Effect of screw diameter on orthodontic skeletal anchorage

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Introduction: Many case reports have documented the successful use of titanium miniscrews for orthodontic anchorage. However, the literature lacks a well-controlled study examining the effect of miniscrew diameter on anchorage force resistance. The purpose of this in-vitro study was to compare the force resistance of larger-diameter monocortical miniscrews to smaller-diameter monocortical miniscrews; and to compare the force resistance of larger-diameter monocortical miniscrews to smaller-diameter bicortical miniscrews. Methods: Ninety-six titanium alloy screws were placed into 24 hemisected maxillary and 24 hemisected mandibular specimens between the first and second premolars. Specimens were randomly and evenly divided into 2 groups. In the first group, 24 large-diameter screws (2.5 × 17 mm) and with 24 small-diameter screws (1.5 × 15 mm) were placed monocortically. In the second group, 24 large-diameter screws (2.5 × 17 mm) were placed monocortically and 24 small-diameter screws (1.5 × 15 mm) were placed bicortically. All screws were subjected to tangential force loading perpendicular to the miniscrew with lateral displacement of 0.6 mm. Statistical analyses, including the paired-samples t test and the 2-samples t test, were used to quantify screw force-deflection characteristics. One-way analysis of variance (ANOVA) with the post-hoc Tukey studentized range test was used to determine any significant differences, and the order of those differences, in force anchorage values among the 3 screw types at maxillary and mandibular sites. Results: Mean mandibular and maxillary anchorage force values of the 2.5-mm monocortical screws were significantly greater than those of the 1.5-mm monocortical screws (P <0.01). No statistically significant differences in mean mandibular anchorage force values were found between the 2.5-mm monocortical screws and the 1.5-mm bicortical screws. However, mean maxillary anchorage force values of the 1.5-mm bicortical screws were significantly greater than those of the 2.5-mm monocortical screws (P <0.01). Data analyzed with 1-way ANOVA with the post-hoc Tukey studentized range tests indicated that the mean mandibular and maxillary force values of the 2.5-mm monocortical screws and the 1.5-mm bicortical screws were significantly greater than those of the 1.5-mm monocortical screws (P <0.01). Based on the 2-samples t test, mean anchorage force values at mandibular sites were significantly greater than at maxillary sites for the 2.5-mm monocortical screws and the 1.5-mm monocortical screws. There were no statistically significant differences in mean anchorage force values between maxillary and mandibular sites for the 1.5-mm bicortical screws. Conclusions: In vitro, larger-diameter (2.5 mm) monocortical screws provide greater anchorage force resistance than do smaller-diameter (1.5 mm) monocortical screws in both the mandible and the maxilla. Smaller-diameter (1.5 mm) bicortical screws provide anchorage force resistance at least equal to larger-diameter (2.5 mm) monocortical screws. An alternative to placing a larger-diameter miniscrew for additional anchorage is a narrower bicortical screw.

doi:10.1016/j.ajodo.2007.07.031

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Many case reports have documented the successful use of titanium miniscrews and variations of surgical screws used for rigid fixation to provide orthodontic anchorage without patient compliance. Compared with traditional endosseous implants, miniscrews offer distinct advantages as anchors: smaller size, flexibility in site placement, ease of placement, less patient trauma, and lower cost.
Additionally, because the primary stability of miniscrews is believed to result from mechanical interlock, a waiting period for osseointegration before orthodontic loading is unnecessary, as is a second surgical procedure (trephination) for removal. On the other hand, because miniscrews are not osseointegrated, their anchorage potential is most likely influenced by the quality and quantity of bone into which they are placed. Case reports have documented problems associated with miniscrew anchorage, including periscrew inflammation and screw mobility. In a prospective study of risk factors associated with miniscrew failures, Cheng et al reported that length had no significant effect on screw survival and that loads of 100 to 200 g could be sustained with no significant differences between successful and failed screws. Although other researchers identified no major differences in the survival of miniscrews placed in keratinized or nonkeratinized mucosa, Cheng et al advised placing them in keratinized mucosa and using caution when working in dense bone regions such as the posterior mandible to avoid bone overheating.

It was suggested that the type of force system used can lead to screw failure. Huja et al cautioned that torsional loading of screws might debond any mechanical or chemical integration between the screw and bone interface. Using maxillae and mandibular cadaver specimens, Brettin et al tested the hypothesis that bicortical miniscrew placement (across the entire width of the alveolus) could provide a force system with superior force resistance and stability (anchorage) compared with monocortical placement. Deflection force values were significantly greater for bicortical than for monocortical screws. The authors concluded that bicortical miniscrew placement provides superior anchorage resistance, reduced cortical bone stress, and superior stability than monocortical placement. In a retrospective study, Miyawaki et al correlated several variables with the success of 134 monocortical screws. Success rates of 0.0%, 83.9%, and 85% were found with screw diameters of 1.0, 1.5, and 2.3 mm, respectively. A high mandibular plane angle was also found to be associated with a significantly lower success rate, but no significant correlation was found between success rate and screw length, type of placement surgery, immediate loading, age, sex, crowding, anteroposterior jaw base relationship, controlled periodontitis, or temporomandibular joint disorder symptoms.

The wide range of reported miniscrew success rates and the absence of accepted clinical protocols suggest the need for further research of these temporary anchorage devices. The literature lacks a well-controlled study examining the effect of miniscrew diameter on anchor-age force resistance. The objective of this in-vitro study was to examine this effect. Specifically, the force resistance of a larger-diameter monocortical miniscrew was compared with that of a smaller-diameter monocortical miniscrew, and the force resistance of a larger-diameter monocortical miniscrew was compared with that of a smaller-diameter bicortical miniscrew.

MATERIAL AND METHODS

The maxillae and mandibles of human cadavers were obtained from the Department of Anatomy and Cell Biology Deeded Body Program at the University of Iowa. Fully dentate and partially dentate specimens were considered acceptable. Fully edentulous or partially dentate specimens with visible, severely atrophic alveolar ridges were excluded. Maxillary specimens were dissected superior to the maxillary sinus to avoid damage to the maxillary alveolar bone and tooth roots and extended distally to the maxillary tuberosity. Mandibular specimens were dissected approximately halfway up the ascending ramus. All maxillae and mandibles were then hemisected, soft tissue was carefully removed, and they were stored in 10% buffered formalin solution.

Periapical radiographs of each specimen were made to verify adequate bone and proper root divergence between adjacent teeth for placement of the miniscrews. The site for placement was between the first and second premolars in both jaws. Twenty-four maxillae from different cadavers and 24 mandibles from different cadavers were used. If either the first or second premolar was missing, the adjacent first or second premolar was used as a reference for screw location based on average tooth size. After radiographic examination, 12 right and 12 left hemi-maxillae from different cadavers, and 12 right and 12 left hemi-mandibles from different cadavers, were deemed acceptable.

In the first experiment (larger-diameter vs smaller-diameter monocortical anchorage), 48 commercially available titanium screws (KLS Martin, Jacksonville, Fla) were placed in 12 hemisected maxillae and 12 hemisected mandibles. Twenty-four large-diameter screws (2.5 × 17 mm) (#25-674-17-1, KLS Martin) and 24 small-diameter screws (1.5 × 15 mm) (#25-675-15, KLS Martin) were placed monocortically. In the second experiment (larger-diameter monocortical vs smaller-diameter bicortical anchorage), 48 screws were likewise placed in 12 hemisected maxillae and 12 hemisected mandibles. Twenty-four large-diameter screws (2.5 × 17 mm) were placed monocortically, and 24 small-diameter screws (1.5 × 15 mm) were placed bicortically.

For each bone specimen, 2 screws were placed between the first and second premolars with 1 more
coronally positioned and the other more apically positioned (Fig 1). The coronally positioned screw was placed 5 mm apical to the maximum height of the interproximal crestal bone. The apically positioned screw was placed 4.5 mm apical to the coronally positioned screw. These distances were selected to ensure that all screws would have adequate bone and proper root divergence without root contact, would not be placed in the mental foramen or the maxillary sinus areas, and would have adequate separation. Based on average bone thickness values, the monocortical screws were placed to a depth of 4 mm to ensure complete penetration of the buccal plate without engaging the lingual cortical plate.16 Bicortical placement was verified by visual observation of the screw as it began to protrude through the external surface of the lingual cortical bone. Figure 2 shows monocortical and bicortical screw placements and force applications from an orthogonal view.

For each experiment, bone specimen assignments were made to ensure an even and random distribution of screw diameters between maxillary and mandibular bone specimens, right and left bone specimens, and coronal and apical bone sites. All screws were placed by 1 operator (C.M.) with a hand driver (blade #25-483-97, handle #25-402-99, KLS Martin) after pilot hole drilling with the manufacturer’s recommended nontapered, 1.1-mm diameter twist drill for the 1.5-mm screws (#25-452-15, KLS Martin) and 1.9-mm diameter twist drill for the 2.5-mm screws (#25-460-19, KLS Martin). A nontapered drill was used to ensure no differences in hole sizes for the bicortical samples, since all screws had a uniform diameter throughout. All screws were placed perpendicular to the buccal bone surface and parallel to the occlusal plane.

After screw placement, periapical radiographs were taken of all specimens to ensure that the screws had not violated the mental foramen, the maxillary sinus, and the roots of any teeth. After verification of satisfactory screw placement, the most distal portion of each bony specimen was embedded in buff laboratory stone to a depth of 1.0 in and allowed to harden for 24 hours in preparation for force application.

To mimic orthodontic force, each miniscrew was subjected to a tangential force oriented perpendicular to the miniscrew (Fig 2). A customized x-y-z table with a mounting device (Brettin et al16) was fabricated to rigidly fixate and orient each specimen embedded in a stone block during testing. Furthermore, a customized grip was designed and machined from stainless steel to fit between the threads of each miniscrew and apply a tangential load at a distance of 3 mm from the screw-bone interface. This distance represented a reasonable space that would be typically occupied by soft tissue in vivo.

Each miniscrew was subjected to a tangential force load perpendicular to the screw but parallel to the occlusal plane by using an Instron diametral materials testing machine (model 1445, Zwick GmbH, Ulm, Germany). The crosshead speed was set at 0.05 mm per second.10,16 During loading, displacement of each screw was measured up to 0.6 mm, which, from pilot studies, represented adequate displacement without slippage at the screw-thread/grip interface.

Each screw was removed, and the bony specimens were sectioned at the mesial and distal aspects of the miniscrew placement site to allow bone thickness
visualization and measurement. Buccal cortical plate, lingual cortical plate, and total alveolar bone width were measured by 1 observer (C.M.) with a fine-tip digital caliper. Each measurement was made twice at each screw placement site, and the average of the measurements was recorded.

Statistical analysis

A paired-samples t test was used to determine whether there were significant differences in force anchorage at each deflection value for both mandibular and maxillary sites: between the 2 diameters of monocortical screws (2.5 and 1.5 mm) and between the larger-diameter monocortical screw (2.5 mm) and the smaller-diameter bicortical screw (1.5 mm). A 2-samples t test was used to determine whether there were significant differences in force anchorage values between maxillary and mandibular, right and left, and apical and coronal sites for the 2.5-mm monocortical screws, the 1.5-mm monocortical screws, and the 1.5-mm bicortical screws. One-way analysis of variance (ANOVA) with the post-hoc Tukey studentized range test was used to determine whether there were significant differences and the order of those differences in force anchorage values among the 3 screw types at the maxillary and mandibular sites. Means and standard deviations were calculated for bone thicknesses. All data analysis was conducted by using SAS software (version 9.1, SAS, Cary, NC) at either the 0.05 or 0.01 level of statistical significance.

RESULTS

Data analysis showed (Figs 3 and 4) that the mean mandibular anchorage force values of the 2.5-mm monocortical screws were significantly greater than those of the 1.5-mm monocortical screws when the deflection increased from 0.04 to 0.6 mm (P <0.01). Moreover, the mean maxillary anchorage force values of the 2.5-mm monocortical screws were significantly greater than those for the 1.5-mm monocortical screws when the deflection increased from 0.14 to 0.6 mm (P <0.01).

No statistically significant differences in mean mandibular anchorage force values were found between the 2.5 mm monocortical screws and the 1.5-mm bicortical screws. However, the mean maxillary anchorage force values of the 1.5 mm bicortical screws were significantly greater than those of the 2.5-mm monocortical screws when the deflection increased from 0.11 to 0.6 mm (P <0.01).

Data analyzed with 1-way ANOVA with the post-hoc Tukey studentized range tests indicated that the mean force values of the 2.5-mm monocortical screws and the 1.5-mm bicortical screws were significantly greater than those of the 1.5-mm monocortical screws when mandibular deflection increased from 0.04 to 0.6 mm, or maxillary deflection increased from 0.07 to 0.60 mm (P <0.01). There were no significant differences between maxillary and mandibular sites for the 1.5-mm bicortical screws. There were no significant differences in mean anchorage force values between the right and left mandibular sites for the 2.5-mm monocortical screws and the 1.5-mm bicortical screws.

Mean anchorage force values at mandibular sites were significantly greater than at maxillary sites for the 2.5-mm monocortical screws when the deflection increased from 0.11 to 0.60 mm (P <0.05). Mean anchorage force values at mandibular sites were significantly greater than at maxillary sites for the 1.5-mm monocortical screws when the deflection increased from 0.24 to 0.60 mm (P <0.05). There were no statistically significant differences in mean anchorage force values between maxillary and mandibular sites for the 1.5-mm bicortical screws. There were no significant differences in mean anchorage force values between the right and left maxillary sites for the 1.5-mm bicortical screws.
left sides for any screw type. Moreover, there were no significant differences in mean anchorage force values between coronal and apical positions for any screw type. Bone thickness means (SD) for maxillary labial, maxillary lingual, mandibular labial, and mandibular lingual cortical bone were 2.11 (0.39), 2.01 (0.70), 2.15 (0.62), and 2.97 (0.69) mm, respectively.

**DISCUSSION**

Two principal findings resulted from this in-vitro study. The first was that larger-diameter monocortical screws provide increased anchorage force resistance compared with smaller-diameter monocortical screws. As illustrated in Figure 3, the mean anchorage force values of the 2.5-mm monocortical screws exceeded those of the 1.5-mm monocortical screws in both the mandible and the maxilla ($P < 0.01$). The second finding was that smaller-diameter bicortical screws can provide anchorage resistance equal to, or even greater than, larger-diameter monocortical screws. As shown in Figure 4, the mean anchorage force values of the 1.5-mm bicortical screws were comparable with the values for the 2.5-mm monocortical screws in the mandible but exceeded the values for the 2.5-mm monocortical screws ($P < 0.01$) in the maxilla.

Additionally, as shown in these figures, mandibular bone sites offered significantly greater mean force resistance than did maxillary bone sites ($P < 0.05$) for both 1.5- and 2.5-mm monocortical screws. This finding agrees with that of Brettin et al.\(^{16}\) but is surprising because of the similar mandibular and maxillary labial cortical thicknesses measured in this sample. However, this similarity in thickness could help to explain the nonsignificant difference between maxillary and mandibular bone sites for the 1.5-mm bicortical screws.

The nonsignificance between the right and left sites was expected. However, the nonsignificance between coronal and apical sites, as also reported by Brettin et al.\(^{16}\) is of interest and might be valuable to practicing orthodontists. That is, since vertical placement, within the limits here, does not impact mean anchorage force resistance, placement of either a monocortical or a bicortical screw in a more coronal position (in attached gingiva) makes sense to limit the possibility of peri-implant inflammation.\(^{5,17}\) In addition to providing an environment of reduced inflammation, the coronal placement of screws might be biomechanically advantageous because they are closer to the center of resistance of the teeth.

Our finding that a 2.5-mm monocortical screw provides superior anchorage resistance compared with a 1.5-mm monocortical screw contrasts with the findings of Miyawaki et al.\(^{17}\) who reported no difference in the 1-year success rates of 2.3 and 1.5 mm screws (85% and 84% successes, respectively). But they also reported a success rate of 0.0% for the 1.0-mm diameter screws. Thus, diameter does appear to play a role clinically, but the effect might be less pronounced at lower loading with larger-diameter screws.

The biologic changes on osseous loading could not be examined in this in-vitro study. However, unlike traditional endosseous implants, which need a waiting period for bone healing and osseointegration, the primary stability of miniscrews is believed to result from mechanical retention of the screw in the bone.\(^{1,16}\) In-vitro studies of miniscrews should, therefore, more closely replicate their immediate loading response in situ after placement.

Recently, Huja et al.\(^{10}\) reported the pull-out strengths of monocortical screws placed in the maxillae and mandibles of dogs. Pull-out forces ranged from 134 to 388 N; these forces are somewhat greater than, but similar to, the force levels we reported here. Although these force levels are greater than those normally used to move teeth, well-controlled in-vitro studies such as these provide valuable insights into anchorage. Furthermore, greater forces are often used by orthodontists to treat patients orthopedically. For instance, after placement of miniplates on the lateral nasal wall for anchorage, Kircelli et al.\(^{18}\) applied facemask protraction to an 11-year-old girl with severe maxillary hypoplasia. The forces applied to the plates were 150 to 350 g.

Clinically, the advantage of a larger (monocortical) screw is its ability to distribute applied forces over greater areas of bone with less bone stress. For this reason, when smaller monocortical screws loosen in thin cortical bone and cannot be retightened, they are typically replaced with larger screws. The drawback of a larger screw is the surrounding anatomic limitations. The results of this study indicate that another alternative is a narrower bicortical screw. A bicortical small-diameter screw is particularly useful when there is insufficient room interproximally to place a larger-diameter monocortical screw. Especially in patients with thin maxillary cortical bone, a bicortical screw might be the miniscrew of choice. The advantage is the same, or better, anchorage resistance as a larger-diameter screw. The disadvantage is that the pilot hole must be drilled through both cortices; this might be difficult in the posterior areas, where cheek retraction is a limitation.

**CONCLUSIONS**

1. In vitro, larger-diameter (2.5 mm) monocortical screws provide increased anchorage force resistance compared with smaller-diameter (1.5 mm)
monocortical screws in both the mandible and the maxilla.

2. Smaller-diameter (1.5 mm) bicortical screws provide anchorage force resistance at least equal to larger-diameter (2.5 mm) monocortical screws.

3. Miniscrew anchorage force resistance is independent of the side of either the maxilla or the mandible. Force resistance is independent of apical or coronal site placement, within the limits of this study, for either the maxilla or the mandible.

REFERENCES