Original Article

Effects of Microgrooves on the Success Rate and Soft Tissue Adaptation of Orthodontic Miniscrews

Tae-Woo Kim[a]; Seung-Hak Baek[b]; Jong-Wan Kim[c]; Young-Il Chang[a]

ABSTRACT

Objective: To evaluate the effect of microgrooves on orthodontic miniscrews in terms of success rate and soft tissue adaptation in animal experiments.

Materials and Methods: The sample consisted of a non-microgroove (NMG) group and a microgroove group (MG; 50 μm pitch and 10 μm depth microgroove on the upper surface of the miniscrew). Miniscrews of 1.6 mm diameter and 6.0 mm length were placed into beagle dogs. Histomorphometric analysis in each group focused on bone-to-implant contact (BIC) and the bone area (BA) of pressure and tension sides. Independent and paired *t*-tests were completed for statistical analysis.

Results: The success rate was found to be higher in the MG group than in the NMG group. The MG group showed significantly higher BIC on the pressure side when compared with the NMG group ($P < .01$). Although the NMG group showed significantly lower BIC on the pressure side than on the tension side at the upper side of the miniscrew ($P < .01$), the MG group revealed no significant differences between BIC on pressure and tension sides. The MG group generally exhibited perpendicular or circular alignment of the gingival connective tissue fiber with the miniscrew; the NMG group showed parallel alignment.

Conclusions: The orthodontic load may affect bone remodeling on the pressure side of the miniscrew and may affect stability. The microgroove could exert some positive effects on soft tissue adaptation and bone healing.

KEY WORDS: Orthodontic miniscrew; Microgroove; Soft tissue adaptation; Bone remodeling; Histomorphometric analysis; Orthodontic load

INTRODUCTION

Recently, the orthodontic miniscrew was introduced as a new device for anchorage reinforcement.[1–3] Because it usually is applied only during orthodontic treatment, this miniscrew is called a temporary anchorage device (TAD).[4] To enhance the success rate, the size, shape, and threads of the miniscrew have been modified.[5–7]

Soft tissue contact with the implant surface could be considered one of the important factors in implant failure.[8–11] One of the main differences between the gingival connective tissue fibers (GCTFs) that surround a natural tooth and those that surround an implant is the orientation of the GCTF just below the gingival surface. In a natural tooth, the GCTFs, which are inserted into the cementum and the bone, are oriented perpendicularly or obliquely to the tooth surface.[9] However, the GCTFs that surround an implant are mainly parallel to the implant surface.[10–12] This position might allow epithelial downgrowth, which may result in deep pocket formation and invasion of microorganisms between the implant and the soft tissue. It also may cause implant failure.[13] Studies have suggested that the presence of a dominant circular system of GCTFs around the abutment was consistent with the concept of a peri-implant "circular ligament."[14–16]

Surface topography could affect cell growth and ori-

[a] Professor, Department of Orthodontics, School of Dentistry and Dental Research Institute, Seoul National University, Seoul, Korea.

[b] Associate Professor, Department of Orthodontics, School of Dentistry and Dental Research Institute, Seoul National University, Seoul, Korea.

[c] Assistant Professor, Department of Dentistry, Seoul National University Bundang Hospital, Seoul, Korea.

Corresponding author: Dr Young-Il Chang, Department of Orthodontics, Seoul National University, 28-2 Yeonkun-Dong, Chongno-Gu, Seoul, 110-749, Korea (e-mail: nusma@freechal.com)

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entation.[17–19] The smooth surface of the miniscrew may allow pronounced downgrowth of the epithelial tissue as opposed to result with a rougher surface.[17] However, the shallow horizontal grooves showed less epithelial downgrowth and a longer connective tissue seal when compared with machined implants.[18] A grooved surface might have a certain conductive effect on connective tissue adhesion during healing, thereby inhibiting epithelial downgrowth.[19]

Because microtextured implants could enhance the tissue healing response through their structural resemblance to the natural extracellular matrix network,[20,21] and since pillars might reduce inflammation and formation of capsules around implants,[22] microtextures could inhibit epithelial downgrowth.[18,19]

The microgroove on the implant surface is known to play a role in proliferation and migration of fibroblasts, formation of thick connective tissue, the adaptation effect of connective tissue, and, finally, maintenance of soft tissue around the implant.[23,24] Stress on the very small surface around the miniscrew may be as great as 33 MPa, although the orthodontic load may be small.[25] High stress concentrations may cause marginal bone resorption around the implants.[26] One group reported that bone remodeling was different between compression and tension sides of the implant used for orthodontic anchorage.[27]

However, few studies have examined the soft tissue adaptation of the orthodontic miniscrew with comparison of the pressure vs the tension side around the miniscrew. This study was conducted to compare the pressure and tension sides around miniscrews and to evaluate the effects of the microgroove on soft tissue.

MATERIALS AND METHODS

The sample consisted of a non-microgroove (NMG) group and a microgroove (MG) group (Figure 1). The microgroove was 50 μm pitch and 10 μm depth in 300 μm on the upper surface of the miniscrew. Miniscrews measured 1.6 mm in diameter and 6.0 mm in length (Jeil Medical Corporation, Seoul, Korea) and were placed into two beagle dogs (male, 20 months old, 15 kg; female, 14 months old, 10.5 kg).

Surgical Procedures

Anesthesia was given through inhalation of halothane and oxygen. Miniscrews were inserted under irrigation and without a drilling procedure into the buccal and palatal sides of the maxilla and the buccal side of the mandible (Figure 2). Two miniscrews were inserted into each buccal side, and eight were inserted into each palatal side. The MG group was placed on the right side of the maxilla and the mandible, and the NMG group was placed on the left side.

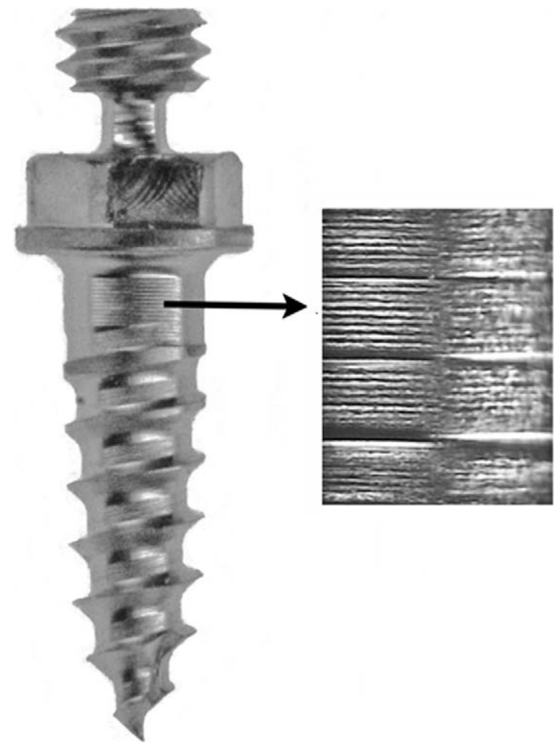

Figure 1. The surface of the orthodontic miniscrew for soft tissue contact in the microgroove (MG) group. The microgroove is 50 μm pitch and 10 μm depth in 300 μm on the surface.

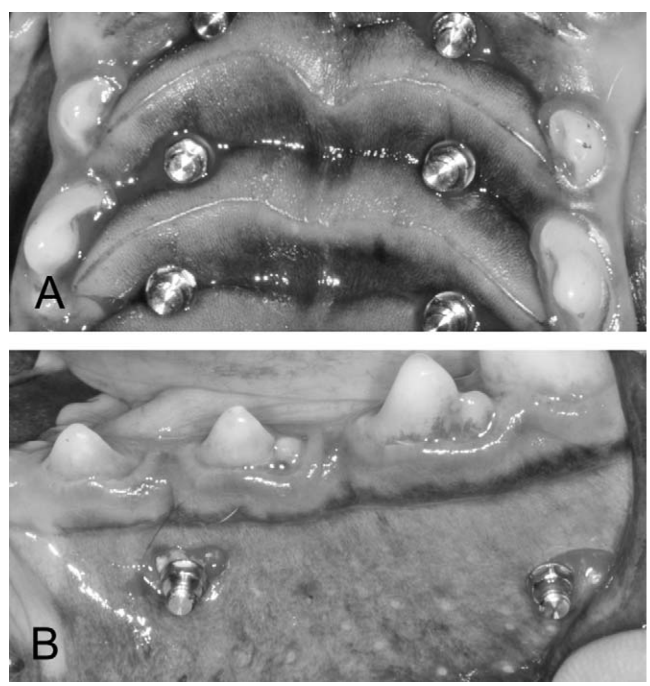

Figure 2. Miniscrews inserted into the palate of the maxilla (A) and the buccal gingiva of the mandible (B).

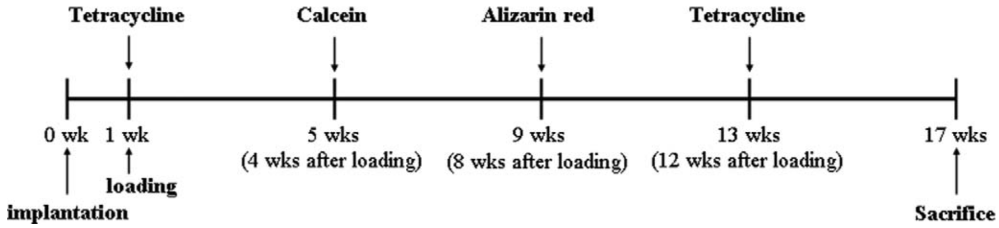

Figure 3. Injection timing of tetracycline, calcein, and alizarin red (Sigma, St Louis, Mo) for fluorescent microscopy observation.

Orthodontic Loading

One week after insertion, a force of 200 to 300 g was applied between the right and left screws in the palate and between the mesial and distal ones in the buccal side of the maxilla and the mandible with the use of a nickel-titanium (Ni-Ti) coil spring (Ormco, Orange, Calif).

Bone Labeling for Fluorescent Microscopy Observation

Three fluorescent dyes (Sigma Co, St Louis, Mo)—tetracycline (25 mg/kg) immediately and 12 weeks after loading, calcein (25 mg/kg) at 4 weeks after loading, and alizarin red (25 mg/kg) at 8 weeks after loading—were injected intramuscularly for fluorescent microscopy observation (Figure 3).

Specimen Preparation

Two beagle dogs were sacrificed for histomorphometric analysis 16 weeks after miniscrews were inserted. Miniscrew specimens along with the surrounding tissue were fixed in 4% paraformaldehyde for 48 hours, were dehydrated sequentially in 70%, 90%, 95%, and 100% alcohol, and were embedded in a light-curing resin (Technovit 7200VLC; Heraeus Kulzer, Dormagen, Germany). Embedded specimens were sliced and ground into 40 to 50 μm with the Exakt cutting and grinding system (Exakt Apparatebau, Nordstedt, Germany).[28] Specimens were prepared so that the pressure side was to the left of the vertical axis of the miniscrew and the tension side was to the right. Specimens were stained with hematoxylin and eosin (HE).

Histomorphometric Analysis

Before the specimens were stained, they were observed under a fluorescent microscope (Nikon Eclipse TE 200; Nikon, Toyko, Japan). Histologic observation was performed with an Olympus BX51 microscope (Olympus Co, Toyko, Japan). The following parameters[29] of the three best consecutive screw threads of each screw were measured with the use of image analyzing software (KAPPA; Opto-electronics GmbH, Kelines Feld, Germany): (1) bone-to-implant contact (BIC), that is, the percentage of total bone contact length on the threads of each screw, and (2) bone area (BA), that is, the percentage of total bone area within the threads of the screw.

Table 1. Loss Rate (%) of the Orthodontic Miniscrew

Area	Orthodontic Miniscrew Loss Rate, % (Loss Number/Total Number)		
	NMG Group	MG Group	Total
Palate	37.50% (3/8)	12.50% (1/8)	25.00% (4/16)
Maxilla	25.00% (1/4)	0.00% (0/4)	12.50% (1/8)
Mandible	0.00% (0/4)	0.00% (0/4)	0.00% (0/8)
Total	25.00% (4/16)	6.25% (1/16)	15.63% (5/32)

MG indicates microgroove group; NMG, non-microgroove group.

Statistical Methods

Fisher's exact test was performed so that differences in the success rate between groups could be examined. Success was defined as no loss and no mobility of the miniscrew. Independent *t*-tests were done to detect differences between the two groups in terms of BIC and BA; paired *t*-tests were used to evaluate the differences between the tension and pressure sides of the miniscrews in each group. $P < .05$ was considered significant.

RESULTS

Loss Rate of the Miniscrew

Five miniscrews (15.63% of the total) failed in this study (Table 1). The loss rate of the NMG group (25.00%) was greater than that of the MG group (6.25%). However, no significant difference in the success rate was noted between groups when Fisher's exact test was performed ($P > .05$).

Histomorphometric Analysis

No significant differences in BIC and/or BA were reported between the two groups, except for BIC on the pressure side (Tables 2 and 3). The BIC on the pressure side in the MG group was significantly higher than that in the NMG group ($P < .01$; Table 2).

Table 2. Comparisons of Bone vs Implant Contact (BIC) Between NMG and MG Groups

	BIC, % (expressed as mean ± SD)		
	NMG Group (n = 12)	MG Group (n = 15)	Sig.
Pressure side	23.39 ± 9.10	40.08 ± 16.85	*
Tension side	44.37 ± 23.59	41.63 ± 14.17	NS
Average	33.88 ± 13.48	40.85 ± 14.44	NS

MG indicates microgroove group; NMG, non-microgroove group; Sig., significance by independent *t*-test; SD, standard deviation; * $P < .01$; NS, not significant.

Table 3. Comparisons of Bone Area (BA) Between NMG and MG Groups

	BA, % (mean ± SD)		
	NMG Group (n = 12)	MG Group (n = 15)	Sig.
Pressure side	50.50 ± 13.88	50.21 ± 16.42	NS
Tension side	51.53 ± 15.68	55.77 ± 16.78	NS
Average	51.01 ± 12.72	52.99 ± 15.09	NS

MG indicates microgroove group; NMG, non-microgroove group; Sig., significance by independent *t*-test; SD, standard deviation. NS, not significant.

Table 4. Comparisons of Bone vs Implant Contacts (BIC) in a Thread Between Upper and Lower Sides on Pressure and Tension Sides and Between Pressure and Tension Sides of the Upper and Lower Portions of the NMG Group

	BIC, % (mean ± SD)		
	Pressure Side	Tension Side	Sig.
Upper side	31.81 ± 8.756	46.95 ± 13.48	**
Lower side	40.71 ± 12.15	35.05 ± 14.90	NS
Sig.	*	**	

NMG indicates non-microgroove group; SD, standard deviation; Sig., significance by paired *t*-tests;
* $P < .05$; ** $P < .01$; NS, not significant.

The pressure sides on the upper portion of the NMG group showed a significantly lower BIC when compared with the tension side ($P < .01$; Tables 2 and 4). However, no significant difference between pressure and tension sides was seen in the MG group (Table 5). A significant difference between the upper and lower sides was noted on both sides of the NMG group and on the tension side of the MG group (Tables 4 and 5).

Histologic Findings

Generally, most implants showed osseointegration with surrounding bone. Harversian systems, lamellar bone, and new bone were seen around the miniscrew (Figure 4). The GCTF in the MG group ran perpendicular to the miniscrew surface or circularly around the miniscrew surface. However, in the NMG group, the GCTF ran parallel to the miniscrew surface (Figure 4).

Table 5. Comparisons of Bone vs Implant Contacts (BIC) in a Thread Between Upper and Lower Sides on Pressure and Tension Sides and Between Pressure and Tension Sides of the Upper and Lower Portions of the MG Group

	BIC, % (mean ± SD)		
	Pressure Side	Tension Side	Sig.
Upper side	46.15 ± 11.24	52.14 ± 14.52	NS
Lower side	48.70 ± 15.81	37.84 ± 19.28	NS
Sig.	NS	*	

MG indicates microgroove group; SD, standard deviation; Sig., significance by paired *t*-tests;
* $P < .01$; NS, not significant.

Fluorescent Microscopic Results

Generally, more bone remodeling could be seen on the pressure side than on the tension side (Figure 5). A site-specific difference in expression pattern was also observed: On the pressure side, more bone remodeling could be seen in the upper part than in the lower part, and the tension side showed the opposite tendency.

DISCUSSION

Tissue adaptation around the implants may be important for more stable use of implants. Therefore, the relationship between the load to the implant and the bone response has been studied. An in vitro study reported that stress concentrations may occur in the marginal peri-implant bone after lateral or oblique load application.[30] Finite element analyses showed that the local strain distribution may have a significant impact on the biological activity of adjacent bone tissue.[31] A high stress concentration may cause marginal bone resorption around implants.[26] Most implant losses were considered to be the result of excessive strains and stresses at the bone/implant interface.[32]

Fluorescent microscopic views (Figure 5) showed active bone remodeling on the upper side of the pressure side and on the lower side of the tension side through tipping of the miniscrew. From the superimposition of labeling, the large orange circles and circles of other colors were broad around the tip and on the pressure side. This means that initial bone remodeling, which was labeled by the first tetracycline, might occur extensively around the tip and on the pressure side.

Four weeks after loading, the bone remodeling labeled by calcein (green color) might happen around the tip of the miniscrew and on the pressure side. Then, the bone remodeling that appears red (from alizarin red) 8 weeks after loading might occur in the lower part of the tension side and in the upper part of the pressure side. Many large, incomplete circles could be seen around the tip and on the pressure side. This indicates that serial bone remodeling might happen

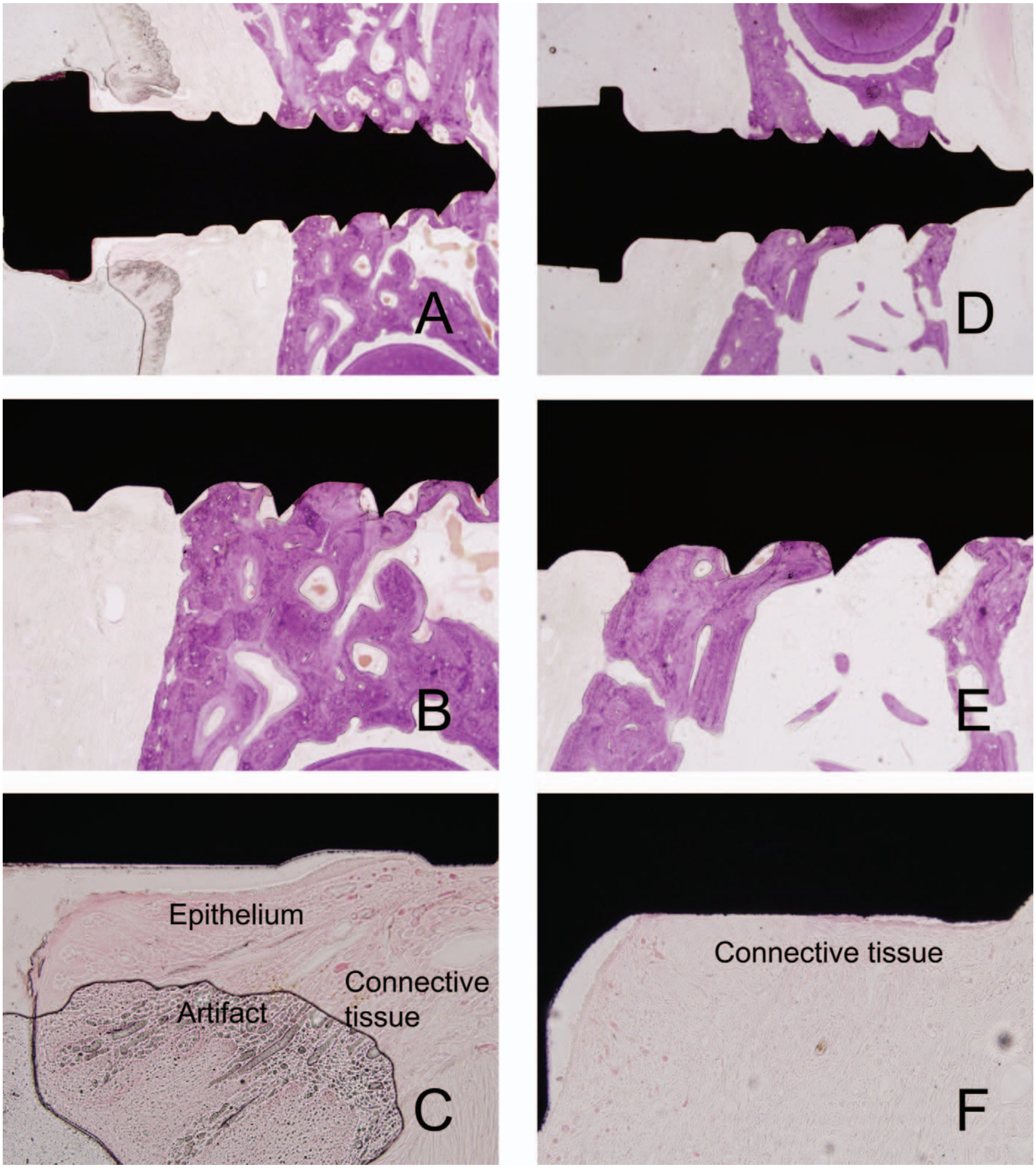

Figure 4. Soft tissue and bone tissue around miniscrews of the non-microgroove (NMG) and microgroove (MG) groups. (A) A miniscrew of the NMG group. (B) The pressure side of the screw from part A of this figure. (C) The soft tissue of the screw in part A. (D) A miniscrew of the MG group. (E) The pressure side of the screw from part D of this figure. (F) The soft tissue of the screw in part D.

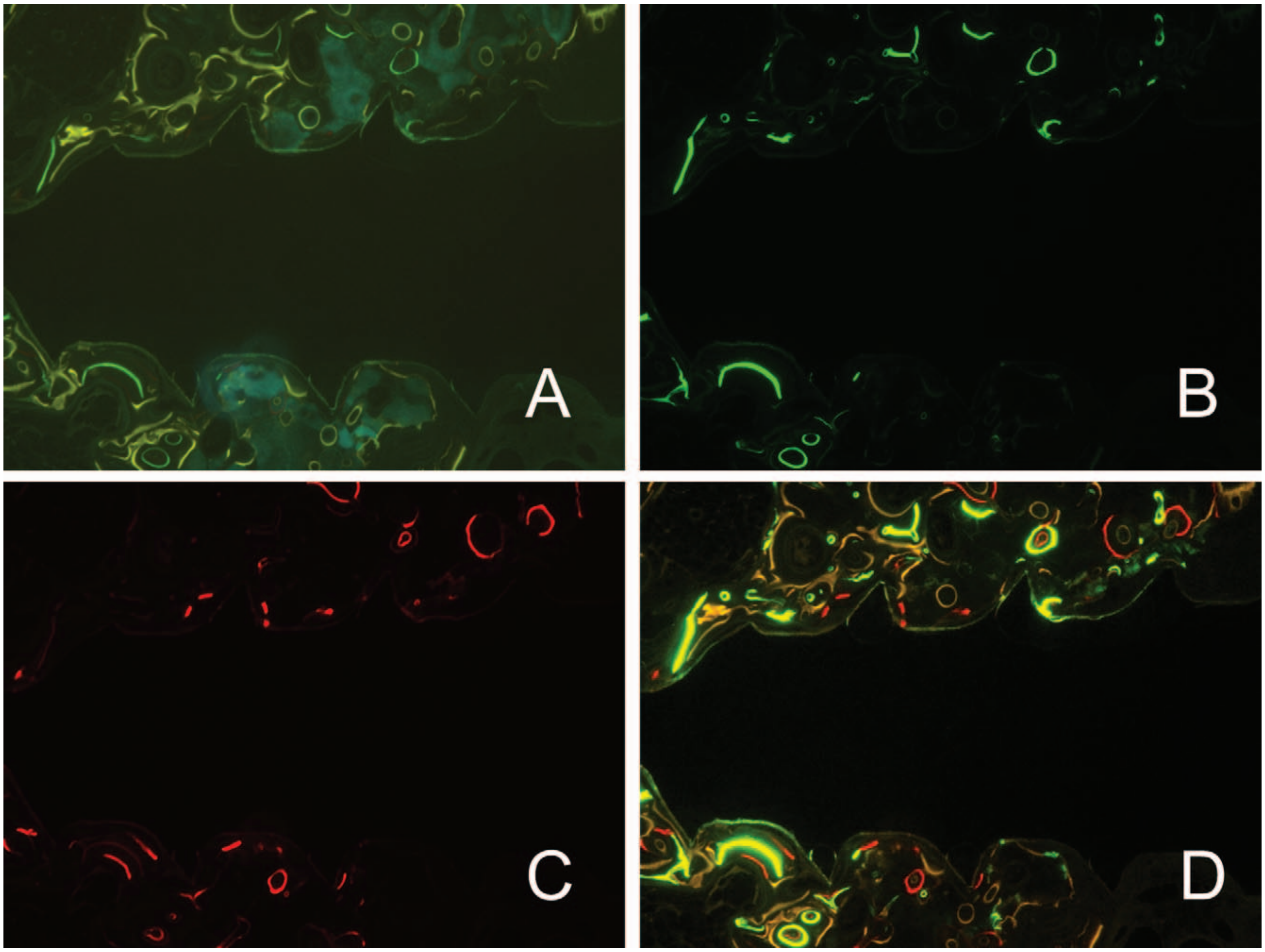

Figure 5. Fluorescent microscopic view. More bone remodeling is seen on the pressure side (left) than on the tension side (right). (A) Yellow or orange caused by tetracycline. (B) Green by calcein. (C) Red by alizarin red. (D) Superimposition of A, B, and C.

and may overlap around the tip and on the pressure side. Small orange circles within green or red circles could be seen all around the miniscrew. This shows that the bone remodeling that was labeled by the last tetracycline 12 weeks after loading might happen all around the miniscrew.

Histomorphometric results from the BIC of the NMG group showed differences between pressure and tension sides in the upper portion ($P < .01$; Tables 2 and 4). On the pressure side of the NMG group, the upper side showed a lower BIC than on the lower side, as opposed to the tension side, on which the upper side showed higher BIC than could be seen on the lower side. The upper portion on the pressure side and the lower portion on the tension side may be the areas in which stress was concentrated because the orthodontic load might induce tipping of the miniscrew to the pressure side.

Excessive loading to bone may reduce bone formation, although bone might exhibit a positive response, such as bone repositioning under 250 psi.[33] Although the orthodontic force from 100 to 300 g is lower than the occlusal force, the stress applied to bone tissue around the miniscrew in a small area may be concentrated and as high as 33 MPa (about 4785 psi).[25] This pressure could be excessive because the miniscrew has a smaller surface area than is seen in a prosthodontic implant. This could induce bone remodeling around the miniscrew. Another study reported that the miniscrews under orthodontic load were tipped to the pressure side and suggested that this might be caused by interposition of the fibrous tissue between the miniscrew and surrounding bone tissue.[34] Results of this study suggest that this event may be caused by active bone remodeling on the pressure side and fibrous tissue interposition. Initial bone remodeling on the upper end of the pressure side of the miniscrew may be harmful to the stability of the miniscrew. The microgroove could support soft tissue adaptation above the pressure side of the miniscrew under active bone remodeling. A difference in alignment of GCTF around the neck of the miniscrew was observed between the MG and NMG groups, although this was not evident in all cases. The MG group showed perpendicular or oblique alignment with the miniscrew surface. However, the NMG group exhibited parallel alignment with the miniscrew surface (Figure 5). This means that the microgroove of the MG group may have a certain conductive effect on connective tissue adhesion, thereby inhibiting downgrowth of the epithelium.[35]

Parallel alignment of the GCTF with the implant surface could not prevent downgrowth of epithelial tissue.[10,11,35] Therefore, results of this study suggest that the microgroove could positively affect the alignment of the GCTF, might induce good soft tissue adaptation to the miniscrew on the pressure side, and could eventually support the stability of a miniscrew while bone remodeling happens in the upper portion of the pressure side. Additional studies on other aspects such as surface treatment and microthreads of the miniscrew are needed to investigate soft tissue adaptation and bone remodeling on the pressure side.

CONCLUSIONS

- A significant difference in the BIC was observed between the pressure and tension sides of the upper portion in the NMG group.
- The MG group generally showed a perpendicular arrangement of connective tissue fibers to the miniscrew, but the NMG group showed a parallel arrangement.
- The microstructure such as microgrooves could have some effects on the arrangement of gingival connective tissue fibers and could positively affect soft tissue and bone tissue adaptation around the miniscrew.

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