Original Article

In vitro and in vivo mechanical stability of orthodontic mini-implants: *Effect of sandblasted, large-grit, and anodic-oxidation vs sandblasted, large-grit, and acid-etching*

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ABSTRACT

Objective: To compare in vivo and in vitro mechanical stability of orthodontic mini-implants (OMIs) treated with a sandblasted, large-grit, and anodic-oxidation (SLAO) method vs those treated with a sandblasted, large-grit, and acid-etching (SLA) method.

Materials and Methods: Fifty-four titanium OMIs (cylindrical shape, drill-free type; diameter = 1.45 mm, length = 8 mm, Biomaterials Korea Inc, Seoul, Korea) were allocated into control, SLA, and SLAO groups (N = 12 for in vivo and N = 6 for in vitro studies per group). In vitro study was carried out on a polyurethane foam bone block (Sawbones, Pacific Research Laboratories Inc, Vashon, Wash). In vivo study was performed in the tibias of Beagles (6 males, age = 1 year, weight = 10 to 13 kg; OMIs were removed at 8 weeks after installation). For insertion and removal of OMIs, the speed and maximum torque of the surgical engine were set to 30 rpm and 40 Ncm, respectively. Maximum torque (MT), total energy (TE), and near peak energy (NPE) during the insertion and removal procedures were statistically analyzed.

Results: In the in vitro study, although the control group had a higher insertion MT value than the SLA and SLAO groups ($P < .01$), no differences in insertion TE and NPE or in any of the removal variables were noted among the three groups. In the in vivo study, the control group exhibited higher values for all insertion variables compared with the SLA and SLAO groups (MT, $P < .001$; TE, $P < .01$; NPE, $P < .001$). Although no difference in removal TE and removal NPE was noted among the three groups, the SLAO group presented with a higher removal MT than the SLA and control groups ($P < .001$).

Conclusions: SLAO treatment may be an effective tool in reducing insertion damage to surrounding tissue and improving the mechanical stability of OMIs. (*Angle Orthod.* 2012;82:611–617.)

KEY WORDS: Surface treatment; Stability; Mini-implants; Sandblasted large-grit; Anodic oxidation; Acid etching

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INTRODUCTION

Although the success rates of orthodontic mini-implants (OMIs) have been reported to range from 84% to 92%,[1–7] the stability of OMIs is associated with host factors (age, gender, skeletal pattern, oral hygiene, and inflammation), bone quality (thickness and stiffness), OMI design (shape and diameter), and insertion and loading modality (implantation location, type of placement surgery, and immediate loading).[5,8–14] In cases of poor host factors and poor bone quality, the number of OMIs must be increased to provide maximum or absolute anchorage and to prevent unwanted movements and rotations. However, the invasiveness and high cost associated with OMIs can be an issue from a patient's perspective. Therefore, numerous studies on the design and insertion modality for OMIs have been performed in attempts to improve their stability.[5,9–14]

Because OMIs with a tapered or conical shape and a large screw diameter may produce overcompression of the cortical bone owing to excessive insertion torque, an accumulation of microdamage (a permanent deformation of the microstructure in loaded cortical bone in the form of fatigue, creep, and eventual cracking), local ischemia, bone necrosis, bone remodeling, and premature loss of the OMI can occur.[12,15–18] Therefore, cylindrically shaped OMIs with a proper screw diameter can be recommended to decrease compression stress in the cortical bone.[18]

In addition, surface treatment of dental prosthetic titanium implants can increase the surface area, provide a better bone-to-implant contact (BIC) environment, and eventually result in osseointegration between the TiO_2 layer of the implant and surrounding bony tissue.[19–24] Acid-etching and anodic-oxidation methods have been used as surface treatment methods.[25] Sandblasted, large-grit, and acid etching (SLA) is a method that involves sandblasting of the implant with 100-μm aluminum particles and acid treatment with HCl and H_2SO_4.[26] Buser et al.[26] reported that titanium alloy material treated with the SLA method had enhanced bone contact and exhibited higher removal torque. Anodic oxidation (AO) is a method that involves the use of 0.1% phosphoric acid solution at 150 to 200 V for several minutes.[27] Yamagami et al.[27] reported that titanium alloy material treated with a combination of sandblasting and anodic oxidation (SLAO) enhanced active bone formation, resulting in stable fixation in the diaphysis of New Zealand white rabbit femurs.

Although surface-treated dental prosthetic implants are prevalent, most OMIs that are used do not undergo surface treatment. If surface treatment is applied to OMIs, the preferred method is SLA. OMIs treated with SLA exhibit a higher removal torque value and thus are expected to resist stronger orthodontic force compared with OMIs with a smooth machined surface.[28] Oh et al.[28] and Kim et al.[29] insisted that OMIs treated with SLA exhibited more favorable bone formation compared with those with a smooth machined surface.

To the authors' knowledge, few studies have evaluated the mechanical stability of OMIs treated with the SLAO method. Therefore, the purpose of this study was to compare the in vivo and in vitro mechanical stability of OMIs treated with the SLAO method or the SLA method. The null hypothesis was that there is no difference in the values of maximum torque (MT), total energy (TE), and near peak energy (NPE) during insertion and removal procedures between the SLA and SLAO groups.

MATERIALS AND METHODS

OMIs and Surface Treatment

A total of 54 titanium OMIs (cylindrical shape, drill-free type, outer diameter = 1.45 mm, inner diameter = 1.0 mm, length = 8 mm, Ti alloy [ASTM F136, Ti-6AL-4V alloy], OAS-T1508, Biomaterials Korea Inc, Seoul, Korea, Figure 1a) were used in this study. The OMIs were allocated into three groups according to the surface treatment method used: SLA group, SLAO group, and control group. For SLA treatment, 100-μm aluminum particles were sprayed onto the OMI surface for 2 minutes at a pressure of 2 bar with a mixed solution of 30% concentrated HCl, 60% concentrated H_2SO_4, and diluting solution (ratio 10:80:10). For SLAO treatment, sandblasting was carried out in the same way as in the SLA method. Anodic oxidation was achieved by treating the implant surface with a mixture of 0.04 M β-glycerolphosphate disodium salt pentahydrate and 0.4 M calcium acetate for 3 minutes at 250 V (Genesys 600-2.6, Densei-Lambda, Tokyo, Japan). A scanning election microscope (S2700, Hitachi, Tokyo, Japan, X1500) was used for visualization of significant differences in the surface topography of the three groups. The control group exhibited a smooth texture; the SLA group presented with an irregular surface topography; and the SLAO group displayed an irregular, porous surface (Figure 1b).

In Vitro Study

Six OMIs per group were installed in a polyurethane foam artificial bone block (Sawbones, Pacific Research Laboratories Inc, Vashon, Wash; Table 1) using a surgical engine (Elcomed SA200C, W&H, Burmoos, Austria; Figure 2a). For insertion and removal of OMIs, engine speed and maximum torque were set to 30 rpm and 40 Ncm, respectively. During the insertion and removal procedures, MT, TE, and NPE were measured. The insertion and removal variables are defined in Figure 3.[30]

In Vivo Study

This study was approved by the Animal Research Committee of Seoul National University (SNU-070508-2), and all experiments were performed in accordance with the Institute of Laboratory Animal Resources Guidelines of Seoul National University.

Six male Beagles (1 year of age, weighing 10 to 13 kg) were used. Atropine sulfate (0.1 mg/kg; Jeil Co, Seoul, Korea) was injected intramuscularly 15 minutes before general anesthesia was provided. Tiletamine/zolazepam (10 mg/kg, Zoletil 50; Virbac Korea Co, Seoul, Korea) and xylazine hydrochloride (2 mg/kg, Rompun; Bayer Korea, Seoul, Korea) were injected

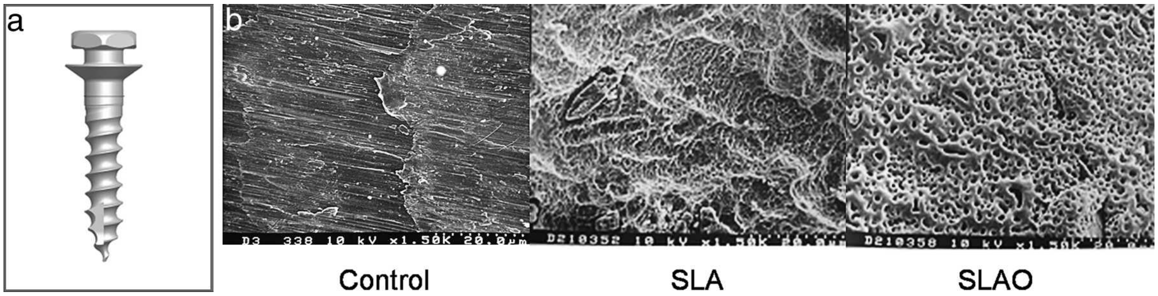

Figure 1. (a) The orthodontic mini-implant (OMI) used in the present study (cylindrical shape, drill-free type, outer diameter = 1.45 mm, inner diameter = 1.0 mm, length = 8 mm, OAS-T1508, Biomaterials Korea Inc, Seoul, Korea). (b) Surface topography (scanning electron microscope, 1500×); from the left, control group, SLA (sandblasted, large-grit, and acid-etching) group, and SLAO (sandblasted, large-grit, and anodic-oxidation) group.

intramuscularly for general anesthesia. At the site of surgery, 1.8 mL of local anesthetic (2% lidocaine with 1:100,000 epinephrine; Huons Co, Jecheon, Korea) was injected.

After shaving and sterilization of the insertion site, the tibia of the Beagle was exposed using a No.15 blade and a periosteal elevator. Installation of OMIs was performed with a random block design to avoid individual- and location-related discrepancies, and to increase the confidence level of the experiment. The OMIs (three OMIs for each tibia; a total of six OMIs for each animal) were inserted perpendicularly into the bone surface using a surgical engine (Elcomed SA200C) with saline solution irrigation to minimize heat generation (Figure 2b). Then, fascia and skin were sutured with absorbable suture material (4-0 Surgisorb, Samyang, Seoul, Korea) to completely cover the OMIs with soft tissue. Analgesics and antibiotics were given to the animals. An additional OMI per group was inserted to observe the degree of osseointegration upon histologic examination.

In the present study, the healing period was set at 8 weeks because the maturity level of surrounding bone structures peaks at 8 to 12 weeks in dogs.[31] No failure of OMIs occurred during the 8 weeks of healing. After removal of OMIs with saline solution, the fascia and the skin were sutured using absorbable suture material. Analgesics and antibiotics were given to the animals.

For insertion and removal of OMIs, engine speed and maximum torque were set to 30 rpm and 40 Ncm, respectively. During insertion and removal procedures, MT, TE, and NPE were measured.

Statistical Analysis

The normality and equality of variance assumption were not violated in the data set according to the Shapiro-Wilk test, Q-Q normality plots, and the Levene test. Random effects due to the individual animal or to the side of implantation (right vs left) were not detected in the mixed model analysis of variance (ANOVA). Therefore, one-way ANOVA with Duncan's multiple comparison test was performed for statistical analysis.

RESULTS

Comparison of the Mechanical Properties of OMIs in the Artificial Bone Block During Insertion and Removal Procedures

During the insertion procedure, the control group presented with a significantly higher insertion MT than was seen in the SLA and SLAO groups ($P < .01$) even though insertion TE and insertion NPE were not significantly different among the three groups. During the removal procedure, none of the removal variables differed significantly among the three groups.

Comparison of the Mechanical Properties of OMIs in the Tibia of Male Beagles During Insertion and Removal Procedures

During the insertion procedure, the control group had significantly higher insertion variable values compared with the SLA and SLAO groups (insertion MT, $P < .001$; insertion TE, $P < .01$; insertion NPE, $P < .001$, respectively). During the removal procedure, no difference in the values of removal TE and removal

Table 1. Mechanical Properties of the Polyurethane Foam[a] Used in the Artificial Bone Block

	Density		Compressive		Tensile	
	pcf	g/mL	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa
Cortical bone	102	1.64	157	16,700	106	16,000
Cancellous bone	40	0.64	32.6	876	19.1	659

[a] Sawbones, Pacific Research Laboratories Inc, Vashon, Wash.

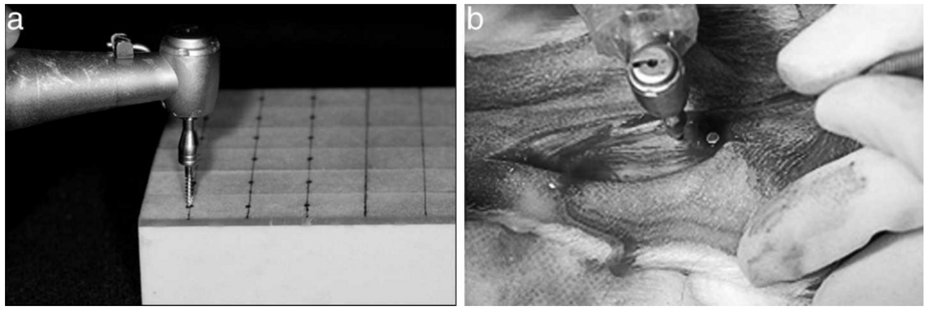

Figure 2. (a) In vitro insertion of OMIs into the artificial bone block of polyurethane foam (Sawbones, Pacific Research Laboratories Inc, Vashon, Wash). (b) In vivo insertion of OMIs into the tibia of a Beagle.

NPE was noted among the three groups. However, the SLAO group had a higher removal MT than was reported in the SLA and control groups ($P < .001$).

DISCUSSION

This study was performed to observe the effects of SLAO surface treatment on in vivo and in vitro mechanical stability of OMIs. Because the artificial bone blocks could not have an osseointegration effect between polyurethane and titanium surfaces of the OMIs, results from the in vitro study can be used for comparison with those from the in vivo study.

In the in vivo study, the finding that the control group had significantly higher values for all insertion variables compared with the SLA and SLAO groups

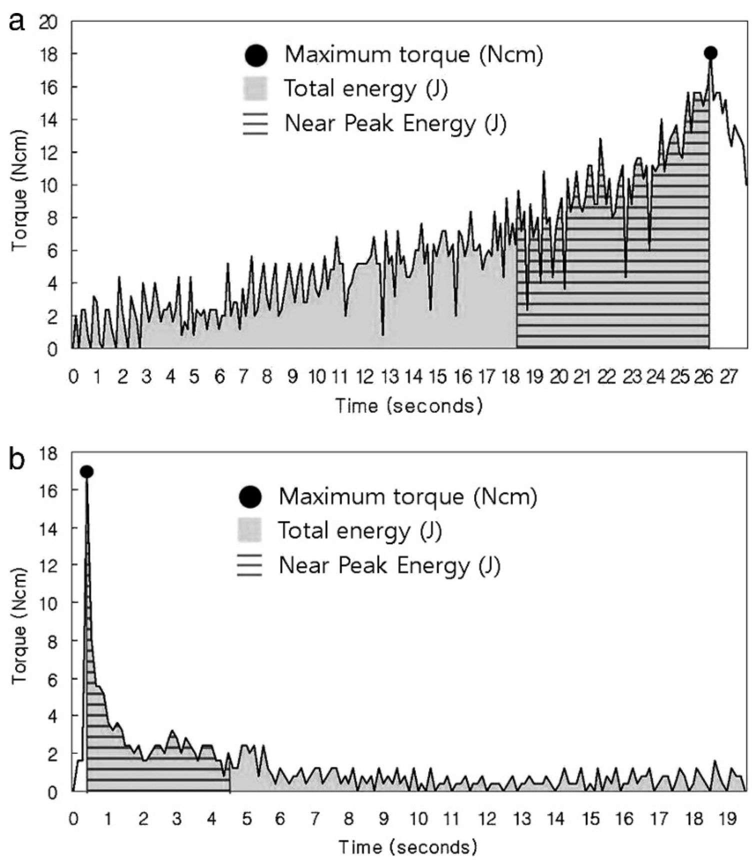

Figure 3. (a) Definition of insertion variables. Insertion maximum torque (MT, Ncm) is the maximum torque recorded during the insertion procedure. Insertion total energy (TE, J) is the total energy recorded from the beginning of insertion to the point at which the insertion MT is reached. Insertion near peak energy (NPE, J) is the energy measured from the point of insertion MT to 8 seconds before that point (four rotations). (b) Definition of removal variables. Removal MT (Ncm) is the maximum torque recorded during the removal procedure. Removal TE (J) is the total energy recorded from the point at which the removal MT is reached to the end of the removal procedure. Removal NPE (J) is the energy measured from the point of the removal MT to 4 seconds after that point (two rotations).

Table 2. Comparison of Mechanical Properties During Insertion and Removal of Mini-implants in Artificial Bone Block for Three Types of Surface Treatment[a,b]

	Variables	Type of Surface Treatment (Mean ± SD)			P Value	Multiple Comparison Test[c]
		Control (N = 6)	SLA (N = 6)	SLAO (N = 6)		
Insertion	Insertion total energy, J	10.53 ± 0.37	11.07 ± 0.47	11.16 ± 0.28	.1120	
	Insertion near peak energy, J	5.35 ± 0.09	5.23 ± 0.16	5.16 ± 0.14	.0790	
	Insertion maximum torque, Ncm	37.27 ± 1.14	34.90 ± 0.62	35.33 ± 1.03	.0015**	(2,3)<1
Removal	Removal total energy, J	2.01 ± 0.13	2.09 ± 0.14	2.20 ± 0.15	.0841	
	Removal near peak energy, J	1.09 ± 0.10	1.03 ± 0.07	1.05 ± 0.03	.4165	
	Removal maximum torque, Ncm	13.60 ± 0.44	13.57 ± 0.48	13.73 ± 0.40	.7711	

[a] One-way ANOVA was performed with Duncan's multiple comparison test.
[b] Control means machined surface; SLA, sandblasted, large-grit, and acid etching; SLAO, sandblasted, large-grit, and anodic oxidation.
[c] In the multiple comparison test column, 1 represents Control; 2, SLA; 3, SLAO.
** $P < .01$.

(insertion MT, $P < .001$; insertion TE, $P < .01$; insertion NPE, $P < .001$, respectively, Table 3) is consistent with the findings of Kim et al.[29]

The difference in the insertion variables between the in vitro and in vivo studies was that the in vitro study revealed differences only in the insertion MT (control group vs SLA and SLAO groups; $P < .01$; Table 2). In contrast, the in vivo study showed differences in all insertion variables (control group vs SLA and SLAO groups; insertion MT, $P < .001$; insertion TE, $P < .01$; insertion NPE, $P < .001$, respectively; Table 3). These findings imply that the smooth surface might result in greater damage to surrounding bony structures than is caused by the treated surface during the insertion procedure. Also, these findings suggest that SLA and SLAO methods might confer implant properties more conducive to insertion than those in the control group. OMI surface roughness produced by surface treatment may provide space for the external discharge of bone particles and blood.

Although the difference in the values of removal MT between SLAO and SLA groups was significant (8.03 Ncm in the SLA group vs 12.80 Ncm in the SLAO group; $P < .001$; Table 3), this same difference was not observed between SLA and control groups (6.57 Ncm in the control group vs 8.03 Ncm in the SLA group; Table 3). This finding is slightly different from that of previous studies, which reported a significant difference in the values of removal MT between SLA and control groups.[26,28,29] The reason for this discrepancy may be differences in types of OMIs, performance of predrilling, experimental methods used, and SLA treatment provided.

Significant differences in the removal variables were not observed among the three groups in the in vitro study (Table 2). However, the in vivo study revealed a significantly higher removal MT in the SLAO group than in the SLA and control groups ($P < .001$; Table 3). These findings could represent indirect but logical evidence that the SLAO method might induce more favorable osseointegration and greater stability than are induced by the SLA method and by machined-surface implants (control group).

The reason why the SLAO group exhibited higher values of removal MT than were seen in the SLA and control groups ($P < .001$; Table 3), despite the lack of differences in values of removal TE and removal NPE among the three groups, seems to be the difference in the duration of the period in which MT was sustained (Figure 4B). The duration of the period in which the MT

Table 3. Comparison of Mechanical Properties During Insertion and Removal of Mini-implants in the Tibias of Male Beagles for Three Types of Surface Treatment[a,b]

	Variables	Type of Surface Treatment (Mean ± SD)			P Value	Multiple Comparison Test[c]
		Control (N = 12)	SLA (N = 12)	SLAO (N = 12)		
Insertion	Insertion total energy, J	10.17 ± 1.50	7.27 ± 1.98	7.03 ± 2.87	.0018**	(3,2)<1
	Insertion near peak energy, J	4.16 ± 0.58	1.98 ± 0.40	1.94 ± 0.62	< .0001***	(3,2)<1
	Insertion maximum torque, Ncm	24.77 ± 3.03	12.43 ± 2.06	13.15 ± 4.40	< .0001***	(2,3)<1
Removal	Removal total energy, J	0.82 ± 0.34	0.84 ± 0.20	0.88 ± 0.32	.8846	
	Removal near peak energy, J	0.37 ± 1.84	0.41 ± 0.15	0.48 ± 0.19	.3402	
	Removal maximum torque, Ncm	6.57 ± 2.88	8.03 ± 3.09	12.80 ± 4.15	.0002***	(1,2)<3

[a] One-way ANOVA was performed with Duncan's multiple comparison test.
[b] Control means machined surface; SLA, sandblasted, large-grit, and acid etching; SLAO, sandblasted, large-grit, and anodic oxidation.
[c] In the multiple comparison test column, 1 represents Control; 2, SLA; 3, SLAO.
** $P < .01$; *** $P < .001$.

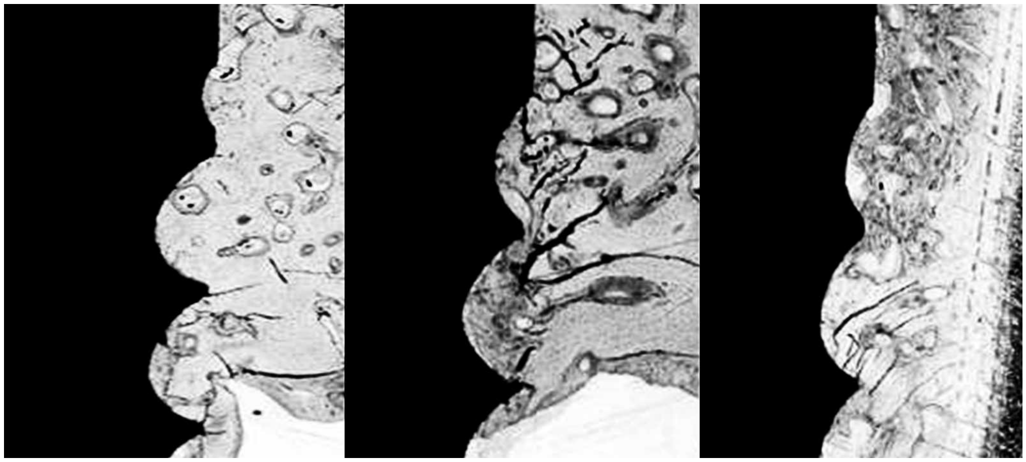

Figure 4. Ground section of samples (20×; staining with Multiple Stain Solution, Polyscience Inc, Warrington, Fla). From the left, control group, SLA group, and SLAO group.

was sustained is defined as the time from the start of removal of counterclockwise rotation of the OMI to destruction of osseointegration between bone and the titanium surface of the OMI. If this sustaining period was fairly short in the SLAO group despite high MT, the area below the graph showing the TE and NPE would be slightly different between the SLAO, SLA, and control groups. This implies that removal MT may change significantly with the degree of osseointegration, but the other removal variables do not (Table 3). In the present study, three ground sections showed somewhat well-osseointegrated OMIs without intervention of the connective tissue (Figure 4). Because differences in removal MT imply the potential for histologic differences, additional studies are needed to evaluate the BIC.

This study has some limitations because orthodontic force was not applied to the OMIs, and histomorphometric analysis was not performed to evaluate the degree of BIC. Therefore, additional studies employing diverse force application conditions are necessary to assess the biomechanical stability of OMIs after force application and to observe histologic changes in bony tissue adjacent to the OMIs.

CONCLUSION

- The null hypothesis was rejected.
- SLAO treatment may be an effective tool in reducing insertion damage to surrounding bone tissue and in improving the mechanical stability of OMIs.

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REFERENCES

1. Miyawaki S, Koyama I, Inoue M, et al. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. *Am J Orthod Dentofacial Orthop*. 2003;124:373–378.
2. Cheng SJ, Tseng IY, Lee JJ, Kok SH. A prospective study of the risk factors associated with failure of mini-implants used for orthodontic anchorage. *Int J Oral Maxillofac Implants*. 2004;19:100–106.
3. Chen CH, Chang CS, Hsieh CH, et al. The use of microimplants in orthodontic anchorage. *J Oral Maxillofac Surg*. 2006;64:1209–1213.
4. Park HS, Jeong SH, Kwon OW. Factors affecting the clinical success of screw implants used as orthodontic anchorage. *Am J Orthod Dentofacial Orthop*. 2006;130:18–25.
5. Motoyoshi M, Hirabahashi M, Uemura M, Shimizu N. Recommended placement torque tightening an orthodontic mini-implant. *Clin Oral Implants Res*. 2006;17:109–114.
6. Wiechmann D, Meyer U, Büchter A. Success rate of mini- and micro-implants used for orthodontic anchorage: a prospective clinical study. *Clin Oral Implants Res*. 2007;18:263–267.
7. Moon CH, Lee DG, Lee HS, Im JS, Baek SH. Factors associated with the success rate of orthodontic miniscrews placed in the upper and lower posterior buccal region. *Angle Orthod*. 2008;78:101–106.
8. Kim JW, Ahn SJ, Chang YI. Histomorphometric and mechanical analyses of the drill-free screw as orthodontic anchorage. *Am J Orthod Dentofacial Orthop*. 2005;128:190–194.
9. Melsen B, Costa A. Immediate loading of implants used for orthodontic anchorage. *Clin Orthod Res*. 2000;3:23–28.
10. Wilmes B, Rademacher C, Olthoff G, Drescher D. Parameters affecting primary stability of orthodontic mini-implants. *J Orofac Orthop*. 2006;67:162–174.
11. Wilmes B, Ottenstreuer S, Su YY, Drescher D. Impact of implant design on primary stability of orthodontic mini-implants. *J Orofac Orthop*. 2008;69:42–50.
12. Kim JW, Baek SH, Kim TW, Chang YI. Comparison of stability between cylindrical and conical type mini-implants: mechanical and histological properties. *Angle Orthod*. 2008;78:692–698.
13. Lim SA, Cha JY, Hwang CJ. Insertion torque of orthodontic miniscrews according to changes in shape, diameter and length. *Angle Orthod*. 2008;78:234–240.

14. Motoyoshi M, Yoshida T, Shimizu N. Effect of cortical bone thickness and implant placement torque on stability of orthodontic mini-implants. *Int J Oral Maxillofac Implants*. 2007;22:779–784.
15. Huja SS, Katona TR, Burr DB, Garetto LP, Roberts WE. Microdamage adjacent to endosseous implants. *Bone*. 1999; 25:217–222.
16. Martin RB. Fatigue microdamage as an essential element of bone mechanics and biology. *Calcif Tissue Int*. 2003;73:101–107.
17. Wawrzinek C, Sommer T, Fischer-Brandies H. Microdamage in cortical bone due to the overtightening of orthodontic microscrews. *J Orofac Orthop*. 2008;69:121–134.
18. Lee NK, Baek SH. Effects of the diameter and shape of orthodontic mini-implants on microdamage to the cortical bone. *Am J Orthod Dentofacial Orthop*. 2010;138:8.e1–8.e8.
19. 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.
20. Cordioli G, Majzoub Z, Piattelli A, Scarano A. Removal torque and histomorphometric investigation of 4 different titanium surfaces: an experimental study in the rabbit tibia. *Int J Oral Maxillofac Implants*. 2000;15:668–674.
21. Klokkevold PR, Johnson P, Dadgostari S, et al. Early endosseous integration enhanced by dual acid etching of titanium: a torque removal study in the rabbit. *Clin Oral Implants Res*. 2001;12:350–357.
22. Lim YJ, Oshida Y, Andres CJ, Barco MT. Surface characterizations of variously treated titanium materials. *Int J Oral Maxillofac Implants*. 2001;16:333–342.
23. Cho SA, Park KT. The removal torque of titanium screw inserted in rabbit tibia treated by dual acid etching. *Biomaterials*. 2003;24:3611–3617.
24. Cho SA, Jung SK. A removal torque of the laser-treated titanium implants in rabbit tibia. *Biomaterials*. 2003;24: 4859–4863.
25. Aalam AA, Nowzari H. Clinical evaluation of dental implants with surfaces roughened by anodic oxidation, dual acid-etched implants, and machined implants. *Int J Oral Maxillofac Implants*. 2005;20:793–798.
26. Buser D, Schenk RK, Steinemann S, et al. Influence of surface characteristics on bone integration of titanium implants: a histomorphometric study in miniature pigs. *J Biomed Mater Res*. 1991;25:889–902.
27. Yamagami A, Yoshihara Y, Suwa F. Mechanical and histologic examination of titanium alloy material treated by sandblasting and anodic oxidization. *Int J Oral Maxillofac Implants*. 2005;20:48–53.
28. Oh NH, Kim SH, Kook YA, et al. Removal torque of sandblasted large grit, acid etched treated mini-implant. *Korean J Orthod*. 2006;36:324–330.
29. Kim SH, Lee SJ, Cho IS, Kim SK, Kim TW. Rotational resistance of surface-treated mini-implants. *Angle Orthod*. 2009;79:899–907.
30. Kim SK, Kwon JY, Heo SJ, Koak JY, Lee JH. Software for measurement of energy absorbed by bone. Korean Patents Registration No. 2007-01-199-004155; 2007.
31. Berglundh T, Abrahamsson I, Lang NP, Lindhe J. De novo alveolar bone formation adjacent to endosseous implants. *Clin Oral Implants Res*. 2003;14:251–262.