[UCI]I804:11046-000000516154

Histomorphometric evaluation of the bone surrounding orthodontic mini-screws according to root proximity

Hyun-Ju Oh

The Graduate School
Yonsei University
Department of Dentistry

Histomorphometric evaluation of the bone surrounding orthodontic mini-screws according to root proximity

A Dissertation
Submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy in Dental Science

Hyun-Ju Oh

June 2018

This certifies that the dissertation of Hyun-Ju Oh is approved

---

Thesis Supervisor: Chung-Ju Hwang

Hyung-SeogYu

Jung-Yul Cha

Jin Kim

Kwang-Mahn Kim

The Graduate School

Yonsei University

June 2018

감사의 글

우선, 저는 본 논문의 시작부터 완성까지 정확하고 세심한 지도로 이끌어 주신 황충주 지도교수님께 머리 숙여 감사 드립니다. 그리고, 교정학 박사과정을 시작하게 기회를 주셨고 격려를 해주셨으며 논문 수정에 대한 조언을 해주신 유형석 교수님께 깊이 감사 드립니다. 또한, 본 연구의 선학으로서 현실적이고 적절한 조언들로 결과를 내는 데에 도움을 주신 차정열 교수님께 진심으로 감사 드립니다. 뿐만 아니라, 바쁘신 시간을 할애하여 본 논문의 심사를 해주셔서 논문의 완성에 도움을 주신 김진 교수님과 김광만 교수님께 감사 드립니다. 실험의 기술적 지원을 해주신 연세대학교 의과대학 에비슨 의생명 연구 센터의 박규리 선생님, 강봉수 선생님, ㈜ 태웅 메디컬 오송 연구소의 박상현 선생님께 감사의 뜻을 전하고 싶습니다. 무엇보다도, 항상 지치지 않고 최선을 다하는 저라는 존재를 만들어 주신 부모님께 항상 감사 드립니다.

2018년 6월

저자 씀

Table of Contents

List of Table

List of Figure

Abstract

Histomorphometric evaluation of the bone surrounding orthodontic mini-screws according to root proximity

Hyun-Ju Oh

Department of Dentistry
The Graduate School, Yonsei University

(Directed by Professor Chung-Ju Hwang)

This study was conducted to perform histomorphometric evaluations of the bone surrounding orthodontic miniscrews according to their proximity to the adjacent tooth roots in the posterior mandible of beagle dogs. Four male beagle dogs were used for this study. Six orthodontic miniscrews were placed in the interradicular spaces in the posterior mandible of each dog (N = 24). The implanted miniscrews were classified into no loading, immediate loading, and delayed loading groups according to the loading time. At 6 weeks after screw placement, the animals were sacrificed, and tissue blocks including the miniscrews were harvested for histological examinations. After analysis of the histological sections, the miniscrews were categorized into three additional groups according to the root proximity: high root proximity, low root proximity, and safe distance groups. Differences in bone–implant contact (BIC, %) among the root proximity groups and among loading time groups were determined using statistical analyses. No BIC was observed within the bundle bone invaded by the miniscrew threads. Narrowing of the periodontal ligament was observed in cases where the miniscrew threads touched the bundle bone. BIC (%) was significantly lower in the high root proximity group than in the low root proximity group and safe distance groups. However, BIC (%) showed no significant differences among the loading time groups. In conclusion, regardless of the loading time, the stability of an orthodontic miniscrew is decreased if it is in contact with the bundle bone as well as the adjacent tooth root .

Key words: Miniscrew, Root proximity, Bone–implant contact, Bundle bone

Histomorphometric evaluation of the bone surrounding orthodontic mini-screws according to root proximity

Hyun-Ju Oh

Department of Dentistry

The Graduate School, Yonsei University

(Directed by Professor Chung-Ju Hwang)

1. Introduction

Orthodontic miniscrews need to remain stationary in the bone to provide appropriate skeletal anchorage.[1,2] However, miniscrews are often subject to displacement under orthodontic loading, without detectable mobility or loosening.[1,3] Under orthodontic loading, miniscrews remain more stable in D1 (primarily dense cortical bone) and D2 (dense to thick, porous cortical bone at the crest and coarse trabecular bone underneath) bone, because the key determinant for stationary anchorage is the bone density.[4] Although the bone density is relatively higher in the adult mandible than it is in the adult maxilla, the overall failure rate for miniscrews in the mandible is 1.5 times higher (19.3%) than that for miniscrews in the maxilla (12.0%).[4]

Previous studies have documented that contact between an orthodontic screw and the adjacent tooth root is associated with screw failure.[4-6] Kang *et al.*[5] reported that over a period of 8 weeks, the failure rate for miniscrews that had invaded the tooth roots in the posterior mandible of beagle dogs was 79.2%. Kuroda *et al.*[7] analyzed dental radiographs obtained after miniscrew insertion and classified each screw according to its proximity to the adjacent root: category I, screw absolutely separate from the root; category II, apex of the screw appearing to touch the lamina dura; and category III, body of the screw overlaid on the lamina dura. They found a significantly low success rate for category III miniscrews, particularly in the mandible. However, this finding is controversial.[8,9] Asscherickx *et al.*[6] performed histomorphometric analyses in their study on beagle dogs in order to identify a correlation between the success rate for orthodontic miniscrews and the distance from the adjacent tooth roots. However, the authors could not perform statistical analyses, because of the limited number of miniscrews remaining as a consequence of a high failure rate. They suggested that the high failure rate was due to the high frequency of root contact, and that marginal portion of miniscrews may be a risk factor for screw failure.

Dogs, particularly beagles, have commonly been used for investigating miniscrews inserted in the interradicular spaces.[10] For orthodontic miniscrews placed in the mandible of beagle dogs, approximately 6 weeks were necessary for sufficient cortical bone healing before orthodontic loading.[11] Although it has been reported that orthodontic miniscrews achieve primary stability mainly through mechanical retention in the surrounding cortical bone,[12] primary stability can also be achieved in trabecular bone.[13] Orthodontic miniscrews achieve partial osseointegration from 3 weeks after insertion; this increases the removal difficulty.[2] Furthermore, it was reported that there was no significant difference in miniscrew stability between immediate loading with a 250-g load and delayed loading,[14-16] although some researchers have recommended delayed loading (from 3 weeks to 3 months).[17-18] Accordingly, the author intended to determine how the amount of bone surrounding an orthodontic miniscrew changes as the miniscrew approaches the adjacent tooth root, with mild orthodontic force loading.

The aim of the present study was to perform histomorphometric evaluations of the bone surrounding orthodontic miniscrews according to their proximity to the adjacent tooth roots in the posterior mandible of beagle dogs. An additional aim was to perform histomorphometric evaluations of the bone surrounding the miniscrews according to the loading time.

2. Materials and methods

2.1. Experimental animals

Four male beagle dogs aged 12–15 months and weighing 10–15 kg were used in this study. The dogs were bred by veterinarians at the Avison Biomedical Research Center at Yonsei University, Seoul, Korea. The experimental protocol was approved by IACUC (Institutional Animal Care and Use Committee of Yonsei University Health System) and the approval number was 2016-0264.

2.2. Miniscrews

A total of 24 cylinder-type miniscrews (OAS-T1507, Biomaterials Korea Co., Seoul, Korea) with a diameter of 1.45 mm and screw thread length of 7.0 mm were used for this study (Figure 1).

2.3. Experimental procedures

The experimental procedures are depicted in Figure 2. Six miniscrews (three on the left and three on the right) were placed in the buccal interradicular space between the third and fourth premolars (loading group), fourth premolar and first molar (loading group), and second and third premolars (no loading group) in each beagle dog (N = 24). On the basis of previous studies describing the anatomy of the beagle mandible, the miniscrews were placed in regions where the width of the interradicular septum was ≥ 2.2 mm and ≤

3.2 mm.[10] The attached gingiva and alveolar mucosa could not be differentiated at the time of screw insertion (Figure 3).

Before miniscrew insertion, the experimental animal received subcutaneous enrofloxacin (0.5 mg/kg) and intravenous ketorolac (1 mg/kg). The miniscrews were inserted under general anesthesia induced by intravenous atropine (0.05 mg/kg), intravenous ropum (2 mg/kg), and subcutaneous alfaxan (5 mg/kg). Anesthesia was maintained by 2% isoflurane inhalation. All surgical procedures were performed under aseptic conditions. The sites of insertion were assessed using fluoroscopy (C-arm, OEC 9900 Elite; GE OEC Medical Systems Inc., Salt Lake city, USA) before insertion; this aided in visualization of the adjacent tooth roots and the inserted miniscrews. After confirmation of the roots and interradicular septa on fluoroscopic images, the insertion sites were marked. Then, 2% lidocaine HCl (1: 100,000 epinephrine) was infiltrated for local anesthesia at the insertion site, and a 2- to 5- mm vertical incision was placed with a # 12 blade. The entire self-drilling insertion procedure was performed under continuous saline irrigation. The insertion angle was perpendicular to the buccal surface, and the insertion orientation was from buccal to lingual. Immediately after miniscrew placement, on the left side in the loading groups, an elastomeric chain (Ormco Co., Orange, CA, USA) was used to load the screws with a 100- to 200-g continuous reciprocal lateral force (immediate loading group, Figure 3). After insertion, each animal received oral amoxicillin clavulanate (14 mg/kg, once a day) and meloxicam (0.2 mg/kg) for 3 days. For 1 week after miniscrew insertion, the dogs received a soft diet. The regions around the miniscrews were irrigated daily with chlorhexidine solution. At 3 weeks, the miniscrews on the right side in loading groups were loaded with a 100- to 200-g continuous reciprocal lateral force applied using an elastomeric chain (delayed loading group). The force on the left side was reactivated by changing the elastomeric chains. At 4 weeks, the animals received intravenous oxytetracycline hydrochloride (TERA-Inj.; Green Cross Co., Yongin, Korea; 25 mg/kg) for fluorescence microscopy. At 6 weeks, the animals were sacrificed under deep general anesthesia with intravenous KCl. Tissue blocks including the miniscrews were harvested.

2.4. Analysis

2.4.1. Miniscrew failure

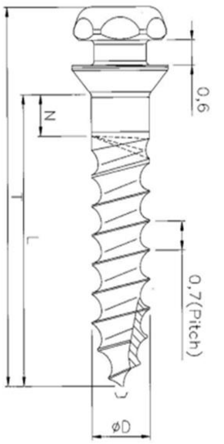
The harvested tissue blocks were sectioned to prepare histological samples and each miniscrew was evaluated for mobility on the tissue block. Mobility was defined and graded as follows using a periodontal grading scale for tooth mobility: grade 0, no mobility; grade 1, detectable mobility; grade 2, mobility up to 1 mm; and grade 3, mobility ≥ 1 mm.[19-20]

2.4.2. Histomorphometry

The tissue blocks were fixed by placing them in a 10% formalin solution for 1 month. After fixation, the blocks were serially dehydrated with 70% to 100% concentrated alcohol for 2 weeks. The dehydrated tissue blocks were embedded in polymethyl methacrylate and cut with a diamond saw parallel to the miniscrew axis, and polished to obtain serial sections (approximately 15-μm-thick) using a cutting/grinding system (the EXAKT: EXAKT Medical Instruments, Oklahoma City, OK, USA). Nondecalcified ground samples were observed under a fluorescence microscope (BX53; Olympus, Japan; excitation filter 340-390 nm, emission filter 515-560 nm) and subsequently stained with hematoxylin and eosin. Histomorphometric parameters were measured on optical microscopy images (BX50; Olympus, Japan). To confirm whether the miniscrews were sectioned parallel to the long axis, the thread lengths were measured again on the tissue sections. Among the many tissue sections, the slice in which the thread length was the closest to the original length was selected. Then, the distance from the miniscrew threads to the adjacent root surface was measured on the mesial and distal sides of each miniscrew, and the shorter distance was used to categorize the miniscrews (Figure 4). Bone–implant contact (BIC, %), defined as the percentage of the implant surface in actual contact with bone or osteoid tissue at a microscopic level,[20-22] was measured (at 50× magnification); only the portions of the miniscrews that were embedded in the bone were included in the BIC measurement.

2.4.3. Statistics

SPSS software (version 23; IBM Co., New York, NY, USA) was used for all statistical analyses. The Kruskal–Wallis test was used to compare the BIC values among the different root proximity and loading time groups. The Mann–Whitney *U*-test was used as a *post- hoc* test. The significance level in all the tests was 0.05 ($p < 0.05$).



	Measurement	(mm)
T	Total length	9.1
L	Screw thread length	7.0
ØD	External diameter	1.45
N	No thread portion	1.0

Figure 1. Representative schematic diagram of an orthodontic miniscrew used in this study (OAS-T1507). A total of 24 cylinder-type miniscrews (OAS-T1507; Biomaterial Korea Co.) with a diameter of 1.45 mm and screw thread length of 7.0 mm were used in this study.

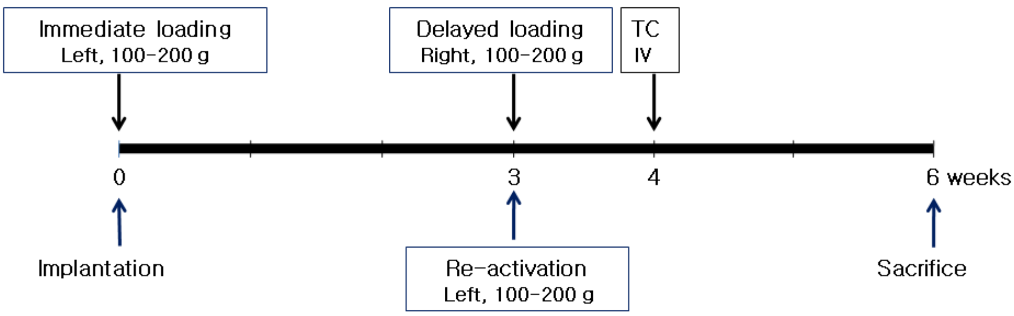


Figure 2. Experimental protocol used in the present study. Immediately after implantation of miniscrews, the miniscrews on the left side were loaded. At 3 weeks after implantation of miniscrews, the miniscrews on the right side were loaded and the force on the left side was reactivated. At 4 weeks after implantation of miniscrews, the animals received intravenous tetracycline for fluorescence microscopy. At 6 weeks, the animals were sacrificed. TC, tetracycline; IV, intravenous.

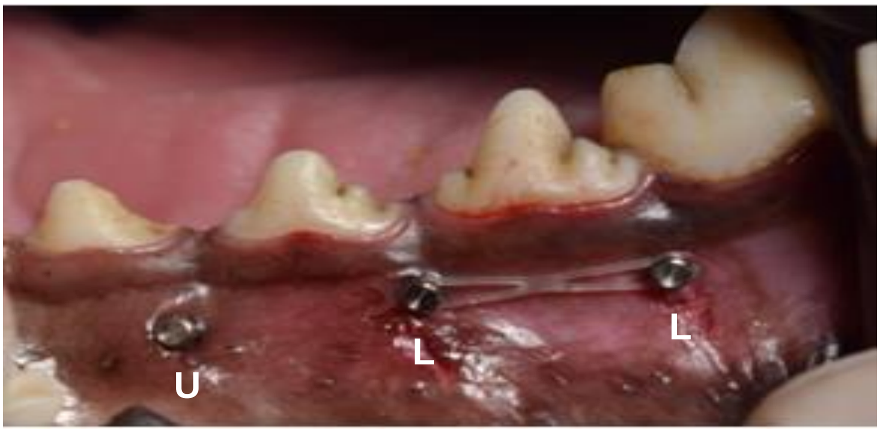


Figure 3. Miniscrews placed in interradicular spaces in the posterior mandible of beagle dogs. An orthodontic force is applied using an elastomeric chain. U: no loading group (screw placed between the second and third premolars). L: loading group (one screw is placed between the third and fourth premolars, while another is placed between the fourth premolar and first molar).

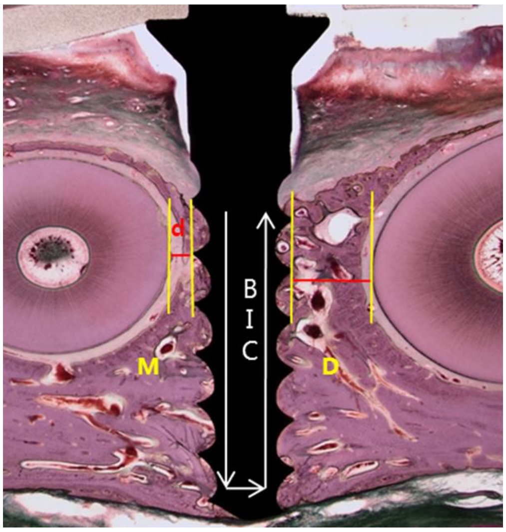


Figure 4. Histomorphometric analysis of a tissue section including an orthodontic miniscrew placed in the posterior mandible of a beagle dog. Image of a hematoxylin and eosin-stained section (12.5×). The distance from the miniscrew threads to the adjacent root surface is measured on the mesial and distal sides (red lines). d: the shortest distance from the miniscrew threads to the adjacent root surface. White arrow: the region of bone implant contact (%) measurement. BIC: bone–implant contact (%). M, mesial side; D, distal side.

3. Results

3.1. Gross mobility

Only one of the 24 miniscrews failed. At 6 weeks after implantation, the failed miniscrew showed grade 3 mobility, whereas the remaining 23 miniscrews did not show mobility (grade 0).

3.2. Categorization of the root proximity groups

On optical images, the miniscrews were categorized into three groups according to the degree of root proximity, which was based on contact with the bundle bone. The high root proximity group included miniscrews that contacted or invaded the adjacent root. In other words, the shortest distance from the miniscrew threads to the adjacent root surface was a negative value. All miniscrews in this group exhibited more than four threads invading the bundle bone (Figure 5A). In the low root proximity group, the shortest distance from the miniscrew threads to the adjacent root surface was within 0.5 mm. The miniscrews involved the bundle bone or periodontal ligament but did not contact the adjacent root surface. All miniscrews in this group exhibited less than three threads touching the bundle bone (Figure 5B). In the safe distance group, miniscrews were placed in the interradicular septum and did not contact the bundle bone (Figure 5C).

3.3. Histological findings

Histological observations showed that the apex of the failed miniscrew, which was in the immediate loading group, contacted the first molar. No BIC was observed around the failed miniscrew.

Part of the periodontal ligament space was narrowed in cases where the miniscrew threads touched the bundle bone (Figure 6A). The bundle bone surrounds the periodontal ligament space and is distinguishable from the surrounding trabecular bone by the absence of large blood vessels such as arteries or veins. Fluorescence microscopy showed that tetracycline was deposited on the surface of the alveolar bone facing the periodontal ligament space at 4 weeks after implantation (Figure 6B).

Figure 7 shows that the miniscrew threads that invaded the bundle bone did not exhibit contact with the surrounding bone. Resorption of roots adjacent to these miniscrews was observed at several sites (Figure 7B and 7D).

Figure 8 shows the root proximity of the miniscrew apex in two miniscrews from the high root proximity group. Both miniscrews were included in the delayed loading group. Around the miniscrew apex, widening of the periodontal ligament and resorption of the adjacent bone were observed (Figure 8C and 8D).

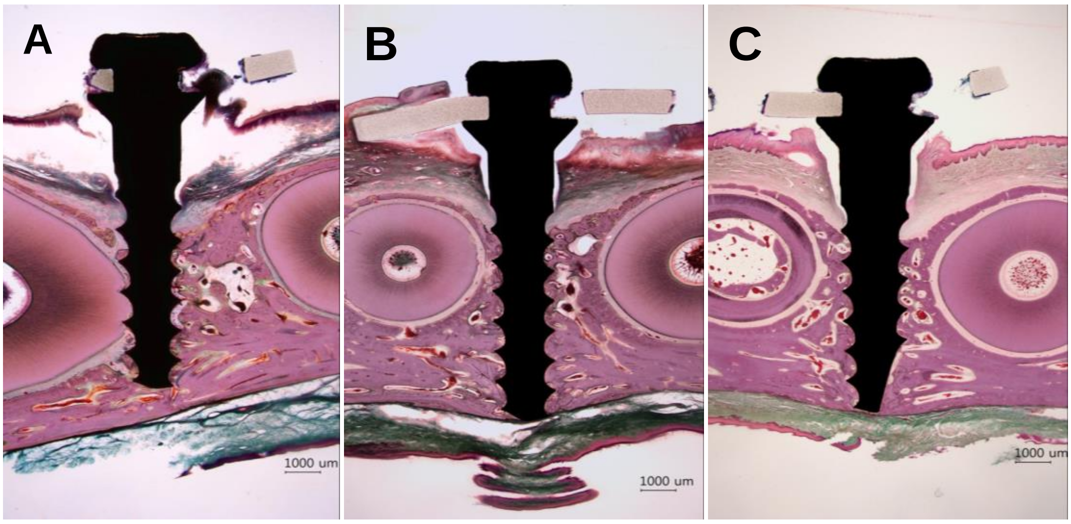


Figure 5. Classification of orthodontic miniscrews according to the proximity to the adjacent tooth roots using hematoxylin and eosin-stained sections (12.5×)

A: High root proximity group

The miniscrew is in contact with the adjacent tooth root.

B: Low root proximity group

The miniscrew is touching the bundle bone or the periodontal ligament but not contacting the adjacent root.

C: Safe distance group

The miniscrew is placed in the interradicular septum, without any contact with the bundle bone.

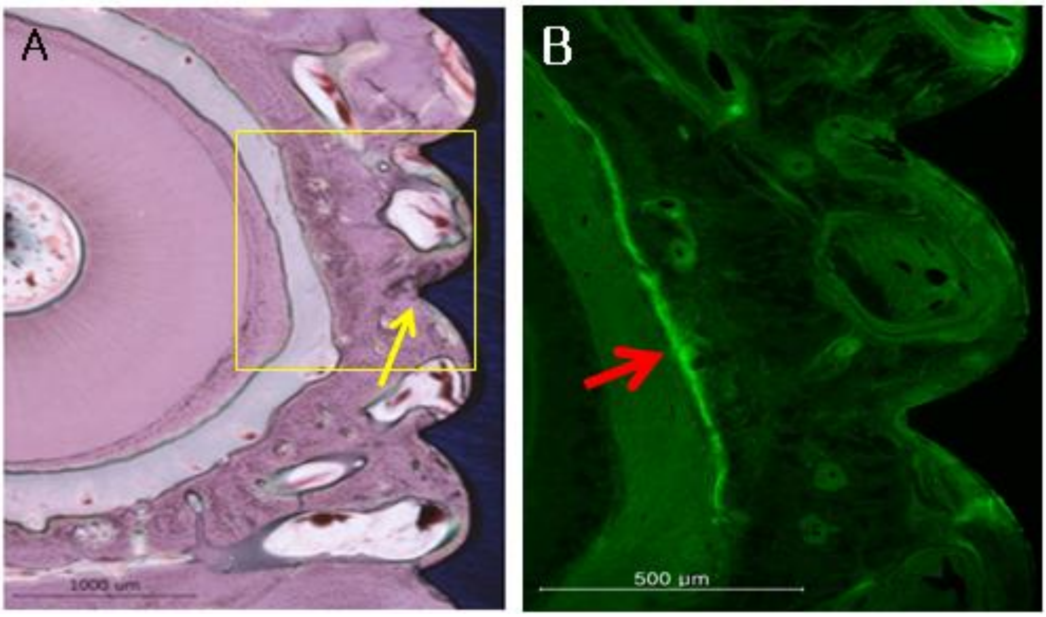


Figure 6. Root proximity of an orthodontic miniscrew without orthodontic loading and low root proximity, with atrophic changes in the adjacent periodontal ligament

A: A hematoxylin and eosin-stained section (50×)

The arrow indicates a miniscrew thread touching the bundle bone. The distance from the miniscrew to the root surface is 0.494 mm. Narrowing of the periodontal ligament space can be observed (area in the box, shown in B).

B: A fluorescence microscopy image with high magnification (100×)

Active bone deposition can be observed as a bright green line (arrow), at the alveolar surface facing the periodontal ligament space.

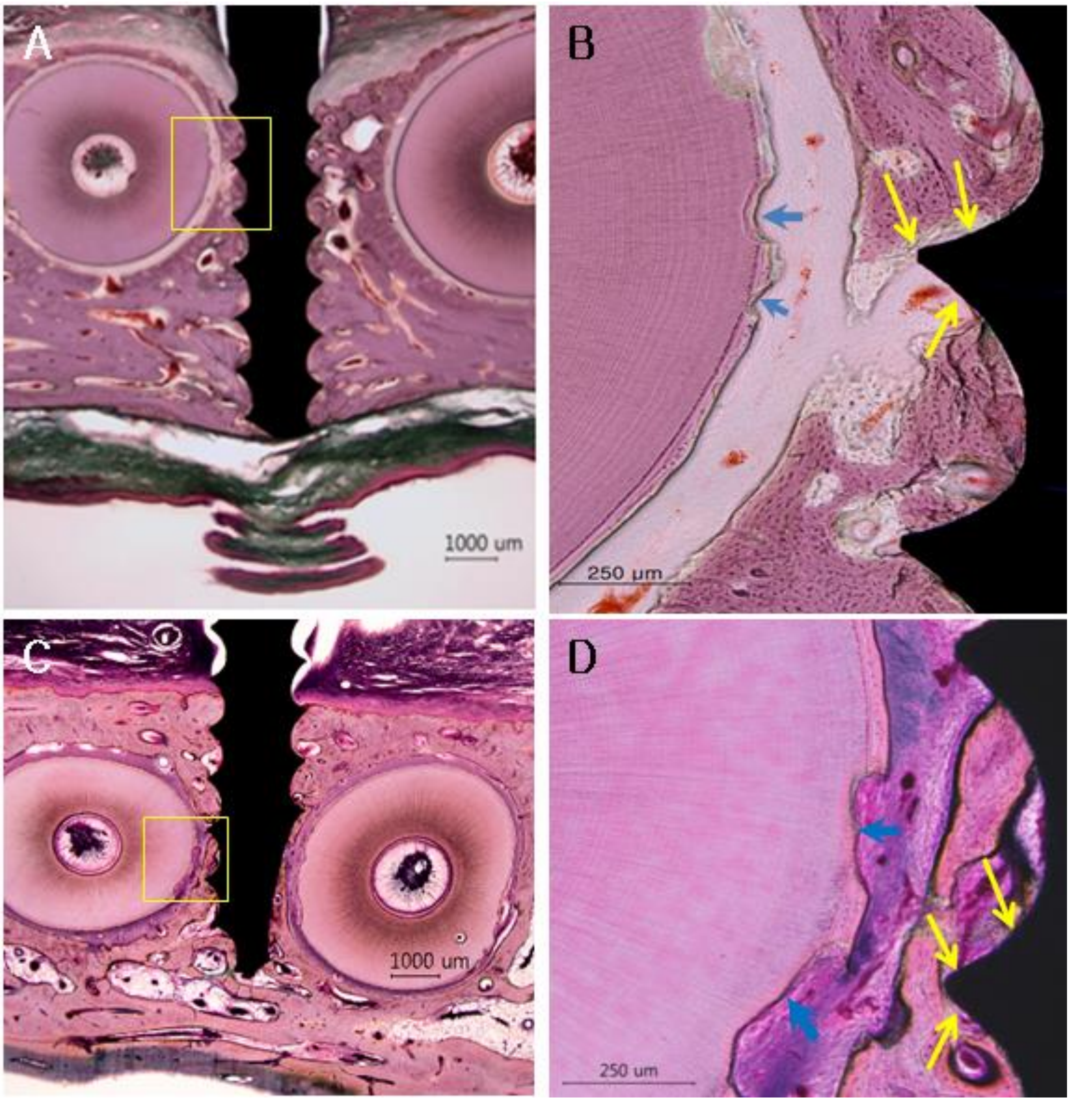


Figure 7. Effect of the proximity of an orthodontic miniscrew body to the bundle bone on the surrounding bone. The images show hematoxylin and eosin-stained sections.

A and **C,** These are miniscrews with low root proximity. The miniscrew threads are invading the bundle bone (boxes, 12.5×). The miniscrew in **A** was loaded immediately after insertion, whereas the miniscrew in **C** was loaded at 3 weeks after insertion. The area in the box in **A** is shown in **B**, while the area in the box in **C** is shown in **D**. **B** and **D,** There is no direct bone–implant contact around the threads within the bundle bone (yellow arrows, 100×). Resorption of the adjacent tooth root can be observed (blue arrows).

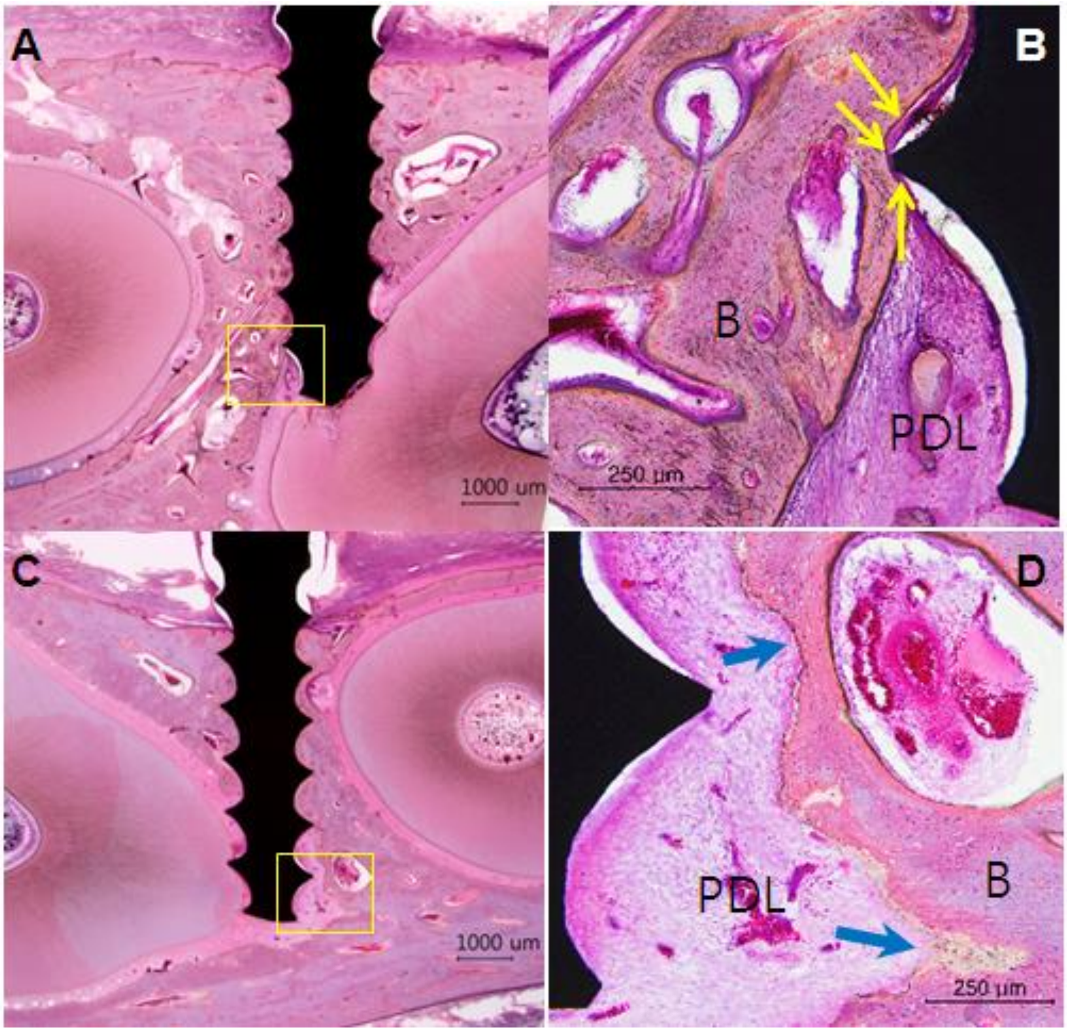


Figure 8. Effect of the proximity of an orthodontic miniscrew apex to the adjacent tooth root on the surrounding bone. The images show hematoxylin and eosin-stained sections. **PDL**: periodontal ligament. **B**: Bone. The miniscrews in **A** and **C** are included in the high root proximity group and in the delayed loading group. **A:** The root contact of a miniscrew apex is observed (12.5×). **B:** Area in the box from A (100×). There is no bone–implant contact within the bone surrounding the miniscrew thread (yellow arrows). **C:** The root contact of the apical portion of a miniscrew. Widening of the periodontal ligament around the miniscrew apex is prominent (12.5×). **D:** Area in the box from C (100×). Resorption areas on the adjacent bone (blue arrows) are observed.

3.4. Histomorphometric analysis

Following repeat measurement of the screw thread length on the tissue sections, the length was found to be within an acceptable range with a deviation of ± 0.26 mm from the original length. The mean length of the miniscrews on the tissue section was 7.22 mm.

Of the 23 successful miniscrews, 11 were included in the high root proximity group, six in the low root proximity group and six in the safe distance group (Table 1). Seven miniscrews in the high root proximity group showed root contact between the fourth premolar and first molar. Table 2 shows subgroups of three root proximity groups classified by loading condition. The mean BIC was 65.72%, 58.07% and 31.61% in the safe distance, the low root proximity, and high root proximity group, respectively. Thus, BIC was significantly lower in the high root proximity group than in the other two groups (Table 3).

The mean BIC in the unloading, immediate loading, and delayed loading groups was 57.67%, 31.39%, and 47.25%, respectively (Table 4), with no significant differences among groups (p = 0.059; Kruskal–Wallis test).

Table 1.The distances from the adjacent tooth roots in the root proximity groups

Root proximity group	Miniscrews (n)	Distances from the two adjacent tooth roots (mm)	
		The shorter distance	The longer distance
Safe distance	6	0.67 ± 0.18	0.87 ± 0.24
Low root proximity	6	0.28 ± 0.17	0.80 ± 0.63
High root proximity	11	-0.22 ± 0.10	1.23 ± 0.84
Total	23		

Values are presented as number only or mean ± standard deviation.

Table 2. Subgroups classified by loading condition within the root proximity groups

Root proximity group	Miniscrews (n)	Loading time (n)			Loading direction (n)	
		Unloading	Immediate	Delayed	Pressure	Tension
Safe distance	6	4	1	1	1	1
Low root proximity	6	2	2	2	1	3
High root proximity	11	2	4	5	2	7
Total	23	8	7	8	4	11

Values are presented as number only. Unloading, Screws without orthodontic loading; Immediate, Screws with immediate orthodontic loading; Delayed, Screws with delayed orthodontic loading. Pressure, Screws with pressure loading; Tension, Screws with tensile loading.

Table 3. Comparison of BIC (%) values among three root proximity groups of orthodontic miniscrews in the posterior mandible of beagle dogs

Root proximity group	Miniscrews (n)	Loading time (n)			BIC (%)
		Unloading	Immediate	Delayed	
Safe distance	6	4	1	1	65.72 ± 5.86
Low root proximity	6	2	2	2	58.07 ± 11.52
High root proximity	11	2	4	5	31.61* ± 14.09
Total	23	8	7	8	

Values are presented as number only or mean ± standard deviation.

Unloading, Screws without orthodontic loading; Immediate, Screws with immediate orthodontic loading; Delayed, Screws with delayed orthodontic loading.

Differences among groups were determined by Kruskal–Wallis and *post- hoc* tests (Mann–Whitney *U*- test). * $p < 0.05$. BIC (%) is significantly different among the three root proximity groups ($p = 0.000$). *Post- hoc* tests show that BIC (%) is significantly lower in the high root proximity group than in the low root proximity group ($p = 0.001$) and safe distance ($p = 0.000$) groups.

Table 4. Comparison of BIC (%) values among three loading times for orthodontic miniscrews placed in the posterior mandible of beagle dogs

Time of loading	Miniscrews (n)	Root proximity group (n)			BIC (%)	*p*-value
		High	Low	Safe		
Unloading	8	2	2	4	57.67 ± 13.62	0.059
Immediate loading	8	5	2	1	31.39 ± 22.48	
Delayed loading	8	5	2	1	47.25 ± 19.91	
Total	24	12	6	6		

Values are presented as number only or mean ± standard deviation.

The immediate loading group included the failed miniscrew with no BIC.

High, Screws with high root proximity; Low, Screws with low root proximity; Safe, Screws at a safe distance from the adjacent tooth roots.

Difference among groups were examined by Kruskal–Wallis tests ($p < 0.05$).

4. Discussion

It remains unclear whether the root proximity of orthodontic miniscrews is a major risk factor for miniscrew failure,[4-9,21] although it has been found to be associated with miniscrew failure.[2,4] The author attempted to investigate how the root proximity of miniscrews affects the bone surrounding the screws and the adjacent roots. Accordingly, the aim of the present study was to perform histomorphometric evaluations of the bone surrounding orthodontic miniscrews according to their proximity with the adjacent tooth roots in the posterior mandible of beagle dogs. I also performed evaluations according to the loading time.

Histological observations revealed that bundle bone invasion by the miniscrews was a factor affecting the bone–implant interface. These results reinforce the postulation that miniscrews belonging to category III, where the entire miniscrew body is overlaid on the lamina dura, show the lowest success rate, particularly in the mandible (35%).[7] Kuroda *et al*.[7] categorized the root proximity of miniscrews on the basis of lamina dura involvement. Furthermore, Watanabe *et al*.[23] performed a quantitative analysis using cone beam computed tomography and reported that the mean distance from the failed miniscrew to the adjacent root surface was 0.81 mm at the apex and 0.90 mm at the mid-section. Previous studies have reported approximate widths of 0.25 to 0.30 mm and 0.22 to 0.54 mm for the periodontal ligament and lamina dura respectively, in humans.[24-26] Therefore, the quantitative results reported by Watanabe *et al*.[12] suggested that the root proximity of miniscrews, which does not necessarily include periodontal ligament or adjacent root surface involvement, could be a risk factor for miniscrew failure.

Histomorphometric analyses performed in the present study revealed that the amount of BIC was significantly low around miniscrews with root contact (high root proximity). The mean BIC for miniscrews contacting adjacent tooth roots was < 35%, while that for miniscrews invading the bundle bone was < 60%. Considering that the orthodontic miniscrews exhibited good osseointegration, ranging from 50.1 ± 14.7 % at 22 days to 82.5 ± 12.6 % at 70 days,[27] in the mandible of beagle dogs, the amount of bone surrounding miniscrews with high root proximity may be insufficient for excellent anchorage. Although the bone–implant interface changed from the bundle bone, BIC in the low root proximity group was not different from that in the safe distance group in the present study, possibly because I could not observe the miniscrew corresponding to category III miniscrews (the entire miniscrew body is overlaid on the lamina dura)[7] in humans. Furthermore, BIC was not significantly different between the immediate loading and delayed loading groups in the present study. Therefore, the author suggests that the loading time is not a critical contributing factor to the hypothesis that the root proximity of orthodontic miniscrews affects the amount of surrounding bone.

Previously, Asscherickx *et al*.[6] tested a hypothesis similar examined in the present study using Beagle dogs. While their study focused on the miniscrew success rate, the author investigated the bone surrounding the miniscrews because I reasoned that stationary miniscrews are fundamentally dependent on support from the trabecular bone and cortical bone. The high failure rate for root-invading miniscrews in beagle dogs could be attributed to several factors, including difficulties in hygiene control and heavy biting force in dogs and the high frequency of root contact due to narrow interradicular spaces. Therefore, in order to decrease the frequency of root contact, the author used miniscrews with a diameter smaller (1.45 mm) than that (1.6 mm or 1.8 mm) of miniscrews used in previous animal studies on root proximity.[28-30] Moreover, to decrease the failure rate for root-contacting miniscrews, the author used the self-drilling insertion method instead of the self-tapping method.[2, 31-35]

To reinforce retrospective radiological studies, histological evaluations of different sections are necessary to obtain precise information.[6] To the best of my knowledge, the present study is the first to histologically focus on the bone–implant interface of orthodontic miniscrews according to the root proximity. Interestingly, atrophic changes in the adjacent periodontal ligament were observed when the miniscrew threads touched the bundle bone in the unloading group. Previous researchers suggested that, under orthodontic loading, periodontal ligament compression could indirectly lead to root resorption because of the migration tendency of miniscrews.[28] Also, a previous animal study reported that, over a period of 15 weeks, and under a 200 to 300 g orthodontic load, root resorption increased from a distance of 0.6 mm between the miniscrew and the root.[29] The present study showed resorption of the adjacent tooth root in cases where the miniscrew threads invaded the bundle bone.

Several limitations of this study should be noted. First, because the sample size was relatively small, and because it was difficult for the operator to intentionally control the distance from the miniscrew to the root, the author categorized the root proximity groups using histological sections. As such, I was unable to perform statistical analyses with a high power or examine the association between the distance from the adjacent root and BIC. Second, the loading direction and the cortical bone thickness could have been different, leading to possible biases. In the future, researchers should conduct well-designed studies to investigate the correlation between partial osseointegration and all classes pertaining to the amount of root proximity or the portion of the miniscrew with root proximity. Furthermore, future studies should observe how root proximity-induced damage to adjacent tooth roots changes under different loading conditions for orthodontic miniscrews.

5. Conclusion

Our findings suggest that, regardless of the orthodontic loading time, the stability of an orthodontic miniscrew is decreased if it contacts the bundle bone as well as the adjacent tooth root. In order to maintain a safe distance from the adjacent tooth root, clinicians should consider positioning orthodontic miniscrews without any contact with the bundle bone in the interradicular septum.

References

1. Liou EJ, Pai BC, Lin JC. Do miniscrews remain stationary under orthodontic forces? Am J Orthod Dentofacial Orthop 2004;126:42-7.

2. Kravitz ND, Kusnoto B. Risks and complications of orthodontic miniscrews. Am J Orthod Dentofacial Orthop 2007;131 (4 Suppl):S43–51.

3. Wang YC, Liou EJ. Comparison of the loading behavior of self-drilling and predrilled miniscrews throughout orthodontic loading. Am J Orthod Dentofacial Orthop 2008;133:38-43.

4. Papageorgiou SN, Zogakis IP, Papadopoulos MA. Failure rates and associated risk factors of orthodontic miniscrew implants: A meta-analysis. Am J Orthod Dentofacial Orthop 2012;142:577–95.

5. Kang YG, Kim JY, Lee YJ, Chung KR, Park YG. Stability of mini-screws invading the dental roots and their impact on the paradental tissues in Beagles. Angle Orthod 2009;79:248–55.

6. Asscherickx K, Vande Vannet B, Wehrbein H, Sabzevar MM. Success rate of miniscrews relative to their position to adjacent roots. Eur J Orthod 2008;30:330–5.

7. Kuroda S, Yamada K, Deguchi T, Hashimoto T, Kyung HM, Takano-Yamamoto T. Root proximity is a major factor for screw failure in orthodontic anchorage. Am J Orthod Dentofacial Orthoped 2007;131 (4 Suppl):S68-73.

8. Kim SH, Kang SM, Choi YS, Kook YA, Chung KR, Huang JC. Cone-beam computed tomography evaluation of mini-implants after placememt: Is root proximity a major risk factor for failure? Am J Orthod Dentofacial Orthp 2010;138:264–76.

9. Janson G, Gigliotti MP, Estelita S, Chiqueto K. Influence of miniscrew dental root proximity on its degree of late stability. Int J of Oral Maxillofac Surg 2013;42: 27-34.

10. Wang Z, Li Y, Deng F, Song J, Zhao Z. A quantitative anatomical study on posterior mandibular interradicular safe zones for miniscrew implantation in the beagle. Ann Anat 2008;190:252–7.

11. Deguchi T, Yabuuchi T, Hasegawa M, Garetto LP, Roberts WE, Takano-Yamamoto T. Histomorphometric evaluation of cortical bone thickness surrounding miniscrew for orthodontic anchorage. Clin Implant Dent Relat Res 2011;13:197–205.

12. Cha JY, Kil JK, Yoon TM, Hwang CJ. Miniscrew stability evaluated with computerized tomography scanning. Am J Orthod Dentofacial Orthop 2010;137:73-9.

13. Marquezan M, Lima I, Lopes RT, Sant'Anna EF, de Souza MM. Is trabecular bone related to primary stability of miniscrews? Angle Orthod 2014;84:500–7.

14. Lee SY, Cha JY, Yoon TM, Park YC. The effect of loading time on the stability of mini-implant. Korean J Orthod 2008;38:149–58.

15. Freire JN, Silva NR, Gil JN, Magini RS, Coelho PG. Histomorphologic and histomorphometric evaluation of immediately and early loaded mini-implants for orthodontic anchorage. Am J Orthod Dentofacial Orthop 2007;131:704.e1-9.

16. Crismani AG, Bertl MH, Çelar AG, Bantleon HP, Burstone CJ. Miniscrews in orthodontic treatment: Reviews and analysis of published clinical trials. Am J Orthod Dentofacial Orthop 2010;137:108-13.

17. Ure DS, Oliver DR, Kim KB, Melo AC, Buschang PH. Stability changes of miniscrew implants over time: A pilot resonance frequency analysis. Angle Orthod 2011;81:994–1000.

18. Motoyoshi M. Clinical indices for orthodontic mini-implants. J Oral Sci 2011;53:407-12.

19. Fleszar TJ, Knowles JW, Morrison EC, Burgett FG, Nissle RR, Ramfjord SP. Tooth mobility and periodontal therapy. J Clin Periodontol 1980;7:495-505.

20. Woods PW, Buschang PH, Owens SE, Rossouw PE, Opperman LA. The effect of force, timing, and location on bone-to-implant contact of miniscrew implants. Eur J Orthod 2009;31:232–40.

21. Youn JW, Cha JY, Yu HS, Hwang CJ. Biologic evaluation of a hollow-type miniscrew implant: An experimental study in beagles. Am J Orthod Dentofacial Orthop 2014;145:626–37.

22. Cho YM, Cha JY, Hwang CJ. The effect of rotation moment on the stability of immediately loaded orthodontic miniscrews: a pilot study. Eur J Orthod 2010;32:614–9.

23. Watanabe H, Deguchi T, Hasegawa M, Ito M, Kim S, Takano-Yamamoto T. Orthodontic miniscrew failure rate and root proximity, insertion angle, bone contact length, and bone density. Orthod Craniofac Res 2013;16;44–55.

24. Nanci A. Dentin-pulp complex. In: Dolan JJ, Pendill J, eds. Ten Cate's Oral Histology: Development and Function. 8th Edition. Elsevier Mosby, 2014:220.

25. Lindhe J. The Edentulous Alveolar Ridge. In: Lindhe J, Karring T, Lang NP, eds. Clinical Periodontology and Implant Dentistry. 5th Edition. Oxford: Blackwell Munksgaard, 2003:53–63.

26. Hubar JS. Quantification of the lamina dura. J Can Dent Assoc 1993;59:997–1000.

27. Büchter A, Wiechmann D, Gaertner C, Hendrik M, Vogeler M, Wiesmann HP, Piffko J, Meyer U. Loaded-related bone modeling at the interface of orthodontic micro-implants. Clin Oral Implants Res 2006;17:714-22.

28. Kim H, Kim TW. Histologic evaluation of root-surface healing after root contact or approximation during placement of mini-implants. Am J Orthod Dentofacial Orthop 2011;139:752–60.

29. Lee YK, Kim JW, Baek SH, Kim TW, Chang YI. Root and bone response to the proximity of a mini-implant under orthodontic loading. Angle Orthod 2010;80:452-8.

30. Brisceno CE, Rossouw PE, Carrillo R, Spears R, Buschang PH. Healing of roots and surrounding structures after intentional damage with miniscrew implants. Am J Orthod Dentofacial Orthop 2009;135:292–301.

31. Park HS, Yen S, Jeoung SH. Histologic and biomechanical characteristics of orthodontic self-drilling and self-tapping miniscrew implants. Korean J Orthod 2006;36:295-397.

32. Cha JY, Hwang CJ, Kwon SH, Jung HS, Kim KM, Yu HS. Strain of bone-implant

interface and insertion torque regarding different miniscrew thread designs using an artificial bone model. Eur J Orthod 2015;37:268–74.

33. Heidemann W, Terheyden H, Gerlach KL. Analysis of the osseous/metal interface of drill free screws and self-tapping screws. J Craniomaxillofac Surg 2001;29:69-74.

34. Kim JW, Ahn SJ, Chang YI. Histomorphometric and mechanical analyses of the drill-free screw as orthodontic anchorage. Am J Orthod Dentofacial Orthop 2005;128:190-4.

35. Türköz Ç, Ataç MS, Tuncer C, Tuncer BB, Kaan E. The effect of drill-free and drilling methods on the stability of mini-implants under early orthodontic in adolescent patients. Eur J Orthod 2011;33:533-6.

Abstract in Korean

치근 근접도에 따른 교정용 미니 스크류 주위 골에 대한 조직형태계측학적 평가

오 현 주

연세대학교 대학원 치의학과

<지도: **황 충 주** 교수>

본 연구는 성견의 하악 구치부의 치근사이공간에 식립된 미니 스크류 주위 골을 인접한 치근에의 근접도에 따라 조직형태계측학적으로 평가하기 위해서 시행되었다. 6개의 교정용 미니 스크류 (총 24개)를 각 성견 (총 4마리)의 하악 구치부의 치근사이공간에 자가 드릴링 방법으로 식립하였다. 성견의 하악골에 식립된 미니 스크류들 중 좌, 우측의 각 1개씩은 부하를 가하지 않았고 (비 부하군), 하악골의 좌측에 식립 된 미니 스크류 2개는 식립 즉시 100-200g의 부하를 가하였으며 (즉시 부하군), 우측에 식립된 미니 스크류 2개는 식립 3주 후에 같은 크기의 힘으로 부하를 가하였다 (지연 부하군). 골 조직의 형광현미경 관찰을 위해 식립 4주 후에 실험동물에 테트라싸이클린을 정맥내 주사하였다. 식립 6주 후에 실험동물을 안락사 시킨 후, 미니 스크류를 포함하는 조직을 채취하여 연마 조직표본을 제작, 관찰하였다. 염색된 조직 표본을 이용하여 인접 치근에서 미니 스크류까지의

거리에 따라 미니 스크류를 3개의 군 (높은 치근 근접도군, 낮은 치근 근접도군, 안전 거리군)으로 분류하였다. 각 미니 스크류 당 BIC (%, 골-임플란트 접촉)를 산출한 후, 치근 근접도 군들과 부하 시기 군들에서 군간에 BIC (%)의 차이가 있는지를 통계학적 분석을 통해 결정하였다. 조직표본 관찰 결과 미니 스크류 나사산이 bundle bone을 건드렸을 때, 인접 치주인대의 위축성 변화가 관찰되었고 미니 스크류의 나사산이 bundle bone을 침범한 경우, bundle bone 내에서는 골-임플란트 접촉이 관찰되지 않았으며 인접 치근의 흡수가 관찰되었다. 뿐만 아니라, 미니 스크류의 첨단 부위가 인접 치근에 접촉된 경우 치주인대 폭경의 현저한 증가와 인접 치조골의 흡수가 관찰되었다. 평균 골-임플란트 접촉 (%, BIC)은 3개의 치근 근접도 군 중 높은 치근 근접도 군에서만 유의하게 낮았고 나머지 2군 사이에서는 유의한 차이가 없었다. 그럼에도 불구하고, 비 부하군, 즉시 부하군, 지연 부하 군들 간에서 BIC (%)는 유의한 차이를 나타내지 않았다. 결론적으로, 본 연구의 결과가 나타내는 것은 교정력의 부하 시기에 상관없이, 교정용 미니 스크류의 안정성은 인접 치근과 접촉된 경우뿐만 아니라 bundle bone과 접촉된 경우에 감소한다는 것이다. 또한, 임상가는 교정용 미니 스크류를 치근사이공간에 위치시킬 때 스크류가 인접 치근으로부터 안전거리를 유지하기 위해서 bundle bone과 접촉되지 않게 하는 것을 고려해야만 한다.

핵심 되는 말: 미니 스크류, 치근 근접도, 골-임플란트 접촉, bundle bone