Effects of intentional damage of the roots and surrounding structures with miniscrew implants

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Introduction: The purposes of the study were to evaluate the immediate damage to roots and periodontal structures after initial miniscrew implant (MSI) placement and the short- and long-term damage after MSIs were left in situ. Methods: The roots of the maxillary second, third, and fourth premolars of 7 mature beagle dogs were randomly assigned to undergo immediate, short-term (left for 6 weeks), or long-term (left for 12 weeks) damage. Intentional damage was inflicted with self-tapping screws (1.8 x 8 mm) placed with a stent. Alternating tetracycline and calcein labels were administered at 6-week intervals. Undecalcified sections were stained and evaluated histologically to determine the extent of damage; healing was evaluated by using fluorescence labels. Results: Histology showed damage to 73.8% of the teeth, ranging from displacement of bone into the periodontal ligament to invasion of the pulp chamber. Displacement of bone into the periodontal ligament and direct damage to the periodontal ligament occurred in 3 (7.2%) instances. Damage was isolated to the cementum of 8 (19.0%) teeth, whereas damage occurred in the dentin of 11 (26.2%) teeth. Loss of bone in the furcation was evident in 3 (7.2%) teeth, and severe damage into the pulp occurred in 6 (14.2%) teeth. No differences in the amounts of damage were evident between the immediate, short-, and long-term groups. Healing often occurred with cementum around the unloaded MSIs. Conclusions: Extensive damage can be caused by MSIs, with little to no differences evident over time. Unloaded MSIs that remain in contact with roots of teeth can show varying degrees of healing. (Am J Orthod Dentofacial Orthop 2009;135:280.e1-280.e9)

In recent years, miniscrew implants (MSIs) have been increasingly used for anchorage control in orthodontic treatment. However, many orthodontists and other specialists are apprehensive about their placement procedures. Limiting factors for placement of the MSI include the proximity of root structures and the angulation needed for anchorage control. MSIs are typically placed interradicularly and can be used either directly or indirectly for anchorage control. Damage to the dentition and surrounding periodontal structures has been documented during MSI placement,1 force application,2 and movement of teeth into an implant site.3 It has also been claimed that damage directly to a root is not possible.4 Recently, Chen et al5 showed that MSIs placed with intentional root contact had significantly increased failure rates. To date, no controlled experimental studies have evaluated tissue reactions when roots are intentionally damaged with MSIs.

Damage to the roots of teeth is well documented with dental implants and fixation screws. During the placement of dental implants, loss of tooth vitality has been noted,6 transection of root apices has occurred,7 and damage has been attributed to a bur during placement.8 Even though most fixation screws in oral surgery are not placed between the roots of teeth, root damage has been documented in several case studies9,10 and case reports.11-13 Prospective studies of fixation screws reported radiographic damage to the roots in 27.1% to 43.4% of the patients.9,10 A retrospective study evaluating fixation screw damage in facial fractures reported root damage in only 0.47% of patients.14

The literature provides various recommendations for MSI placement, from 2.5 mm of bone around the MSI to protect surrounding vital structures,15 1.0 mm between the periodontal ligament (PDL) and the MSI,16 to 5.0 mm between adjacent roots for adequate space for placement of MSIs.17 Because an MSI can be displaced up to 1.5 mm during loading, Liou et al2 recommended a minimum distance of 2.0 mm between the MSI and the root to allow for such movements.
The experimental literature rarely reports side effects associated with MSI placement. Asscherickx et al, who evaluated damage caused by MSIs radiographically and histologically, suggest that healing occurs. Only 1 experimental study has evaluated the consequences of leaving MSIs in contact with tooth roots for any length of time, but the focus was on stability rather than the consequent tissue reactions.

The specific aims of this study were to evaluate the damage to roots and periodontal structures after initial MSI placement, and after MSIs have been left in situ for 6 weeks (short term) and for 12 weeks (long term). Histologic evaluations were performed because evaluations of root damage by radiographic means alone are limited by the size that the lesions must attain before they can be identified.

MATERIAL AND METHODS

We used 7 skeletally mature male beagle dogs weighing 15 to 30 lbs, between 20 and 24 months of age. After arrival at the facility (day –17), all animals were quarantined for not less than 10 days and fed a balanced soft diet.

The procedures and the timeline of the investigation were the same for all dogs (Fig 1). Before the experiment, MSI placement procedures were developed to ensure damage to the roots of the teeth. By using a fresh pig maxilla, an MSI placement stent with stainless steel indicator rings was developed to guide the MSI into the roots of the teeth. The first dog was used to standardize the procedures and enhance efficiency during the interventions; the remaining 6 dogs were started 4 weeks later. Before each intervention and record-taking session, the animals were sedated with ketamine (2.2 mg/kg/IM) and xylazine (0.22 mg/kg/IM). While anesthetized, their vital signs were monitored and recorded by trained personnel. Initial records were collected during the first intervention. The MSIs were placed during the 3 subsequent interventions. A total of 6 MSIs were placed in the maxilla interradicularly between the second, third, and fourth premolars of each animal (Fig 2), with 2 MSIs placed at each intervention. The MSIs were randomly assigned to each dog’s maxilla to assess long-term damage (left in situ for 12 weeks), short-term damage (left in situ for 6 weeks), and immediate damage (placed immediately before necropsy).

The first intervention was performed on day –7. While the dogs were sedated, full arch impressions were taken with heavy and light body polyvinylsiloxane material (Aquasil VPS, Dentsply, York, Pa) with custom impression trays. From the cast, a custom MSI placement stent was fabricated (Fig 3). A removable vacuum-formed clear tray of thermoplastic copolymer was made with Essix ACE (Dentsply Raintree Essix, Metairie, La). Indicator arms were fabricated from .018-in stainless steel wire and affixed to the clear tray with acrylic resin. The arms served as an initial guide for MSI placement and for changes made according to periapical radiographs taken before MSI placement. An accurate and constant radiographic technique was ensured by using an acrylic mold (Fastray, Bosworth, Skokie, Ill) fabricated for each quadrant from the polyvinylsiloxane impressions (Fig 4). The mold was made to hold 1 indicator arm, 1 aiming ring, and 1 film holder (Dentsply). Placement was standardized by fitting the apparatus to the crowns of the maxillary canines and fourth premolars of each animal. Records—photographs, periapical radiographs (27 × 54-mm Kodak Ultra-speed, Eastman Kodak, Rochester, NY), and evaluations of infection and MSI stability—were made at each intervention and each records visit (Fig 1).

On day 0, periapical radiographs were taken with and without the placement stent in place to ensure that damage would be caused during MSI placement; changes were made to the placement stent if the rings did not overlap the tooth root. The MSIs were self-tapping screws (1.8 × 8 mm; IMTEC, Ardmore, Okla). Two MSIs were placed at each intervention. They were placed after drilling a pilot hole through the buccal cortex only with a slow-speed drill (1.1 mm in diameter) and copious irrigation. Root contact was verified based on
postplacement periapical radiographs and the subjective sensation of changes in tactile resistance while placing the MSIs.

After the second and subsequent interventions, postoperative analgesics (butorphanol, 0.2 mg/kg/IM; ibuprofen, 200 mg every other day for 3 days) and antibiotics (penicillin and benzathine, 300,000 iu/10 lbs/IM) were administered for pain and infection. The last MSIs were placed on day 84 to assess immediate damage with the procedure previously described. The animals were then killed with Beuthanasia-D (Schering-Plough, Kenilworth, NJ) at a dosage of 1 cc intracardiac. The animals were dosed with tetracycline (25 mg/kg/IV) at the end of the second intervention, with calcein (10 mg/kg/IV) at the third intervention, and again with tetracycline (25 mg/kg/IV) at day 83 to label the tissues for histologic examination.

At necropsy, 1 L of 70% ethanol was perfused through each animal. The teeth were sectioned en bloc, and each tooth was placed in a scintillation vial. The blocks were fixed for 7 days in 70% ethanol. Undecalcified specimens were subsequently embedded in methylmethacrylate, and serial sagittal sections were cut 100 to 120 μm thick and ground to approximately 75 μm. Fluorescent images were captured by using an Eclipse 80i microscope (Nikon, Melville, NY) to evaluate newly mineralized hard tissues.20 Tissues were then stained with Stevenol's blue and van Gieson picro-fuchsin, and the slides were evaluated for damage to the tooth root and surrounding structures. Histologic images were taken by using an Axiopt microscope (Zeiss, Thornwood, NY). Identifiable damage was defined as loss or compression of the PDL, displacement or loss of bone, and destruction of the root. The specimens were grouped based on the type of damage. Healing was defined as new PDL, cementum layer, and bone regeneration.

RESULTS

The tactile resistance of the MSIs when they contacted teeth was substantially greater than the resistance of the control MSIs placed adjacent to the teeth.

Of the 42 teeth examined histologically, damage by the MSIs was found in 31 (73.8%) teeth (Table). The damage ranged from the displacement of bone into the PDL to invasion of the pulp chamber. Displacement of bone into the PDL and direct damage to the PDL occurred in 3 (7.2%) instances. Damage was isolated to the cementum of 8 (19.0%) teeth, and damage occurred in the dentin of 11 (26.2%) teeth. Loss of bone in the furcation was evident in 3 (7.2%) teeth, and severe damage into the pulp occurred in 6 (14.2%) teeth. Eleven (26.2%) teeth showed no signs of damage. Of the 42 MSIs, 4 were lost before the dogs were killed, and another 4 MSIs were mobile when the dogs were killed.

Displacement of bone into the PDL space was seen in 2 (4.7%) teeth after immediate placement of the MSI (Fig 5). Both teeth showed normal widths of the PDL on either side of the displaced bone. After damage to the PDL alone, the long-term group showed PDL healing and migration of fibrous connective tissue around the MSI (Fig 6).

Damage into the cementum was evident at all 3 time intervals (Fig 7). Immediate damage (0 week) produced...
Table. MSIs that caused immediate, short-term, and long-term damage to specific hard- and soft-tissue structures

<table>
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<tr>
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<th>Immediate damage (0 wk)</th>
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<th>Long-term damage (12 wk)</th>
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Fig 5. Immediate placement of an MSI causing the displacement of bone (Bo) to compress the PDL adjacent to a tooth root (T): A, 25 times magnification; B, 100 times magnification.

a distinct indentation into the cementum layer of the tooth (Fig 7, A). At the short-term interval (6 weeks), a layer of new cementoid was evident. A fibrous band of PDL-like tissue was also evident between the MSI and the damaged cementum layer (Fig 7, B). After 12 weeks, more healing of the cementum and the PDL had occurred (Fig 7, C). The new cementum was not uniform in distribution. Abnormal attachment of bone directly to the cementum occurred around the MSI (Fig 7, C).

Immediate damage often produced a clean cut well into the dentinal layer (Fig 8, A). After 6 weeks, healing of the defect was evident with a thin line of cementoid tissue (Fig 8, B). However, some areas did not show the new layer of cementoid tissue, indicating that healing had not occurred. The damage after 6 and 12 weeks (Fig 8, C) ranged from minor penetration into the dentin to severe penetration with almost the entire MSI embedded in the root. As also demonstrated over the short term, the fluorochrome labels showed areas of healing over the long term (Fig 9). However, there were areas where healing had not occurred. Damage into dentin was so extensive in 1 tooth that a fracture line could be seen, with evidence of mineralized tissue in the defect.

Evidence of necrotic tissue, inflammation, and loss of bone in the furcation was evident after short- and long-term damage (Fig 10). Of the 3 teeth with furcation defects, 1 MSI had been lost, another was mobile, and only 1 was stable when the dog was killed.

Damage to the pulp was also evident at all 3 time intervals. Four MSIs were placed directly into the pulp chamber, and 2 penetrated into the pulp. Fracture lines were seen in two thirds of the teeth with pulpal damage (Fig 11, A). Immediate damage showed destruction of the pulp chamber in 1 tooth and perforation through the apex in another. As previously described for cementum and dentin damage, some repair of the dentin with cementum occurred over the short term, despite the MSI. Only small amounts of cementum healing were evident. After long-term damage, cementoid tissue formed next to the dentin, even when the tooth apex had fractured off (Fig 11, B). There also was a fibrous layer evident around the MSI.

Four MSIs were lost during the interventions, and 4 were mobile when the dogs were killed. The 4 mobile MSIs had been mobile throughout the experimental period. Three MSIs were lost at 6 weeks; 1 of them showed repair with migration of bone into the defect and evidence of a new layer of cementum and PDL-like tissue formation. Another tooth had damage into the dentin with no evidence of healing and with necrotic tissue next to the defect. The third tooth had necrotic tissue in the furcation.
with evidence of bone loss. The fourth tooth, with 12 weeks of damage, had extensive loss of bone and evidence of cementum healing along the surface of the root. This MSI was mobile at 6 weeks and was lost subsequently. One 6-week MSI and three 12-week MSIs were mobile when the dogs were killed. Necrotic and fibrous tissues were evident around 3 of these 4 MSIs. Damage was extensive to both the surrounding bone

**Fig 6.** Long-term damage to the PDL by an MSI left adjacent to a tooth root (T). The presence of fibrous tissue (FT) is noted adjacent to the MSI: A, 25 times magnification; B, 100 times magnification.

**Fig 7.** Damage to the cementum (Ce) by an MSI during A, immediate, B, short-term, and C, long-term placement and the formation of an abnormal attachment (AA) of bone to cementum. Left column, 25 times magnification; right column, 100 times magnification.
and the tooth root. The fourth mobile MSI was associated with a tooth that was also mobile when the dog was killed. This dog showed evidence of bone loss and periodontal disease at the initial records. Histologically, no supporting bone was evident around the MSI or the tooth root.

**DISCUSSION**

The placement of MSIs can produce immediate damage to teeth, periodontium, and bone. The damage can range from displacement of bone into the PDL space to pulpal damage and root fracture. It was previously

**Fig 8.** Damage to the dentin (D) by an MSI in the A, immediate, B, short-term, and C, long-term groups. Left column, 25 times magnification; right column, 100 times magnification.

**Fig 9.** Healing after 6 weeks despite the MSI. Healing of the root (T) with cementum (Ce) noted in the stained section: A, at 25 times magnification and B, in the fluorescent image at 20 times magnification.
suggested that only minimal damage occurs when an MSI contacts a tooth root.\textsuperscript{4,21,22} Our study shows that damage caused by an MSI can be extensive. Loss of tooth vitality\textsuperscript{6} and transection of root apices\textsuperscript{7} have been previously noted during the placement of endosseous implants and fixation screws. MSIs can also produce an osteotomy through the roots, as previously demonstrated with implants.\textsuperscript{23} Importantly, the MSIs we used were self-tapping; self-drilling MSIs, with sharpened tips to facilitate placement, might be expected to make it more difficult to detect changes in placement resistance. Although our results cannot be directly transferable to humans, knowing that damage can occur during placement emphasizes the need for thorough treatment planning before placement, knowledge of underlying anatomical structures, and informed consent of the patients.

Resistance might be a better indication of root contact than radiographs taken after placement. Normally, resistance increases as the MSI is placed, but the increases are small. The resistance that was noted during placement of the MSI approximately doubled when the roots were contacted or penetrated. Importantly, the operator (M.H.) felt no obvious change in resistance when fracturing the root or contacting the cementum. In contrast to resistance, the periapical radiographs included several instances when damage was thought to have occurred, but it actually had not. The histology showed that damage did not occur 26.2\% of the time, despite radiographs indicating damage or contact. Radiographs have limitations; they provide a 2-dimensional representation of a 3-dimensional object and therefore can give the illusion of root damage.\textsuperscript{19} Radiographs only show a lesion after it attains a certain dimension.\textsuperscript{19} Although it has been claimed that patients should feel increased pressure or pain on percussion and mastication if the root is contacted, this has not been substantiated by research.\textsuperscript{24}

Damage to the pulp by placement of an MSI can produce detrimental and irreversible effects. Damage to the pulp occurred in 14.2\% of the MSIs placed in this study. This type of damage, however, usually warrants either root canal therapy or extraction of the damaged tooth.\textsuperscript{25} Pulp damage has been noted during implant placement.\textsuperscript{6} Even when the pulp chamber was not directly invaded, loss of vitality was noted when bone cuts or screws were placed too close to the root apices.\textsuperscript{19} With an elective procedure such as MSI placement, thorough diagnostic records and radiographs are necessary.
Short- and long-term damage appear to have the same detrimental effects as immediate damage. Based on previous reports, significant root resorption was expected for MSIs that remained in contact with the teeth over time. Jahangiri et al\(^3\) found that root resorption occurred as a tooth was moved into contact with an implant. However, for root resorption to occur, the cementum layer must be breached, and there must be a constant stimulus.\(^{26}\) There was only 1 instance of damage to the pulp that resulted in root resorption. MSIs left in contact with a root with no force applied apparently do not provide sufficient stimulus for root resorption. If forces had been applied to the MSIs, the short- and long-term damage might have been significantly worse. This emphasizes the need for future studies evaluating the consequences of MSIs left in contact with teeth with continuous forces applied.

Short- and long-term healing was evident despite the presence of the MSI and the extensive damage to the root and surrounding structures. In 1 tooth, where the MSI had fallen out, healing of the bone into the defect occurred after 6 weeks (Fig 12). The healing of cementum increased between the short- and long-term groups, as described by Briceno et al.\(^{27}\) The sequence of healing begins with the migration of inflammatory cells and the presence of a clot. The defect fills with new granulation tissue followed by cementoid tissue in the periphery of the defect. With time, the cementum layer become thicker and covers more of the defect.\(^{28}\) As the depth of the damage increased, healing became more variable with less cementum adjacent to the MSI. If the pulp was invaded by the MSI, little or no healing took place, as shown by the lack of mineralized tissue (Fig 13). In 1 tooth with a fractured apex, mineralized tissue had migrated into the defect. Holland et al\(^{29}\) found that the status of the root canal has a substantial effect on healing, not preventing it but, rather, slowing the process. It is possible that greater amounts of healing would have been evident if the study had been longer. Without the application of force on the MSI, healing occurs regardless of the depth of damage to the tooth.

Inflammation increases the damage caused by MSIs. Of the 8 MSIs that were either lost or mobile, 7 showed bone loss and necrotic tissue. Three teeth demonstrated extensive bone loss in the furcation, which was evident radiographically and histologically. These MSIs might have been preventing the migration of cellular components necessary for repair. It was shown that ingrowths of epithelium from the gingival pocket or the oral gingiva can totally or partially prevent reattachment.\(^{30}\) Mobile MSIs also showed necrotic tissue and bone loss. In 3 cases, the damage was adjacent to the MSI, even though it was not in direct contact with the tooth root. This was possibly because the necrotic tissue served as a stimulus for root resorption. In 1 instance, when the MSI was placed into the pulp chamber, an area of resorption appeared to be adjacent to the MSI. There is an increased risk of root resorption and ankylosis when periodontal healing is exposed to chronic irritants.\(^{31}\) The root of a tooth in the long-term group had an area of ankylosis possibly due to a chronic irritant. A favorable environment for root resorption includes destruction of the protective surface covering the mineralized tissue, the presence of vascular connective tissue, or an inflammatory stimulus such as bacteria or trauma.\(^{19}\) This suggests that inflammation can be detrimental to an MSI that touches a tooth root.

Fig 12. Healing shown by A, mineralized tissue at 25 times magnification and B, as seen in fluorescence after loss of an MSI and healing of 6 weeks into the defect at 20 times magnification (Bo, bone; PDL, periodontal ligament; Ce, cementum).

Fig 13. Lack of healing after placement of an MSI into the pulp of a tooth (T): A, Stevenol’s blue with van Gieson picro-fuchsin; B, fluorescent image with lack of fluorescence seen in the defect (*).
CONCLUSIONS

Based on these experimental results pertaining to 7 beagles, we conclude that (1) the placement of MSIs can produce immediate and extensive damage to periodontal structures, (2) short- and long-term damage of unloaded MSIs is similar to immediate damage, (3) short- and long-term healing was evident for MSIs remaining in contact with the tooth root, and (4) inflammation increases the risk of further damage caused by MSIs.

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REFERENCES
