Original Article

Evaluation of the effect of force direction on stationary anchorage success of mini-implant with a lever-arm–shaped upper structure

Ki-Ho Park[a]; Eun-Man Lee[b]; Seung-il Shin[c]; Seong-Hun Kim[d]; Young-Guk Park[e]; Su-Jung Kim[f]

ABSTRACT
Objective: To compare the effect of clockwise and counterclockwise torque on the primary stability of a mini-implant with a lever-arm–shaped upper structure.
Materials and Methods: Twenty-four white rabbits were used for this study. Two screw-type mini-implants were placed in each tibia. In all, 96 screws were inserted. Two weeks later, a 2-N force was applied to the mini-implants without an upper structure in eight rabbits (control group). The mini-implants of the other 16 rabbits were loaded with an upper structure (experimental group). In the experimental group, the two left mini-implants were loaded in a clockwise direction (CW group) and the two right implants were loaded in a counterclockwise direction (CCW group). The rabbits were sacrificed at 1 week or 8 weeks after loading in both control and experimental groups. The removal torque value (RTV) was measured in 15 of 16 mini-implants in each group and the remaining implant was processed for histologic examination.
Results: At 1 week there were no significant differences in the mean RTV between the control, CW, and CCW groups. At 8 weeks, the RTV was higher in the control and experimental groups than in the respective 1-week groups. At 8 weeks, there were no significant differences in the RTV between the control and CW groups, but the CCW group showed a lower RTV.
Conclusions: CCW torque can decrease the stability of a mini-implant, whereas a CW torque has no effect. (*Angle Orthod.* 2011;81:776–782.)

KEY WORDS: Mini-implant; Removal torque; Stability; Osseointegration; Rotational force

INTRODUCTION

Various aspects of force affect the stability of mini-implants, including the timing of force application, its magnitude, and its direction. There have been many studies about the optimal timing of force loading. Some authors have insisted that a healing period after the placement of mini-implants is indispensible for the stability of the implant,[1–6] while others have stated that the early loading is possible since the orthodontic force applied was within the primary stability gained by the mechanical binding between the mini-implant and surrounding bone.[7–12] There are no reports of the maximum force that can be tolerated by a mini-implant. However, most studies have used a force of 1.5 to 3 N to test mini-implants.[2,3,13–15]

Most previous mini-implant studies used mini-implants without a lever-arm–shaped upper structure,[16–18] so they estimated only simple lateral forces (Figure 1). Therefore, few studies have reported on the effect of force direction with a rotational moment on the stability of the mini-implant. However, when an orthodontic force is applied to a mini-implant with a lever-arm–shaped upper structure, either a clockwise moment or counterclockwise moment is applied (Figures 2 and 3). Therefore, studies investigating the effect of force direction on the stability of mini-implants are needed.

Costa et al.[7] reported that mini-implant failure can occur when the torque moment is applied in a unscrewing direction clinically. Huja et al.[19] suggested

[a] Assistant Professor, Department of Orthodontics, Kyung Hee University, Seoul, South Korea.
[b] Public Health Dentist, Jangseong Public Health Center, Jangseong, South Korea.
[c] Clinical Instructor, Department of Periodontology, Kyung Hee University, Seoul, South Korea.
[d] Associate Professor, Department of Orthodontics, Kyung Hee University, Seoul, South Korea.
[e] Professor, Department of Orthodontics, Kyung Hee University, Seoul, South Korea.
[f] Assistant Professor, Department of Orthodontics, Kyung Hee University, Seoul, South Korea.
Corresponding author: Prof Su-Jung Kim, Department of Orthodontics, Kyung Hee University, 1, Hoegi-dong, Dongdaemun-gu, Seoul, Korea
(e-mail: ksj113@khu.ac.kr)

Accepted: March 2011. Submitted: September 2010.
Published Online: May 26, 2011

 DOI: 10.2319/092810-566.1

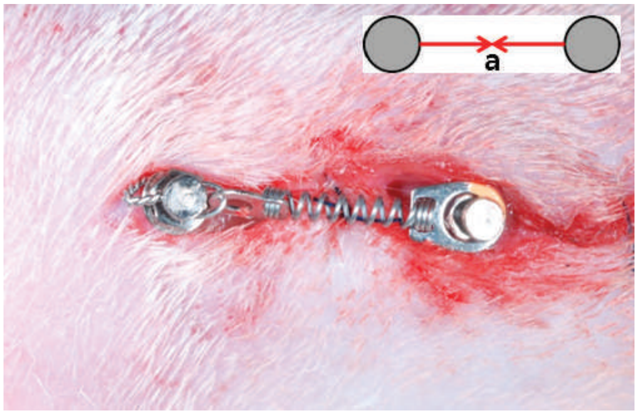

Figure 1. Force loading on the mini-implants without upper structures. Schematic diagram of the mini-implants without upper structures (upper right). a indicates the direction of force (only simple lateral force was applied).

that a rotational force would break the mechanical and chemical bonds between the mini-implant and bone. Cho et al.[14] investigated the effects of torque moment on mini-implant stability by examining the histological findings and success rate. The aforementioned studies measured the clinical success rate or examined histological samples to assess the effect of rotational moment on the stability of mini-implants.[7,14,19] However, none of them examined the stability of mini-implants using removal torque values (RTVs).

Clinical determination of a mini-implant's anchorage can be done by measuring the removal torque. The concept of removal torque was first introduced by Carlsson et al.[15] for the development of an implant design. Klokkevold et al.[20] interpreted higher RTVs as indicative of increased bone-to-implant contact and osseointegration.

The aim of this study was to estimate the effect of force direction on the stability of mini-implants with a lever-arm–shaped upper structure by examining histological findings and measuring removal torque after applying a clockwise or counterclockwise moment in two time frames: at the first week, prior to formation of bridging callus; and at the eighth week, after formation of bridging callus.

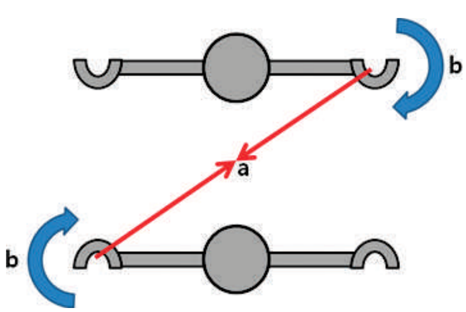

Figure 2. A schematic diagram of clockwise loading on lever-arm–shaped upper structures. a indicates the direction of force; b, clockwise moment.

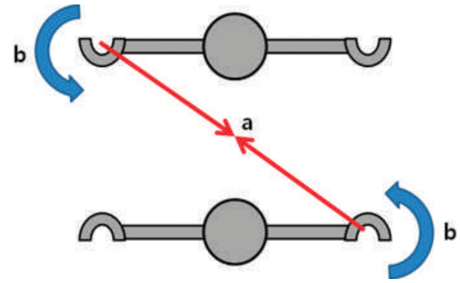

Figure 3. A schematic diagram of counterclockwise loading on lever-arm–shaped upper structures. a indicates the direction of force; b, counterclockwise moment.

MATERIALS AND METHODS

Materials

The protocol of the animal study was approved by the Ethics Committee on Animal Research at Kyung Hee Medical Center, Kyung Hee University. A prototype mini-implant, 7 mm in length and 1.6 mm in diameter that had been sandblasted and acid etched in its threaded portion (Figure 4), and a lever-arm–shaped upper structure, was used in this study (Figure 5).

Placement of Mini-implants

Twenty-four New Zealand white rabbits were used. The rabbits were divided into two groups containing 12 rabbits each according to the duration of loading (1 week or 8 weeks). In the control group, a 2-N force was applied to the mini-implants without an upper structure. In the experimental groups, a 2-N force was applied to the upper structure (clockwise group, counterclockwise group).

Each rabbit was anesthetized intramuscularly with Zoletil 50 (zolazepam and tiletamine, 0.2 mL/kg; Virbac, Carros Cedex, France). The hair around the implantation site (tibia near the femur of the hind leg) was removed completely using a depilatory. The

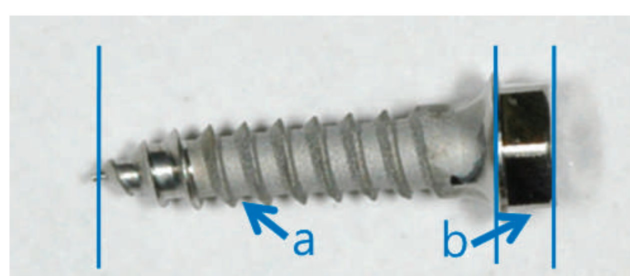

Figure 4. Screw part of new mini-implant. a indicates the implant body; b, implant head.

Figure 5. Upper structure of new mini-implant.

surgical site was scrubbed with Potadine (povidone iodide) and the tibia was exposed by incisions with a no. 15 blade. A flap was reflected with a periosteal elevator and the mini-implants were placed using a manual driver with cooling water. The first implant was placed in the tibia 20 mm away from the femur, and the second implant was placed 10 mm distal to the first mini-implant (Figure 6). Implants were placed bilaterally in all animals.

No initial load was applied and, after sufficient saline irrigation, the implantation area was sutured with chromic 4-0 sutures (AILEE, Seoul, Korea) in the muscle and with 4-0 black silk (AILEE) in the skin.

Two weeks after implantation, the head of the screw part was exposed by a second surgery. A nickel-titanium closed-coil spring (Ormco, Orange, Calif) was applied to the coronal portion of the mini-implants without an upper structure with a 2-N force in eight rabbits (Figure 7).

In the remaining 16 rabbits, a 11-mm-long upper structure was attached to the exposed head of the threaded portion of the implant in the parallel position and a nickel-titanium closed-coil spring (Ormco) was engaged. A 2-N clockwise force was applied to the left tibia, and a counterclockwise 2-N force was applied to the right tibia (Figures 8 and 9).

Figure 7. Force loading (prototype without upper structure).

Euthanasia and Tissue Preparation

The rabbits were sacrificed at either 1 or 8 weeks after loading using an overdose of Zoletil 50 (zolazepam and tiletamine, 0.2 mL/kg, Virbac). The implanted sites were exposed and excised, including 5 to 10 mm of bone tissue surrounding the implanted site. The peak RTV of the 15 mini-implants in each group was measured using an analog torque gauge (6BTG, TOHNICHI, Tokyo, Japan). The remaining mini-implant in each group was processed for histological observation.

Tissue blocks, including the mini-implants, were harvested and fixed in 10% formalin solution for 1 month. After fixation, the tissue samples were serially dehydrated in 80% to 100% concentrations of alcohol, embedded in polymethylmethacrylate, and hardened under vacuum conditions using a light-curing unit. The resin-embedded tissue blocks were sectioned using a sawing machine (BS3000N, Exakt, Norderstedt, Germany), and undecalcified samples 50 μm thick were prepared with a microgrinding machine (4110, Exakt) and stained with hematoxylin-eosin.

Figure 6. Placement of a new mini-implant.

Figure 8. Clockwise loading.

Figure 9. Counterclockwise loading.

Statistical Analysis

Statistical analyses were carried out using SPSS software (13.0). The data of the three groups in each loading group (1 and 8 weeks) was tested using one-way analysis of variance and a Duncan post hoc test. The differences in RTV of each loading method between the 1-week and 8-week groups were compared using a *t*-test. A $P < .05$ was considered significant.

RESULTS

Results of Removal Torque Testing

In the 1-week group, the RTV was similar in all three groups (Table 1). In the 8-week group, there was no significant difference in the RTV between the control group and clockwise group, but the counterclockwise group had a lower RTV than the other groups (Table 2). In the control and experimental groups, the RTV was significantly higher at 8 weeks than at 1 week (Table 3).

Histological Findings

Destructive bone fragments caused by mechanical trauma while placing the mini-implant and soft tissue were observed histologically in the 1-week samples (Figures 10 through 12). There were no histological differences between the control and experimental groups (both clockwise and counterclockwise groups). Owing to new bone apposition in the 8-week group, which was independent of the force application method, the amount of mini-implant/cortical bone contact increased compared to the 1-week group (Figures 13A, 14A, 15A). However, the counterclockwise group showed a larger bone defect area between the mini-implant and the cortical bone than the clockwise and control groups (Figures 13B, 14B, 15B).

Table 1. Removal Torque Values (in Ncm) of the 1-Week Group

Group	Sample Size	Mean	SD
Control	15	5.63A	0.931
Clockwise loading	15	5.81A	0.881
Counterclockwise loading	15	5.37A	0.791

A Groups with different letters are significantly different from each other ($P = .05$).

Table 2. Removal Torque Values (in Ncm) of the 8-Week Group

Group	Sample Size	Mean	SD
Control	15	10.1C	0.946
Clockwise loading	15	9.72C	0.891
Counterclockwise loading	15	7.32B	0.743

B,C Groups with different letters are significantly different from each other ($P = .05$).

DISCUSSION

Stability is the most important consideration when using mini-implants for anchorage. Various factors affect the stability of mini-implants when force is applied, including the timing/duration of application, direction, and magnitude of force.

In the present experiment, orthodontic force was applied 2 weeks after mini-implants were placed. Some previous studies insisted that a long healing period after implantation is necessary to ensure the stability of an implant. Wehrbein et al.,[2] Saito et al.,[3] and Roberts et al.[5] applied a 2-N force and allowed a healing period longer than 8 weeks after implantation. Roberts et al.[1] concluded that the formation of a bridging callus is essential for achieving stability and resistance to an applied force. They also reported that immediate loading after placement is not recommended because 6 weeks, 12 weeks, and 18 weeks are needed for rabbits, dogs, and humans, respectively, for a bridging callus to form.

However, others insisted that early loading or immediate loading is possible if the orthodontic force is within the primary stability gained by the mechanical binding between the mini-implant and surrounding bone. Majzoub et al.[8] demonstrated histologically that endosseous implants can be used as an anchor for orthodontic tooth movement during the early post-insertion healing period (2 weeks). Deguchi et al.[9] reported that, even with immature surrounding bone, a mini-implant in adult dogs can tolerate an orthodontic

Table 3. Comparison of Removal Torque Values (in Ncm) of Each Loading Group Between 1 and 8 Weeks

Group	Mean (1 wk)	Mean (8 wk)	Sig.[a]
Control	5.63	10.1	*
Clockwise loading	5.81	9.72	*
Counterclockwise loading	5.37	7.32	*

[a] Sig., significance of periods by *t*-test.
* Values are significantly different from each other ($P = .05$).

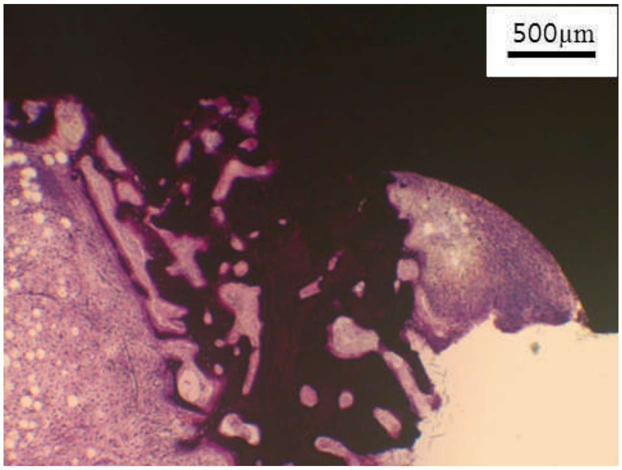

Figure 10. Control group at 1 week (×40).

load 3 weeks after implant insertion and suggested that a mini-implant could be used as an anchor, even with a shorter healing period. Recently Park[10] reported that orthodontic force loading is possible as soon as the soft tissue is healed. In the present experiment, an orthodontic force was applied 2 weeks after mini-implant placement based on the findings from earlier studies that early loading of mini-implants is possible.[8–10]

There are no reports on the maximum force tolerated by a mini-implant. However, most studies used a force of 1.5 to 3 N to test mini-implants.[2,3,13–15] In the present study, a 2-N force was applied, which falls within this range.

In the present study, an orthodontic force was applied with a rotational moment. This is different from most reports, which used a unilateral horizontal force. Costa et al.,[7] Huja et al.,[19] and Cho et al.[14] examined the stability of mini-implants when a rotational moment was applied. However, unlike the present study, they did not examine the stability of a mini-implant through measurement of removal torque.

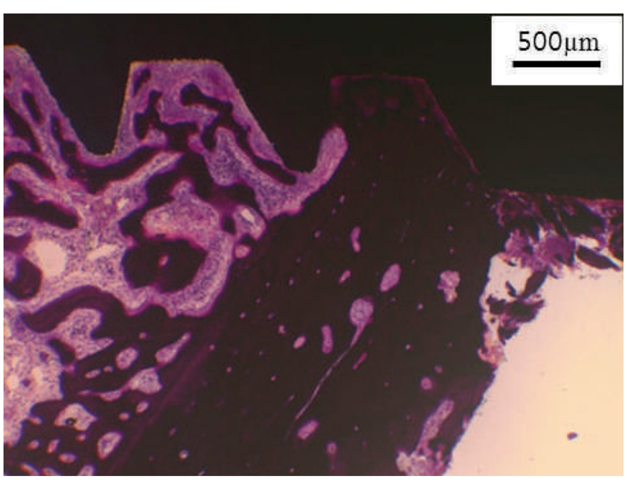

Figure 11. Clockwise group at 1 week (×40).

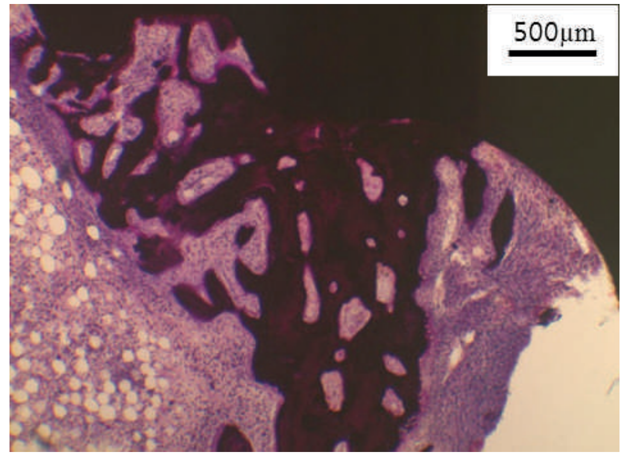

Figure 12. Counterclockwise group at 1 week (×40).

In the present study, in the 1-week group (ie, 3 weeks after implantation), the RTV was similar in the control, clockwise, and counterclockwise groups. This suggests that at 1 week, a 2-N force in either the clockwise or counterclockwise direction does not affect the stability of mini-implants. There were no significant differences in the histological findings of the mini-implant/cortical bone interface between the control, clockwise, and counterclockwise groups. The Cho et al.[14] study, which applied immediate loading, also observed no differences between clockwise and counterclockwise groups after 3 weeks of implantation in terms of bone-to-implant contact. Therefore, it can be concluded that there was no difference in stability between the clockwise and counterclockwise groups after 3 weeks of implantation, which is within the period of bridging callus formation. In addition, there was no difference in stability for immediately loaded implants and implants loaded after 2 weeks.

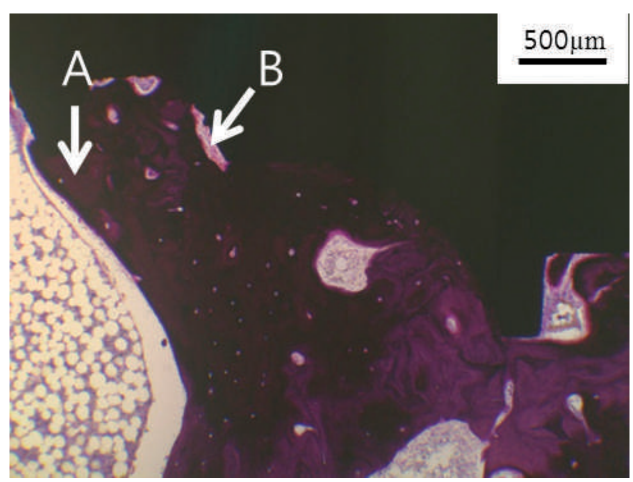

Figure 13. Control group at 8 weeks (×40). (A) New bone proliferation throughout the implant surface. (B) Surface area of defects at the interface.

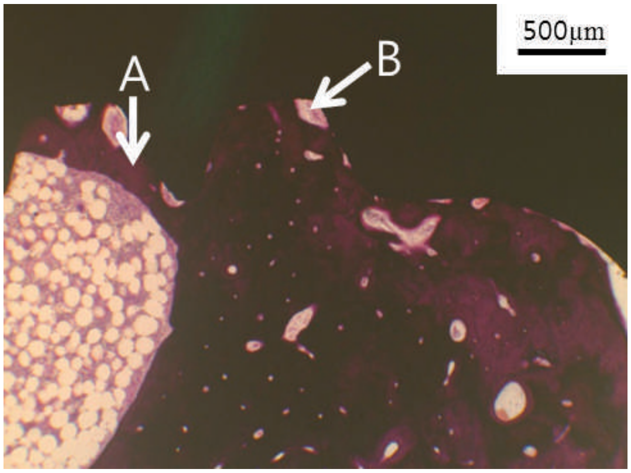

Figure 14. Clockwise group at 8 weeks (×40). (A) New bone proliferation throughout the implant surface. (B) Surface area of defects at the interface.

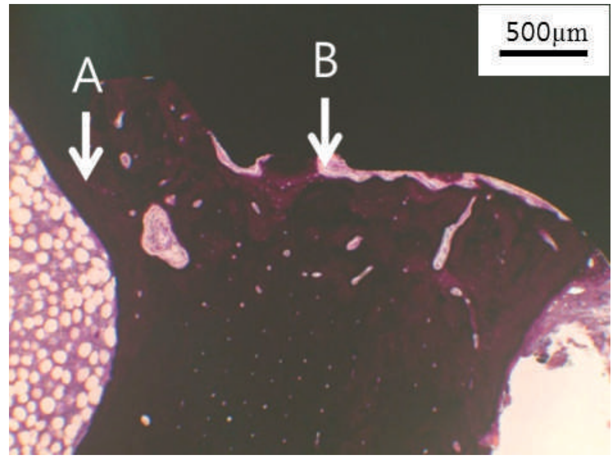

Figure 15. Counterclockwise group at 8 weeks (×40). (A) New bone proliferation throughout the implant surface. (B) Surface area of defects at the interface.

The RTV of the mini-implants in all groups increased between 1 and 8 weeks. Roberts et al.[1] concluded that the formation of a bridging callus is essential for achieving stability and withstanding an applied force and reported that 6 weeks is required for a rabbit to form a bridging callus. The increased RTV in the 8-week group can be explained by the histological findings. Histologic examination of the 8-week samples showed a larger mini-implant/cortical bone interface than the 1-week samples. These results are similar to those of Cho et al.,[14] who reported significantly higher bone-to-implant contact around implants that had healed for 12 weeks than around implants that had healed for 3 weeks, regardless of which loading method had been used.

In this study, the counterclockwise group showed a lower RTV than the control and the clockwise groups at 8 weeks. Also, no significant difference was observed between the clockwise and control groups at 8 weeks. The histological findings indicated that the counterclockwise group had a larger bone defect area at the mini-implant/cortical bone interface than the control group and the clockwise group. Cho et al.[14] observed lower bone-implant contact in the counterclockwise group than in the clockwise group at 12 weeks. Orthodontic force was loaded in the direction of mini-implant loosening in the counterclockwise group, which could be considered a cause of the lower bone-implant contact. Implant failure without infection under these conditions is caused, in most cases, by excessive pressure on the bone–implant interface.[21–23] Loading with a counterclockwise rotational moment could induce excessive pressure on the bone/mini-implant interface, decreasing the stability of the implant. Therefore, it is recommended that a force system that produces a counterclockwise moment on mini-implants should be avoided. Also, in the counterclockwise group, a longer healing period is recommended, since greater stability was achieved after 8 weeks than after 1 week in the present study.

Further studies of mini-implant stability relative to the magnitude of force and the time elapsed prior to loading are required. Finally, additional studies of the RTV of the prototype should be performed beyond 8 weeks to determine long-term stability. The cortical bone thickness of the rabbit tibia varies widely and there is a rapid tissue turnover rate. Therefore, these results should be applied with caution to the clinical situation.

CONCLUSIONS

- After 8 weeks, significant increases in both RTV and bone-implant contact were observed for all groups, suggesting that delayed loading may be preferable to immediate loading.
- In the 8-week group, there were no significant differences between the control and clockwise groups, but the RTV was lower in the counterclockwise group. In addition, the counterclockwise group had a larger bone defect area in the bone-implant interface than did the clockwise group.
- Counterclockwise torque could decrease the stability of a mini-implant after 8 weeks, whereas a clockwise torque has no effect. Therefore, a force system that produces a counterclockwise moment to mini-implants should be avoided.

ACKNOWLEDGMENT

This research was supported by special funds for new researchers of Medical Center, Kyung Hee University (#20070694), Seoul, South Korea.

REFERENCES

1. Roberts WE, Helm FR, Marshall KJ, Gongloff RK. Rigid endosseous implants for orthodontic and orthopedic anchorage. *Angle Orthod*. 1989;59:247–256.
2. Wehrbein H, Glatzmier J, Yildirim M. Orthodontic anchorage capacity of short titanium screw implants in the maxilla. *Clin Oral Impl Res*. 1997;8:131–141.
3. Saito S, Sugimoto N, Morohashi T, et al. Endosseous titanium implants as anchors for mesiodistal tooth movement in the beagle dog. *Am J Orthod Dentofacial Orthop*. 2000;118:601–607.
4. Turley PK, Kean C, Schur J, Stefanac J, Gray J, Hennes J, Poon LC. Orthodontic force application to titanium endosseous implants. *Angle Orthod*. 1988;58:151–162.
5. Roberts WE, Nelson CL, Goodacre CJ. Rigid implant anchorage to close a mandibular first molar extraction site. *J Clin Orthod*. 1994;28:693–704.
6. Odman J, Lekholm U, Jemt T, Thilander B. Osseointegrated implants as orthodontic anchorage in the treatment of partially edentulous adult patients. *Eur J Orthod*. 1994;16:187–201.
7. Costa A, Raffaini M, Melson B. Miniscrews as orthodontic anchorage. A preliminary report. *Int J Adult Orthod Orthognath Surg*. 1998;13:201–209.
8. Majzoub Z, Finotti M, Miotti F, Giardino R, Aldini NN, Cordioli G. Bone response to orthodontic loading of endosseous implants in the rabbit calvaria: early continuous distalizinng forces. *Eur J Orthod*. 1999;21:223–230.
9. Deguchi T, Takano-Yamamoto T, Kanomi R, Hartsfield JK Jr, Roberts WE, Garetto LP. The use of small titanium screws for orthodontic anchorage. *J Dent Res*. 2003;82:377–381.
10. Park HS. A new protocol of the sliding mechanics with micro-implant anchorage (MIA). *Korean J Orthod*. 2000;30: 677–685.
11. Zubery Y, Bichacho N, Moses O, Tal H. Immediate loading of modular transitional implants. A histologic and histomorphometric study in dogs. *Int J Periodontics Restorative Dent*. 1999;19:343–353.
12. Kyung SH, Lim JK, Park YC. The use of miniscrew as an anchorage for the orthodontic tooth movement. *Korean J Orthod*. 2001;31:415–424.
13. Favero L, Brollo P, Bressan E. Orthodontic anchorage with specific fixtures: related study analysis. *Am J Orthod Dentofacial Orthop*. 2002;122:84–94.
14. Cho YM, Cha JY, Hwang CJ. The effect of rotation moment on the stability of immediate loaded orthodontic miniscrews: a pilot study. *Eur J Orthod*. 2010 May 13. [Epub ahead of print]
15. Carlsson L, Rostlund T, Albrektsson B, Albrektsson T. Removal torques for polished and rough titanium implants. *Int J Oral Maxillofac Implants*. 1988;3:21–24.
16. Park HS, Yen S, Jeong SH. Histologic and biomechanical characteristics of orthodontic self-drilling and self-tapping microscrew implants. *Korean J Orthod*. 2006 Aug;36(4): 295–307.
17. Oh NH, Kim SH, Kook YA, Lee KH, Kang YK, Mo SS. Removal torque of sandblasted large grit, acid etched treated mini-implant. *Korean J Orthod*. 2006;36(5): 324–330.
18. Sun SB, Kang YG, Kim SH, Mo SS, Kook YA. Influence of immediate loading on the removal torque value of miniscrews. *Korean J Orthod*. 2007 Dec;37(06):400–406.
19. Huja SS, Kitsky AS, Beck FM, Johnson KA, Larsen PE. Pullout strength of monocortical screws placed in the maxillae and mandibles of dogs. *Am J Orthod Dentofacial Orthop*. 2005;127:307–313.
20. Klokkevold PR, Nishimura RD, Adachi M, Caputo A. Osseointegration enhanced by chemical etching of the titanium surface. A torque removal study in the rabbit. *Clin Oral Implants Res*. 1997;8:442–447.
21. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg*. 1981;10:387–416.
22. Meyer U, Vollmer D, Runte C, Bourauel C, Joos U. Bone loading pattern around implants in average and atrophic edentulous maxillae: a finite-element analysis. *J Craniomaxillofac Surg*. 2001;29:100–105.
23. De Buchter A, Wiechmann D, Koerdt S, Wiesmann HP, Piffko J, Meyer U. Load-related implant reaction of mini-implants used for orthodontic anchorage. *Clin Oral Implants Res*. 2005;16:473–479.