European Journal of Orthodontics 32 (2010) 614–619
doi:10.1093/ejo/cjq008
Advance Access Publication 13 May 2010

The effect of rotation moment on the stability of immediately loaded orthodontic miniscrews: a pilot study

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SUMMARY The aim of this study was to evaluate the effect of the direction and magnitude of the rotation moment to loaded orthodontic miniscrews on stability.

In six adult male beagle dogs (12 months old), 36 orthodontic miniscrews were inserted into the mandibular buccal alveolar bone without drilling. Immediately after insertion, 24 miniscrews were loaded with 1- and 2-Ncm nickel titanium (NiTi) coil springs with either a clockwise or counterclockwise rotation moment while 12 miniscrews were left unloaded. Following an observation period of 3 or 12 weeks, the animals were killed and the miniscrews with the surrounding bone were prepared for histomorphometric evaluation. Bone-to-implant contact (BIC) and the ratio of bone volume/total volume (BV/TV) were measured. BIC and BV/TV were statistically compared using the Kruskal–Wallis *H* and Mann–Whitney *U* tests.

Three of the miniscrews loaded with 2 Ncm counterclockwise rotation moment were lost within 3 weeks. At 12 weeks after insertion, the counterclockwise group showed a statistically significantly lower BIC in comparison with the clockwise group.

The results suggest that a rotation moment to loaded orthodontic miniscrews, as well as the direction and magnitude of the rotation moment, can influence miniscrew stability. Counterclockwise rotational moments can be a risk factor impairing miniscrew stability.

Introduction

In orthodontic treatment, securing appropriate anchorage is one of the most important factors in achieving the treatment goal. In the past, approaches included using as many teeth as possible for anchorage or relying on biomechanics requiring patient cooperation, such as extraoral appliances. However, shortcomings of these approaches included the limited anchorage value of teeth and the inconvenience and negative aesthetics of using extraoral appliances, with treatment outcome depending on the level of patient cooperation. Successful substitution for these methods became available with the advent of osseointegrated implants as anchorage for orthodontic treatment (Albrektsson, 1983; Creekmore and Eklund, 1983; Ive, 1990). Recently, osseointegrated implants, onplants, miniplates, and miniscrews have been developed and are widely used in clinical orthodontics (Roberts *et al.*, 1989; Kanomi, 1997; Costa *et al.*, 1998; Umemori *et al.*, 1999; Wehrbein *et al.*, 1999; Park *et al.*, 2001).

Among these, orthodontic miniscrews have several advantages in comparison with osseointegrated implants: minimal anatomic limitations on insertion, simple surgical procedures, and feasibility of immediate loading. (Costa *et al.*, 1998; Ohmae *et al.*, 2001; Kuroda *et al.*, 2007). However, a relatively high failure rate of 10–15 per cent has been a persistent problem when using miniscrews as stable anchorage for orthodontic treatment (Miyawaki *et al.*, 2003; Motoyoshi *et al.*, 2005).

Among various factors mediating the stability of orthodontic miniscrews, the primary focus has been the magnitude and loading time of orthodontic force and its effect on stability (Park *et al.*, 2006). In addition, most studies involved application of a constant direction of horizontal unilateral orthodontic force to miniscrews (Favero *et al.*, 2002; Park *et al.*, 2006). As the range of applications for orthodontic miniscrews broadened, a lever arm or orthodontic wire was attached to the miniscrew head area. In these cases, rotation moments are generated either clockwise or counterclockwise to the implanted miniscrews (Costa *et al.*, 1998; Park, 2006).

Costa *et al.* (1998), in a study of 14 patients, reported that a moment applied on the miniscrews in the screw-removing direction led to miniscrew failure; they concluded that applying a rotational moment to orthodontic miniscrews should be avoided. In addition, Huja *et al.* (2005) found that the force rotating the miniscrews may break the mechanical and chemical bindings (biological bonding) between miniscrews and bone. There are previous clinical studies and observations on the effect of rotation moment on the stability of miniscrews (Costa *et al.*, 1998; Park, 2006), but research focused on histological analysis with regard to miniscrews and bone is scarce. With osseointegrated implants, however, it has been reported that even with loading of rotation force to the implants, no clinical differences were observed, and osseointegration occurred histologically (Roccuzzo *et al*., 2001; Cochran *et al*., 2002; Moriya *et al*., 2006).

In the present study, a rotational moment was applied after placement of orthodontic miniscrews. Using histomorphometric analysis, the effect of the direction and magnitude of the rotation moment on the stability of orthodontic miniscrews was examined.

Materials and methods

Animal care and all experimental procedures were approved by the institutional review board, Animal Experiment Committee at Yonsei University. Six male beagle dogs (12 months old) weighing 12.0 kg were used in this study. The dogs were fed a soft diet for 1 week after insertion of miniscrews. All six dogs remained in good health throughout the experimental period.

The miniscrews used in this study (OAS-1507C, Biomaterials Korea Inc., Seoul, Korea) were the non-drilling column type, 1.45 mm in diameter and 7 mm in length. A total of 36 miniscrews were used. In order to load the rotation moment to the miniscrews, hook-shaped stainless steel wires (0.9 mm in diameter, 7 mm in length; Remanium, Dentaurum, Ispringen, Germany) were attached to the head portion of the inserted miniscrews. The head portion of the miniscrews was sandblasted to obtain a correct bond strength when attaching the hook-shaped wires. Twelve miniscrews were left unloaded and served as the controls.

Computed tomographs were taken prior to the insertion of the miniscrews to determine the appropriate insertion site. The proximity to the dental roots was also assessed (Figure 1).

All experimental and control miniscrews were inserted in the mandibular buccal alveolar bone. In the controls, the miniscrews were inserted in the distal area of the mandibular second premolar, and in the experimental groups, between the third and fourth premolars and between the dental roots of the first molar. Insertion of miniscrews was performed by an experienced operator under local anaesthesia. A 15- to 20-mm incision was made on the mandibular buccal gingiva, and a mucoperiosteal flap was elevated. The miniscrews were inserted manually without drilling under continuous saline irrigation. Miniscrew insertion angulation was 70–90 degrees to the gingival surface in consideration of the buccolingual width of the alveolar bone. After insertion of the miniscrews, the hook-shaped wires were bonded with primer (Metal Primer, Reliance, Itasca, Illinois, USA), resin bonding adhesive (Transbond™ XT, 3M Unitek, Monrovia, California, USA), and light cured (Ortholux, 3M Unitek) in order to apply the rotation moment. After bonding, the periosteum flap was replaced, and the incised gingiva was sutured with a 3-0 suture (Mersilk®, Ethicon, San Angelo, Texas, USA). The suturing material was removed after 1 week.

The miniscrews in the control group were left unloaded, while those in the experimental groups were loaded immediately after insertion. As the moment was defined as the product of the force times the perpendicular distance from the point of force application to the centre of resistance, the magnitude of force could be calculated (rotation moment (1 or 2 Ncm) = the length of lever arm wires (0.7 cm) × magnitude of horizontal force). To obtain a 1 Ncm rotation moment, a force of 142 g was needed. The force was applied using a NiTi coil spring (Ormco, Glendora, California, USA) that was reactivated every 3 weeks.

For both the clockwise and counterclockwise moment loading groups, orthodontic force was applied for either 3 or 12 weeks (Table 1). Allocation to the each loading group was determined randomly between the two sides of the mandible. After miniscrew insertion, 10 mg/kg cefazoline was administered for 3 days to prevent infection, and during the experimental period, daily oral rinsing was performed with chlorhexidine to maintain good oral hygiene.

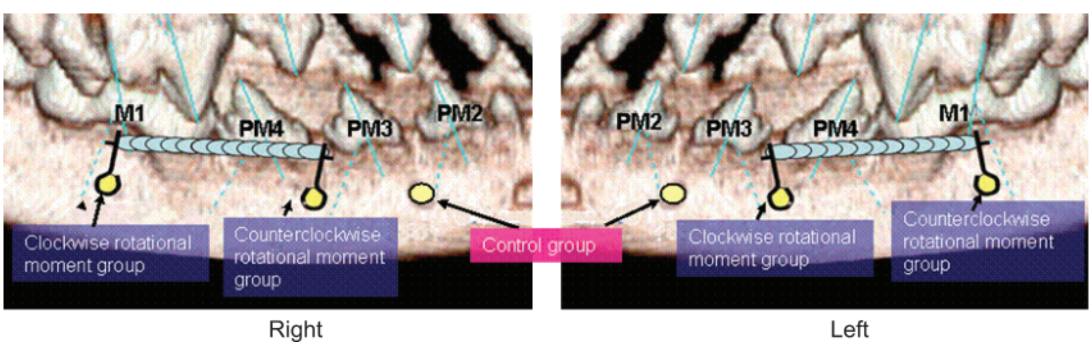

Figure 1 Schematic image of miniscrew insertion position. The miniscrews in the experimental groups were inserted into the mandibular buccal alveolar bone between the third (PM3) and fourth (PM4) premolars and between the dental roots of the first molar (M1). Miniscrews in the control groups were inserted into the mandibular second premolar (PM2) distobuccal alveolar bone. An orthodontic wire was attached to the head of the miniscrew in the experimental groups. Groups in which a rotational moment was applied were reciprocally loaded by a NiTi coil spring.

Table 1 Distribution of the 36 implants and variables (time, direction, moment) in the different groups.

Groups	Experimental group		Control group	
	3 weeks	12 weeks	3 weeks	12 weeks
0 Ncm			6	6
1–2 Ncm clockwise	4	8		
1–2 Ncm counterclockwise	4	8		
Number of implants	8	16	6	6

After 3 or 12 weeks observation, the animals were killed with an intravenous injection of sodium chloride under deep anaesthesia. Tissue blocks, including the miniscrews, were harvested and fixed in 10 per cent formalin solution for 1 month. After fixation, the tissue samples were serially dehydrated with a 70–100 per cent concentration of alcohol, embedded in polymethylmethacrylate, and hardened under vacuum conditions using a light curing unit. The resin-embedded tissue blocks were sectioned using a diamond saw (Maruto, Tokyo, Japan), and undecalcified samples 100–110 µm thick were prepared with a hard tissue grinding system (Maruto) and stained with toluidine blue. Tissue slides were imaged at ×100 under a light microscope (Leica DC 300F, Leica Microsystems, Wetzler, Germany) and stored as a BMP file. Measurements were performed with the Image-Pro Version 3.0 program (Media Cybernetics, Inc., Betheseda, Maryland, USA). Histomorphometry was performed within 800 µm of the miniscrews, with measurement of the bone-to-implant contact (BIC) and the ratio of bone volume/total volume (BV/TV). BIC was defined as bone in direct contact with the miniscrew surface. The percentage of BIC was calculated as total BIC divided by the total length of the miniscrew surface × 100. BV was defined as sum of bone area within 800 µm of the miniscrew and TV as the total area within 800 µm of the miniscrew surface. The percentage of BV/TV was calculated as BV divided by TV × 100. The percentage of BIC and BV/TV was measured on the cortical bone.

Statistical analysis

Statistical calculations were carried out using the Statistical Package for Social Sciences (Windows v 11.0, SPSS Inc., Chicago, Illinois, USA). Kruskal–Wallis *H* and Mann–Whitney *U* tests were performed to determine whether a significant difference could be detected among the experimental periods and the groups.

Results

Of the 36 miniscrews, three loaded with a counterclockwise rotation moment were lost within 3 weeks, an overall success rate of 91.7 per cent. The clockwise rotation moment loading group showed a 100 per cent success rate, but the 2 Ncm counterclockwise rotation moment loading group showed only a 50 per cent success rate, with three miniscrew failures (Table 2). Because of the high failure rate of the counterclockwise group loaded with 2 Ncm, histomorphometric analysis was performed only on the group loaded with 1 Ncm.

Table 2 Number of orthodontic miniscrews and success rate by group.

	n (miniscrews)	Success	Failure	Success rate (%)
Control	12	12	0	100
1 Ncm clockwise	6	6	0	100
1 Ncm counterclockwise	6	6	0	100
2 Ncm clockwise	6	6	0	100
2 Ncm counterclockwise	6	3	3	50

In the 3-week groups, both the clockwise and counterclockwise loading groups showed a low BIC in comparison with the control group; however, the difference was not statistically significant ($P > 0.05$). In the 12-week groups, the clockwise group showed a BIC of 73.9 per cent, and the counterclockwise group a BIC of 63.2 per cent, a significant difference ($P < 0.05$; Table 3).

The BIC of miniscrews in the clockwise group was significantly higher at 12 weeks in comparison with the 3-week group ($P < 0.05$). In the counterclockwise groups, significant differences were not detected ($P > 0.05$; Figures 2 and 3). For each loading time, no significant differences between the experimental and the control group were observed ($P > 0.05$). Regarding BV/TV ratio, there was no significant difference between each loading period in the control group ($P > 0.05$). However, there was a significant increase in BV/TV ratio in the clockwise and counterclockwise group in the period between 3 and 12 weeks ($P < 0.05$; Table 4, Figures 2 and 3).

Discussion

Various factors affect the stability of orthodontic miniscrews, including the surgeon, the patient, factors related to the miniscrews themselves, the magnitude of orthodontic force, and loading periods (Miyawaki *et al.*, 2003). The success rate of miniscrews ranges from 83.9 to 91.6 per cent (Cheng *et al.*, 2004; Motoyoshi *et al.*, 2005; Park *et al.*, 2006).

The success rate of orthodontic miniscrews between the two experimental groups in the present study differed depending on the direction of the applied rotation moment. In the clockwise group, the miniscrews showed a 100 per cent success rate; however, three miniscrews failed in the 2-Ncm counterclockwise group, giving a success rate of only 75 per cent. The success rate of the counterclockwise group was

Table 3 Comparison of bone-to-implant contact (%) among the groups for each period.

Period (weeks)	Group						
	Experimental				Control		P*
	Clockwise		Counterclockwise				
	Mean	SEM	Mean	SEM	Mean	SEM	
3	54.4	6.7	48.1	0.6	70.2	11.6	NS
12	73.9	3.5	63.2	4.3	69.1	7.8	<0.05

NS, not significant; SEM, standard error of mean.
*Kruskal–Wallis H test; significance between clockwise and counterclockwise groups at 12 weeks.

Table 4 Comparison of bone volume/total volume (%) among the groups for each period.

Period (weeks)	Group						
	Experimental				Control		P*
	Clockwise		Counterclockwise				
	Mean	SEM	Mean	SEM	Mean	SEM	
3	63.9	8.9	59.8	3.5	74.6	9.1	NS
12	83.5	1.6	81.5	4.1	86.9	1.3	NS

NS, not significant. SEM, standard error of mean
*Significance of groups by Mann–Whitney U test.

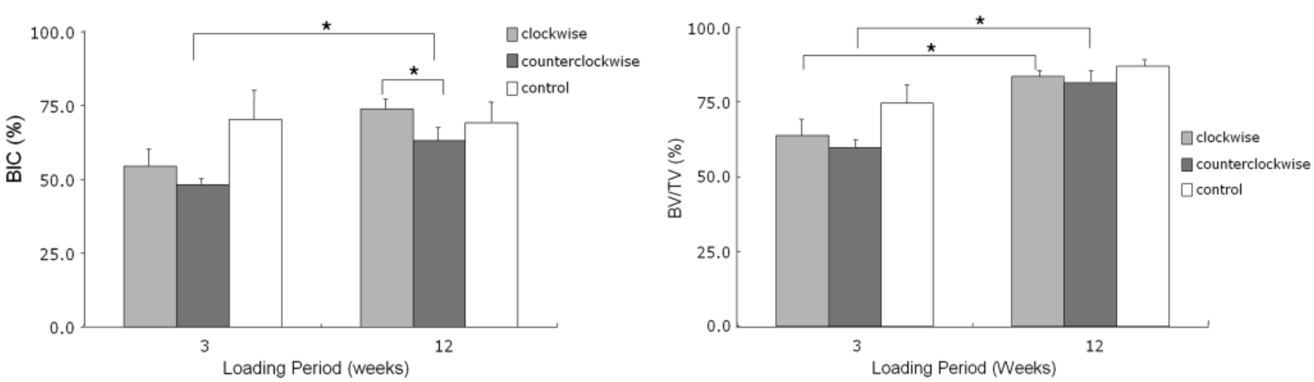

Figure 2 Comparison of bone-to-implant contact (BIC) and bone volume/total volume (BV/TV) among the groups for each period. * $P < 0.05$.

relatively lower than that previously observed for orthodontic miniscrews without a rotation moment. José *et al.* (2007) reported a success rate of 100 and 77.78 per cent for a control and experimental group, respectively, with 78 miniscrews in six beagle dogs. In another study, there were no miniscrew failures in the mandibles of beagle dogs (Kim *et al.* 2008).

The load delivered to osseointegrated implants and orthodontic miniscrews substantially influences bone density and remodelling of adjacent alveolar bone (Melsen and Lang, 2001; Buchter *et al.*, 2006). In osseointegrated implant cases, if high pressure is focused on the bone–implant interface, bone resorption of adjacent bone results. Implant failure without infection under these conditions results, in most cases from excessive pressure loaded to the bone–implant interface (Adell *et al.*, 1981; Meyer *et al.*, 2001; Buchter *et al.*, 2005). In the present study, there was no failure of miniscrews with

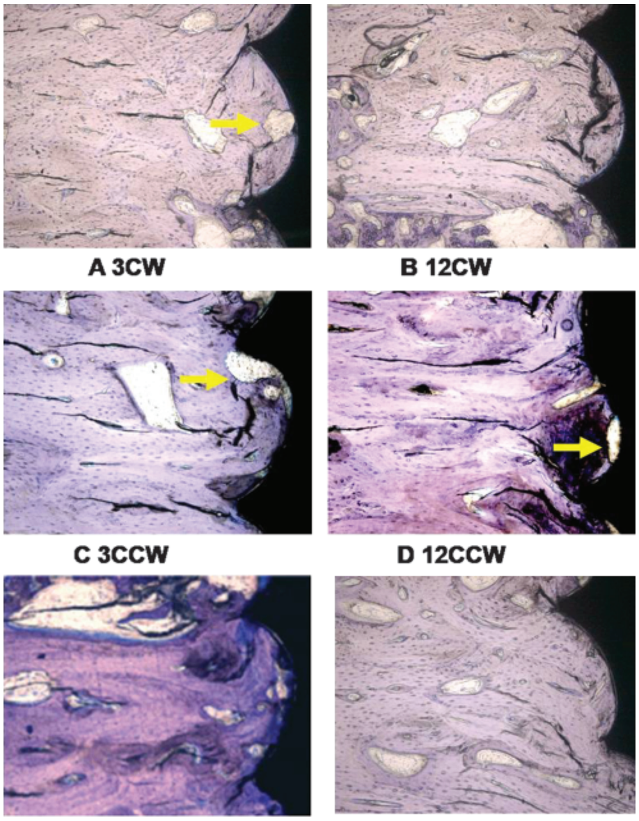

Figure 3 Histophotometric comparison of orthodontic miniscrews from the control (C) and experimental groups (CW: clockwise, CCW: counterclockwise). Toluidine staining (×100). A, 3CW, miniscrew group with clockwise moment at 3 weeks; B, 12CW, miniscrew group with clockwise moment at 12 weeks; C, 3CCW, miniscrew group with counterclockwise moment at 3 weeks; D, 12CCW, miniscrew group with counterclockwise moment at 12 weeks; E, 3C, control group at 3 weeks; and F, 12C, control group at 12 weeks. Arrows show extensive bone resorption at the miniscrew–bone interface. Bar: 100 μm.

a 1 Ncm rotation moment, regardless of the direction. On the other hand, when loaded with a 2 Ncm counterclockwise rotation moment, the miniscrews failed. In other words, loading with a counterclockwise rotation moment with a large magnitude could induce excessive pressure on the bone–miniscrew intersurface, decreasing the success rate. However, at a magnitude of 1 Ncm, stability was maintained regardless of direction, implying that miniscrews are stable against a physiological rotation force (Buchter *et al.*, 2006). In the present research, approximately 150 cN of lateral force was loaded for the 1 Ncm rotation moment group (given by the formula: moment = force × distance). This force can be considered within the range of that expected for the traction of orthodontic teeth in clinical orthodontics.

The BIC at 12 weeks after implantation in the counterclockwise group was significantly lower compared with that in the clockwise group. In a clinical study in humans, Liou *et al.* (2004) investigated the location of orthodontic miniscrews prior to and after loading. The miniscrews were clinically stable, but among 16 patients, seven showed movement during the loading of orthodontic force. In the present experiment, orthodontic force was loaded in the direction of miniscrew loosening in the counterclockwise group, which could be considered a cause of the low BIC.

Orthodontic force was loaded immediately after miniscrew implantation. In osseointegration dental implant cases, a 2- to 6-month healing period is recommended for complete osseointegration. It has been reported that in cases of early loading, fibrous tissues may infiltrate the BIC, and insufficient healing periods can be a cause of implant mobility (Brånemark *et al.*, 1997; Majzoub *et al.*, 1999). In orthodontic miniscrew cases, however, immediate loading was performed based on the results of studies proposing this approach (Deguchi *et al.*, 2003; Buchter *et al.*, 2005). Particularly as light forces are generally used in orthodontic tooth movement, the healing period for miniscrews is shorter than conventional implants, so immediate loading can be acceptable (Cornelis *et al.*, 2007). Immediate force application in this study did not impair the clinical stability of the miniscrews; however, as it may have a mediating effect in association with miniscrew movement, additional studies pertinent to the loading time of orthodontic force are required.

In the clockwise group in the current study, the BIC of the two experiment groups at 12 weeks was significantly increased in comparison with 3 weeks following implantation. In addition, at 3 weeks post-implant, the experimental groups, compared with the controls showed low ratios of BIC and BV/TV. In terms of the loading time of orthodontic force, immediate loading itself did not result in an adverse effect on miniscrew stability. However, in this study, orthodontic force was loaded with a rotation moment, different from previous reports on immediate loading with a unilateral horizontal force (Melsen and Costa, 2000; Favero *et al.*, 2002). Thus, it could be interpreted that, at 3 weeks after implantation, in comparison with the control group, this loading in association with the rotation moment resulted in low BIC and low BV/TV.

When the stability of orthodontic miniscrews against rotation forces was compared, miniscrew failures were noted only in the counterclockwise groups. BIC after 12 weeks of orthodontic force was significantly lower in the counterclockwise than in the clockwise group. Therefore, the clinical technique of loading miniscrews with a counterclockwise rotation moment may be a risk factor for reduced miniscrew stability. It is recommended that a force system that produces a counterclockwise moment to miniscrews should be avoided. The connection of two miniscrews or miniscrews connected to teeth as indirect anchorage can be a stable anchorage system (Melsen and Verna, 2005; Leung *et al.*, 2008). However, even with a counterclockwise rotation moment, the miniscrew still can be used as stable anchorage by controlling the magnitude of force. Further evaluation is required of miniscrew stability relative to the direction of rotation moment, varying magnitudes of force, the time elapsed before loading, and implantation methods. Additionally, future studies should be extended beyond 12 weeks to determine long-term stability.

Conclusion

Although the transferability of animal experimental findings to humans has to be addressed with some reservation, the following findings may be of clinical relevance. When a rotation moment is loaded to orthodontic miniscrews, the direction and magnitude of the rotation moment can influence miniscrew stability. A counterclockwise rotation moment may be a risk factor for reducing miniscrew stability.

Funding

College of Dentistry, Yonsei University (6-2007-0068).

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