SURGICALLY ENHANCING THE SPEED OF TOOTH MOVEMENT: CAN WE ALTER THE BIOLOGY?

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ABSTRACT

Surgical treatment indeed can enhance the outcomes of orthodontic treatment. Another potential benefit of surgical intervention is the possibility of expediting orthodontic treatment. This chapter provides an overview of corticotomy-assisted orthodontics and its application to molar protraction using temporary anchorage devices. The regional acceleratory phenomenon is considered to be a potential biological mechanism for achieving increased tooth movement velocity during corticotomy-assisted orthodontics. This phenomenon also might enhance the speed of the post-surgical orthodontic phase in patients undergoing orthognathic surgery. The possibility of eliminating the pre-surgical phase in combination with increased tooth movement in the post-surgical phase may result in shorter treatment times for these patients. Two case reports will illustrate the concepts of corticotomy-assisted molar protraction with miniscrews and the "surgery first" concept using miniplates.

The variety of materials, concepts and techniques of modern orthodontics has evolved incrementally since the time of Edward Angle. Some may argue that the fundamentals of tooth movement remain the same. However, although the principles of physics may be immutable, definite progress has occurred in the area of material sciences. Indeed, development of new wires, brackets and springs has populated the orthodontic literature for the last 40 years. Even now, new brackets are being designed with the ambition of improving efficiency and esthetics.

Clearly, treatment efficiency is one of the goals of every practitioner. Improved efficiency is accomplished by managing those aspects of orthodontics that are amenable to modification such as biology and mechanics. For example, many current appliances claim to reduce friction or "eliminate it" all together. These "frictionless" appliances purport no loss of the applied force and, therefore, greater predictability of the biomechanics. *How* this reduction in friction is accomplished, however, has not been well substantiated. Moreover, based on the evidence, improved efficiency using these new appliances is controversial at the very least.

Juxtaposed against the uncertainty of these new appliances' benefits is a comprehensive understanding of bone biology in response to orthodontic tooth movement. Substantial research has been published in the area of biology of orthodontic tooth movement in animal models. It has become clear that bone biology can be modified in order to increase treatment efficiency. In the studies that have been performed primarily in animal models, the physiologic and biologic players have been well delineated. These models revealed that the presence of cytokines, such as RANKL, enhances the speed of orthodontic tooth movement. For many reasons, the clinical application of these biological substances in humans is unlikely to be adopted in the near future.

Although injecting cytokines into humans may not be feasible, a more gross manipulation of the biological bone cascade – by means of segmental alveolar decortications – currently is becoming an attractive technique used to increase the efficiency of orthodontic tooth movement. The underlying theory with this method is that corticotomy surgery alters the bone biology through mechanical perturbation of the dentoalveolar complex. Further, this biologic agitation appears to enhance tooth movement resulting from the subsequent application of mechanical stimulus of an orthodontic force.

HISTORY

Surgical segmentation of alveolar bone of the teeth has been reported since the end of the 19th century (Guilford, 1898). Köle (1959) thoroughly described the clinical application of orthodontically moving teeth after interproximal bone segmentation as a means to expedite tooth movement. He suggested that teeth can be segmented and moved as "small boxes" through bone remodeling without involving the periodontal ligament. His technique was described as an adjunct in the correction of numerous types of malocclusions, including tooth protrusion and deep bites combined with different treatment protocols such as nonextraction and space closure approaches. Using this method, he claimed orthodontic treatment could be accomplished in six to twelve weeks.

Köle's surgical technique for the correction of crowding consisted of elimination of the interproximal cortical bone on both labial and lingual aspects of the teeth up to and including the entire alveolar height while leaving the spongy bone intact (Köle, 1959). Additionally, a subapical osteotomy was performed below the segmented teeth. The orthodontic appliance he described was a removable plate with a labial bow and a screw that was activated for sagittal movement of 0.25 mm per week. Alternatively, he suggested an Angle appliance could be used for tooth movement. Adjustments were made with unspecified force values. However, based on a weekly 0.25 mm activation of the expansion screw, it can be inferred that these forces were relatively high. No side effects such as loss of vitality, root resorption or deleterious periodontal effects were reported.

Gantes and coworkers (1990) reported on the periodontal status of five adult patients with different malocclusions (majority Class II) who received orthodontic treatment assisted by corticotomies. This sample was compared to a group of orthodontically treated patients of the same age and with the same type of malocclusion. The corticotomies consisted of an interproximal vertical groove through the labial and lingual cortical plate of the six anterior teeth. Patients in the corticotomy group who had extractions had the buccal and lingual cortical plate removed at the extraction sites. The reported mean treatment time was 14.8 months for the corticotomy group *vs.* 28.3 months for the experimental group. Due to the segmental technique used for tooth movement in the corticotomy group, however, the frequency of appointments and total chair time was similar for both groups. Although treatment times were reported, the primary focus of this article was on the periodontal clinical effects. Both groups had similar probing pocket depths and slight attachment level changes. Unlike previous findings, apical root resorption was observed in the corticotomy group as well as the control group.

Wilcko and colleagues (2001) reported on two adult patients with a Class I malocclusion and moderate to severe crowding who received corticotomies to accelerate tooth movement. The surgical procedure consisted of interproximal vertical grooves on the labial and lingual cortices of all teeth. A subapical horizontal scalloped corticotomy connected the vertical grooves. In addition, numerous circular perforations were drilled on the cortical bone surfaces and a resorbable allograft was packed over the corticotomies and exposed cortical bone. They called this procedure Periodontally Accelerated Osteogenic Orthodontics (PAOO). Orthodontic adjustments were performed on average every two weeks. Treatment duration for both patients was approximately six months, including twelve orthodontic adjustments. No periodontal sequelae or apical root resorption was observed. A second exploratory surgery for one of the patients fifteen months after the corticotomies revealed increased bone thickness and adequate amount of bone covering the roots of the teeth, even after obtaining significant expansion of the dental arches with the orthodontic treatment.

REGIONAL ACCELERATORY PHENOMENON

The reported increase in the rate of tooth movement with corticotomy-assisted orthodontics has been attributed to a biological process denominated regional acceleratory phenomenon (RAP). This process was described initially by Frost (1989*a*,*b*) based on observations of bone fracture healing. In summary, he described a series of orchestrated events consisting of increased cellular activity during healing around the fracture site. These events were characterized by reduction in bone density due to the accelerated bone turnover. The cortical bone porosity appeared to be related to osteoclastic activity that may have contributed to tooth mobility. It has been suggested that the peak of such phenomenon is one or two months after the insult, with effects lasting six to 24 months (Yaffe *et al*., 1994).

Mueller and coworkers (1991) not only reported on a regional acceleratory phenomenon, but also observed a systemic acceleratory phenomenon, where increased osteoblastic activity is apparent at a distant site to the fracture healing area. Wilcko and colleagues (2008) rebut with the claim that the transient osteopenia and increased tissue turnover is related directly to the proximity and intensity of the surgical insult.

ANIMAL EXPERIMENTS

Recent studies have been published using different animal models in order to understand the remodeling process after corticotomy-assisted orthodontics. Iino and colleagues (2007) evaluated tooth movement velocity in twelve Beagle dogs. The methodology was a split mouth design with corticotomies on the buccal and lingual alveolar bone of the mandibular third premolar, and a coil spring delivering a 0.5N mesial orthodontic force. The contralateral third premolar received the same orthodontic force but without the corticotomy. An increase in the speed of tooth movement was reported in the first two weeks in the corticotomy quadrant. The rate of tooth movement thereafter was similar on the experimental and sham sides. Histologically, it was shown that hyalinization was present in the periodontal ligament every week on the control side, while the experimental side had hyalinization only during the first week. An increase in tartrate resistant acid phosphatase (TRAP) positive cells on the experimental side also was noted, suggesting increased osteoclastic activity. The findings demonstrate that corticotomies combined with orthodontic force application increases the rate of tooth movement and is associated with histological changes reflecting increased bone turnover.

In a study in rats, Lee and coworkers (2008) set out to compare the rate of tooth movement between a group of rats subjected to orthodontic force application alone and two additional groups of rats subjected to the same orthodontic force in combination to a corticotomy or an osteotomy. In addition, they evaluated bone density at three time points for up to two months in all the groups with surgically-assisted orthodontic tooth movement and groups with corticotomy and osteotomy alone. No significant difference was found in the rate of tooth movement at 21 days between the control orthodontic force only group and those in which orthodontic forces were applied in conjunction with corticotomy or osteotomy, although a tendency for more movement was seen with osteotomy-assisted orthodontics. Bone density among all groups was highly variable. The changes in corticotomy-assisted orthodontics were consistent with RAP after 21 days. After two months, there were no differences in bone density levels surrounding the bone of the experimental and contralateral teeth.

CORTICOTOMIES TO EXPEDITE MOLAR PROTRACTION INTO EDENTULOUS SPACES

Corticotomies have been advocated by some clinicians for adult patients with severe crowding who request short orthodontic treatment duration. This technique also has been used recently as an adjunct to other orthodontic tooth movements. Oliveira and colleagues (2008), as well as Hwang and Lee (2001) described a case report of corticotomies as an aid for molar intrusion. Spena and coworkers (2007), using a case report, described corticotomy-assisted maxillary molar distalization. Both of these publications reported a reduction in treatment time.

Fischer (2007) reported on six consecutive patients with bilateral palatally impacted canines that were subjected to corticotomies in conjunction with the exposure procedure. The results indicated an approximate 30% reduction in treatment time between the canine with corticotomy-assisted orthodontic eruption in comparison to the contralateral orthodontics-alone eruption. Chung and colleagues (2001) and Lee and coworkers (2007) also reported a reduction in treatment time for patients with bimaxillary protrusion with space closure after corticotomies and extraction of four premolars.

More recently, with the advent of skeletal anchorage, clinicians have been exploring the option of closing edentulous spaces in the posterior region through protraction of teeth adjacent to the edentulous space. Traditional orthodontics-only mechanics in these patients is time consuming, with a rate of tooth movement of approximately 0.5 mm per month (Roberts *et al*., 1990). Considering that molar edentulous sites often are large, molar protraction could take up to 20 months for a 10 mm space. Nagaraj and colleagues (2008) recently published a case report of molar protraction using miniscrews involving 8 mm of space closure in 15 months, with a total treatment duration of 28 months. It is important to note that space closure using miniscrews in these types of patients primarily consists of movement of one unit (protraction of the posterior segment); thus, space closure occurs from only one front. As opposed to the more demanding and time-consuming space closure involving only one front, patients with minimum anchorage requirements where the space is closed symmetrically will undergo faster space closure.

Corticotomies potentially could reduce the treatment time dramatically in patients who require significant amount of molar protraction. Figure 1 shows a patient who previously had three years of orthodontic treatment. She was concerned with the prognosis of the retained primary second molars. The panoramic radiograph revealed moderate to severe root resorption of the second primary molars, most notably the right molar. Additionally, a significant amount of recession was detected on the mesial root of both molars, which extended almost to the apex. Both primary molars had increased mobility. Occlusally the patient had an anterior openbite accentuated by a significant bilateral openbite at the premolars. The primary molars had no occlusal contact. The maxillary arch was constricted moderately with mild crowding. The mandibular arch was crowded moderately. The patient also had a crossbite tendency in the buccal segments with the left second molars in crossbite.

The patient had been referred to the orthodontic clinic by the Division of Prosthodontics with the concern that an implant required to replace exfoliating primary molars would not receive any occlusal function, and an unesthetic outcome would result if an occlusal contact was to be obtained in the final restoration. Following consultation with the

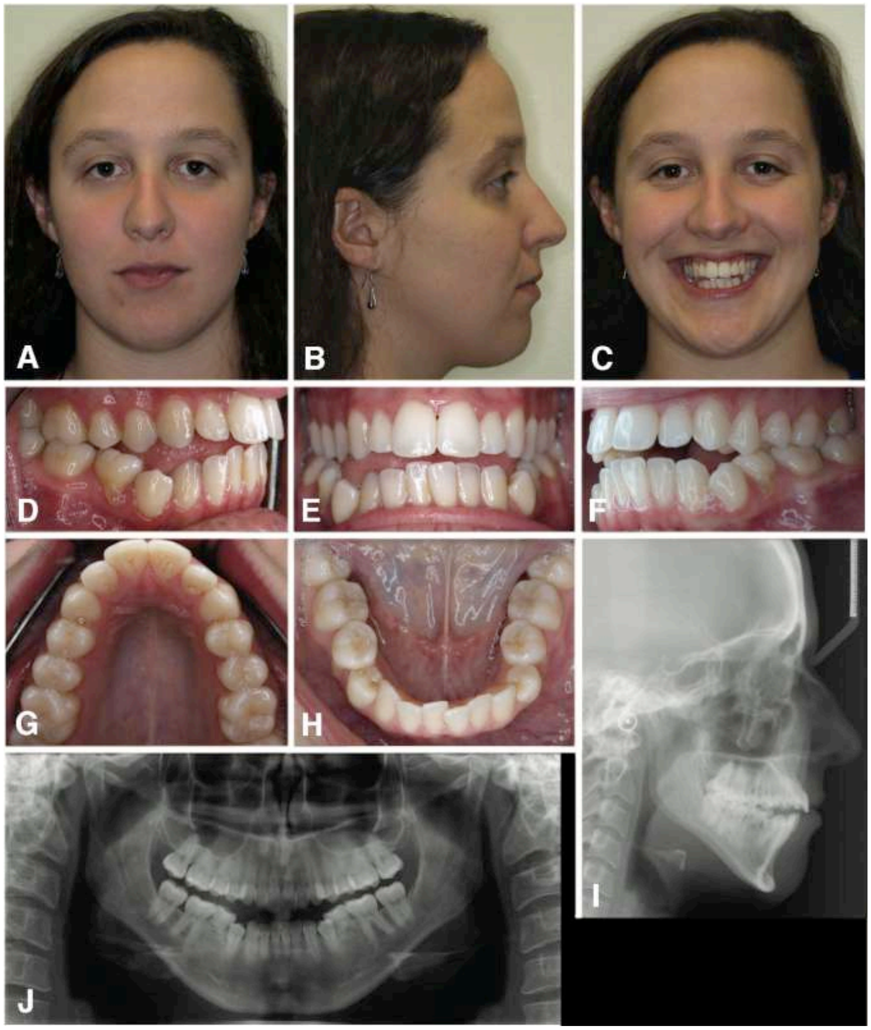


Figure 1. Pre-treatment images depicting the poor prognosis of the mandibular primary second molars and the absence of the second premolars. The patient also presented with a dolicofacial pattern with anterior and lateral openbite with no occlusal contacts other than the first and second molars.

Orthodontic Division, it was proposed to the patient to extract the primary molars and close the spaces with orthodontic treatment, thereby addressing the openbite and eliminating the need to restore the missing second premolars. Because the patient wanted to expedite the treatment time with fixed appliances, a protocol involving corticotomies on the mandibular first and second molars was followed. The upper arch was to be treated with clear aligners with the specific objective of arch alignment and slight expansion in the molar region.

A lingual arch with loops connecting the bands of the permanent first molars was cemented with 3 mm clearance off the lingual surface of the mandibular incisors. The second molars were bonded and a passive stainless steel wire segment (0.016″ x 0.022″) connecting the first and second molars was cinched back behind the second molars. The patient then was referred to the periodontist for extraction of the primary second molars. Two weeks later, mucoperiostal flaps were elevated and interproximal vertical corticotomies made on the labial aspect of the mandibular molars with a piezosurgical microsaw (Fig. 2; Vercellotti and Podesta, 2007). The vertical groove corticotomies were performed mesial to the first and second molars bilaterally and extended just below the crestal bone to the apex. Dried-freeze demineralized bone allograft (DFDBA) was packed on the buccal surface covering the grooves and exposed labial cortical bone surface, including a dehiscence on the first molar. The grafted bone increased the width of the edentulous ridge, creating an adequate bone trough for the translation of the mandibular molars. The flaps were approximated with closure by first intention, and a miniscrew was placed distal to the right and left first premolars. The patient was allowed to heal for two weeks; thereafter, power arms were placed extending from the auxiliary tube of the first molar. A NiTi coil connected the power arms to the miniscrews delivering a mesial translatory force.

The patient was evaluated every four weeks for adjustment of the lingual arch as the molars protracted. After approximately 5 mm of molar protraction, obtained during a six-month period, it was decided to bond the teeth anterior to the edentulous space in order to add control to the appliance as the first molars had tipped moderately in a mesial direction.

Figures 3 through 6 show the progress and current treatment status. Two millimeters of space closure remains on the right edentulous site with full closure on the left side. However, the lower arch needs to be leveled with some intrusion of the mandibular second molars. This leveling will be accomplished though indirect anchorage from the miniscrew. The arch will be leveled from first molar to first molar and thereafter the whole arch will be connected to the screw and an intrusive force delivered to the second molar. To complete the orthodontic treatment, alignment and slight expansion in the maxilla will be obtained using clear aligners.

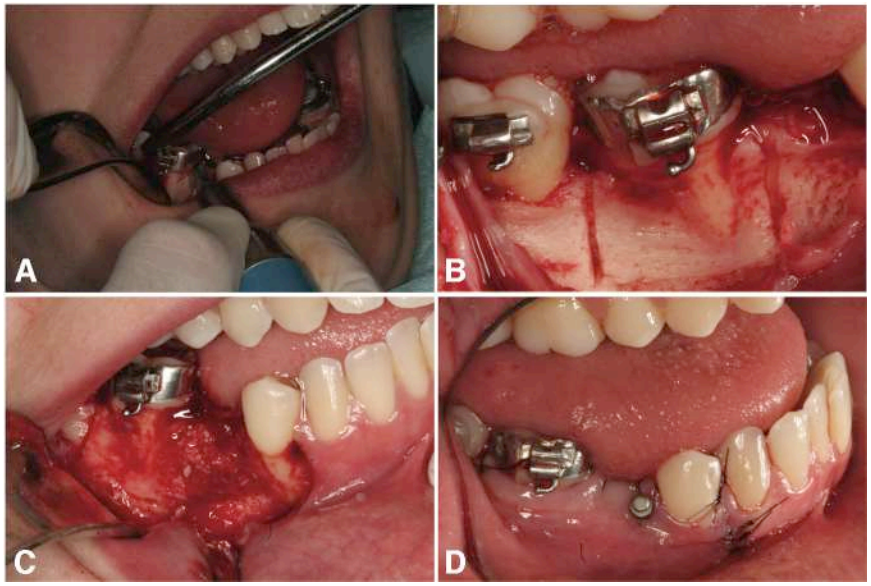


Figure 2. *A* and *B:* Corticotomy procedure using a piezosurgical microsaw. *C:* Dried-freeze demineralized bone allograft (DFBDA) was packed on the cortical bone to cover the bone dehiscences and build the volume of the edentulous site. *D:* A miniscrew was placed distal to the first premolar.

Overall, the majority of the edentulous space has been closed, although at the expense of moderate tipping of the first and second molars. Although the mechanics delivered were intended to translate the posterior segments, tipping could not be obviated as these teeth were supra-erupted and needed to be displaced not only anteriorly but also inferiorly. Space closure occurred at a rate that appears to be 40% faster than traditional orthodontic mechanics for this type of tooth movement. This example is only one case, however, and any conclusion on speed of tooth movement is difficult to make as space closure rate depends on type of tooth movement (translation *vs.* tipping). Moreover, it is well known that significant intra-individual and inter-individual variation is common in tooth movement rates (Ren *et al*., 2003).

Finally, although these types of patients could benefit from enhanced speed of tooth movement, it still is not clear if this surgical bone perturbation enables faster orthodontic treatment. Moreover, the biologcal mechanism involved is obscure; therefore, the type and extent of the corticotomies needed to trigger an accelerated tooth movement response remain unknown. The techniques described herein involved interdental

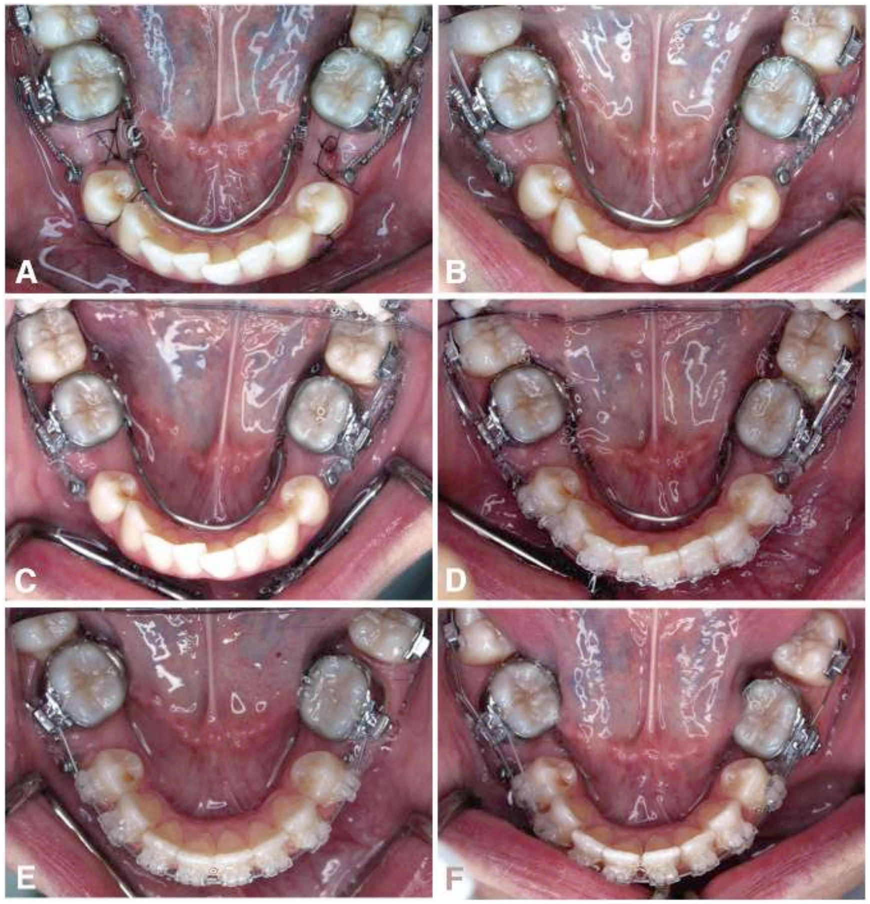


Figure 3. Occlusal view of treatment progress. *A:* Two weeks after corticotomies. *B:* After two months. *C:* After four months. *D:* After six months. *E:* After eight months. *F:* After ten months.

vertical grooves on the labial side. In contrast, others have described interdental vertical grooves on both the labial and lingual sides. Still others have combined labial and lingual interproximal vertical grooves and cortical round groove indentations. Wilcko and colleagues (2003) found no difference in rates of tooth movement in a split mouth design between vertical grooves and cortical round groove perforation. However, these findings are based on a report of one patient in whom only vertical groove corticotomies were performed on the buccal side. It also appears that grafting may be an important prerequisite, especially as the teeth move at a faster rate into a deficient edentulous ridge.

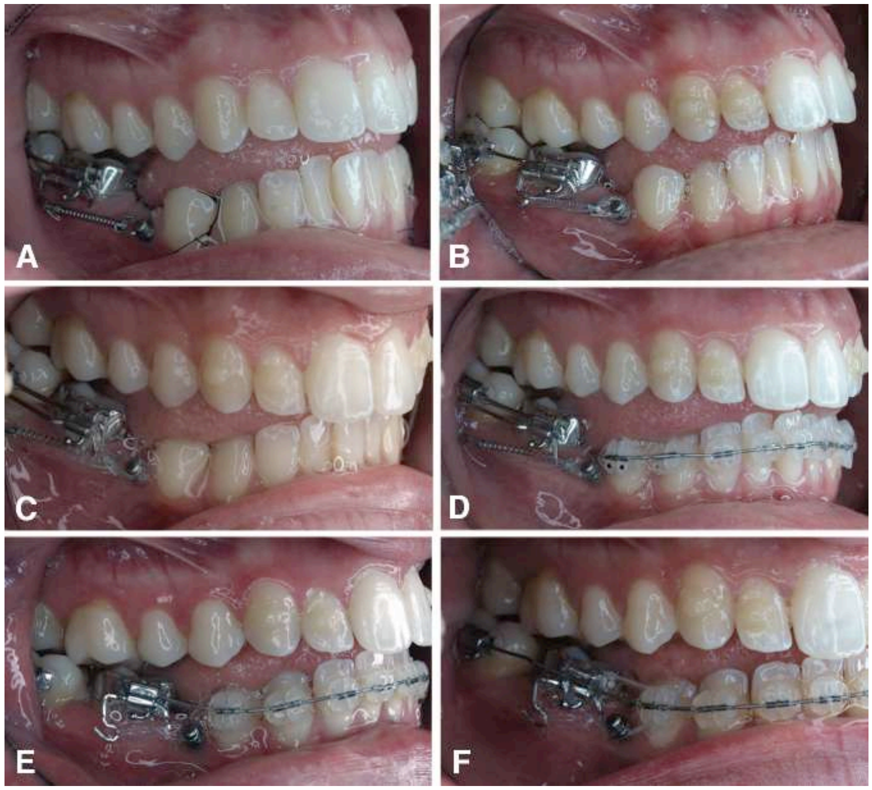


Figure 4. Right lateral view of treatment progress. *A:* Two weeks after corticotomies. *B:* After two months. *C:* After four months. *D:* After six months. *E:* After eight months. *F:* After ten months.

REGIONAL ACCELERATORY PHENOMENON IN PATIENTS UNDERGOING ORTHOGNATHIC SURGERY WITH ORTHODONTICS

Patients with dentofacial deformities generally require complex treatments involving combined orthodontics and orthognathic surgery. The prevalent treatment paradigm for these patients involves a three-phase approach.

In the first phase, decompensations of the teeth are accomplished, usually at the expense of a transitory esthetic outcome. Depending on the severity of the crowding and if extractions are involved, this phase usually lasts a period of nine to twelve months. The second phase

Figure 5. Left lateral view of treatment progress. *A:* Two weeks after corticotomies. *B:* After two months. *C:* After four months. *D:* After six months. *E:* After eight months. *F:* After ten months.

is the surgical procedure to correct the basal bone relationships and achieve a good occlusion. Finally, the third stage consists of the finishing stage that may last another nine to twelve months of treatment.

Typically, the pre-surgical orthodontic phase in these patients is needed in order to establish the direction and magnitude of the surgical movements predictably. In addition, this decompensation phase eliminates potential occlusal interferences, enabling a good occlusal outcome right after surgery (Proffit and White, 2003). This outcome is achieved through proper tooth alignment until the insertion of rigid archwires allows the mobilization of the whole arch during surgery.

Figure 6. Frontal view of treatment progress. *A:* Two weeks after corticotomies. *B:* After two months. *C:* After four months. *D:* After six months. *E:* After eight months. *F:* After ten months.

An alternative strategy for these patients may involve the elimination of the first phase of treatment. By eliminating the pre-surgical phase and implementing a "surgery first" approach, the patient does not have to endure an additional period of time with the dentofacial deformity, which is aggravated during the first phase of treatment. In addition, the elimination of one of the phases has the potential benefit of significantly reducing treatment time. This reduction in treatment time is obtained simply through the elimination of initial decompensation phase that reduces treatment time by nine to twelve months. The "surgery first" approach also may trigger the regional acceleratory phenomenon. Although this topic needs further investigation, it may be hypothesized that the osteotomies have a regional effect on the dental osseous environment, possibly resulting in physiologic conditions that are conducive to an accelerated alignment phase following the surgery.

SURGICAL TECHNIQUE

Because the proper tooth inclinations and alignments are achieved after surgery, this approach involves formulating a careful surgical plan. The surgery is planned based on the predicted orthodontic movements and the most ideal facial esthetic outcome desired. In order to ensure a good occlusal outcome, surgical skeletal anchorage plates are placed.

Skeletal anchorage has redefined the practice of orthodontics. The envelope of discrepancy for orthodontic correction, described by Proffit and Ackerman (1994) has been broadened and now has a new layer. With skeletal anchorage, teeth can be moved over larger spans. This new envelope, therefore, blurs the line between the range of movement yielded with surgery and movement achieved by means of conventional orthodontic appliance therapy alone. Taking advantage of this potential, the placement of skeletal anchorage plates during “surgery first” cases serves as insurance in achieving the desired occlusal outcome when pre-surgical orthodontic phase is to be circumvented. For example, if the patient relapses or minor errors occur in the surgical outcome, the plates allow for controllable, predictable dental movements and ultimately more efficient attainment of optimal occlusion.

CASE REPORT

A patient who underwent a “surgery first” approach is presented in Figure 7. This 16-year-old female patient presented with a severe dentofacial deformity including a severe facial concavity due to maxillary retrognathism and moderate mandibular prognathism. A mild vertical and transverse asymmetry was evident in frontal view. More specifically, the occlusal plane was slightly lower on the right side and the mandible deviated approximately 3 mm toward the right side. A slight crossbite tendency was noticed in the buccal segments due to the anteroposterior discrepancy in the dental arches. Maxillary and mandibular incisor inclinations were nearly ideal. The incisor display was deficient both at rest and upon smiling. The occlusal canine relationship was Class III with a significant reverse overjet. The maxillary first premolars were missing due to extraction performed by her dentist at an earlier age to alleviate crowding.

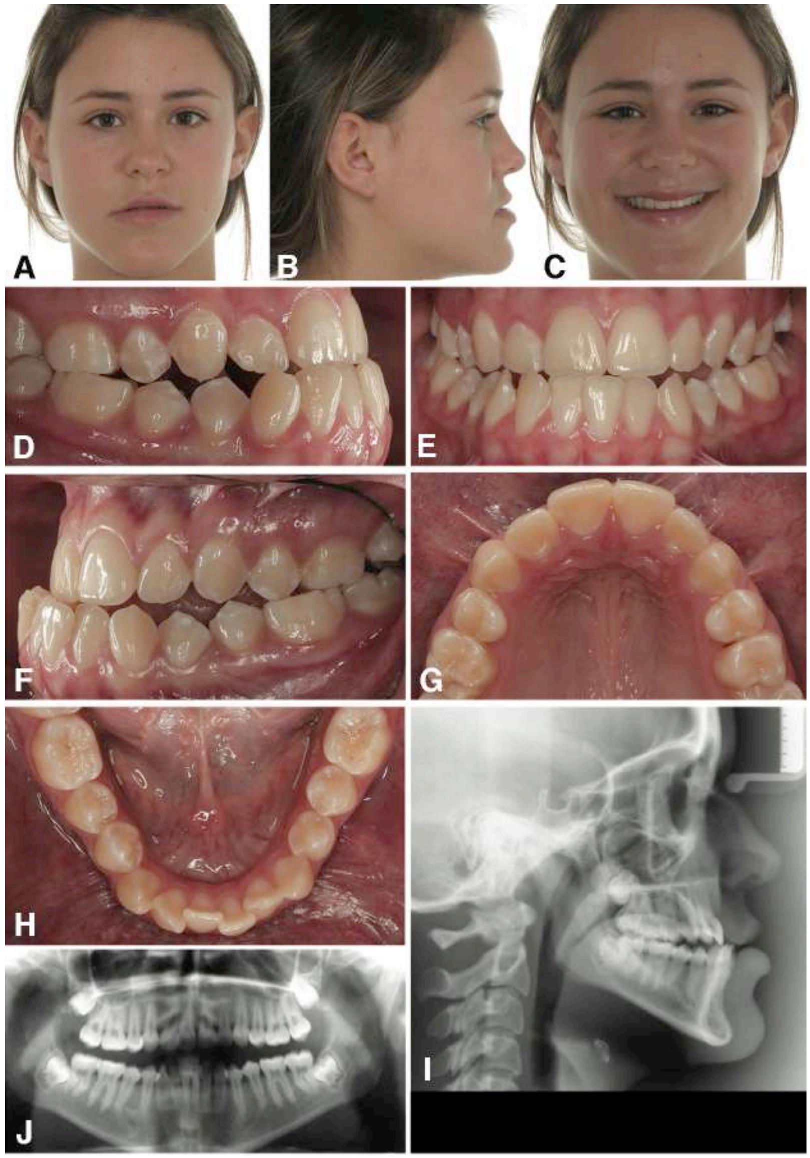


Figure 7. Pre-treatment records of a 16-year-old female with a concave profile and Class III malocclusion.

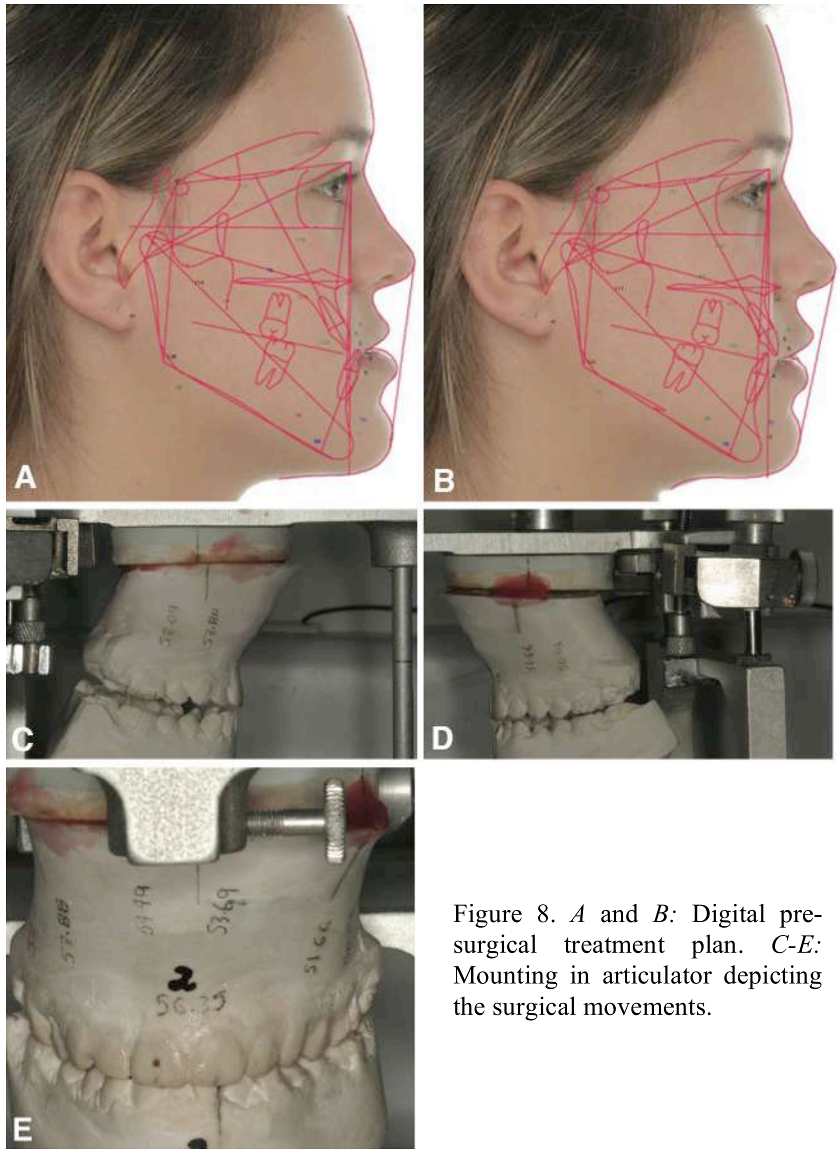


Figure 8. *A* and *B:* Digital pre-surgical treatment plan. *C-E:* Mounting in articulator depicting the surgical movements.

The treatment plan for the patient was 3 mm of maxillary advancement with 2 mm of downward displacement in the anterior region. The mandible was to be set back 4 mm on the left and 3 mm on the right to address the mandibular asymmetry and dental midline deviation (Fig. 8). Occlusally, the patient was to finish in a Class II molar and a Class I canine occlusion.

Fixed appliances were bonded one week prior to the orthognathic surgery procedure. Brackets distal to the lateral incisors had hooks in order to be able to fix the surgical splints during the surgical procedure. No orthodontic wires were placed for the surgical intervention. The maxilla was mobilized anteriorly and rotated clockwise to improve smile display. Vertically it was impacted posteriorly 1 mm on the left side to resolve the occlusal cant. The mandible was set back through a BSSO 4 mm on the left and 3 mm on the right. Third molars were extracted at the time of surgery. Two plates were placed in the maxilla in order to fix it in its new position. In addition, two skeletal anchorage plates were fixed in the infrazygomatic crest. The plates emerged intraorally through the mucogingival junction at the first molar area. The mandible was fixed with three bicortical screws. After flap closure, a 0.016″ x 0.016″ NiTi wire and a 0.014″ NiTi wire were placed on the maxilla and mandible, respectively. Intermaxillary elastics were prescribed between the maxillary and mandibular buccal segments and from the skeletal anchorage plates to the mandibular premolars (Fig. 9).

After two weeks, the patient presented with mild swelling and relative good intermaxillary relationships. Alignment of the arches was continued and intermaxillary elastics were used to obtain a better occlusal relationship in the buccal segments. After three months, the occlusal relationship was almost ideal and the finishing phase was started (Fig. 10).

Eight months after the surgical procedure, the patient was debonded. A maxillary vacuform retainer was delivered and a mandibular canine to canine fixed lingual retainer bonded. Final records reveal a significant esthetic improvement and a good occlusal result achieved after a short treatment time (Fig. 11).

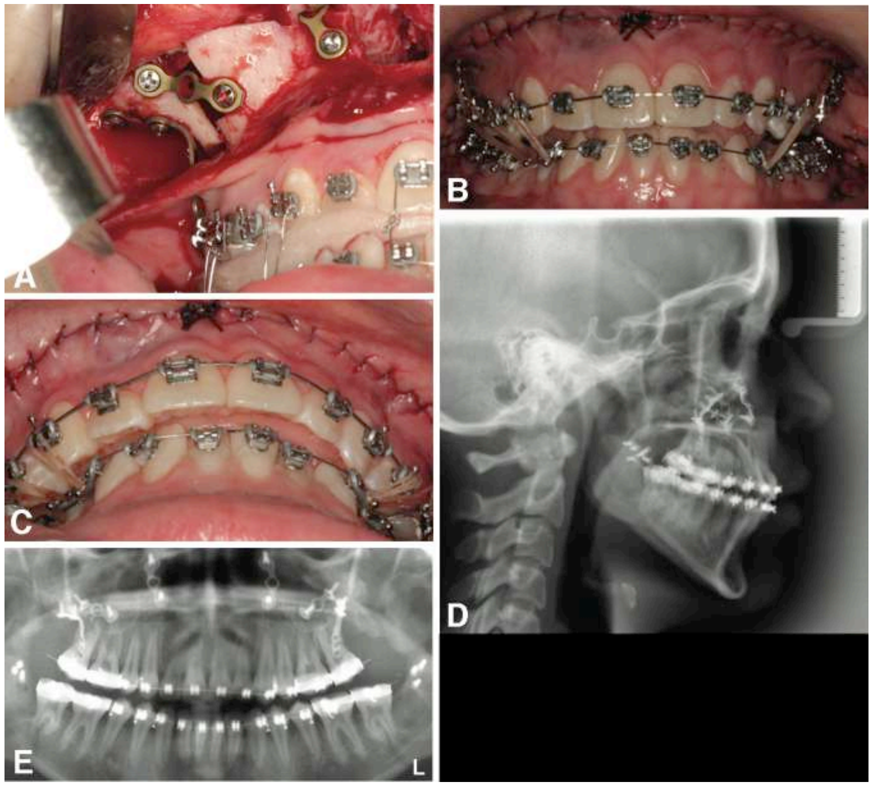
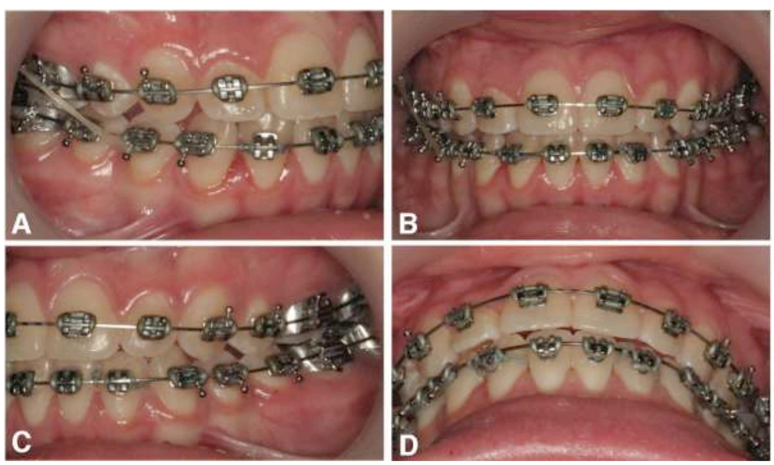


Figure 9. *A:* Surgical maxillary LeFort 1 advancement with plate fixation and an additional miniplate emerging intraorally from the infrazygomatic crest through the mucogingival junction. *B* and *C:* Immediate intraoral post-surgical result with NiTi archwires inserted during this visit. *D* and *E:* Post-surgical x-rays.



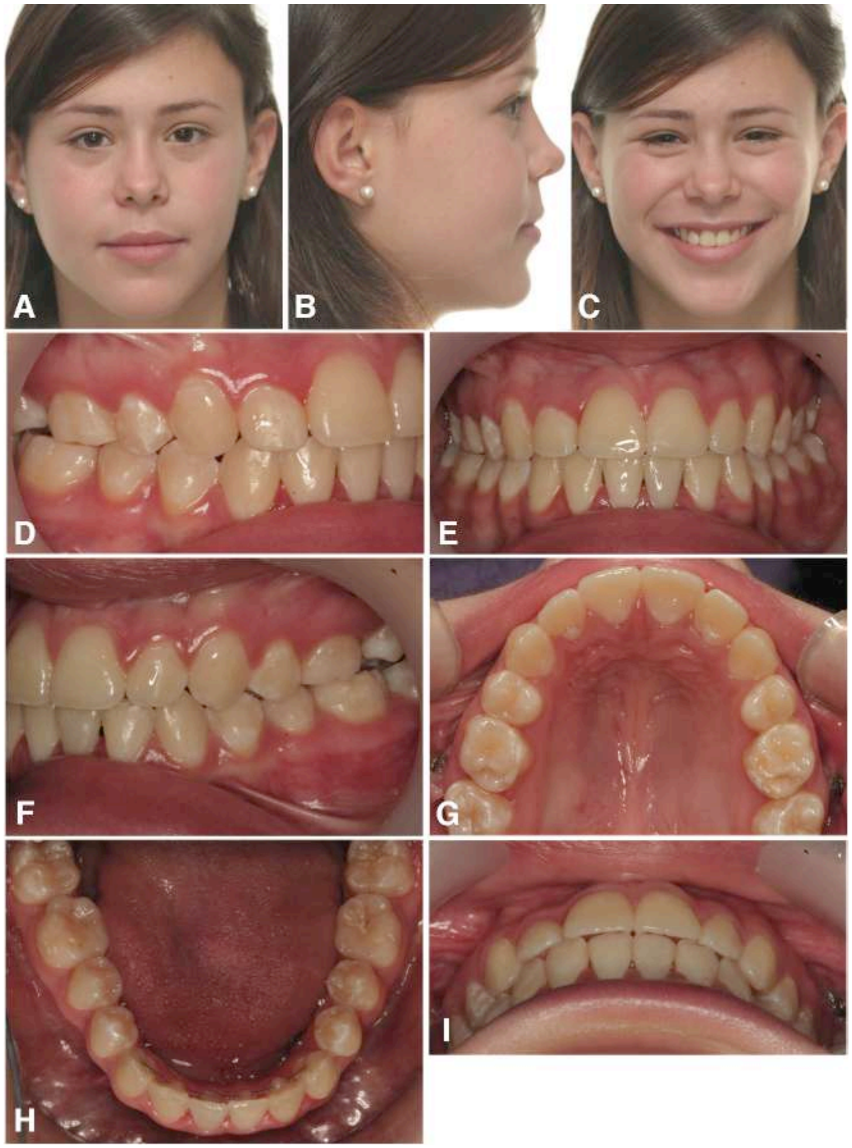


Figure 11. Final treatment records after eight months in treatment.

← Figure 10. Three-month progress after surgery.

CONCLUSIONS

- Understanding the biology of bone remodeling and tooth movement may help elucidate pathways that enable the enhancement in the speed of orthodontic treatment.
- Clinical trials may help elucidate whether or not corticotomies increase the rate of tooth movement.
- The exact extent of the surgical corticotomy procedure that maximizes the efficiency in tooth movement, if at all, remains to be determined.
- "Surgery first" approach eliminates the pre-surgical phase with a potentially significant reduction in treatment time.
- The RAP may enhance tooth movement after orthognathic surgery.

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REFERENCES

Chung KR, Oh MY, Ko SJ. Corticotomy-assisted orthodontics. J Clin Orthod 2001;35:331-339.

Fischer TJ. Orthodontic treatment acceleration with corticotomy-assisted exposure of palatally impacted canines. Angle Orthod 2007;77:417-420.

Frost HM. The biology of fracture healing: An overview for clinicians. Part I. Clin Orthop Relat Res 1989*a*;248:283-293.

Frost HM. The biology of fracture healing: An overview for clinicians. Part II. Clin Orthop Relat Res 1989*b*;248:294-309.

Gantes B, Rathbun E, Anholm M. Effects on the periodontium following corticotomy-facilitated orthodontics: Case reports. J Periodontol 1990;61:234-238.

Guilford SH. *Orthodontia or Malposition of the Human Teeth: Its Prevention and Remedy*. Philadelphia: TC Davis & Sons 1898.

Hwang HS, Lee KH. Intrusion of overerupted molars by corticotomy and magnets. Am J Orthod Dentofacial Orthop 2001;120:209-216.

Iino S, Sakoda S, Ito G, Nishimori T, Ikeda T, Miyawaki S. Acceleration of orthodontic tooth movement by alveolar corticotomy in the dog. Am J Orthod Dentofacial Orthop 2007;131;448:e1-8.

Köle H. Surgical operations on the alveolar ridge to correct occlusal abnormalities. Oral Surg Oral Med Oral Pathol 1959;12:515-529.

Lee JK, Chung KR, Baek SH. Treatment outcomes of orthodontic treatment, corticotomy-assisted orthodontic treatment, and anterior segmental osteotomy for bimaxillary dentoalveolar protrusion. Plast Reconstr Surg 2007;120:1027-1036.

Lee W, Karapetyan G, Moats R, Yamashita DD, Moon HB, Ferguson DJ, Yen S. Corticotomy-/osteotomy-assisted tooth movement microCTs differ. J Dent Res 2008;87:861-867.

Mueller M, Schilling T, Minne HW, Ziegler R. A systemic acceleratory phenomenon (SAP) accompanies the regional acceleratory phenomenon (RAP) during healing of a bone defect in the rat. J Bone Miner Res 1991;6:401-410.

Nagaraj K, Upadhyay M, Yadav S. Titanium screw anchorage for protraction of mandibular second molars into first molar extraction sites. Am J Orthod Dentofacial Orthop 2008;134:583-591.

Oliveira DD, de Oliveira BF, de Araujo Brito HH, de Souza MM, Medeiros PJ. Selective alveolar corticotomy to intrude overerupted molars. Am J Orthod Dentofacial Orthop 2008;133:902-908.

Proffit WR, Ackerman JL. Diagnosis and treatment planning in orthodontics. In: Graber TM, ed. *Orthodontics Current Principles and Techniques*. St Louis: Mosby 1994:3-95.

Proffit WR, White RP. Combining surgery and orthodontics: Who does what, when? In: Proffit WR, ed. *Contemporary Treatment of Dentofacial Deformity.* St Louis: Mosby 2003:245-267.

Ren Y, Maltha JC, Kuijpers-Jagtman AM. Optimum force magnitude for orthodontic tooth movement: A systematic literature review. Angle Orthod 2003;73:86-92.

Roberts WE, Marshall KJ, Mozsary PG. Rigid endosseous implant utilized as anchorage to protract molars and close an atrophic extraction site. Angle Orthod 1990;60:135-152.

Spena R, Caiazzo A, Gracco A, Siciliani G. The use of segmental corticotomy to enhance molar distalization. J Clin Orthod 2007; 41:693-699.

Vercellotti T, Podesta A. Orthodontic microsurgery: A new surgically guided technique for dental movement. Int J Periodontics Restorative Dent 2007;27:325-331.

Wilcko WM, Ferguson DJ, Bouquot JE, Wilcko MT. Rapid orthodontic decrowding with alveolar augmentation: Case report. World J Orthod 2003:4:197-205.

Wilcko WM, Wilcko T, Bouquot JE, Ferguson DJ. Rapid orthodontics with alveolar reshaping: Two case reports of decrowding. Int J Periodontics Restorative Dent 2001;21:9-19.

Wilcko MT, Wilcko WM, Bissada NF. An evidence-based analysis of periodontally accelerated orthodontic and osteogenic techniques: A synthesis of scientific perspectives. Semin Orthod 2008;14:305-316.

Yaffe A, Fine N, Binderman I. Regional accelerated phenomenon in the mandible following mucoperiosteal flap surgery. J Periodontol 1994; 65:79-83.