achieved without any sign of root resorption. Application of MOPs stimulated osteoclast activity that temporarily decreases bone density to produce a more friendly environment for root movement

second molar until third molars erupt. It must be noted that the aligned eruption of the third molar is not guaranteed since the guidance of the adjacent tooth is not available in that scenario. In this patient, mesial movement of the root is the proper path for uprighting the second molar. MOPs were applied on the mesial area of the lower second molar, and proper mechanics corrected molar inclination in a short period of time. Uprighting the second molar is considered a late-alignment stage and should be postponed until the rest of the teeth are properly secured by a rigid wire (Fig. 7.3). MOPs can help root movement without significant root resorption.

In patient #4, due to loss of the first molar early in life, significant tilting of lower second and third molars with mesial and lingual direction caused bite collapse. In this case, not only do the teeth need uprighting, but due to the full eruption of both teeth, the closure of space is more feasible. Using MOPs around the lower second molar and third molar in combination with proper uprighting and space closure mechanics in the late-alignment stages, the treatment was completed without any side effects (Fig. 7.4).

7.5.3 Treatment Plan for Differential Intrusion in Adults

For many adults, intrusion of anterior teeth alone or in combination with extrusion of posterior teeth, to open the bite, is required for successful treatment. These patients usually have a very dense alveolar bone, and intrusion of anterior teeth in these cases is slow and may cause significant root resorption.

With the use of MOPs, treatment of patients with anterior bite plate can progress quickly. Patient #5 required significant bite opening. Therefore, along with one-couple system sectional mechanics, MOPs were applied around anterior teeth. This mechanics caused both extrusion of posterior teeth and intrusion of anterior teeth facilitated by MOPs (Fig. 7.5).

Fig. 7.4 Patient #4 had lost the lower first molar years earlier. In the absence of a restorative solution, the posterior teeth tilted mesiolingually so severely that most of the occlusal surface of both lower second and third molars could not be seen from the buccal view. The extraction of the wisdom tooth followed by uprighting of the second molar and placement of an implant in the area of the first molar was considered as an option. A second option, more beneficial for the patient, was proposed and included uprighting both teeth and closing the missing molar space so the third molar could function as a second molar, and the patient would not need an implant. Proper mechanics and application of MOPs, mostly mesial of both teeth, facilitated movement. Significant amount of root movement was achieved in the presence of MOPs without any sign of resorption

Fig. 7.5 Patient #5 had a severe deep bite and crowding both on upper and lower arches. The patient refused treatment for many years because of the duration of treatment with fixed appliances. Using segmental mechanics and MOPs, it was possible to resolve the crowding and at the same time open the bite, in a short period of time without any side effects

7.5.4 Treatment Plan for Missing Permanent Teeth in Teens

While MOPs to accelerate tooth movement may be useful at any age, it mostly benefit adults by decreasing bone density. Children and teens usually have lower bone density compared to adults, and therefore, the applications of MOPs for its catabolic effects in children are limited. In addition, due to wider sutures and more responsive condylar cartilage, it is much easier to produce skeletal changes in

Fig. 7.6 Patient #6 is missing the lower permanent second premolar. The lower second primary molar is still present. Parents chose to close the space in a short period of time to prevent the child having to place an implant later on as an adult and at the same time avoid extracting the third molar. Therefore, the primary molar was extracted, and the first molar was protracted in the presence of MOPs without any root resorption, in a short period of time

children and teens than adults. Therefore, unlike adults that mostly rely on cortical drifting to compensate for skeletal deformities, children and teens can respond quickly to orthopedic treatment, and therefore the application of anabolic effects of MOPs in children and teens is also limited. However, in certain scenarios such as closure of space due to agenesis of the permanent tooth, application of MOPs in teens may result in faster and more predictable movement especially if the treatment duration is of concern. MOPs may change the treatment plan decision from keeping the primary tooth to extracting the primary tooth and mesializing the posterior teeth (Fig. 7.6). This option may avoid the need for a future implant and crown. Additionally, protraction of posterior teeth into the space of the missing tooth may help create enough space for eruption of third molars which reduces the possibility of its impaction and/or need for extraction.

Primary teeth that do not have a successor permanent tooth cannot be maintained forever and their loss cannot be predicted. In these patients, loss of the tooth during adult life confronts the patient and clinician with the need for replacement with an implant and sometimes additional orthodontic treatment.

In patients with a missing permanent tooth and an ankylosed primary tooth, the adjacent teeth are tilted toward the ankylosed tooth, and the lack of alveolar bone development may result in a bone defect in the area. The correction of this problem requires not only the catabolic effects of MOPs to decrease bone density but also the anabolic effects of MOPs to activate bone formation in the area. Patient #7 has an ankylosed primary tooth, is missing both upper premolars, and presents with a severe lateral open bite. Due to the traumatic extraction of the ankylosed tooth, the bone defect in the upper right quadrant was aggravated, which compromised the ability to place an implant in the area. Therefore, it was decided to use the anabolic properties of MOPs to slowly and gradually move the posterior teeth into the area of the defect, activating cortical drift. Note that the molar was moved not only vertically but also from an area of the arch where the alveolar ridge was wide

Fig. 7.7 Patient #7 was missing both upper first and second premolar. The primary upper second molar was present and ankylosed. Due to lack of proper diagnostic as a child, these adult patients presented with deficient vertical growth of alveolar bone, severe lateral open bite, and class III relation of the jaws. Due to the ankyloses, the surgical extraction of the upper primary molar was traumatic and resulted in further bone loss in the area, making implant placement challenging. After discussion with the surgeon and dentist, it was decided to use MOPs to stimulate both sagittal and vertical cortical drifting to protract the upper first molar into the area of premolars and correct lateral open bite. Cortical drifting not only facilitates bone formation in the deficient area but also allows the accommodation of a larger tooth in a narrow area of the alveolar ridge

buccolingually into a narrower ridge, and therefore cortical drifting had to occur in all dimensions. Due to the difficulty of this correction, light forces and slow movement were used (Fig. 7.7).

7.5.5 Treatment Plan for Spacing in Adults

If a patient has general or localized spacing in the arches, the majority of movement occurs when it is possible to apply rigid wires that allow mesiodistal movement of teeth to close the spaces. In these cases, while MOPs can be used at the alignment stage, its main indication is at the post-alignment stage where spaces will be consolidated into segments and then segments will be retracted or protracted.

Patient #8 presented with excessive spacing, a large overjet, and deep bite. Since the posterior occlusion was good, the main focus was on sectional aligning of upper anterior teeth followed by intrusion and retraction of the anterior segment. All movements were facilitated significantly with MOPs. After these movements were accomplished using sectional mechanics, the patient's occlusion was finalized with a complete fixed appliance setup in the upper and lower arches (Fig. 7.8).

Initial

Final (9 months later)

Fig. 7.8 Patient #8 has significant spacing between upper anterior teeth and a constricted lower arch in need of arch development. MOPs were applied during space closure of the anterior segment, as well as during retraction and intrusion of the anterior segment in the post-alignment stage

7.5.6 Treatment Plan for Expansion or Development of Arch in Adult

For adult patients with posterior crossbite or patients with narrow upper and lower arches, it is possible to stimulate cortical drifting while applying transverse forces to safely expand the arches. If the clinician plans to use an expander, shallow perforations should be applied with the expander activation and continued until desired arch width has been achieved. In this case, application of deep perforations will not accelerate the rate of tooth movement since the rate of movement is dictated by the expander that should be opened very slowly, once every 2 days.

Patient #9 was an adult patient that required significant expansion and at the same time retraction of lower anterior teeth for correction of anterior crossbite. Using cortical drifting in combination with an expander, the upper arch was developed. In this patient, the lower first premolars were extracted and lower anterior teeth retracted in combination with drifting of the lower anterior lingual cortical plate, until proper overjet and overbite were achieved (Fig. 7.9).

Patient #10 had a narrow upper and lower arch with black buccal corridors. Patient chose non-extraction treatment, and therefore, it was decided to expand the upper and lower arches in combination with cortical drifting to address the esthetic concern and to create enough space in for retraction of anterior teeth and correction of the severe overjet (Fig. 7.10).

7.5.7 Treatment Plan for Open Bite in Adults

For patients that require closure of severe open bite through intrusion of posterior teeth or extrusion and retraction of anterior teeth, MOPs can be extremely useful. Patient #11 had a significant open bite. She refused any surgery or even extractions.

Initial

Final (18 months later)

Fig. 7.9 Patient #9 is an adult with severe class III jaw relation and a skeletal transverse deficiency. The patient could benefit from orthognathic surgery; however, she refused any surgical intervention. Therefore, it was decided to use cortical drifting to both expand the upper arch and retract lower anterior teeth after extraction of lower first premolars

Limitation of treatment was explained to the patient, and it was decided to expand and intrude the posterior segment using TADs. First, a TAD was placed apically and away from the posterior segment. The following visit, application of MOPs and light intrusion forces to the posterior segment was initiated (Fig. 7.11). Segmental mechanics in this situation are preferable. After enough intrusion was achieved, MOPs were used around anterior teeth to facilitate their retraction and establish the proper overjet and overbite.

Some open bite cases can benefit from extraction of upper and lower first premolars and significant retraction of upper and lower anterior segments. Patient #12 is an example of cases that can benefit from retraction of upper and lower anterior teeth to correct an open bite (Fig. 7.12). Since the majority of these patients require extractions, one important clinical consideration is the timing of extraction. While extractions in some cases need to be performed immediately to allow the progress of treatment, when it is possible to delay the extractions as in this case, it is advisable to postpone the extractions until the teeth are ready to be

Initial

Final (16 months later)

Fig. 7.10 Patient #10 is an adult with class II division one malocclusion, a severe increase in overjet and deep bite with palatal impingement. Both upper and lower arches were very narrow with black corridors on both sides when smiling. Significant expansion of upper and lower arches was achieved in the presence of MOPs to promote cortical drifting. This expansion provided enough space for retraction of upper anterior teeth without the need for extractions

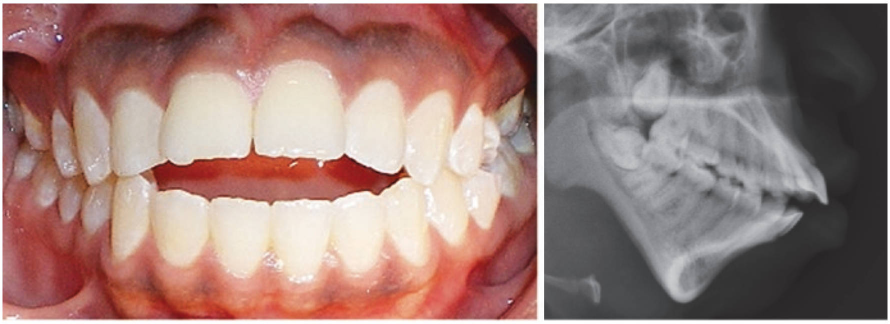
Initial

Final (17 months later)

Fig. 7.11 Patient #11 is an adult with a severe skeletal open bite, proclined upper and lower anterior teeth, and class III molar and canine occlusal relation in the left side and class II molar and canine relation in the right side. The patient refused both orthognathic surgery and extractions. After thorough discussion on the limitations of treatment, cortical drifting was accomplished to correct transverse deficiency and open bite. Combining MOPs with asymmetrical mechanics, a functional occlusion was reestablished with class I molar in the right side and class III molar in the left side

moved into the extraction space. Extractions can function as the best source of cytokines, which can help in accelerating the rate of tooth movement. Three months after extractions, application of MOPs was started and was repeated every other month until complete closure of space with significant cortical drifting.

Initial



Final (16 months later)

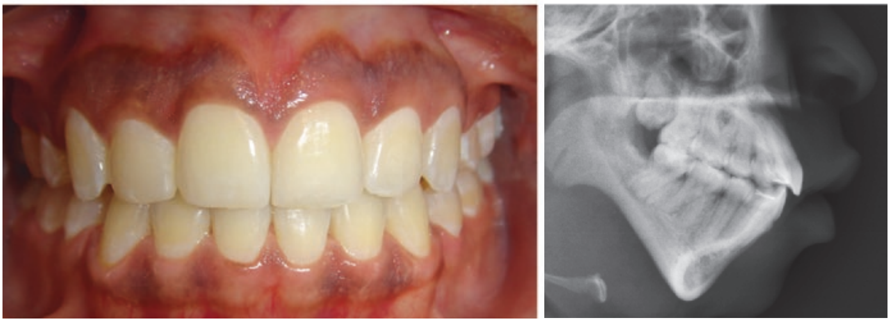


Fig. 7.12 Patient #12 is an adult with severe open bite and severe proclination of upper and lower anterior teeth. To address both proclination and open bite, extraction of the upper and lower first premolar was suggested. To maximize the retraction, application of TADs for posterior anchorage and MOPs to facilitate movement of anterior segments was planned. Extractions were postponed until the patient was ready for retraction of anterior teeth. MOPs started 3 months after extraction and continued until retraction was completed

7.5.8 Treatment Plan for Large Extraction Space and Sinus Invasion

If a patient has a large edentulous space, closure of the space has two benefits: Firstly, under conditions of severe bone resorption and sinus invasion, stimulating bone formation by moving an adjacent tooth through the area may avoid the need for complex procedures such as grafting and sinus lift in the area. This option also prevents unnecessary implant placement and allows the use of natural teeth, such as a wisdom tooth as a replacement (instead of extracting these teeth) (Fig. 7.13). This option should only be offered to patients if they plan to have orthodontic treatment. For patients that do not need orthodontic treatment, closure of space by this method may be considered excessive and unpractical. Secondly, by moving the adjacent tooth or teeth into the space, it is possible to produce a bony bed for an implant in the area distal to the moving tooth which can offer a restorative solution without need for bone grafts (Fig. 7.14).

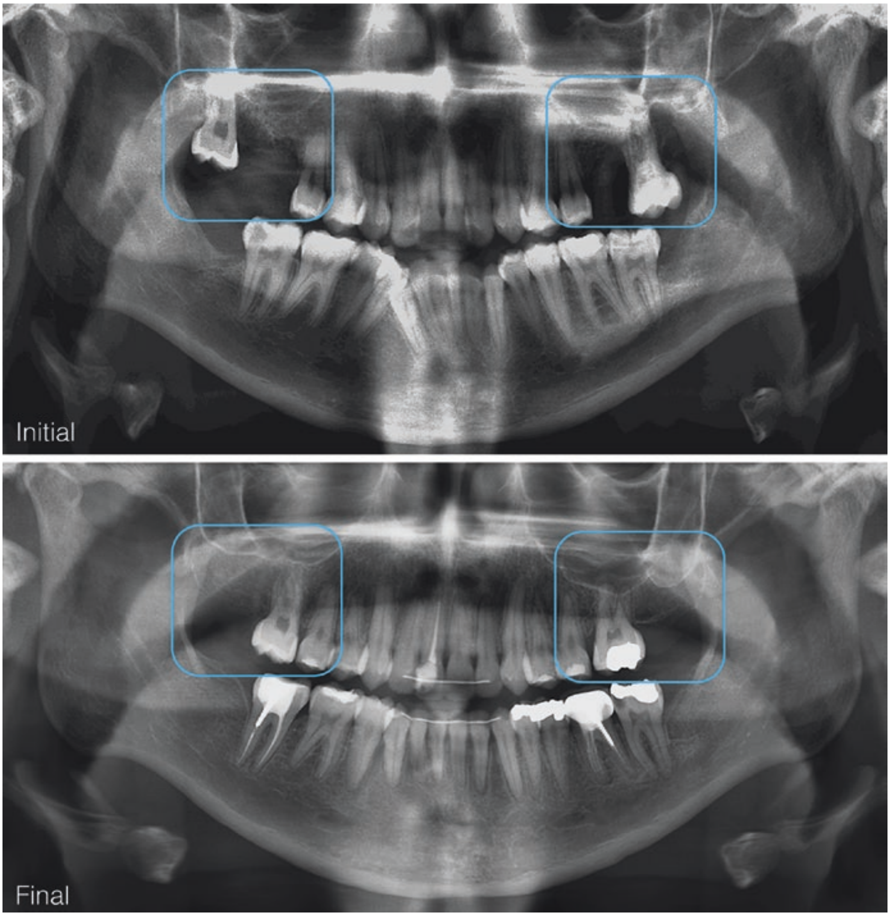
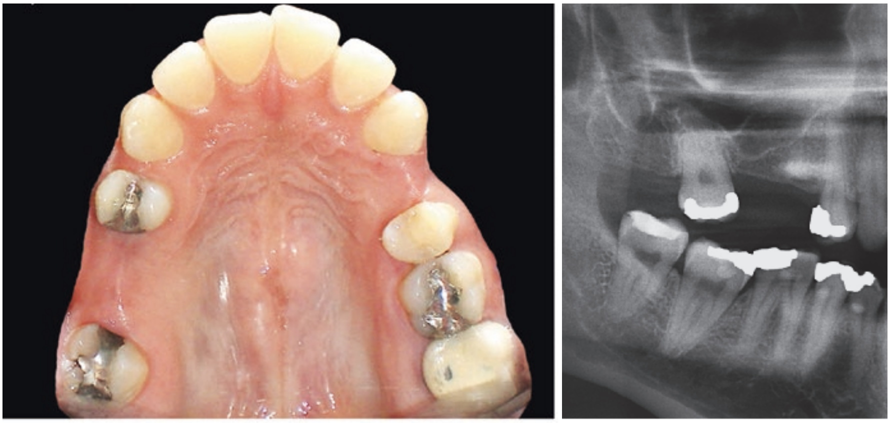


Fig. 7.13 Patient #13 lost upper first and second molars years earlier. Due to lack of a restorative solution and bone loss in the area, there was not enough bone for placement of implants. It was decided to move the third molars mesial for replacement of upper first molars. Using light forces and shallow MOPs, third molars moved forward without root resorption or significant tilting, in a short period of time. Note the magnitude of bone formation distal to the third molars. Due to loss of several teeth in the lower arch, there was no need for implants in the upper arch

7.5.9 Treatment Plan for Pre-prosthetic or Post-prosthetic Orthodontic Treatment

For patients that require significant movement such as opening spaces prior to prosthetic restoration with implant placement, intrusion of a tooth or segment of the dental arch before full mouth reconstruction, MOPs can be used in the pre-alignment stage (segmental mechanics) or post-alignment stage (continuous wire mechanics) in combination with rigid wires. For example, patient #15 required more overjet

Initial



Final (15 months later)

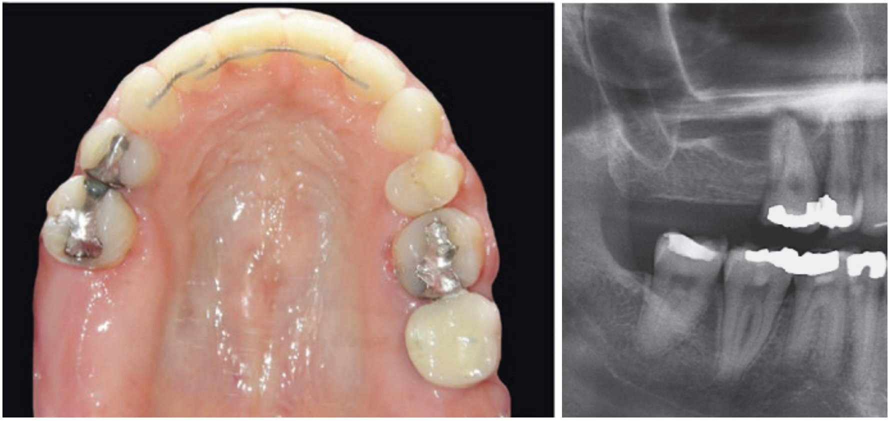


Fig. 7.14 Patient #14 lost the second premolar and first molar years earlier on the right quadrant. Due to severe bone resorption in the area and the sinus invasion, implant placement to replace both teeth was not possible. Since the patient requested orthodontic treatment for many other reasons, it was decided to move the second molar mesially and use the bone distal to the second molar for an implant. In this case since opposing teeth exist in the lower arch, an implant in the upper arch was recommended. The good quality bone distal to the upper right second molar eliminated the need for grafting

before insertion of upper laminates to prevent occlusal trauma which could cause failure of the prosthetic restorations. In addition, more space was needed for the implant that was placed prematurely. After initial leveling and aligning, MOPs were applied at the post-alignment stage around both the teeth adjacent to the implant and the upper anterior teeth. With proper mechanics and MOP application, the space for the molar crown and the necessary overjet for laminates was created (Fig. 7.15).

Another common scenario that occurs when only after the prosthetic restorations are completed does the dentist request your help to correct the occlusion. While

Initial

Final (8 months later)

Fig. 7.15 Patient #15 received an implant to restore the missing upper left first molar prematurely and required laminates in the upper incisors. However, due to lack of adequate overjet, the prognosis was not good. Using MOPs at the post-alignment stage, the upper arch was developed to accommodate the molar crown and provide enough overjet for placement of laminates, with excellent esthetic results

proper communication could prevent this situation, in these cases with correct application of MOPs, it is possible to provide a reasonable result in a short period of time. In the case of patient #16, four implant-supported crowns were placed in the anterior teeth prematurely. After insertion of the crowns, the patient expressed discontent with the esthetic result and the negative overjet. After discussion with the dentist, it was decided not to remove the crowns and to address the problem by retraction of lower dentition, considering that the patient had lost several teeth in the lower arch. Using TADs as anchorage and MOPs to accelerate the rate of tooth movement, the lower dentition was retracted in a short period of time without significant involvement of the upper teeth (Fig. 7.16).

7.5.10 Application of MOPs with Clear Aligners

MOPs can be utilized with both fixed and removable appliances to obtain a catabolic and anabolic effect. If a clinician plans to use MOPs with clear aligners to increase the rate of tooth movement, the intervals of time between aligners should be decreased so that active forces are constantly applied to the teeth. It is not reasonable to activate the biological response without stimulating the movement. It is advisable to incorporate MOPs into the treatment plan based on the movement designed for each aligner, therefore targeting MOP applications to teeth that are intended to move. If a tooth is not ready to move based on the aligner design, MOPs should not be applied around that tooth. Similarly, application of MOPs with aligners will facilitate the limited expansion that is possible with these appliances.

Initial

Final (11 months later)

Fig. 7.16 Patient #16 received four anterior crowns prematurely. After restorative work was completed, the patient was disappointed with esthetic result and concerned about his negative overjet. After discussions with the dentist, it was decided not to touch the upper crowns but retract lower anterior teeth into a functional occlusion. Using TADs for maximum anchorage and MOPs to accelerate the rate of retraction, the lower teeth were retracted and proper overjet and overbite established in a short period of time, without significant movement of upper teeth

7.6 Summary and General Rules of Application of MOPs

1. Define the patient needs for catabolic or anabolic effects of MOPs.
2. For anabolic effects of MOPs, define the area where cortical drifting is needed.
3. For catabolic effects of MOPs, define the target tooth (or teeth) at each stage of treatment.
4. For anabolic effects of MOPs, start earlier or simultaneous with the application of force and use shallow perforations. For catabolic effects, start at the time that you are ready to move the tooth and use deeper perforations.
5. For catabolic effects of MOPs, apply the MOPs close to the target teeth for that stage of treatment and do not apply MOPs close to anchor teeth.
6. For anabolic effects, apply light force, while for catabolic effects, you can gradually apply higher forces.
7. For anabolic effects, reactivate slowly and maintain the light force for longer periods of time. For catabolic effects, reactivate your forces frequently and gradually increase the magnitude of force, with proper mechanics.
8. For both catabolic and anabolic effects, apply the MOPs every month or at least every other month.
9. For predictable results, apply MOPs until desired movement is completed.