Maxillofacial screws are increasingly being used in orthodontics to provide anchorage for tooth movement. The objective of this study was to determine the biomechanical stability as well as the bone tissue response of screws at 6 weeks postinsertion in a canine model. Seven skeletally mature male dogs received 102 screws (2 × 6 mm or 2 × 8 mm) at predetermined sites. Twenty screws became loose or were lost during the 6-week undisturbed healing period. Forty-eight screws were randomized for mechanical testing and 34 for histology. Peak pullout strength was recorded and 80-μm sections were examined for histomorphometric parameters. Statistical analyses were conducted by analysis of variance and Tukey-Kramer method. Mean ± SE peak pullout strengths for the various sites ranged from 153.5 ± 37.6 N to 389.3 ± 32.5 N with no significant (P > .05) differences at immediate placement and 6 weeks postinsertion. Bone contact ranged from 79% to 95%. Histomorphometric analyses indicated higher bone formation rate in the mandible than in the maxilla and a gradient of decreasing turnover with increasing distance from the screw interface. These results provide the clinical orthodontist with an estimate of the holding power of these screws and an understanding of early biological healing response associated with self-drilling screws.

Establishing anchorage for orthodontic movement is critical to treat malocclusions successfully. Skeletal anchorage involves using screws or implants inserted into bone to support orthodontic tooth movement. Recent case reports have drawn much attention to this promising form of anchorage. Although multiple case reports advocate the use of screws for orthodontic anchorage, specific questions remain regarding their clinical use. Reported success rates of screws vary from 50% to 89%, with success defined as sustenance over the course of orthodontic treatment and the absence of inflammation and clinical mobility. Reported healing time before load application varies in the literature, with some reports of immediate loading and others allowing 2
weeks of soft tissue healing before loading of these screws. The objective of the current study was to evaluate the holding power of monocortical screws as a function of cortical bone purchase and to examine their adaptation physiology to bone at 6 weeks postinsertion (T6). The time point of 6 weeks was chosen because it allowed for the initial osseous healing and reflected a common clinical practice for many orthodontists. It was hypothesized that (1) peak pullout strengths and cortical bone thickness at the sites of screw insertion would be different at T6 when compared with immediate placement (T0) and (2) adaptation physiology of these screws would consist of modeling and remodeling events similar to those observed in bone supporting endosseous implants.

**Materials and Methods**

Seven healthy skeletally mature male beagle dogs received a total of 102 self-drilling screws (Synthes USA, Monument, Colo). The animal protocol was approved through The Ohio State University Institutional Laboratory Animal Care and Use Committee. All screws were 2 mm in diameter and were manufactured from a titanium alloy (Ti-6Al-7Nb). The dogs were 14 to 18 months old and weighed 9 to 14 kg. Screw insertion sites were randomly assigned to either mechanical pullout testing or histological analyses before start of study. Assignments were made to ensure even but random distribution of sites for each test. Approximately two thirds of the screws were used for the mechanical testing and one third were used for the histological analyses.

At the time of surgery, each dog was sedated with acepromazine (2 mg), anesthetized with intravenous (IV) ketamine (100 mg) and diazepam (5 mg), intubated, and maintained on isoflurane (2.0%–2.5%). Lidocaine HCl 2% with 1:50 000 epinephrine (0.5 mL) was infiltrated at each surgical site for hemostasis. Each dog had 14 to 15 screws placed in predetermined sites in the maxilla and mandible. The methods have been described in detail. Depending upon the availability of the alveolar bone stock for screw placement, the site of insertion of the screw was covered by either attached or movable mucosa. In sites covered by attached mucosa, each screw was inserted directly into the cortical bone until the undersurface of the screw head was approximately flush with the attached tissue. In sites covered with movable mucosa, an incision of approximately 2 to 3 mm was made through the mucosa to the bone. Soft tissue was reflected with a periosteal elevator, and the screw was inserted until the undersurface of the head had approximately 0.5 mm of clearance with the bone surface. No pilot hole was drilled before insertion of the screws. The screws were inserted perpendicular to the cortical bone surface with the intent of obtaining monocortical anchorage. In all cases, care was taken to avoid trapping soft tissue in the screw threads or compressing soft tissue under the screw heads. One operator inserted all screws with a hand driver. In the palate, 8-mm-length screws were used to accommodate the increased soft tissue thickness; 6-mm-length screws were used in the remaining sites.

All dogs received buprenorphine (0.12 mg) before recovery from anesthesia. Oral amoxicillin (250 mg) was administered at 12 hours presurgery and then every 12 hours postsurgery for 5 days. Dogs were restricted to a soft diet for 3 days and then fed standard dry dog chow and water. Intratemporal bone labels were administered IV to mark forming bone surfaces, with tetracycline (10 mg/kg) administered 8 days and 1 day before screw placement and calcein (5 mg/kg) administered 33 days and 40 days after screw placement. The screws were allowed to heal undisturbed for 6 weeks.

After the healing period, each dog was euthanized with pentobarbital IV (6 mL) in accordance with the recommendation of the American Veterinary Medical Association Panel on Euthanasia. Bone specimen preparations for mechanical testing were identical to those reported previously. For histological analyses, ~80-μm undecalcified sections were obtained by an Exakt system (Exakt Technologies, Oklahoma City, Okla) and following standard protocols. One section was obtained buccolingually through the center of each screw and its supporting bone.

Histomorphometric analyses were performed with an Olympus BX 51 microscope (Tokyo, Japan) with appropriate filters for calcine. All static and dynamic measurements were made at ×100. An intercept and point hit method was used for histomorphometric analyses. Bone volume/total volume (BV/TV, %), mineral apposition rate (MAR, μm/d), and bone formation rate (BFR, %/y) were calculated for the screw-supporting bone (0–4 mm on each side of the implant). Interlabel width to calculate MAR was measured at ×200. For each dog, 2 cross sections of the left femoral middiaphyses were analyzed to provide baseline bone turnover. This is important because variations in cortical bone...
ANALYSES OF MONOCORTICAL SCREWS AT PLACEMENT AND 6 WEEKS LATER

Table 1

<table>
<thead>
<tr>
<th>Site</th>
<th>T6 Mean</th>
<th>T0 Mean</th>
<th>T6 SE</th>
<th>T0 SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mx Ant</td>
<td>153.5^A</td>
<td>168.9^A</td>
<td>37.6</td>
<td>32.5</td>
</tr>
<tr>
<td>Palate</td>
<td>204.8^B</td>
<td>180.6^B</td>
<td>30.5</td>
<td>27.3</td>
</tr>
<tr>
<td>Mx Post</td>
<td>233.1^AB</td>
<td>231.1^A</td>
<td>32.7</td>
<td>32.5</td>
</tr>
<tr>
<td>Md Mid</td>
<td>269.7^AB</td>
<td>275.4^A</td>
<td>32.5</td>
<td>34.8</td>
</tr>
<tr>
<td>Md Post</td>
<td>389.3^B</td>
<td>387.5^B</td>
<td>32.5</td>
<td>34.8</td>
</tr>
</tbody>
</table>

*Significant differences (P < .05). No significant differences in peak pullout force and cortical bone thickness were found between T0 and T6 at any of the sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>T6 Mean</th>
<th>T0 Mean</th>
<th>T6 SE</th>
<th>T0 SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mx Ant</td>
<td>1.25^AB</td>
<td>1.43^A</td>
<td>0.19</td>
<td>0.23</td>
</tr>
<tr>
<td>Palate</td>
<td>1.59^A</td>
<td>1.79^A</td>
<td>0.16</td>
<td>0.23</td>
</tr>
<tr>
<td>Mx Post</td>
<td>1.03^A</td>
<td>1.65^A</td>
<td>0.17</td>
<td>0.21</td>
</tr>
<tr>
<td>Md Mid</td>
<td>1.54^A</td>
<td>1.97^A</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>Md Post</td>
<td>1.92^B</td>
<td>1.98^AB</td>
<td>0.17</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Statistical analyses

Biomechanical Testing

Pullout force and cortical bone thickness at the sites of screw insertion were each analyzed by a factorial analysis of variance (ANOVA) with animal (with repeated measures), anatomical site, and time point as independent variables. Post hoc testing was done using the Tukey-Kramer method. Peak pullout strength was analyzed with a regression model with cortical bone thickness as the independent variable.

Histomorphometric Analyses

A factorial ANOVA with animal (with repeated measures) and jaw as the independent variables was used to analyze between-jaw differences, and a similar analysis with the Tukey-Kramer method was used for among-site differences. To normalize the distributions, a log transformation was necessary for BFR and MAR data, and a sine transformation was necessary for between-jaw comparisons of BV/TV data.

Results

The 7 dogs survived the experimental period uneventfully. Twenty of the 102 screws placed in the canine jaws either became loose or were lost during the 6-week period: 12 were in the mandibular anterior site, 4 were in the maxillary anterior site, 2 were in the mandibular posterior site, and 2 were in the palatal site. Of the 82 surviving screws, 48 were tested for peak pullout strength and 34 were processed for histological analyses. On histological examination, 7 of the 34 screws demonstrated fibrous tissue encapsulation and were not analyzed by histomorphometry: 5 were from the maxillary anterior region, 1 was from the maxillary posterior, and 1 was from the mandibular anterior. Results are reported as mean ± SE.

Biomechanical testing

Pullout Strength

Results of the ANOVA indicated a significant effect for implant site (F = 11.2, df = 5/34, P < .0001). The day (T0 or T6) and the site by day interaction were not significant (P > .50). The mean peak pullout strengths varied among insertion sites (Table 1) and ranged from 153.5 to 389.3 N. After 6 weeks of healing, mean peak pullout strengths were significantly (P < .05) higher in the mandibular posterior site (389.3 ± 32.5 N) than in the maxillary anterior site (153.5 ± 37.6 N) and the palatal site (204.8 ± 30.5 N).

Cortical Bone Thickness

Results of the ANOVA indicated a significant effect for implant site (F = 7.42, df = 5/33, P < .0001). The day and the site by day interaction were not significant (P > .05). Cortical bone thickness varied among anatomical sites (Table 1) and ranged from 1.03 to 1.94 mm. Mean cortical bone thickness was significantly (P < .05) higher

turnover ranging from 2% to 10% per year have been reported. In addition, abnormal femoral values may indicate bone pathology. To analyze the modeling response, linear measurements were made of the periosteal, cortical passage, and endosteal thickness from ×40 images of the screw-bone interface by using computer software (AnalySIS Soft Imaging System GmbH, Munster, Germany). The cortical passage is the thickness of the bone at the time and site of screw placement. These measurements were made on both sides of the screw, and the 2 values were averaged. To measure bone contact with the screw, a line was scribed to identify the external contour of the screw at ×100. Similarly, multiple line segments representing regions of bone contact with the screw were drawn. The ratio of the sum of line segments representing bone contact to the line representing the length of the external contour of the screw was used to calculate the percent bone contact. Between-jaw and among-site comparisons were made for the histomorphometric study because of the clinical relevance of both comparisons.
in the mandibular posterior site (1.94 ± 0.17 mm) and the mandibular midsite (1.92 ± 0.17 mm) than in the maxillary posterior site (1.03 ± 0.17 mm).

A significant (r = 0.59, P < .0001, n = 47) relationship existed between cortical bone thickness and peak pullout strengths at T6.

**Histomorphometric analyses**

The sample size for histomorphometry from each region after excluding for failures was as follows: maxillary anterior, n = 2; maxillary mid, n = 5; maxillary posterior, n = 4; palate, n = 6; mandibular anterior, n = 1; mandibular mid, n = 5; and mandibular posterior sites, n = 4. Failures at 6 weeks resulted in a small sample size in the maxillary anterior and mandibular anterior. These 2 sites were not included in the statistical analyses. Results may be seen in Tables 2 and 3, which represent analyses. Results may be seen in Tables 2 and 3, which represent analyses. Results may be seen in

Bone Contact

Screw-bone contact of 78% to 94% was evident at T6. There were no significant differences between the jaws (P > .23) or among the 5 sites (P > .42) (Tables 2 and 3).

Bone Volume/Total Volume (%)

There were no significant differences (P > .47) between the maxilla and mandible (Table 2). However, when the 5 sites were examined (Table 3), significant (P < .05) differences were noted between the palate and the following 3 sites: mandibular posterior, maxillary mid, and maxillary posterior.

Mineral Apposition Rate (μm/d)

There were no significant differences (P > .25) noted between the maxilla and mandible (Table 2) or among the 5 sites (P > .15) (Table 3). The MAR for the femoral sections was 0.8 μm/d.

**Bone Formation Rate (%/y)**

Significant differences in BFR were found between the jaws (35.5% ± 9.1% per year for the mandible vs 11.6% ± 2.0% per year for the maxilla, P = .002) and between the mandibular mid and maxillary posterior (40.72% ± 15.43% per year vs 7.66% ± 3.19% per year, respectively; P = .026) as seen in Tables 2 and 3. The BFR was significantly (P < .018, ANOVA) greater in the bone directly adjacent (0–1 mm) to the screw (32.7% ± 7.8% per year) than in the bone farther (1–4 mm) from the screw (10.2% ± 2.5% per year).

**Tables 2 and 3**

**Between-jaw comparisons for histomorphometric variables†**

<table>
<thead>
<tr>
<th>Site</th>
<th>Variable</th>
<th>Site</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandible</td>
<td>MAR</td>
<td>Maxilla</td>
<td>MAR</td>
</tr>
<tr>
<td>(n = 9)</td>
<td>(μm/d)</td>
<td>(n = 15)</td>
<td>(μm/d)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.8</td>
<td>Mean</td>
<td>0.7</td>
</tr>
<tr>
<td>SE</td>
<td>0.2</td>
<td>SE</td>
<td>0.2</td>
</tr>
<tr>
<td>BV/TV (%)</td>
<td>85.1</td>
<td>BV/TV (%)</td>
<td>88.5</td>
</tr>
<tr>
<td>BFR (%/y)</td>
<td>35.5</td>
<td>BFR (%/y)</td>
<td>11.6*</td>
</tr>
<tr>
<td>PassTh (μm)</td>
<td>2017.2</td>
<td>PassTh (μm)</td>
<td>1571.1</td>
</tr>
<tr>
<td>PrTh (μm)</td>
<td>67.8</td>
<td>PrTh (μm)</td>
<td>257.0**</td>
</tr>
<tr>
<td>EnTh (μm)</td>
<td>0.0</td>
<td>EnTh (μm)</td>
<td>24.1</td>
</tr>
<tr>
<td>BC (μm)</td>
<td>94.2</td>
<td>BC (μm)</td>
<td>84.7</td>
</tr>
</tbody>
</table>

†MAR indicates mineral apposition rate; BV/TV, bone volume/total volume; BFR, bone formation rate; PassTh, passage thickness; PrTh, periosteal thickness; EnTh, endosteal thickness; BC, bone contact.

*P = .002.

** Among-site comparisons for histomorphometric variables‡**

<table>
<thead>
<tr>
<th>Site</th>
<th>Variable</th>
<th>Site</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Md Mid (n = 5)</td>
<td>MAR</td>
<td>Mx Mid (n = 5)</td>
<td>MAR</td>
</tr>
<tr>
<td>Mean</td>
<td>0.90</td>
<td>Mean</td>
<td>0.64</td>
</tr>
<tr>
<td>SE</td>
<td>0.27</td>
<td>SE</td>
<td>0.30</td>
</tr>
<tr>
<td>BV/TV (%)</td>
<td>90.39AB</td>
<td>BV/TV (%)</td>
<td>85.21A</td>
</tr>
<tr>
<td>BFR (%/y)</td>
<td>40.72A</td>
<td>BFR (%/y)</td>
<td>11.94AC</td>
</tr>
<tr>
<td>PassTh (μm)</td>
<td>2222.13A</td>
<td>PassTh (μm)</td>
<td>1232.77C</td>
</tr>
<tr>
<td>PrTh (μm)</td>
<td>122.01A</td>
<td>PrTh (μm)</td>
<td>137.15AB</td>
</tr>
<tr>
<td>EnTh (μm)</td>
<td>0.00</td>
<td>EnTh (μm)</td>
<td>0.00</td>
</tr>
<tr>
<td>BC (%)</td>
<td>94.40</td>
<td>BC (%)</td>
<td>78.23</td>
</tr>
</tbody>
</table>

‡MAR indicates mineral apposition rate; BV/TV, bone volume/total volume; BFR, bone formation rate; PassTh, passage thickness; PrTh, periosteal thickness; EnTh, endosteal thickness; BC, bone contact.

*Sites with different superscript letters denote significant differences (P < .05) and are described in the “Results” section.

S. S. Huja et al

Journal of Oral Implantology 113

Downloaded from http://meridian.allenpress.com/joib/doi/pdf/10.2341/11-02-0484 by guest on 06 March 2020
Findings demonstrate bone con-
siderably exceeded 0.0001, n
and cortical bone thickness
at T6 did not signif-
antly change (Table 1) at T6 did not signif-
ificantly change during the early healing stages
because of the immature interfa-
cial bone. The present hypothesis
was also based on previous his-
ological studies reporting in-
creased bone remodeling activity
at the screw- or implant-bone
interface.24,25 It has been demon-
strated that bone within 1 mm of
an implant surface exhibits a sus-
tained elevated remodeling rate
and a lower microhardness.26
The elevated rate prevents the
supporting bone from fully min-
eralizing.26 Although the histo-
logical findings reflect events
similar to endosseous implant
healing,27 barring the failures,
this biological response does not
result in a decrease in pullout
strengths at T6 to a level that
would prevent clinical utilization
of these screws.

The most significant experi-
mental difference between the T0
and T6 time points is the absence
of a biological response at T0 (ie,
at the time of insertion). This is
highlighted by failures of the
screws at various sites at T6. The
retention at T0 is entirely based on
the strength of the bone and the
design of the screw, and no such
failures were recorded at T0. The
screw failures are a clinical prob-
lem and have been reported. For
example, in a clinical prospective
study,12 approximately 15 of 140
screws exfoliated over the period
of their intended use. Ten failures
occurred within the first month,
and the remaining 5 failed after
3 to 12 months of loading.

Comparisons between the T0
study and the T6 study have
limitations. Two sets of dogs were
used at 2 different times, and
although all dogs were skeletally
mature and 1 to 2 years old,
individual differences could
exist. To maintain consistency
across the studies, one operator
placed all screws under similar
conditions. All dogs were of the
same breed, sex, and approximate
weight. The screws were placed
in the same region for each dog,
but identical sites, orientations,
and depths of penetration could
not be precisely replicated during
placement. This potential varia-
ion, however, is representative
of what may be expected in
a clinical situation. Additionally,
cautions must be used in directly
extrapolating the results of this
animal study to humans.

At the time of sacrifice, it was
noted that 20 of 102 screws were
loose (not anchored in bone but
only by soft tissue) or were com-
pletely missing. It is not known
at what point the screws became
loose during the 6-week healing
period. For all the screws, bone
purchase was felt at the time of
placement. The occlusion of the
dogs did not appear to interfere
with the screws, and the attend-
ing veterinary staff noted no un-
usual behavior (eg, pawing at
the screws). It is known that primary
stability and subsequent survival
of screws is influenced by the
quality and quantity of the bone
into which they are placed.28,29
The majority of failures occurred
in the mandibular and maxillary
anterior regions. On the basis of
the histology, it was concluded
that a combination of thin cortical
bone and small bone volume
because of root proximity in this
region10 made placement and re-
tention of these screws difficult.
However, it is reasonable to
assume that factors other than bone

Callus and Bone Thickness
No significant differences were
noted for the between-jaw (P >
.16) and among-site (P > .40)
endostein thickness (Table 3).
When comparing the jaws, the
maxillary periosteal thickness was
greater than the mandibular peri-
osteal thickness (P > .03). How-
ever, the maxillary posterior site
had significantly greater (P < .05)
periosteal thickness than did the
mandibular mid and mandibular
posterior sites.

The passage thickness was not
significantly different (P > .09)
when comparing by jaw (Table 2).
When among-site comparisons
were made, the mandibular mid
site was significantly different
(P < .05) in passage thickness
from the maxillary mid site. No
other significant differences were
found for cortical passage thick-
ness at other sites.

Discussion
Results of this study indicate that
T6 peak pullout strengths of
screws and the cortical bone
thickness vary as a function of
insertion site, and peak pullout
strengths of the screws are di-
rectly related to cortical bone
thickness. Peak pullout strengths
and cortical bone thickness (Table 1)
at T6 did not signif-
ificantly change (P > .90) from the
T0 time point reported earlier.
Both studies exhibited a linear
relationship between the peak
pullout strength and cortical bone
thickness, with the combined T0
and T6 data resulting in r = 0.48
(P < .0001, n = 76). The histological
findings demonstrate bone con-
tact with the screw and modeling
or remodeling events that are
consistent with bone healing.

The experimental time period
of this study (6 weeks) was driven
by the interest in establishing
clinical guidelines on the pullout
characteristics and a description
of the bone histology in the early
stages of clinical use of these
screws. It is thought that screws
may be more vulnerable to failure
during the early healing stages
because of the immature interfa-
cial bone. The present hypothesis
was also based on previous his-
tological studies reporting in-
creased bone remodeling activity
at the screw- or implant-bone
interface.24,25 It has been demon-
strated that bone within 1 mm of
an implant surface exhibits a sus-
tained elevated remodeling rate
and a lower microhardness.26
The elevated rate prevents the
supporting bone from fully min-
eralizing.26 Although the histo-
logical findings reflect events
similar to endosseous implant
healing,27 barring the failures,
this biological response does not
result in a decrease in pullout
strengths at T6 to a level that
would prevent clinical utilization
of these screws.

The most significant experi-
mental difference between the T0
and T6 time points is the absence
of a biological response at T0 (ie,
at the time of insertion). This is
highlighted by failures of the
screws at various sites at T6. The
retention at T0 is entirely based on
the strength of the bone and the
design of the screw, and no such
failures were recorded at T0. The
screw failures are a clinical prob-
lem and have been reported. For
example, in a clinical prospective
study,12 approximately 15 of 140
screws exfoliated over the period
of their intended use. Ten failures
occurred within the first month,
and the remaining 5 failed after
3 to 12 months of loading.

Comparisons between the T0
study and the T6 study have
limitations. Two sets of dogs were
used at 2 different times, and
although all dogs were skeletally
mature and 1 to 2 years old,
individual differences could
exist. To maintain consistency
across the studies, one operator
placed all screws under similar
conditions. All dogs were of the
same breed, sex, and approximate
weight. The screws were placed
in the same region for each dog,
but identical sites, orientations,
and depths of penetration could
not be precisely replicated during
placement. This potential varia-
ion, however, is representative
of what may be expected in
a clinical situation. Additionally,
cautions must be used in directly
extrapolating the results of this
animal study to humans.

At the time of sacrifice, it was
noted that 20 of 102 screws were
loose (not anchored in bone but
only by soft tissue) or were com-
pletely missing. It is not known
at what point the screws became
loose during the 6-week healing
period. For all the screws, bone
purchase was felt at the time of
placement. The occlusion of the
dogs did not appear to interfere
with the screws, and the attending
veterinary staff noted no un-
usual behavior (eg, pawing at
the screws). It is known that primary
stability and subsequent survival
of screws is influenced by the
quality and quantity of the bone
into which they are placed.28,29
The majority of failures occurred
in the mandibular and maxillary
anterior regions. On the basis of
the histology, it was concluded
that a combination of thin cortical
bone and small bone volume
because of root proximity in this
region10 made placement and re-
tention of these screws difficult.
However, it is reasonable to
assume that factors other than bone

Discussion
Results of this study indicate that
T6 peak pullout strengths of
screws and the cortical bone
thickness vary as a function of
insertion site, and peak pullout
strengths of the screws are di-
rectly related to cortical bone
thickness. Peak pullout strengths
and cortical bone thickness (Table 1)
at T6 did not signif-
ificantly change (P > .90) from the
T0 time point reported earlier.
Both studies exhibited a linear
relationship between the peak
pullout strength and cortical bone
thickness, with the combined T0
and T6 data resulting in r = 0.48
(P < .0001, n = 76). The histological
findings demonstrate bone con-
tact with the screw and modeling
or remodeling events that are
consistent with bone healing.

The experimental time period
of this study (6 weeks) was driven
by the interest in establishing
clinical guidelines on the pullout
characteristics and a description
of the bone histology in the early
stages of clinical use of these
screws. It is thought that screws
may be more vulnerable to failure
during the early healing stages
because of the immature interfa-
cial bone. The present hypothesis
was also based on previous his-
tological studies reporting in-
creased bone remodeling activity
at the screw- or implant-bone
interface.24,25 It has been demon-
strated that bone within 1 mm of
an implant surface exhibits a sus-
tained elevated remodeling rate
and a lower microhardness.26
The elevated rate prevents the
supporting bone from fully min-
eralizing.26 Although the histo-
logical findings reflect events
similar to endosseous implant
healing,27 barring the failures,
this biological response does not
result in a decrease in pullout
strengths at T6 to a level that
would prevent clinical utilization
of these screws.

The most significant experi-
mental difference between the T0
and T6 time points is the absence
of a biological response at T0 (ie,
at the time of insertion). This is
highlighted by failures of the
screws at various sites at T6. The
retention at T0 is entirely based on
the strength of the bone and the
design of the screw, and no such
failures were recorded at T0. The
screw failures are a clinical prob-
lem and have been reported. For
example, in a clinical prospective
study,12 approximately 15 of 140
screws exfoliated over the period
of their intended use. Ten failures
occurred within the first month,
and the remaining 5 failed after
3 to 12 months of loading.
thickness and the biological healing response may have been responsible for the unexpectedly high failure rate in the mandibular anterior region. One potential solution would be to use a smaller-diameter (1.5 mm) screw in the mandibular anterior region; however, screws of a smaller dimension may pose a different set of problems.31

Pullout test results during the 2 time points suggested that no differences existed at T0 and T6. Although pullout strengths were greater in the posterior mandible when compared with the maxillary anterior region, it is important to note that variables other than cortical bone thickness also may help explain the clinical success of these screws.

Histomorphometric analyses from this study can be compared with a recent study that used similar quantification methods.24 In comparing the 2 studies, the higher bone contact in the present study may be attributed to the use of self-drilling screws.32 The second study reported higher MAR and consequently a higher BFR at T6.24 Although the researchers did not report the BFR in the dog femur, it may be possible that baseline remodeling was higher because of the younger age of the dogs. The femoral BFR values are within the normal range for turnover and indicate lack of metabolic disease that altered the remodeling rate; however, overall results of the histomorphometric analyses were similar.

The linear measurement of cortical passage thickness is an estimate of the bone available at the various sites at time of insertion. The cortical plate thickness varied from approximately 0.8 to 2.4 mm. At some sites, only 1 thread engaged the cortical bone (Figure 1), whereas at other sites 3 threads (Figure 2) of the screw engaged the cortical bone, providing for more primary stability. Measurements of passage thickness made on the histological sections were more accurate than the measurements made after pullout (Table 1) because of the destructive nature of this test. Nonetheless, similar ranges were obtained by both methods.

It is desirable that the screws can be removed easily without the use of trephines. Thus, the screws are intentionally not subjected to surface treatments (eg, sandblasting, etching, plasma spraying) designed to increase the percentage of bone attachment. At the end of treatment, integration is easily overcome by hand removal with a surgical driver. For this reason, primary stability is critically important for early survival.33

The ability to utilize implant and screw anchorage has greatly affected the clinical practice of orthodontics. At T6, peak pullout strengths of monocortical screws and the cortical bone thickness surrounding the screws varied among the regions in the canine maxilla and mandible. No significant change in pullout strength was found for T6 compared with T0. The results of this study provide the clinical orthodontist with an estimate of the holding power of these screws as a function of cortical bone purchase. After correction for load orientation,18 a static holding power of approximately 122 N (95% CI, 93–150 N)
for 1 mm of cortical bone purchase and ~174 N (95% CI, 147–205 N) for 2 mm of cortical bone purchase was achieved. The adaptation of the screw at T6 included a modeling and remodeling healing response similar to that described for endosseous implants.

ACKNOWLEDGMENTS

Funding from the American Academy of Implant Dentistry, Section of Orthodontics at The Ohio State University is acknowledged. The generous donation of screws from Synthes (USA) is greatly appreciated.

REFERENCES


