An Evidence-Based Analysis of Periodontally Accelerated Orthodontic and Osteogenic Techniques: A Synthesis of Scientific Perspectives

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Interdisciplinary orthodontic tooth movement (OTM) can synthesize tissue engineering principles with periodontal regenerative surgery to create rapid orthodontic tooth movement and reduce side effects like root resorption, relapse, inadequate basal bone, and bacterial time-load factors (ie, infection). Normal metabolism seen in a natural healing response is accelerated resulting in a more stable clinical outcome. Specifically, modern computed tomographic imaging suggests what were thought be "bony blocks" undergo demineralization both on the surface and within the alveolar bone proper (reversible osteopenia). Periodontal analysis shows that with demineralization the remaining collagenous soft tissue matrix of the bone is transported with the root in the direction of the movement. When retained in the desired position the matrix remineralizes demonstrating malleability of the alveolus previously thought to be unattainable. This natural demineralization-remineralization phenomenon appears fairly complete in adolescents albeit benignly less complete in adults. The new interpretation of the rapid movement as "bone matrix transportation" has made it possible to design a surgical approach, which permits extraction space closure in 3 to 4 weeks. This protocol allows conventional OTM 300% to 400% faster, increases the envelope of movement 2- to 3-fold and alveolar augmentation (periodontally accelerated osteogenic orthodontics or PAOO), and increases alveolar volume providing an alternative to bicuspid extraction. (Semin Orthod 2008;14:305-316.) © *2008 Published by Elsevier Inc.*

The 21st century is referred to as the Century of the Biologist and the dentofacial dimension of the orthodontic specialty is a front stage player in the script of scientific progress. Over the last two decades, the refinements of an attempt to engineer an "optimal response" of alveolar bone to applied "optimal force" has propelled both the periodontal and the orthodontic specialties directly into the field of surgical dentofacial orthopedics the way distraction osteogenesis and the publication of the human genome have made clinical medical orthopedics more biologically sophisticated in its mechanical therapeutic manipulation. Specifically, the molecular dynamics of osteogenesis in stressed bone defines pathways similar to steady-state homologues not yet fully defined.

We would suggest that most salient in this inevitable progress, the spirit of interdisciplinary collaboration in the orthodontic specialty has taken traditional orthodontic tooth movement

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(OTM) protocols and synthesized periodontal tissue engineering and regenerative surgery, not only a method of rapid orthodontic tooth movement, but also provided every young clinician with a protocol that also reduces side effects like root resorption, relapse, inadequate basal bone, and bacterial time/load factors, that is, caries and infection. Interestingly, on a clinical level, this innovation elicits a latent enthusiasm for the treatment in both adolescents and population cohorts that previously avoided OTM.

The commonly held notion that preexisting alveolar volume is immutable has placed substantial limitations on the amount of tooth movement thought to be safely achievable and still provide a stable result. For well over four decades the Department of Orthodontics at the University of Washington has collected diagnostic records on more than 600 patients that were 10 or more years into retention.[1] After 10 years of retention, satisfactory mandibular alignment was maintained in less than 30% of patients. Relapse was generally accompanied by a decrease in arch length and width. Interestingly, Rothe and coworkers in a study of mandibular incisor relapse have reported that patients with thinner mandibular cortices after debonding are at increased risk for dental relapse.[2]

The new technique described here provides an increased net alveolar volume after orthodontic treatment. This is called the periodontally accelerated osteogenic orthodontics (PAOO) technique. It is a combination of a selective decortication-facilitated orthodontic technique and alveolar augmentation.[3-6] With this technique, one is no longer at the mercy of the preexisting alveolar volume, and teeth can be moved 2 to 3 times further in [1/3] to [1/4] the time required for traditional orthodontic therapy.[3-6] It can be used to treat moderate to severe malocclusions in both adolescents and adults and can reduce the need for extractions. Except for severe Class III skeletal dysplasia, PAOO can replace some orthognathic surgery, and because of the low morbidity, patients 11 to 78 years old have been treated with marked biologic impunity.

Historical Review

Only the biologic rationale and evidence-based veracity is new. Rudimentary surgical intervention to affect the alveolar housing and speed tooth movement has been used in various forms for more than a hundred years. It was Heinrich Köle's publication in 1959,[7] however, that set the stage for the subsequent evolution of refined decortication-facilitated orthodontics. Köle believed that it was the continuity and thickness of the denser layer of cortical bone that offered the most resistance to tooth movement. He theorized that by disrupting the continuity of this cortical layer of bone that he was actually creating and moving segments of bone in which the teeth were embedded. He believed that these outlined blocks of bone could be moved rapidly and somewhat independently of each other because they were connected by only less dense medullary bone, which would act as the nutritive pedicle and maintain the vitality of the periodontium. The blocks of bone were outlined using vertical interradicular corticotomy cuts both facially and lingually and these were joined 10 mm supra-apically with an osteotomy cut through the entire thickness of the alveolus. (Note: The modern refined selective alveolar decortication [SAD] and PAOO protocols explicitly contraindicate this surgical element.) From Köle's work arose the term "bony block" to describe the suspected mode of movement following corticotomy surgery, a more morbid procedure than modern, refined modes of therapy discussed here.

Köle reported that the major active tooth movements were accomplished in 6 to 12 weeks. It is important to note that most of the movements described by Köle were relatively gross movements accomplished with borderline orthopedic forces delivered through removable appliances fitted with adjustable screws. He addressed most movements including space closing. In accomplishing space closing he utilized a wedge-shaped ostectomy at the extraction site thus, apparently, leaving only the interseptal layer of bone over the proximal surfaces of the adjacent teeth. In his diagrams, it does appear that he extended the ostectomy beyond the apex of the canine, but left the interseptal bone intact over the apical one-third of the second bicuspid. Curiously, this would have resulted in a thinner layer of bone being left on the distal aspect of the canine that was to be distalized than on the mesial aspect of the second bicuspid.

Köle reported that after treatment there was no periodontal pocket formation. He also reported that at 6 months after treatment vitality testing of the teeth was always positive and radiographically there was no evidence of root resorption. Over time the supra-apical connecting osteotomy cuts used by Köle were replaced with corticotomy cuts. Where extraction/space closing was involved it would appear that the vertical ostectomy was typically retained. Gantes and coworkers in 1990 reported on corticotomy-facilitated orthodontics in five adult patients in whom space closing was attempted with merely orthodontic forces.[8] The mean treatment time for these patients was 14.8 months, with the distalization of the canines being mostly completed in 7 months. The mean treatment time for the traditional orthodontic control group was 28.3 months. The surgery included circumscribing corticotomy cuts both facially and lingually around the six upper anterior teeth. The upper first bicuspids were removed and the bone over the extraction sockets was removed both buccally and lingually. It would appear that Gantes and coworkers did not thin the interseptal bone on the distal of the canine to be distalized and the 7 months of canine retraction suggest a failure to exploit full use of an induced therapeutic decalcification. This would account for the contrast between the root resorption he reported and the notable absence of resorption subsequently reported by other, more modern researchers.

The interpretation of the rapid tooth movement being attributable to "bony block" movement prevailed in the reported literature until 2001 when Wilcko and coworkers[3] reported that in a surface computed tomographic (CT) scan evaluation of selectively decorticated patients it was discovered that the rapid tooth movement was not the result of bony block movement, but rather to a transient localized demineralization-remineralization phenomenon in the bony alveolar housing consistent with the wound healing pattern of the regional acceleratory phenomenon (RAP), developed by Frost and Jee and described in the periodontal literature by Yaffe and coworkers[9] The demineralization of the alveolar housing over the root surfaces apparently leaves the collagenous soft tissue matrix of the bone, which can be carried with the root surface and then remineralizes following the completion of the orthodontic treatment. Ferguson and coworkers have further defined this to be an osteopenic process.[5,6] Wilcko and coworkers have also demonstrated that it is not the design of the selective alveolar decortication that is responsible for the rapid tooth movement[4] but rather the degree of tissue metabolic perturbation per se.

Case Reports

Materials and Methods

The surgeries were performed under IV sedation and local anesthesia. Patients 1 and 2 were pure SAD-facilitated orthodontic cases, and patients 3 and 4 were PAOO cases. There was no mobilization of any bony segments. The orthodontic adjustments were made at 2-week intervals and removable retainers were utilized after debonding. The CT scans were performed with hospital-based high-resolution scanners. A wax bite was used to slightly separate the maxilla and mandible.

Patient 1 (Decortication-Facilitated Orthodontics in an Adolescent)

A male, age 14, presented with minor to moderate anterior crowding and a Class I molar relationship. The total treatment time from bracketing to debracketing was 3 months 2 weeks. Following the reflection of full thickness flaps, circumscribing corticotomy cuts were performed both labially and lingually around the six upper and six lower anterior teeth (Fig 1). The posterior teeth were utilized for anchorage.

Pretreatment, posttreatment, and 2-year retention surface CT scans of the lower arch are seen in Fig 2. At 2.5 months after debracketing it

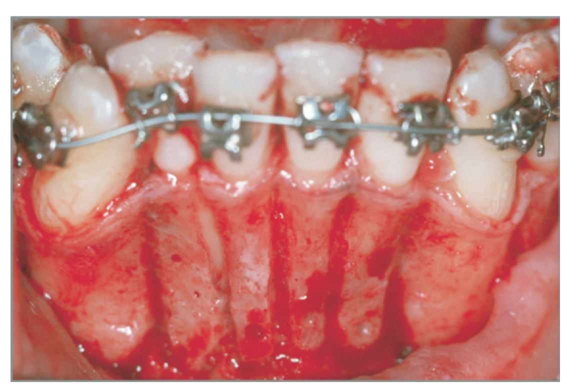

Figure 1. Patient 1: Male, age 14, circumscribing decortication, mandibular cuspid to cuspid teeth (teeth numbers 22-27). Dibart 2007, reprinted with permission. (Color version of figure is available online.)

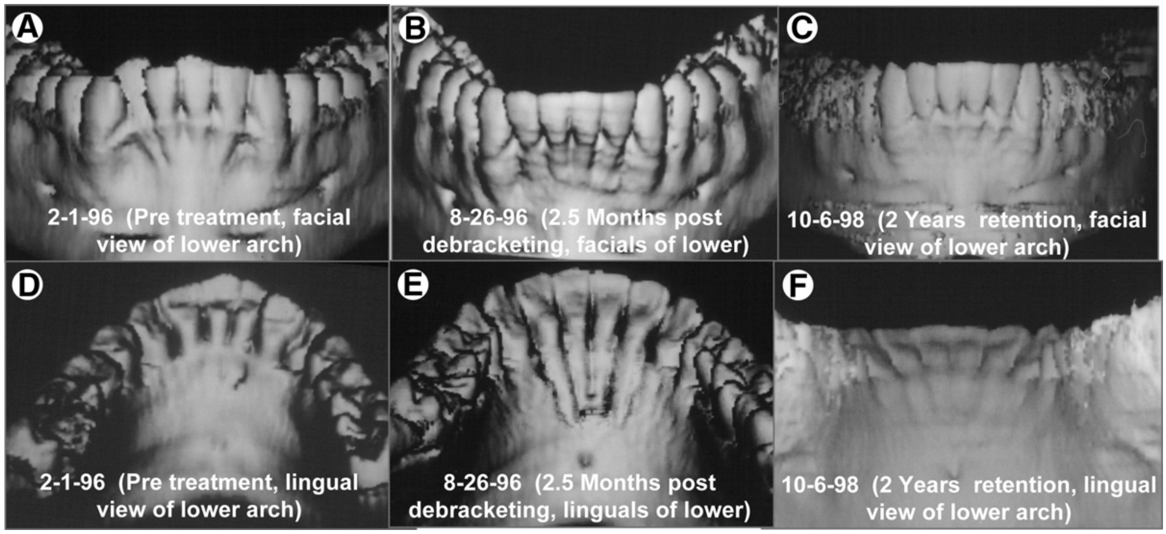

Figure 2. (A,B,C) Patient 1 (adolescent): Labial imaging, pretreatment, posttreatment, and retention surface computed tomographic scans of lower arch, anterior, and lingual views. The appearance is that of a demineralization-remineralization phenomenon. Note transient decalcification but fully reversible alveolus (Dibart 2007, reprinted with permission). (D,E,F) Patient 1 (adolescent): Lingual imaging: Note that reversible alveolar resorption at "tension side" (lower lingual aspect) of lower incisor proclination and regeneration 2 years later demonstrate lingual cortical bone regeneration.

is very apparent that the integrity of the outlined bony blocks was lost. There is the appearance of almost a complete lack of mineralized bone over both the labial and the lingual root surfaces of the treated teeth, but the osseous organic matrix is intact. At 2 years retention, however, the alveolar housing over both the labial and the lingual root surfaces has completely reappeared.

These findings are more indicative of a demineralization-remineralization phenomenon consistent with RAP and certainly not bony block movement. The most profound demineralization is seen in close proximity to the corticotomy cuts. No apparent demineralization can be seen approximately one tooth distant from the nearest corticotomy cut indicating the specific therapeutic range of the regional effect.

Patient 2 (Decortication-Facilitated Orthodontics in an Adult)

A female, age 39, presented with moderate anterior crowding and a Class I molar relationship. The total treatment time from bracketing to debracketing was 4 months 2 weeks. Following full thickness flap reflection circumscribing SAD cuts were performed both labially (Fig 3) and lingually around the six lower anterior teeth, but only on the labials of the six upper anterior teeth. The posterior teeth were used for anchorage.

A comparison of pretreatment, posttreatment, 2.5 years' retention, and 11.5 years' retention surface CT scans can be seen in Fig 4. There is no indication of bony block movement in this series of CT scans. In the postdebracketing scan there appears to be an absence of mineralized

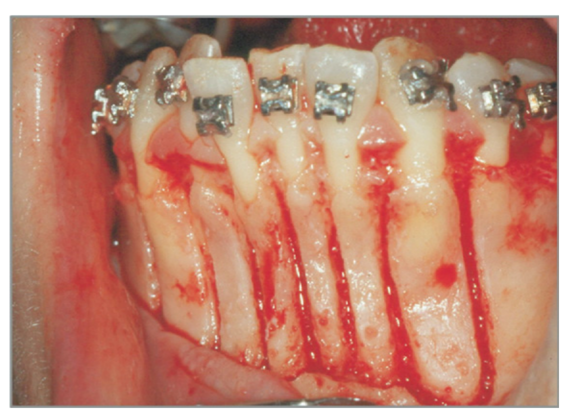

Figure 3. Patient 2: Female, age 39, circumscribing decortication, mandibular cuspid to cupid teeth (teeth numbers 22-27). (Color version of figure is available online.)

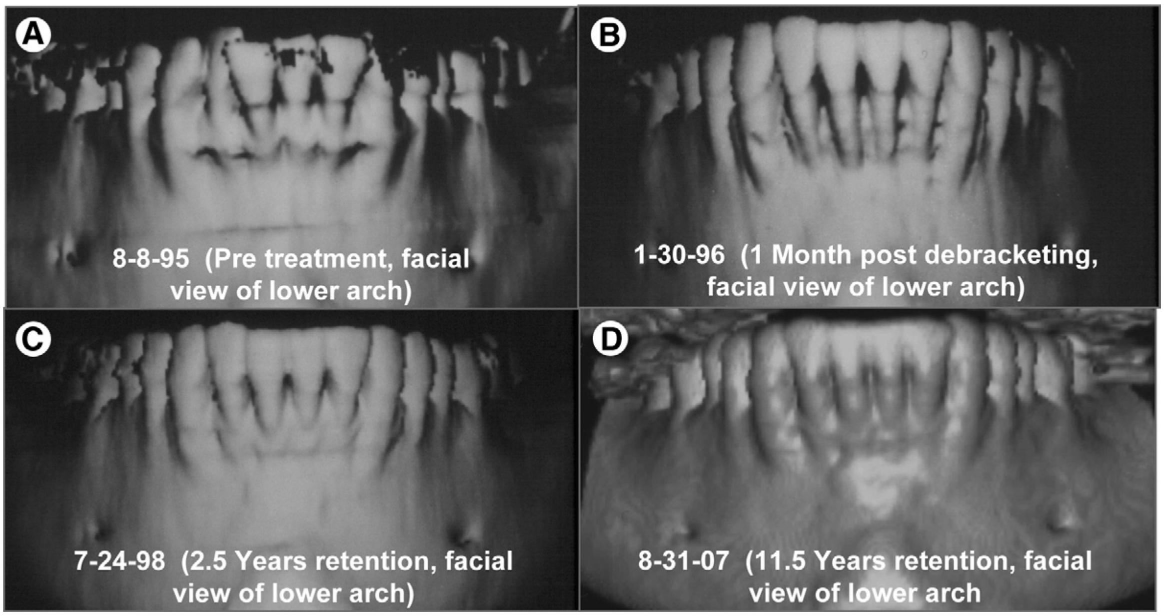

Figure 4. Pretreatment and posttreatment surface computed tomographic (CT) scans of lower arch in an adult; anterior view demonstrates the demineralization-remineralization phenomenon. (A) Patient 2 pretreatment CT scan demonstrates thin "washboard" alveolar labial cortex. (B) Panel illustrates the effects of decortication-facilitated orthodontic therapy with fixed appliances 1 month after debonding. Note the apparent lack of mineralized bone over the root prominences of the lower anterior teeth. (C) At 2.5 years retention there appears to be partial remineralization of the alveolar housing over the root prominences of the lower anterior teeth in comparison to the pretreatment (CT) scan. (D) At 11.5 years retention the height of the crestal bone still appears to be somewhat reduced in comparison to the pretreatment (CT) scan.

bone over the labial surfaces of the roots of the lower anterior teeth in close approximation to where the circumscribing corticotomy cuts had been made. In the 2.5 years' retention surface CT scans there appears to be a return of the layer of mineralized bone over the roots of the lower anterior teeth but at a slightly reduced height in comparison to the pretreatment CT scan. At 11.5 years' retention the height of the crestal bone is still somewhat reduced in comparison to the pretreatment CT scan. This also appears to be a demineralization-remineralization phenomenon, but not quite complete as seen in adolescent patient 1.

Patient 3 (PAOO Treatment for Dentoalveolar Augmentation)

A male, age 23, presented with Class I molar and canine relationships, severe upper and lower crowding, severe upper arch constriction in the anterior and bicuspid areas, and bilateral crossbites in the anterior and posterior areas. It was estimated that the length of treatment utilizing traditional orthodontics would be 2 to 2.5 years. The patient opted for the PAOO treatment and his case was completed in 6 months 2 weeks from bracketing to debracketing. The pretreatment and 2.5 years' retention photographs of the palate can be seen in Fig 5A and B, respectively.

The PAOO surgery was performed during the week following the bracketing and archwire activation. Since all of the teeth would be undergoing movement, selective alveolar decortication was performed both facially and lingually around all of the remaining upper and lower teeth utilizing circumscribing corticotomy cuts and intramarrow perforations. Note the sparseness of the bone on the labial (Fig 6A) and lingual aspects (Fig 6B) of the lower anterior teeth. The activated bone and exposed root surfaces were then covered with the bone grafting material (Fig 6C). The archwires were advanced rapidly with the adjustments being made at 2-week intervals. Since most of the constriction in the upper arch was mesial to the molars, it was possible to

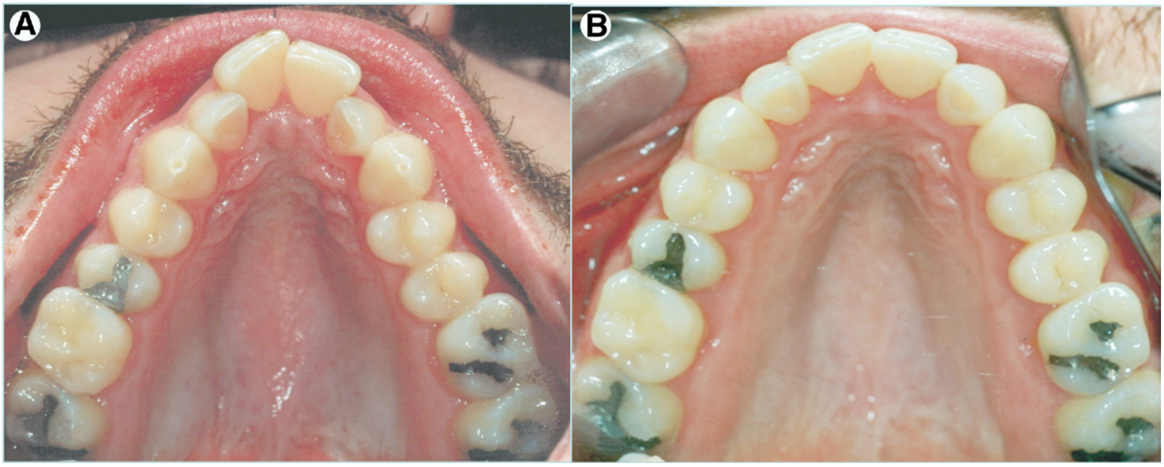

Figure 5. (A) Patient 3: Male, age 23, before PAOO treatment (decortication and tooth movement into bone grafts) palatal view. Note thinness of palatal alveolus at bicuspid area. (B) Patient 3: Thirty months (2.5 years) after debonding. (Color version of figure is available online.)

expand and round out the upper arch with the use of only archwires in approximately 12 weeks. Interestingly, there was no significant opening of the mid-palatal suture during treatment. This would suggest the alveolus per se may be considered an operative orthopedic entity from a "whole bone perspective" irrespective of the periodontal ligament (PDL) or circum-maxillary sutures.

The pretreatment CT scans in Figs 7 and 8 clearly show the sparcity of bone on the labial and lingual aspects of the roots that was confirmed following the reflection of the full thickness flaps. This was especially evident in the lower anterior area (Fig 6A, B) where there was a tall thin symphysis and where significant bony dehiscences were found. Not only were bony dehiscences found on the labial aspects of the roots, but also on the lingual aspect of the lower central incisors where they extended almost to the apices of these two teeth. It was noted in the 2.5 years' retention surface CT scans in Figs 7 and 8 that the labial and lingual root prominences were no longer evident and there now appears to be ample bone over the roots of the teeth both labially and lingually. This was confirmed when this case was reentered using full thickness flaps and bone biopsies removed over root surfaces where there had previously been no bone.[3] As a result of the alveolar augmentation the roots of the lower anterior teeth were

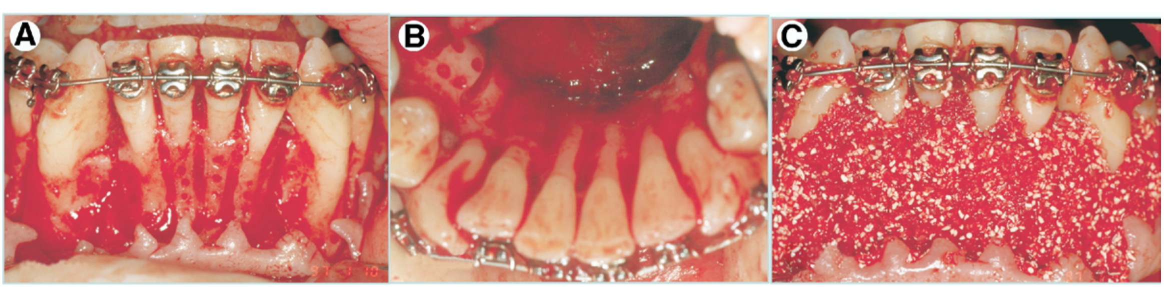

Figure 6. Demonstration of the PAOO (decortication plus bone graft) procedure in an adult orthodontic patient with thin alveolar cortices at the lower incisors. (A) Patient 3: Bone is activated with selective alveolar decortication (SAD) from left to right lower second molar to second molar (teeth numbers 18–31), facial view of lower arch. (B) Bone activation (SAD), lingual view of lower arch. Note that there are alveolar dehiscences on the lingual root prominences of the lower central incisors that extend almost to the apices of these two teeth. (C) Bone grafting material (demineralized bone matrix, or DBM; also know as demineralized freeze-dried bone allograft, or DFDBA) with a popular (mineral content only) xenograft extender placed over the SAD-activated bone. (Color version of figure is available online.)

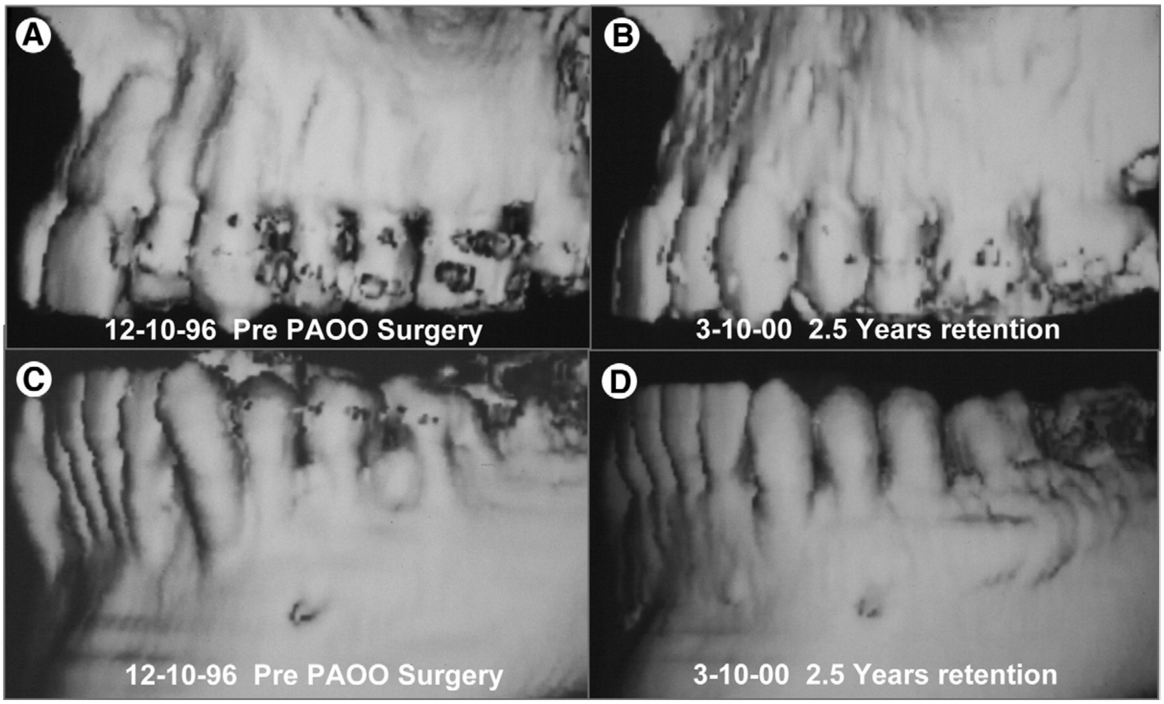

Figure 7. Patient 3. Maxillary arch computed tomographic (CT) scans. (A) Maxillary alveolus surface CT scans before PAOO treatment, left oblique view. (B) Maxillary alveolus surface CT scans after 2.5 years of retention. Note increased volume of stable bone over the roots. (C) Mandibular alveolus surface CT scans before PAOO treatment, left oblique view. (D) Mandibular alveolus surface CT scans after 2.5 years of retention. Note increased volume of stable bone over the roots. PAOO, periodontally accelerated osteogenic orthodontics.

then confined labially and lingually between two uninterrupted layers of bone. It is suggested that the alveolar augmentation eliminated the dentoalveolar deficiency that was created when the teeth were tipped labially.

Patient 4 (PAOO Treatment with a Bicuspid Extraction Protocol)

A male, age 14, presented with a Class II molar malocclusion with the upper canines displaced and

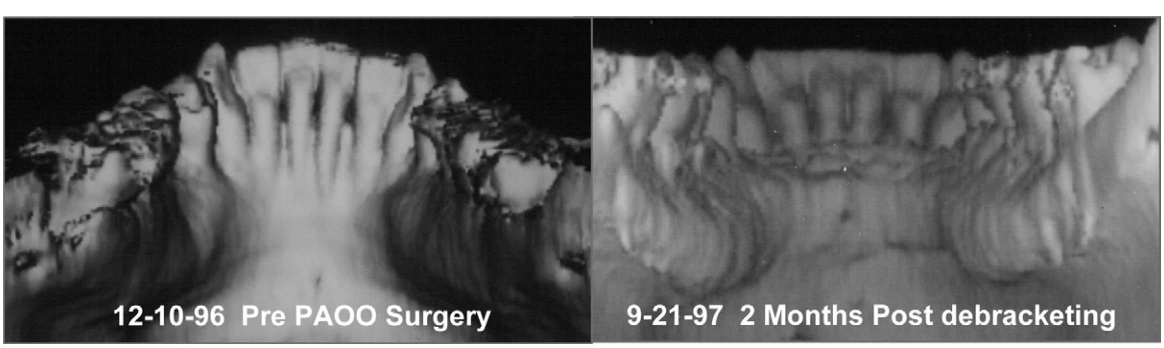

Figure 8. Patient 3. Before and after PAOO treatment surface computed tomographic scans of mandibular lingual alveolus demonstrate that notable increases in alveolus volume are evident as soon as 2 months after fixed appliances are removed and after about 7 months of accelerated orthodontic tooth movement. PAOO, periodontally accelerated osteogenic orthodontics.

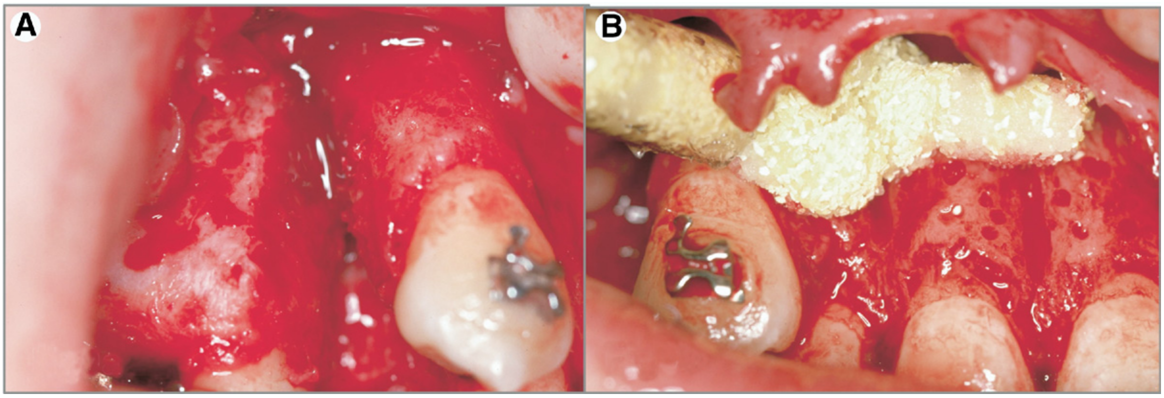

Figure 9. (A) Patient 4: Male, age 13, selective alveolar decortication, upper right second molar (tooth 2 to upper left to second molar (tooth 15). (B) Grafting material being placed over the activated bone and in the ostectomy site. Dibart 2007, reprinted with permission. (Color version of figure is available online.)

crowded out of the arch superiorly. In the lower arch SAD was performed both labially and lingually around the six lower anterior teeth, the lower posterior teeth being used for anchorage. In the upper arch the alveolar bone was activated in a similar fashion around the six upper anterior teeth. The upper first bicuspids were then removed and ostectomies performed at the extraction sites. The ostectomies extended almost to the apices of the canines and the bone was dramatically thinned on the distal circumferences, midfacial to midlingual, of the roots of the canines (Fig 9A). The activated bone was then covered with the bone-grafting material (Fig 9B).

At 1 month after surgery, the adjustable screw retraction device was inserted (Fig 10A). The patient adjusted this device at home and in 3 weeks the space closing had mostly been completed (Fig 10B). The case was then brought to completion with archwire therapy and traditional orthodontic forces. The total PAOO treatment time from bracketing to debracketing was 6 months.

Pretreatment and 10.5 years' retention surface CT scans of the upper arch are shown in Fig 11. The increase in the alveolar volume is readily apparent. The extraction sites of the upper first bicuspids were consolidated with the alveolar augmentation. This case has remained stable and there has been no reopening of the closed spaces. Furthermore, it demonstrates how well conventional orthodontic and dentofacial orthopedic forces can be employed without significant alteration of one's favorite OTM clinical protocol. Only the response is reengineered.

Discussion

The stable clinical outcomes demonstrated in this article owe more to the orchestration of conven-

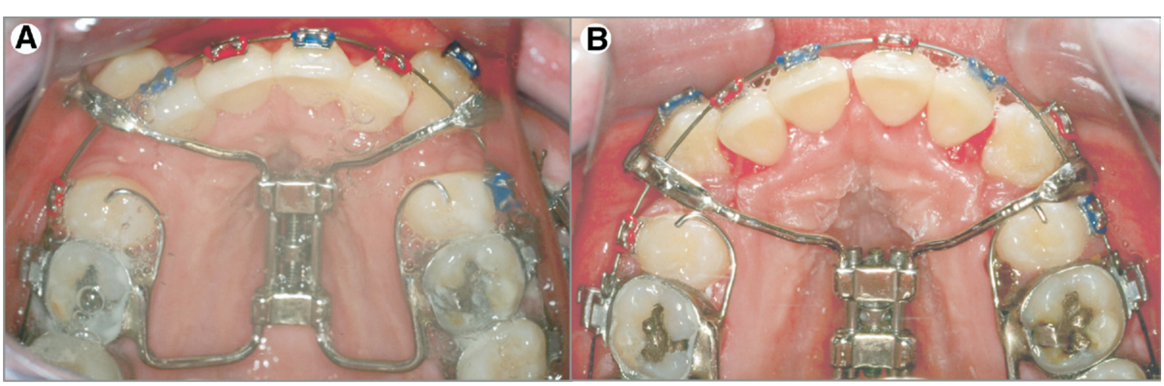

Figure 10. (A) Retraction device inserted. (B) Three weeks after retraction device activation. Dibart 2007, reprinted with permission. (Color version of figure is available online.)

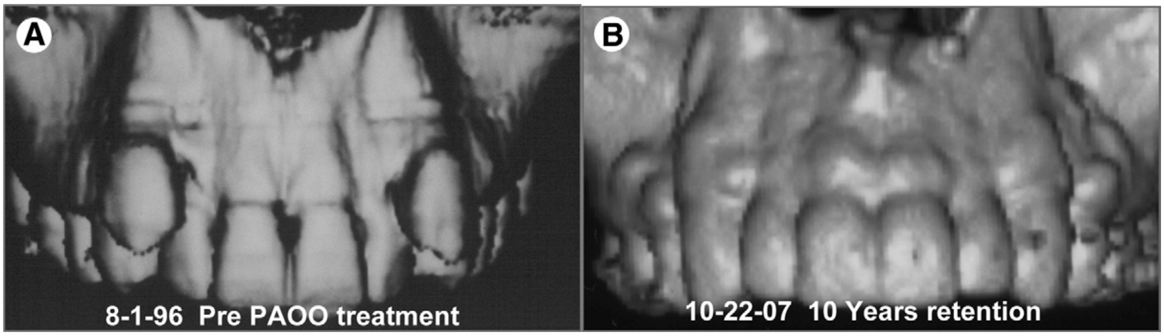

Figure 11. Pretreatment and 10-year retention surface CT scans; labial view of upper arch demonstrate that even in bicuspid extraction treatment the stability and amount of augmented alveolar bone is stable. (A) Panel shows severe maxillary "arch length deficiency" and ostensible need for bicuspid extraction in a traditional biomechanical protocol. (B) Panel shows that PAOO treatment is compatible with traditional bicuspid extraction treatment protocols and results in stable alveolar form a decade later. PAOO, periodontally accelerated osteogenic orthodontics.

tional, well-accepted traditional techniques than to revolutionary materials that have defined orthodontic progress in the past. It is the humility of the clinician-scientist and his or her willingness to embrace concepts from sister sciences that will continue to lead us to more evolutionary treatment refinements for our patients. For example, in adolescent patient 1, where the corticotomy-facilitated orthodontics was utilized to accomplish "decrowding," the pretreatment, posttreatment, and 2 years' retention surface CT scans are highly suggestive of a natural but accelerated metabolism, a demineralization-remineralization phenomenon at work (Fig 2). The remineralization in this adolescent appears to be rather complete. It is suggested, based on modern scientific biological concepts and anatomical imaging innovations, that after the relatively thin alveolar housing over the labial and lingual root surfaces undergoes demineralization, the collagenous soft tissue matrix of the bone remains and can consequently be readily transported with the root surfaces, "bone matrix transportation."

When retained in the desired positioning the collagenous soft tissue matrix will remineralize with time. This same type of process appears to be at work in adult patient 2, albeit slightly less complete, yet remains within a safe, clinically normal range. It is suggested that this is merely indicative of the difference in the vitality and thus recuperative potential of the adult versus adolescent tissues. Interestingly, Fuhrmann has shown that after traditional orthodontic therapy in adults there is also bony dehiscence formation over the roots that only partially resolves during retention.[10] Even at 3 years' retention he noted significant bony dehiscence that had not repaired itself, most notably on the facial aspect of the lower anterior teeth. Thus, any assessment of presumptive deleterious bone effects of OTM must prudently await a 2- to 3-year period. In light of the authors' clinical studies it would seem that previous criticism of orthodontic effects on the alveolus might have been impetuous or premature considering the state of imaging science at the time.

To adapt this scenario to extraction space closing would merely require that only a thin layer of bone be left over the root surface in the direction of the intended tooth movement. In this manner, bone matrix transportation can be also utilized to rapidly close spaces. After a 2-week postoperative waiting period to permit demineralization, spaces can be closed in 3 to 4 weeks with orthopedic forces or in 6 to 8 weeks with efficient orthodontic forces. This would seemingly add validity to Köle's claims of being able to complete most major movements in 6 to 12 weeks.[7]

SAD-facilitated orthodontics is a physiologically driven process, and an uninterrupted vascular supply to the operated areas is critical in maintaining the vitality of the hard and soft tissues. "Mobilization" of any outlined single-tooth blocks of bone (luxation) is absolutely contraindicated and can lead to intrapulpal and intraosseous morbidity and will not increase the distance that the tooth can be moved. "Green-stick fracturing" and luxation of small dentoalveolar segments will serve no useful purpose since these segments will lose their structural integrity as a result of the demineralization associated with the osteopenia. Additionally, the luxation can jeopardize the integrity of the neurovascular bundle exiting the apex of the teeth and result in devitalization.

Sebaoun and coworkers have analyzed the alveolar and periodontal response to selective alveolar decortication as a function of time and proximity to the injury in a rat model.[6,11] Since traditional orthodontic tooth movement per se will in itself stimulate a mild RAP response, tooth movement was thus intentionally not included in the experimental design. The dynamics of the periodontium change in response to the decortication injury could thus be clarified.

Sebaoun and coworkers reported that selective alveolar decortication injury resulted in an overwhelming activating stimulus for both the catabolic process (resorption response) and the anabolic process (formation response) in the periodontium. This bone modeling behavior peaked at 3 weeks after decortication surgery at which time the catabolic response (osteoclastic count) and anabolic response (apposition width and rate) were 3-fold higher. Additionally, adjacent to the injury the calcified spongiosa content of the alveolar bone decreased 2-fold and the PDL surface increased by 2-fold. Thus, there was a dramatic increase in the tissue turnover by the third week after decortication surgery, which dissipated to normal steady state by 11 weeks after surgery. The increased bone turnover was localized to the area immediately adjacent to the injury. These results are the first histologic and systemic evidence to support the concept hypothesized by Wilcko and coworkers[3,4] that SAD facilitates orthodontic tooth movement as a result of a demineralization-remineralization phenomenon rather than by bony block movement. Selective alveolar decortication results in a transient osteopenia and increased tissue turnover, the degree of which is directly commensurate with the intensity and proximity of the surgical physiologic insult. This is a condition that favors tooth movement with reduced root resorption. The PDL activity is enhanced by the decortication surgery, but it is the spongiosa that most likely plays the dominant role in rapid tooth movement. This may also have a positive impact on posttreatment settling and stability. Even though the osteopenia is a transient condition, it is surmised that tooth movement perpetuates the decalcified condition in the healthy alveolus.

There are numerous advantages in combining the modified corticotomy-facilitated orthodontics with alveolar augmentation. The most obvious is that we no longer need to be solely at the mercy of the preexisting alveolar volume and shape. The alveolus can now be reshaped and enlarged to accommodate the straightened teeth in their new positioning. The pretreatment and 2.5 years' retention surface CT scans of patient 3 demonstrate this (Figs 7, 8). With adequate reflection of the flaps this increase in bony volume can, to at least some extent, also impact on the shape and volume of the coronal aspect of the basal bone. In this respect, we are not only impacting on the dentoalveolar aspect, but also on the alveolar skeletal aspect. Since there is a 2- to 3-fold increase in the distance that the teeth can be moved, this obviously translates to a dramatic reduction in the need for extractions and perhaps even some orthognathic surgery.

From a basic science perspective, what is most impressive is the manifest ability of OTM with PAOO to increase alveolar volume for ample alveolar support for the roots of the teeth even in the resolution of severely crowded situations as seen in patient 3. Whereas 5 mm of crowding is typically considered the limit of overlapping that can be satisfactorily addressed with traditional orthodontics this can easily be extended to 10 to 12 mm of crowding if the PAOO technique is utilized. This increase in the limits of orthodontic tooth movement can also be seen in other movements such as extrusion and intrusion.[5,6] This ability to move teeth a much greater distance and yet provide for an expanded alveolar base and increased alveolar volume to support the straightened teeth makes it possible to treat certain selected cases that could have previously only been adequately addressed with orthognathic surgery. The alveolar augmentation can correct the dentoalveolar defecting that presumptively results when the teeth are tipped labially and can also provide for a degree of subtle facial "morphing."

Overcompression of the periodontal ligament can lead to hyalinization necrosis, the removal of which can be associated with root resorption. In an evaluation of the PAOO data base, Machado et al reported a 1.1 millimeter reduction in apical root resorption of the maxillary central incisors in comparison to traditional orthodontics.[12]

As concerns stability, Ferguson states, "PAOO has contributed greater stability of orthodontic clinical outcomes and less relapse." Summarizing he states, "immediate post orthodontic treatment results following nonextraction therapy are statistically the same with or without PAOO. However, during retention, the clinical outcomes of PAOO patients improved and did not demonstrate relapse."[6]

Murphy, synthesizing emerging concepts in cell and molecular biology, has used the term "in vivo tissue engineering" to further define the ability to morph bone with orthodontic tooth movement done in conjunction with periodontal bone activation and alveolar augmentation.[13] He goes on to state that even though the alveolar bone does exist at the grace of the radicular surfaces of the teeth, as explained by functional and spatial matrix hypotheses of Moss and Singh, respectively,[14,15] it is evident that new regional phenotypes can be epigenetically reengineered by moving teeth through a healing bone graft, and thus, redefine or reestablish original morphotype. He also suggests that the ability to readily reshape the alveolar housing and simultaneously increase the alveolar volume may impact on the subjacent bone and provide for some degree of facial recontouring.

Very frequently there are preexisting alveolar inadequacies such as fenestrations and dehiscences over the root surfaces. As long as the root surfaces in these defects are vital and as long as there has been no apical epithelial migration, these alveolar deficiencies can be corrected with the alveolar augmentation.[3-6] Only resorbable grafting materials are utilized. Medications that reduce the turnover rate of the bone and increase calcium uptake can potentially be problematic. The bisphosphonates, and perhaps even some calcium nutritional supplements, would fall into this category. Additionally, we believe the osteopenia that facilitates the tooth movement is a sterile inflammatory process and certain medications especially the nonsteroidal anti-inflammatory drugs (NSAIDs) could counteract this. Defining the inflammatory pathways that could be contributing to the underlying bone physiology that impact this process is an area in need of considerable research.

Summary and Conclusions

Concerning the mode of movement, this is a technique that requires the demineralization of a relatively thin layer of bone on the surface of the root of the tooth in the direction of the intended movement. This transient, reversible demineralization (osteopenia) of the thin layer of bone permits the root of the tooth to carry the demineralized collagenous matrix of the bone with it. At the completion of the tooth movement the remaining demineralized collagenous bony matrix will remineralize. The surface CT scan analyses of patients 1 and 2 would suggest that this remineralization process is more complete in adolescents than in adults. It is suggested that this is most likely attributable to the increased vitality and thus recuperative potential of the bone in the younger patients. The increase in the rate of bone turnover of the osteopenic process likely assists in the settling process after debracketing and in doing so contributes to improved stability during retention.

The fact that the teeth can be moved more rapidly, thus resulting in shortened treatment times, is certainly advantageous to the patient's periodontal health because less time in fixed appliances reduces patient "burnout" and substantially reduces the time available for relatively benign commensal bacterial biofilms to assume qualitative changes and convert to a destructive cytotoxic ("periodontopathic") potential often seen when fixed appliances have remained on the teeth for more than 2 to 3 years. The significance of the increase of the rate of tooth movement, however, pales in comparison to the fact that the teeth can be moved two to three times further than would be possible with traditional orthodontics alone, and that the cases can be completed with an increased alveolar bone volume. This increased alveolar volume can provide for a more intact periodontium, a decreased need for extractions, a degree of facial reshaping, and an increase in the bony support for both the teeth and the overlying and soft tissues. Ferguson and coworkers have suggested that the increased stability provided by PAOO may be due to "loss of tissue memory from high tissue turnover of the periodontium, as well as increased thickness of the alveolar cortices from the augmentation grafting."[6] The ability to increase the posttreatment alveolar volume and cover vital root surfaces can result in the repair of preexisting alveolar dehiscences over root prominences and lessen the likelihood of new dehiscence formation, which can be a contributing factor to gingival recession.

From an esthetic perspective the PAOO technique not only addresses tooth alignment, but also facial features and, as such, is truly in vivo tissue engineering. With a combination of both in-office periodontal surgery and orthodontic treatment, we can now more routinely address the esthetics of the entire lower face. The PAOO technique requires the utilization of numerous modified diagnostic and treatment parameters, but once these are mastered the orthodontist has a powerful new treatment option to offer his or her patients. With the increasing number of adults considering orthodontic treatment, the propensity for adults and even some nongrowing adolescents for periodontal problems, the PAOO technique can be an especially attractive treatment option and be a "win-win" situation for both the orthodontist and the patient.

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