REVIEW ARTICLE

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Temporary orthodontic anchorage devices for improving occlusion

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Structured Abstract

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The objective of the study was to provide insight into clinical and laboratory aspects of mini-screw implant (MI) research conducted in the Department of Orthodontics at Baylor College of Dentistry. Excerpts were selected from clinical and laboratory MI research utilizing one type of implant and one consistent placement protocol to illustrate the clinical usage of MI as skeletal anchorage during Class II bimaxillary correction. In addition, a translational animal model was utilized to illustrate possible side-effects of MI placement. Our studies have shown that successful and consistent clinical results are possible with MI use. Although iatrogenic trauma may occur during the placement of MI, a translational research model has provided data used to develop a placement protocol in order to avoid this dilemma. Absolute skeletal anchorage is a reality with MI use and can be used for successful orthodontic outcomes in the correction of Class II bimaxillary protrusion malocclusions to ideal Class I occlusions. Moreover, meticulous care has been shown to be essential with treatment planning and during placement of MI. Significant and extensive damage can occur with poor placement while healing is possible following minor trauma.

Key words: anchorage; bimaxillary protrusion; iatrogenic trauma; mini-screw implants; orthodontics

Introduction

The purpose of this paper is to reflect on selected aspects of mini-screw implant (MI) research conducted in the Department of Orthodontics at Baylor College of Dentistry, Texas A&M University System Health Science Center, Dallas, Texas. The utilization of maximum anchorage with mini-screw implants (MIA) will be illustrated clinically with reference to Class II division 1 bimaxillary protrusion correction, and translational research with an experimental animal model will show the impact of placement complications. The clinical project was approved by the Institutional Review Board (IRB) and the animal project approved by the Institutional Animal Care and Use Committee (IACUC), Baylor College of Dentistry.

Orthodontic anchorage

Successful orthodontic treatment is dependent on control of Newton's third law of motion which dictates that there will be an equal and opposite reaction to every force applied during orthodontic tooth movement. Moreover, adequate anchorage control is imperative to eliminate unwanted tooth movement during treatment. Thus orthodontic anchorage applications are constant battles to overcome the active vs. re-active forces generated during tooth movement.

Dr. Charles H. Tweed (1, 2), one of the pioneers of the discipline of orthodontics, was exemplary in the use of the edgewise appliance. His philosophy for success included a sound diagnosis, a study of the problem, setting appropriate treatment goals and promoting preparation of proper anchorage. The concept of anchorage has been part of orthodontic treatment for more than a century (3) and includes such basic principles as utilization of large vs. small teeth or the enface root surfaces of teeth (4, 5), occipital anchorage from a headgear (6) and intermaxillary dental anchorage from Class II and III elastics (7).

Most orthodontic textbooks provide information with respect to anchorage classification (8–10). The classifications often refer to maximum anchorage which is mostly a combination of stationary intra- or inter-maxillary anchorage and extraoral headgear anchorage. Wright (11) noted that true anchorage was not available within the mouth. Strang (12) added that anchorage in the oral cavity must be described simply as 'resistance to movement' and that stationary anchorage was a myth; he continued by stating that extra-oral occipital anchorage provided the required anchorage. An investigation on the use of occipital anchorage in orthodontic treatment showed that the effectiveness of any orthodontic appliance depended on its anchorage control (13). Moreover, the control of the anterior vertical dimension depended on the proper selection of extraoral anchorage (14).

The planning and selection of an appropriate anchorage set up or device is thus very important, but in addition careful consideration must be given to the forces applied. This is especially important in anchorage conservation during space closure such as following extractions. One realizes that the biology of tooth movement has an impact on anchorage and even maximum anchorage utilizing dental units as anchorage results in the loss of space of at least one third of the extraction space. To avoid these dental side effects De Pauw and co-workers (15) recommended the use of ankylosed teeth or intraoral implants for anchorage. Thus, anchorage can be defined as 'a secure hold sufficient to resist a heavy pull' which implies a source of attachment that is absolutely stable and rigid. A systematic review of anchorage showed that three main anchorage situations exist: 1) anchorage of molars during space closure after premolar extractions, 2) anchorage in the incisor or premolar region (or both) during distal movement of molars, and 3) the use of implants, mini-screws, or similar techniques to produce skeletal anchorage. The authors of this systematic review suggested that further research was needed (16).

Mini-implant anchorage

Traditional anchorage resources, such as headgear or facemask, require patient cooperation, which if not forthcoming may result in unpredictable treatment outcomes. Therefore, an alternate form of dependable anchorage use is needed, hence, orthodontists have pursued intra-oral anchorage points that are immobile, biocompatible, easy to use and independent of patient compliance.

Gainsforth and Higley (17) were the first to report on the possibility of orthodontic anchorage in basal bone via an implant. Even though their results were largely unsuccessful, the notion of implant derived anchorage was established. The introduction of the concept of osseointegration by Brånemark in 1965 provided the means by which implant assisted anchorage could impart infinite anchorage (18, 19). The evolution and acceptance of osseointegrated implants as a restorative alternative was commonplace by the early 1980s. In several laboratory and clinical studies orthodontic applications of the endosseous implant have been evaluated and demonstrated to be effective for use under orthodontic type loads (20–29).

With the profession becoming more comfortable with the use of implant assisted anchorage, this approach is appearing more frequently in treatment planning. This interest has encouraged development of numerous implant derived anchorage adjuncts to orthodontic treatment such as the palatal implant, retromolar implant, onplant, zygoma ligature wires, skeletal anchorage system and the mini-implant (MI) or temporary anchorage device (TAD). Numerous reports have illustrated the biomechanical advantages of utilizing a TAD such as mini-implant anchorage (MIA) (30–38). However, before these adjuncts gain widespread use, the potentials and limitations of MI's should be established by well-controlled clinical and laboratory studies.

The advent of implant-assisted anchorage has provided two fundamental benefits. First, it has completely eliminated the need for patient compliance in anchorage preservation. Second and more importantly, infinite anchorage provided by the MI allows teeth to be moved maximally in the desired direction without any adverse effect on the anchor. The use of MIA will be illustrated by the clinical correction of a Class II division 1 bimaxillary protrusion, using a case that is part of a prospective clinical research study (Figs 1–8). The patient presented with a main compliant of crowded and protrusive teeth. The correction of this type of malocclusion is often associated with an extraction protocol as well as utilization of maximum anchorage.

Mini-implant anchorage case report

Undesirable tooth movement can occur when anchorage is not controlled. The most evident scenarios can be illustrated in a bimaxillary protrusive or Class II division 1 malocclusion requiring extraction therapy, as shown in this case report (Figs 1–8). In these situations it is often desirable to maintain the posterior teeth in their pre-treatment location with zero anchorage loss. The objective is to move the anterior teeth posteriorly into the extraction space in order to obtain the greatest amount of total profile or overjet reduction. Should anchorage loss occur during the latter process it is possible to end with an uncorrected malocclusion. Moreover, once anchorage has been lost, it is very difficult to regain.

In the current case, the patient at the start of treatment had a convex profile with incompetent lips, exacerbated by the Class II malocclusion and protrusive incisors. The cephalometric summary at the start of treatment shows measurements outside the normal range and included (see Fig. 2):

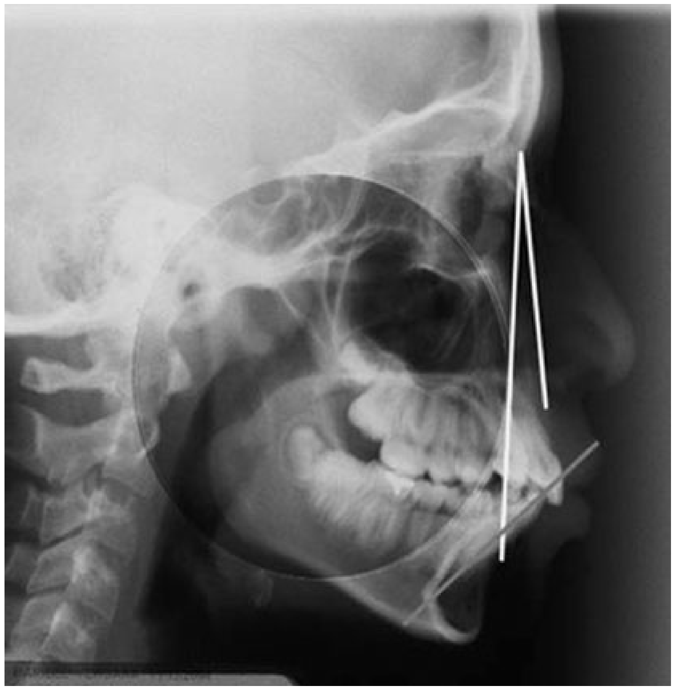

Fig. 2. Cephalogram with ANB and lower incisor reference lines at pre-treatment.

Fig. 1. Typical patient with Class II division 1 bimaxillary protrusion malocclusion requiring maximum anchorage. Facial images of a 12-year-old female subject at the start of treatment.

Fig. 3. Intraoral photos at start of active treatment. Note the Class II Division 1, crowding and anterior crossbite. Glass ionomer bite raisers were placed on maxillary first molars to allow for atraumatic correction of the anterior crossbite. Fixed 018′ SPEED self-ligation appliance was used in conjunction with mini-screw implants placed between the maxillary first molar and second bicuspids and tied with 0.010′ stainless steel ligature for maximum anchorage (Type A). Application of immediate loading/indirect anchorage (An *in vivo* laboratory study by Owens et al. (61) provided guidance as to force application and tooth movement as well as anchorage stability).

Fig. 4. One year progress of treatment. Note that the MI was utilized both for indirect and direct anchorage ('headgear action'). Class II elastics enhance the molar correction while Class I reciprocal anchorage helped to close mandibular extraction space.

1. Class II molar relationship.
2. Lower incisor proclination (IMPA; L1-APo).
3. Skeletal Class II relationship (ANB).
4. Protrusive maxilla (SNA; point A convexity; Point A-Nasion perpendicular).
5. Retrusive mandible (SNB; Pogonion-Nasion perpendicular).
6. Protrusive lip position (to E-plane).

Orthodontic treatment involved extraction of the four first bicuspids to provide space and required maximum posterior anchorage for the correction of the crowding and reduction of the protrusive dentition. Following extraction of the bicuspids, two MI's were placed between the maxillary second bicuspids and first molars using topical anesthesia (TAC 20 Topical: C-Lidocaine 20%; Tetracaine 4%; Phenylephrine 2%). The treatment used the MI's for maximum anchorage during incisor retraction (Figs 3–6) and resulted in minimal maxillary anchorage loss and substantial positive changes in tooth alignment, occlusal relationship and facial profile (Figs 6–8). Pre- and post-treatment comparisons of photographs confirm the positive changes in facial esthetics and incisor position (Figs 1 and 7). A cephalometric analysis at the completion of treatment (Fig. 8) shows an esthetic facial profile harmony (E-line), Class I molar relationship, skeletal Class II correction (ANB), and good control of vertical dimension (FMA).

Ideal characteristics for an implant anchorage system as reflected in the case report

The ideal requirements for an optimal implant-derived orthodontic anchorage system include the following: small dimensions, easy placement and removal, minimal surgical morbidity, capacity for immediate loading, simple and reliable attachment of auxiliaries, withstand clinically required loading, stability during utilization, broad area of application (not site-specific), and economical costs.

Design considerations

Various companies have entered the market to provide mini-implants. The obvious common feature is the size of the MI (smaller than 3 mm diameter and up to 11 mm length). However, there are also subtle differences in the thread design, profile, composition and head design, and these may affect the manner in which the MI is used. The MI used in the present clinical

Fig. 5. Post-treatment occlusal photographs showing acceptable arch from and tooth alignment.

project has a rounded head with a hexagonal base that requires a specialized driver for placement. Both the head and neck of the MI have a small aperture through which a ligature may be passed for attachment (Fig. 3). The rounded head also permits the attachment of various accessories such as intra-maxillary elastic traction (Fig. 4).

Locations for use

The primary limitation of traditional endosseous implants is site specificity due to their relatively large size. The reduced size of the MI allows great versatility with respect to potential sites for use (30). A radiographic evaluation of the availability of bone for placement of MI's has shown that adequate bone exists in the inter-radicular space mesial to the maxillary first molars and vertically halfway apically of the root length (39). Moreover, this was emphasized as "Safe Zones" following a volumetric tomographic study providing a guide for MI positioning in the maxillary and mandibular arches (40). A safe site buccally was indicated in the inter-radicular space between the first molar and second premolar, at 5–8 mm from the alveolar crest (Fig. 3).

The surgical procedure

Mini-screw implants may be placed by various techniques, including a two-stage (flap surgery and pilot hole followed by MI placement and healing), single stage (pilot hole prior to MI placement) and direct procedure (no pilot hole and direct placement of MI). All three methods may be accomplished under local anesthesia by regional infiltration and/or topical anesthesia. Nerve blocks are not only unnecessary but undesirable. A complication during placement could entail hitting a vital structure such as a root and without a nerve block, the patient may be able to sense the complication thus allowing an alternate placement and avoiding any permanent negative sequelae.

The Baylor experience indicates the use of a single stage procedure where the MI is placed directly through the overlying soft tissue following the creation of a pilot hole at slow speed with an appropriate diameter bit and copious irrigation. The MI is then inserted with the corresponding driver until it reaches

Fig. 6. Post-treatment Class I occlusion after 2 years of active treatment. The outcome shows a healthy, functional and esthetic occlusion.

Fig. 7. Facial images at end of treatment for comparison with pre-treatment as shown in Fig. 1. Note in these photographs the harmonious soft tissue balance, esthetic smile and normal or orthognathic chin position.

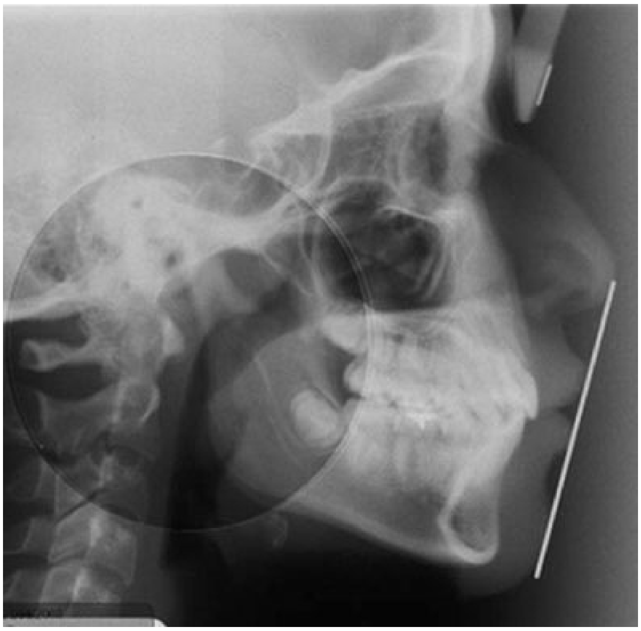

Fig. 8. Post-treatment cephalogram with reference E-line. Refer to Fig. 2 for comparison to evaluate the treatment changes such as the translation of the maxillary incisors, uprighting of the mandibular incisors and good vertical dimension control with subsequent forward mandibular response to harmonize the soft tissue profile.

its appropriate position. The MI is then immediately loaded (Fig. 9).

Important aspects of placement include (41–45):

- *Preference for a small pilot hole*: Both non-drill-free and drill-free MI's are available, thus providing a wide selection to provide for numerous applications. The drill-free MI has a sharp end which may easily damage the root surface, thus one must exercise caution during placement.
- *Over drilling the pilot hole leads to inadequate primary stability*: Handpiece stability is essential when preparing the pilot hole prior to MI placement. During placement of the MI, the operator must also ensure evaluation in three-dimensions for correct and atraumatic MI insertion.
- *Adequate bone must be available around MI to provide adequate bone to implant contact*: Cortical thickness is most critical, while medullary bone is less important.
- *Minimize surgical trauma:* Thread in the MI with precision and avoid any 'wiggling' of the MI driver. Also, avoid heat build-up and extended time while drilling the pilot hole ($>47°C$; >1 min).

Mini-implants and root damage: an animal model

The possibility of damaging a tooth root, PDL, or nerve has been suggested by several authors (46–48). Although the likelihood of such damage has never been clearly quantified for MI, trauma associated with fixation screws used for skeletal immobilization during orthognathic surgical procedures has been well documented (49). The incidence of root damage with fixation screws varies from 0.47% to as high as 43.3% (50, 51). Damage ranges from scratches on roots to pulpal penetration, with various outcomes including uneventful healing, required endodontic treatment, or extractions (49, 51–54). Moreover, the periodontal literature demonstrates the ability of root repair (55–57).

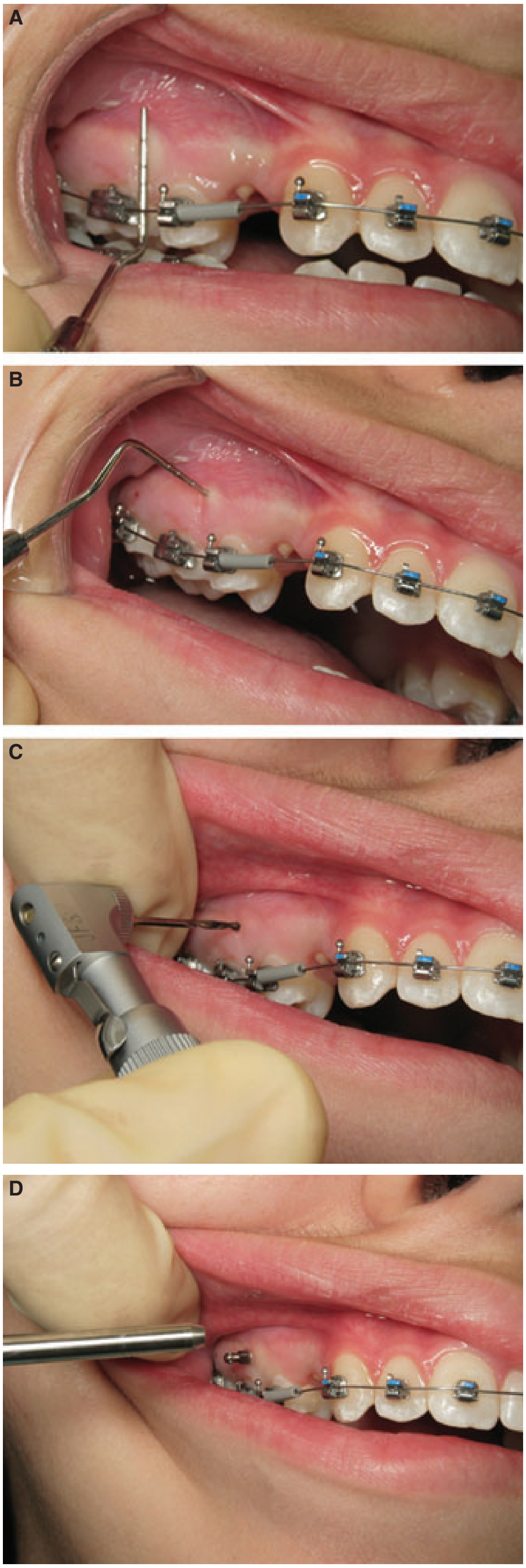

Fig. 9. Placement procedure for the one stage Baylor College of Dentistry procedure. Note: (A) the determination of the insertion site (height and mesio-distal position); (B) testing for anesthesia and gingival depth using a periodontal probe; (C) pilot hole preparation only penetrating the cortex; (D) insertion of the MI.

When the current authors reviewed the orthodontic literature it was noted that complete cementum repair in Beagle dogs was possible after unintentional damage of the roots by bone anchors (58), thus we used this model for further investigation. Two animal studies followed to obtain more detailed information with respect to root damage and healing following MI placement (59, 60). The methodology of the projects ensured intentional damage of the roots followed by observation over a 12-week period. Radiographic images documented root damage following MI placement and removal, while clinical and histological investigations provided additional data on the extent of damage and healing phases. The surface areas of the damaged lesions as well as reparative process were obtained by the *MetaMorph*® analysis of the damaged and healed areas at 6-and 12-week intervals. The Mann-Whitney non-parametric test was used for the statistical analysis of the healing process and measured significant differences ($p < 0.05$) in the percentage of cementum, PDL and bone between the 6- and 12-week groups.

The results showed that the torque measurements during placement of the MI were highly indicative of when the implant was entering root structure. Torque measured in control situations where no tooth contact was made was on average 23.8 Ncm (range: 16.6–31.0 Ncm), compared to 50.7 Ncm (range: 36.4–65.2 Ncm) when tooth contact was made. Thus tooth contact significantly increased torque measurements and the potential for MI breakage (Fig. 10), resulting in experimental torque values being set to not exceed 55 Ncm during the project.

Normal healing following root damage with MI includes the presence of a new cementum layer, PDL restoration to a functional width, and bone regeneration in the area of damage (Fig. 11). Radiological images confirmed the healing after 12 weeks (Fig. 12). The cementum healing was found to double during 6–12 weeks of healing (Fig. 13). As expected, gingival soft tissues healed uneventful. Histological evaluation showed that under favorable conditions root healing can occur following damage with mini-screw implants. Our data indicated that 64.3% of damaged roots demonstrated normal healing after 6–12 weeks. When considering all implant-tooth contacts, the normal healing phenomena significantly exceeded deleterious effects of abnormal healing.

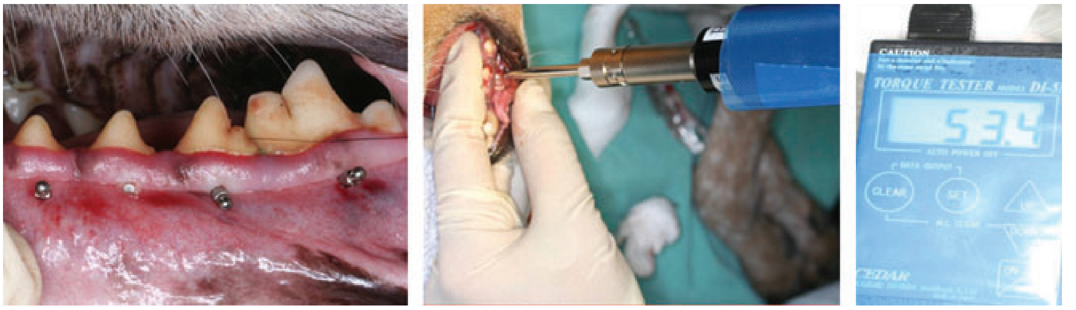

Fig. 10. Left to right: Mini-screw implant breakage compared to the intact implants. The torque tester shows a high torque value close to MI breakage.

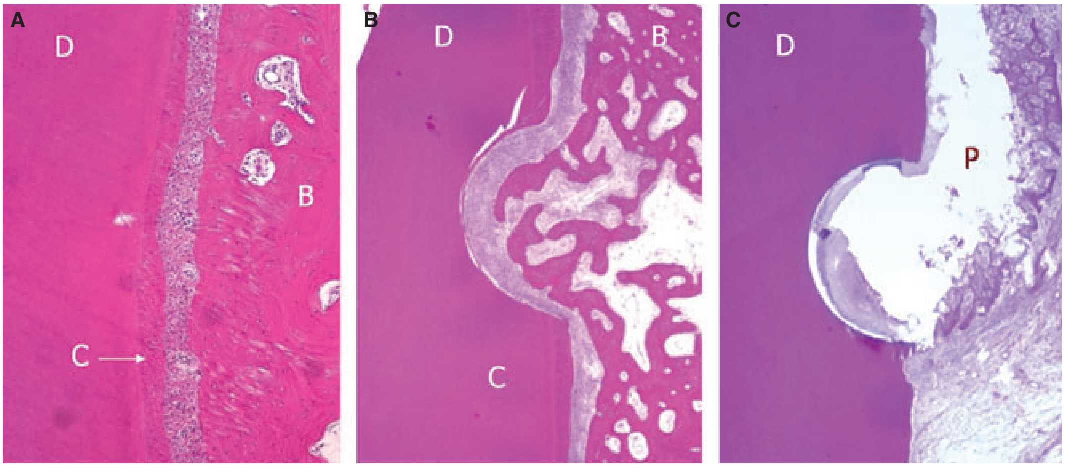

Fig. 11. Histological evidence of normal healing is visible in these demineralized sections following minor (periodontal ligament penetration) to severe damage (pulpal penetration). Note the repair of the PDL to (A) normal dimensions after 6 weeks of healing compared to (B) healing following dentine penetration, but (C) destruction when pulpal penetration occurs. Labels in Figure: D, dentin; C, cementum; B, alveolar bone; P, pulp.

When the pulpal canal was undermined, abnormal healing was found including bony degeneration in the furcation area (Fig. 14) and no PDL or bone regeneration (Fig. 15). Small and very limited areas of ankylosis were seen in a minor number of specimens where damage to the roots had occurred. The PDL otherwise appeared normal and the authors could only speculate whether this seemingly limited damage would have an effect on the longevity of the teeth.

Clinical observations from this animal study suggest a number of guidelines to facilitate successful application of the mini-screw implants. These include:

1. It is important to create inter-radicular space if adequate space is not present in the determined placement zone. This could be easily attained by root angulation or an open-coil spring between selected teeth. The MI should be inserted when there is adequate space, preventing damage to vital structures.
2. Caution needs to be exercised when selecting the position for inserting the MI. An appropriate protocol for assessment of safe zones for placement must be followed (39, 40).
3. It is imperative to first evaluate radiologically the anatomy of the regions where the MI's are to be placed as a precaution to avoid tissue injury, and then to evaluate the region again following the procedure to confirm placement and ensure successful insertion.

Overall our findings showed that mini-screw implants provide a viable option during treatment requiring maximum anchorage that otherwise would be dependent on headgear use and reliance on patient compliance in order to attain a successful outcome.

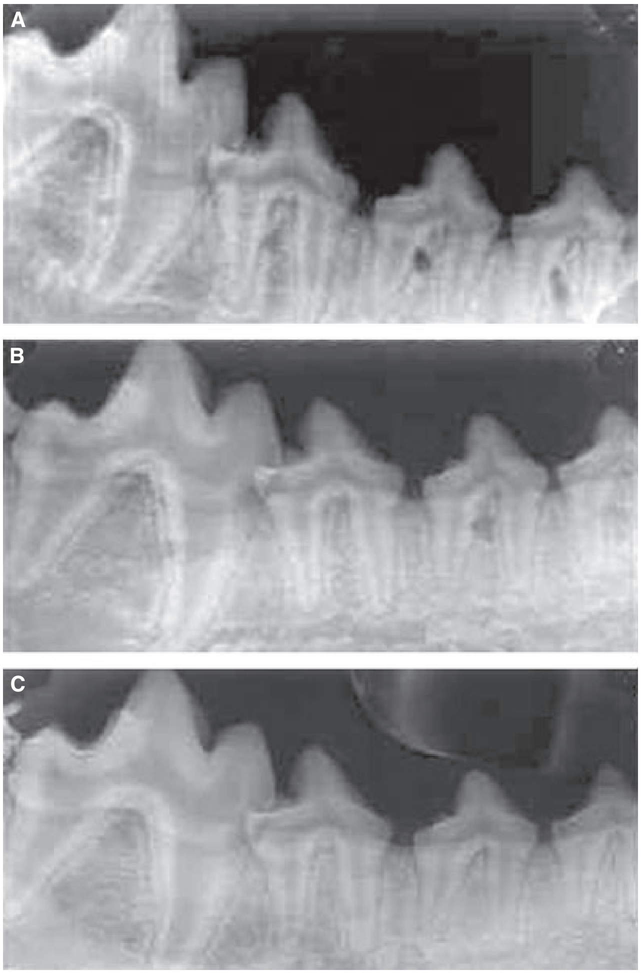

Fig. 12. Radiological images showing typical healing after: (A) immediate removal, (B) 6-week and (C) 12-week healing period.

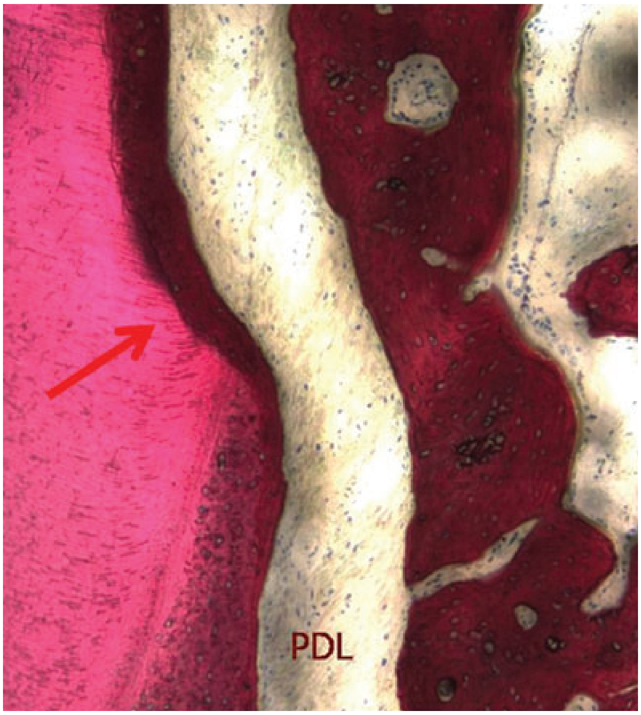

Fig. 13. Cementum repair (arrow) after 12 weeks of healing. The percentage approximately doubled during this period compared to 6 weeks.

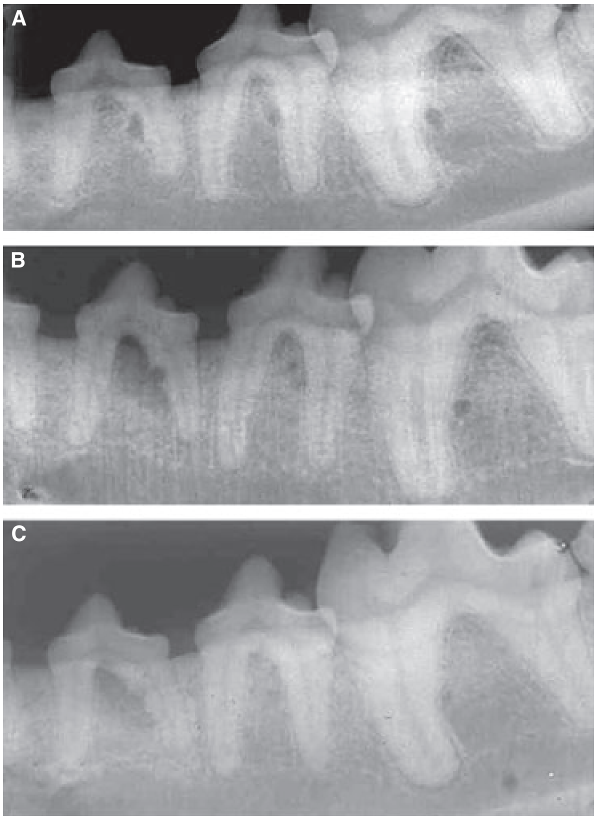

Fig. 14. Radiological images showing abnormal healing after: (A) immediate removal, followed by (B) a 6-week and (C) 12-week healing period. Note the radiolucency remains in the furcation of the premolar (left) as an indication of abnormal healing.

Conclusions

The Baylor College of Dentistry mini-screw implant research experience indicates that:

1. MI's meet our skeletal anchorage goals.
2. Successful and consistent clinical results are possible with MI use.
3. Caution is recommended with the application to avoid iatrogenic trauma.
4. Determine the appropriate use following adequate clinical evaluation.
5. Absolute anchorage with MI's results in successful orthodontic outcomes.
6. Meticulous care is essential with planning and during placement of MI's; thus be familiar with the anatomy in the area of placement.
7. Significant and extensive damage can occur with inappropriate MI placement; however, healing is possible following minor trauma.

Fig. 15. Pulpal penetration is followed by degeneration as illustrated in this undemineralized section.

8. An increase in resistance during placement of a MI is an indication of root contact; removal of the screw will most likely lead to healing of the root defect and the adjacent tissues.

Clinical relevance

The introduction of mini-screw implants (MI) as part of the orthodontic armamentarium aids in the constant struggle to overcome the active vs. re-active forces generated during tooth movement. The prevention of unwanted or re-active tooth movement by using mini-screw implant skeletal anchorage results in the successful correction of bimaxillary protrusion malocclusions. The non-compliance nature of this anchorage medium is a tremendous bonus to the clinician. Moreover, translational research provides evidence to show the impact of placement complications and lends data for clinical use in avoiding this potential iatrogenic trauma.

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