Bone damage associated with orthodontic placement of miniscrew implants in an animal model

S. Brooke Shank,a F. Michael Beck,b Andrew M. D’Atri,c and Sarandeep S. Huja d
Columbus, Ohio

Introduction: The purposes of this study were to quantify bone damage associated with insertion of 2 types of miniscrew implants and to relate the amount of bone damage to monocortical plate thickness. Methods: Nondrilling (n = 28) and self-drilling (n = 28) miniscrew implants (6 x 1.6 mm, Dentaurum, Newtown, Pa), and pilot holes (n = 26) were placed bilaterally in the maxillae and the mandibles of 5 adult dogs immediately after death. Bone blocks were cut, bulk stained with 1% basic fuchsin, embedded in methyl methacrylate, sectioned, and mounted. Monocortical plate thickness was measured adjacent to the miniscrew implant insertion site. Damage amounts were quantified at distances of 0 to 0.5 mm (adjacent region) and 0.5 to 1 mm (distant region) from the bone-implant interface. Total fractional damaged area (%), fractional microcracked area (%), and fractional diffuse damaged area (%) were quantified by using standard histomorphometric methods. Results: The mean monocortical plate thickness of the specimens from the mandible (2.2 mm) was significantly (P <0.001) greater than that of the maxillary specimens (0.9 mm). In the mandible, the 3 damage parameters were greater with self-drilling miniscrew implants than with nondrilling miniscrew implants; however, there were no differences in the damage parameters in the maxilla. Conclusions: Bone damage accumulation is related to the type of miniscrew implant and the thickness of the bone. (Am J Orthod Dentofacial Orthop 2012;141:412-8)

The use of skeletal anchorage in orthodontics is not a new concept, but its routine application and acceptance in orthodontic practice has been more recent. Like other advances in orthodontics, the clinical application of skeletal anchorage has preceded a thorough understanding of the biologic and biomechanical bases. Survival rates of miniscrew implants used for orthodontic anchorage range from 57% to 95.3%, with most studies reporting survival rates around 84%.1-3

Several studies have attempted to address factors responsible for the success of miniscrew implants. Primary stability is generally accepted to be important and can be measured by evaluation of insertion torque, removal torque, and pull-out strength. Variables that result in higher primary stability include smaller pilot hole diameters,4 increased cortical bone thickness,4-6 increased bone density,6 and use of self-drilling miniscrew implants.7,8Unlike nondrilling miniscrew implants, self-drilling miniscrew implants have a sharp cutting tip and do not require a pilot hole before insertion. Miniscrew implants placed in the mandibles of beagles had greater primary stability than those placed in the maxillae.9 However, in humans, the success rates of miniscrew implants placed in the maxilla are consistently greater than those in the mandible.1,10-12 This suggests that other factors beside primary stability may be important in determining the success of miniscrew implants.

Although primary stability is generally associated with increased success, it is possible that factors that increase primary stability also increase the amount of bone damage associated with miniscrew implant insertion.13,14 For example, the sequence of microdamage...
and extensive remodeling may decrease bone-implant contact and lead to miniscrew implant failure.\textsuperscript{15}

There is a need to understand how implant-related and bone-related factors influence the level of bone damage. A few studies have investigated factors that alter the amount of bone damage associated with miniscrew implant insertion. For example, greater microdamage was associated with asymmetric thread profiles of implants,\textsuperscript{16} increased diameter and conical shape of miniscrew implants,\textsuperscript{13} and overtightening of miniscrew implants.\textsuperscript{13,17} A recent qualitative study demonstrated that self-drilling miniscrew implants created greater bone damage than did nondrilling miniscrew implants.\textsuperscript{14} However, quantitative data from the jaw bone are lacking. The objective of this study was to quantify the amount of bone damage associated with the insertion of self-drilling and nondrilling miniscrew implants in bone of different monocortical thicknesses in nonvital tissues.

**MATERIAL AND METHODS**

Five mixed-breed dogs, ages 2 to 2.5 years, were obtained immediately after euthanasia. These animals had been used as the healthy controls in an unrelated study that had Institutional Animal Care and Use Committee approval. Each dog was killed by intravenous administration of pentobarbital, as recommended by the American Veterinary Medical Association Panel on Euthanasia. Immediately after death, orthodontic miniscrews (6 × 1.6 mm; Dentaurum, Newtown, Pa) were placed at predetermined locations, bilaterally, in the jaws. A horizontal incision was made in the soft tissues to expose the underlying maxillary and mandibular bones. With the intent of sampling bone with a range of thicknesses, we inserted miniscrew implants bilaterally in the posterior maxilla, posterior mandibular self-drilling miniscrew implants, 8 middle mandibular nondrilling miniscrew implants, 9 middle mandibular self-drilling miniscrew implants, 9 posterior mandibular nondrilling miniscrew implants, 9 posterior mandibular self-drilling miniscrew implants, and 9 posterior mandibular self-drilling miniscrew implants.

Each slide was examined to identify the section located closest to the center of the implant or pilot hole defect. This section was selected for quantification of bone damage associated with each type of miniscrew implant or pilot hole drill insertion. The slides were blinded to conceal jaw location and type of miniscrew implant. All data were collected by 1 investigator (S.B.S.). Each specimen was examined by using an epifluorescent microscope (BX 51; Olympus, Tokyo, Japan) at 200× magnification. The first millimeter of buccal cortical bone adjacent to the insertion site was examined (Fig 2). Bone at 0 to 0.5 mm from the implant interface was defined as the “adjacent region,” and bone 0.5 to 1 mm from the implant interface was called the “distant region.” The rationale for division into these regions...
was based on our observation that most damage was limited to the first 1 mm from the interface, and a general decrease was noted in the damage from the adjacent to the distant regions. By examining at a high magnification (200×), we were able to clearly visualize the damaged bone (Fig 3). Amounts of bone damage on both the apical and coronal sides of the insertion site were quantified by using standard histomorphometric methods. Two features of microdamage were quantified for the cortical bone specimens: microcracks defined as small linear defects typically 100 μm in length, and diffuse damage: patches of intensely stained mineralized matrix that have been disrupted by local intense deformation. Other forms of microdamage such as crosshatching and microcallus fractures are more frequently observed in trabecular bone and thus were not included in our study of cortical bone. Using a Merz grid, the following histomorphometric variables were quantified: bone hits, hits on microcracks, and hits on diffuse damage. The thickness of the buccal plate of cortical bone was also measured on both the apical and coronal sides of the insertion site by using a calibrated computer program (MicroSuite; Olympus, Center Valley, Pa). Six randomly chosen specimens were requantified 3 weeks later to evaluate intrarater reliability.

From the primary variables, the following secondary parameters were calculated: total fractional damaged area ([microcrack hits + diffuse damage hits]/bone hits×100), fractional microcracked area ([microcrack hits/bone hits]×100), and fractional diffuse damaged area ([diffuse damage hits/bone hits]×100). The total fractional damaged area represented the percentage of bone with damage, whether diffuse damage or microcracks. Mean values for diffuse damage and microcracks were summed to represent the total amount of damaged bone in each specimen. Although the 2 types of damage are distinct, the addition of these values represented the fraction of bone area that was damaged and, conversely, indicated the amount bone that was undamaged.

Means and standard deviations were calculated for all specimens. Intraclass correlation coefficients were used to describe intrarater reliability. Intraclass correlation coefficients were calculated for monocortical bone thickness, fractional microcracked area, and fractional diffuse damaged area. Repeated measures analysis of variance (ANOVA) with Tukey-Kramer adjustments was used to compare the cortical plate thickness from the 3 regions and to describe the differences in total fractional damaged area, fractional microcracked area, and fractional diffuse damaged area between types of mini-screw implants, between jaws, and between adjacent and distant regions. Significance was set at P <0.05.

RESULTS

The intraclass correlation coefficient values for monocortical thickness, fractional microcracked area, and fractional diffuse damaged area were 1.0, 0.99, and 0.95, respectively. Means (standard deviations) for monocortical bone thickness measurements of specimens from the posterior maxilla, middle mandible, and posterior mandible were 0.92 mm (0.25), 2.27 mm (0.39), and 2.20 mm (0.22), respectively. The monocortical thickness of specimens from the posterior maxilla was significantly different from that of the middle

**Fig 1.** Image of the right mandible depicts the middle mandibular and posterior mandibular regions for miniscrew implant and pilot hole placements. Each triad consisted of 1 nondrilling miniscrew implant, 1 self-drilling miniscrew implant, and 1 pilot hole. A triad is indicated by the circle in the image. Close root proximity of the self-drilling miniscrew implant in the posterior mandibular region necessitated reinsertion in a nearby location of an additional miniscrew implant of the same type.
mandible and the posterior mandible ($P < 0.001$), whereas the middle mandible and the posterior mandible were not significantly different ($P = 0.46$). Therefore, specimens from the middle and posterior mandible were combined and compared with the maxillary specimens.

Means and standard deviations of total damage fractional area, microcrack fractional area, and diffuse damage fractional area are presented in the Table. In all specimens, the amount of damage decreased as the distance from the implant-bone interface increased. Self-drilling miniscrew implants had significantly greater total fractional damaged areas ($P < 0.005$) and fractional microcracked areas ($P < 0.02$) than did nondrilling miniscrew implants in the distant regions of the mandible. A significantly greater fractional diffuse damaged area was associated with the self-drilling miniscrew implants than with the nondrilling miniscrew implants ($P < 0.005$) in the mandibular adjacent region. The ratio of microcracks to diffuse damage increased as bone thickness increased and as distance from the bone-implant interface increased in both the self-drilling and nondrilling groups. There were no statistically significant differences in any damage parameter between miniscrew implant types in the maxillary specimens.

**DISCUSSION**

The focus of this study was to compare the amount of bone damage associated with the insertion of 2 types of miniscrew implants (nondrilling and self-drilling) in bone of various monocortical thicknesses. All measurements had excellent intrarater reliability. Self-drilling miniscrew implants were associated with greater bone damage than were nondrilling miniscrew implants in the mandible when the mean monocortical bone thickness was 2.2 mm. However, there were no significant differences in damage between self-drilling and nondrilling miniscrew implants in the maxilla with a mean monocortical bone thickness of 0.9 mm.

Mandibular bone had greater microcrack:diffuse damage ratios than did maxillary bone with both types of miniscrew implants. More energy is required to generate microcracks when there is diffuse damage caused...
by the toughening phenomenon of bone associated with diffuse damage. Diffuse damage disperses the crack-forming energy. Therefore, an increased microcrack:diffuse damage ratio in areas of increased monocortical thickness indicated greater cracking energy generated by miniscrew implant insertion.

In a previous clinical study, the insertion torque of successful mandibular miniscrew implants was found to be significantly lower than the insertion torque of failed miniscrew implants. Based on these findings, it was recommended that insertion torque should not exceed 10 Ncm. Torque values greater than 10 Ncm could be detrimental to the long-term stability of the miniscrew implant by generating stress levels capable of inducing ischemia of the bone and inhibiting bone remodeling. Our study is consistent with the findings of that study because self-drilling miniscrew implants, which previously have been associated with higher insertion torque values than nondrilling miniscrew implants, were associated with greater bone damage in the mandibular specimens.

The insertion of screws and implants into bone has been associated with microcracks. The pattern of damage described in a previous study was similar to that found in our study, with intensely stained areas around the implant-bone interface, microcracks extending into the interstitial bone, and microcracking across osteons. We observed a higher percentage of damaged bone, which could be ascribed to the use of epifluorescent microscopy. The epifluorescent method detected 3.4× more microcracks than did bright-field microscopy and is thus a more sensitive method for the detection of microcracks than is the bright-field method.

The impact of bone damage on the long-term stability of a miniscrew implant is still not completely understood. In this experiment, we quantified only the bone damage observed in nonvital bone. Some bone damage from insertion of miniscrew implants is inevitable, but limiting the amount of bone damage associated with insertion is likely to be beneficial to the long-term stability of a miniscrew implant. The type of miniscrew implant chosen for a maxillary location would not make a significant difference in the bone damage generated, but a nondrilling miniscrew implant is recommended for thicker bone locations such as the mandible to limit the amount of damage. In the maxilla, other factors such as the ease of insertion of self-drilling miniscrew implants might influence the clinician’s choice.
The means (and standard deviations) of physiologic microcracks range from 0.15 (0.16) microcracks per square millimeter in men to 0.23 (0.14) in women. 27 Unloaded dog femurs contained 0.04 (0.03) microcracks per square millimeter, and cyclically loaded dog femurs contained 0.07 (0.06) microcracks per square millimeter. 28 In our study, microcracks per square millimeter were over a thousand-fold greater than the numbers of cracks reported under physiologic conditions. In 1 representative area of 0.5 mm² of bone adjacent to the miniscrew implant, there were over 170 microcracks. Except in the pilot hole samples, microcracks were far too numerous and closely spaced to count. Therefore, the number of hits on microcrack-filled bone, representing area, was quantified and used to calculate the percentage of microcracked bone. This method has been used previously for the quantification of extensively microcracked bone. 28 In another study, microcracks were counted, but the number of microcracks was lower than in our study. 13 The methods of staining and quantifying microcracks between the 2 studies were entirely different. The difference in microcrack counts between these studies could be due to the greater thickness of our bone specimens and their use of hematoxylin and eosin staining with bright-field microscopy, rather than a stain specific for microdamage.

Certain aspects of the design of this study should be considered when interpreting the results. The miniscrew implants were inserted with the manufacturer’s hand driver; thus, no mechanical insertion device was used in their placement. Every effort was made to insert the miniscrew implants with uniform pressure. Some minor lateral movement might have occurred that could not be eliminated. However, the use of a hand driver is more consistent with a clinical setting. The alternate choice would be to use a stand-mounted driver, but this would complicate placing the miniscrew implant immediately after death with the jaws intact. However, this approach would reduce insertion-related variability. We chose to remove the miniscrew implants from our bone samples before staining because we wanted to ensure that the basic fuchsin would be able to penetrate the defect created by the miniscrew implant or the pilot drill. The presence of a miniscrew implant in the defect might have hindered the access of the stain and resulted in limited stain penetration in the area of interest. The process of reversing the miniscrew implants before staining might have created some additional bone damage. Miniscrew implants and pilot holes placed as substitutes for specimens with root proximity or direct root contact were placed within a few hours after the original miniscrew implants. This difference in placement timing was unlikely to have affected the condition of the bone and the resulting damage. Degradation of the bone tissue begins a few hours after removal from the body, but the additional miniscrew implants were placed within this time frame. 29 The miniscrew implant type chosen for a certain jaw location is likely to affect the survival of the miniscrew implant. Microdamage extends farther from self-drilling miniscrew implants in the mandible compared with nondrilling miniscrew implants. Furthermore, the level of diffuse damage adjacent to the bone-implant interface in thicker bone is greater with self-drilling miniscrew implants than with nondrilling miniscrew implants. Perforation of the cortical plate with a 1-mm round bur for bone thicknesses of 1.5 to 2.5 mm and predrilling with a pilot hole drill in bone thicknesses greater than 2.5 mm have been recommended. 30 Our findings indicate that greater bone damage is more likely to be associated with a self-drilling miniscrew implant than with a nondrilling miniscrew implant in bone with a monocortical thickness of about 2.2 mm, which was the mean value of the mandibular specimens.

<table>
<thead>
<tr>
<th>Insertion type</th>
<th>Region</th>
<th>Maxillary PH</th>
<th>Maxillary ND MSI</th>
<th>Maxillary SD MSI</th>
<th>Mandibular PH</th>
<th>Mandibular ND MSI</th>
<th>Mandibular SD MSI</th>
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<tr>
<td>TDx</td>
<td>Adjacent</td>
<td>14.2 (7.7)</td>
<td>82.0 (16.3)</td>
<td>83.5 (14.3)</td>
<td>18.4 (7.0)</td>
<td>72.7 (9.8)</td>
<td>87.8 (10.8)</td>
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<td>Dist</td>
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<td>24.6 (14.7)</td>
<td>34.6 (22.2)</td>
<td>0.9 (1.3)</td>
<td>29.1 (10.9)</td>
<td>54.2 (19.4)</td>
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<tr>
<td>MDx</td>
<td>Adjacent</td>
<td>5.6 (5.4)</td>
<td>17.1 (10.0)</td>
<td>15.2 (5.5)</td>
<td>12.7 (6.3)</td>
<td>40.5 (10.5)</td>
<td>30.2 (11.9)</td>
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<tr>
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<td>Dist</td>
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<td>19.8 (14.4)</td>
<td>0.9 (1.3)</td>
<td>26.0 (10.0)</td>
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<tr>
<td>DDx</td>
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<td>64.8 (17.2)</td>
<td>68.3 (13.1)</td>
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<td>32.2 (12.0)</td>
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<td>Dist</td>
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<td>14.7 (12.8)</td>
<td>0.0 (0.1)</td>
<td>3.2 (3.2)</td>
<td>12.0 (11.7)</td>
</tr>
</tbody>
</table>

TDx, Total fractional damaged area; MDx, fractional microcracked area; DDx, fractional diffuse damaged area; PH, pilot hole; ND, nondrilling; MSi, miniscrew implant; SD, self-drilling.

Significant differences (P <0.05) in jaw and region are depicted by different superscript letters.
in our study. If the goal is to limit the extent of microcracks and diffuse damage, nondrilling miniscrew implants can be used in the bone when monocortical thickness often exceeds 2 mm, such as the mandible. In contrast, the choice of a self-drilling or a nondrilling miniscrew implant in the maxilla with bone about 1 mm thick will be determined by factors other than bone damage.

CONCLUSIONS

Self-drilling miniscrew implants are associated with greater bone damage than are nondrilling miniscrew implants in bone with a monocortical thickness of about 2 mm or greater. There is no difference in bone damage between self-drilling and nondrilling miniscrew implants in bone with a monocortical thickness of about 1 mm or less. Bone damage accumulation is related to the type of miniscrew implant and the thickness of bone.

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REFERENCES