Original Article

Rotational Resistance of Surface-Treated Mini-Implants

Seong-Hun Kim[a]; Shin-Jae Lee[b]; Il-Sik Cho[c]; Seong-Kyun Kim[d]; Tae-Woo Kim[e]

ABSTRACT

Objective: To test the hypothesis that there is no difference in the stability and resistance to rotational moments of early loaded sandblasted and acid-etched (SLA) mini-implants and those of machined-surface implants of the same size and shape.

Materials and Methods: A randomized complete block design was used in 12 skeletally mature male beagle dogs. Ninety-six orthodontic mini-implants were tested. Two types of implants were used: some had SLA surface treatment and some had machined surfaces without coating. After 3 weeks of healing, rotational moments of 150 g were applied. The success rates, maximum torque values, angular momentum, and total energy absorbed by the bone were compared. All values were subjected to mixed-model analysis to evaluate the influence of surface treatment, rotational force direction, and site of implantation.

Results: The maximum insertion torque and angular momentum of SLA implants were significantly lower than those of machined implants ($P = .034$, $P = .039$). The SLA implants had a significantly higher value for total removal energy than the machined implants ($P = .046$). However, there were no significant differences in total insertion energy, maximum removal torque, and removal angular momentum between the 2 groups. There was no significant difference between clockwise and counterclockwise rotation in all measurements.

Conclusion: SLA mini-implants showed relatively lower insertion torque value and angular momentum and higher total energy during removal than the machined implants, suggesting osseointegration of the SLA mini-implant after insertion. (*Angle Orthod.* 2009;79:899–907.)

KEY WORDS: Partial osseointegration; Mini-implant; Torque value; Rotational moment; Angular momentum

INTRODUCTION

Clinicians appreciate the characteristics of orthodontic mini-implants, such as easy insertion and removal, minimal discomfort, and ability to withstand immediate or early loading.[1–3] In a patient with healthy periodontium and good bone quality and quantity, success is likely regardless of which kind of mini-implant is used.

Previous studies have insisted that osseointegration is not necessary for the orthodontic mini-implant because only mechanical retention, not osseointegration, is necessary to provide stable anchorage for orthodontic treatment.[4,5] However, there are obvious limitations to stability if bone quality is poor, or if dynamic forces or moments are applied to the implant, leading to reports of resorting to multiple implants for a single force application.[6–8] Some recent studies of osseointegrated implants reported no difference in stability between implants with different surface treatments when measuring rotational forces.[9,10] However, some studies demonstrated that a counterclockwise moment could degrade implant stability.[6,7] The small diameter of orthodontic mini-implants leads to less stability under rotational moments, since the removal torque value is directly proportional to the square of the implant diameter.[11]

Mechanical and surface treatments intended to pro-

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Accepted: November 2008. Submitted: March 2008.

vide better osseointegration can help to increase the stability of mini-implants subjected to moments or dynamic forces.[12–17] Moreover, rotational stability will provide the clinician with additional and very useful biomechanical options. Studies of osseointegration have revealed a preference for large-grit sandblasting and acid etching (SLA) for the best stability.[2,13–15] Reports of an SLA mini-implant have shown good stability and effectiveness when applying rotational moments.[14–18] For example, a clinical method for en masse retraction of anterior teeth without any buccal segment orthodontic appliances was shown to be possible because of this resistance to rotational moments.[16] Although numerous surface modifications have been introduced and used in prosthetic implants, surface-treated orthodontic mini-implants and their resistance to rotational moment have not been widely used or studied.

The purpose of this study was to determine the effect of surface treatment on osseointegration and resistance of mini-implants against the rotational moment as determined by success rate, insertion, and removal torque value analysis.

MATERIALS AND METHODS

These experimental protocols and the methods were approved by the The Catholic University Uijongbu St. Mary's Hospital Ethics Committee for Research on Animals. Twelve beagles (7 to 11 months old) weighing 11 to 16 kg were used in this study. Eight mini-implants were inserted in the buccal bone of the maxilla and mandible of each animal ($n = 96$) for the evaluation of the success rate when rotational moments were applied. Eight of the animals were used to measure the torque value, while the other four were used to evaluate the histology of mini-implants under rotational moments. The histologic findings will be reported in a separate article.

We used two types of mini-implants (CIMPLANT Co, Seoul, Korea) that were 1.8 mm in diameter and 8.5 mm in overall length and had a separate coronal portion. One type was SLA surface (SLA group; Figure 1A,B). The other implants had a machined surface (machined group; Figure 1C,D). The cortical bone was drilled with a 1.5-mm-diameter guide drill (Stryker Leibinger Co, Freiburg, Germany) under saline irrigation (Figure 2A), and the screw part of mini-implant was inserted using a surgical engine (Figure 2B–D). This surgical engine (Elcomed SA200C, W&H, Bürmoos, Austria; Figure 2B) can measure and record the torque at 0.125-second intervals. It was calibrated at each time for the exact measurement.[19] The rotational speed of the surgical engine was set as 30 rpm at 0.5 cycle/s and the maximum torque was fixed at 50 Ncm at the time of insertion and removal. The insertion of

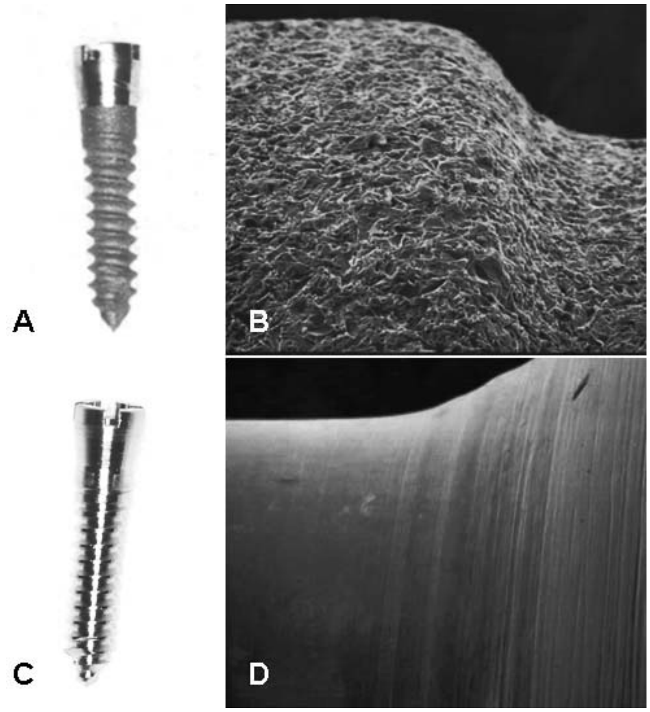

Figure 1. (A) The screw part of an SLA mini-implant. (B) SEM of SLA surface (×300). (C) The screw part of a machined mini-implant. (D) SEM of machined surface (×200).

each mini-implant followed a randomized balanced complete block design, so that the implants retained a certain amount of distance from each other and to minimize the differences in their positions and variations in the animals (Figure 3). In a pilot study, as preliminary experimental designs, stainless steel extension lever arms and a Ni-Ti coil spring were used to apply rotational momentum; however, the result of an 8-week study of two beagles with 16 mini-implants showed that those designs were not appropriate in beagles (Figure 4A,B). An alteration was needed to the experimental design to minimize irritation to intraoral soft tissues. Rather than the coil spring, a 0.016- × 0.022-inch Ni-Ti wire was installed, providing a rotational moment of around 150 g/cm to the mini-implants for 5 weeks on the upper structure after a healing period of 3 weeks (Figure 4C,D). According to Deguchi et al,[20] the 3 weeks of healing in dogs corresponds to 4 to 5 weeks of healing in humans, which is sufficient healing time to apply orthodontic forces. At the end of the experiment, the removal torque was measured and the animals were sacrificed under general anesthesia (Figures 4E,F and 5).

Torque Value Analyses

Maximum torque, angular momentum, and total energy were measured at the insertion and removal of the mini-implants and the measurements are de-

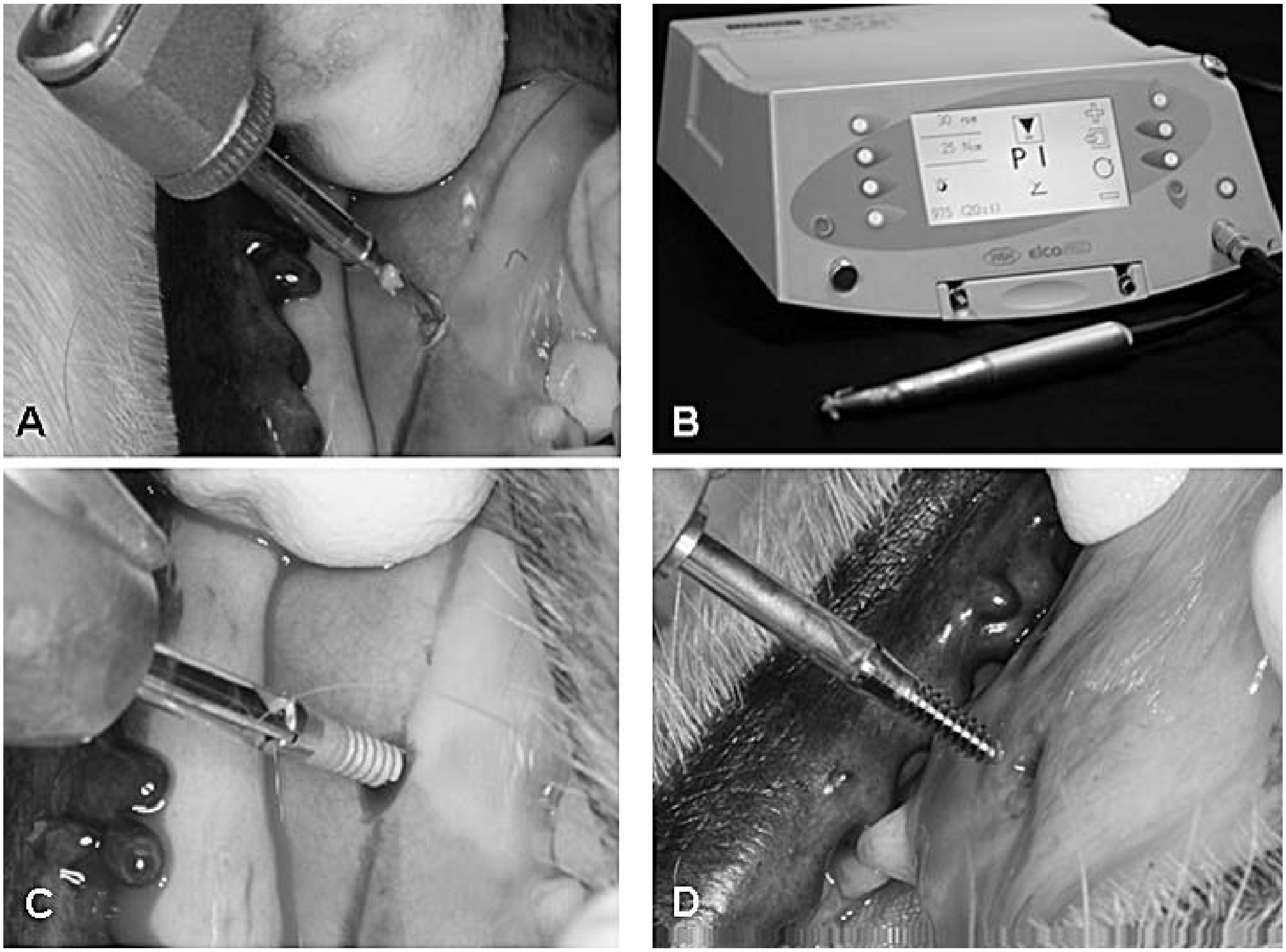

Figure 2. Placement procedure of mini-implant. (A) Cortical penetration using guide drill. (B) Surgical engine that can measure and record the torque at 0.125-second intervals. (C) Placement of SLA mini-implant. (D) Placement of machined mini-implant.

scribed in Table 1 and shown in Figure 6. Total energy (J) at insertion was measured from initial insertion up to the time of maximum torque, while at removal it was measured from the time of maximum torque to the time of complete removal of mini-implants. The total energy and angular momentum were calculated by the computer program produced by JAVA.[21]

Statistical Analysis

Statistical analyses were carried out using SAS 9.1 (SAS Institute, Cary, NC). After the normality and equality of variance of the data were checked, a mixed-model analysis (procedure mixed) was used to compare the maximum torque, angular momentum, and total energy during insertion and removal. The influences of surface treatment, rotational force direction, and implantation sites were determined on the three dependent variables. The tests were performed within a single subject according to the randomized complete block design. Because the randomly assigned various conditions were tested in a within-subject design, those variables related to insertion and removal were not supposed to be independent of each other; at the same time, to control for the effect of individual animals, a mixed-model analysis was performed. All values were considered significant when $P < .05$.

RESULTS

Failure of Mini-Implants

Of the 96 mini-implants placed, 33 were lost within the first 3 weeks of healing and 15 were lost between rotational moment periods (Table 2). Therefore, a success rate of 50% was obtained. The failures appeared to be random and were not associated with the choice of maxilla or mandible, side, mesiodistal position, rotational force direction, or surface treatment. There was no significant difference between the variables relating to insertion or removal ($P > .05$).

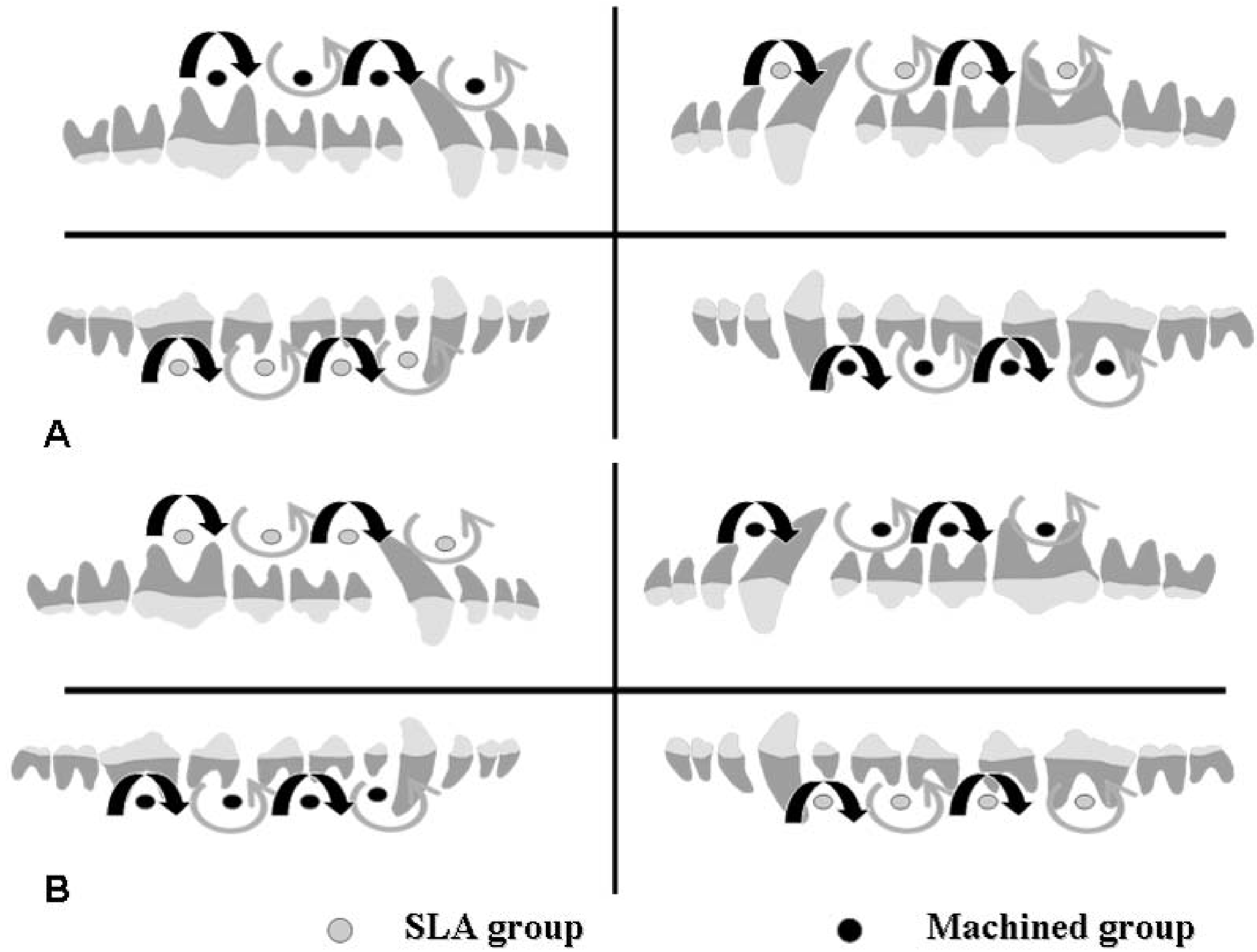

Figure 3. Implantation sites of orthodontic mini-implants. A randomized complete block design was used.

Torque Value Analyses

At the end of the loading period, 48 of the 96 mini-implants were still in situ (Table 3). Of these, 32 mini-implants in eight beagle dogs were evaluated for torque value analyses.

Insertion Torque Value Analyses

Maximum insertion torque value and insertion angular momentum were significantly lower in the SLA group than in the machined group ($P = .034$). However, there was no significant difference in total energy between the two groups ($P = .107$). The insertion torque value, angular momentum, and total energy were lower in the maxilla than in the mandible ($P < .0001$). There was no significant difference in all measurements between the clockwise and the counterclockwise groups ($P > .05$).

Removal Torque Value Analyses

The maximum removal torque value was relatively higher in SLA implants than in machined implants, but there was not a statistically significant difference between groups ($P = .073$). Removal angular momentum was not significantly different between the two groups ($P = .095$). However, the total removal energy was higher in the SLA group than in the machined group ($P = .046$). There were no significant differences between the clockwise and counterclockwise groups, or between maxillae and mandibles ($P > .05$).

DISCUSSION

Although titanium mini-implants have osseointegration potential, conventional self-tapping mini-implants that are used to resist a linear force perpendicular to the implant axis rely primarily on mechanical retention. For three-dimensional movement of teeth, which re-

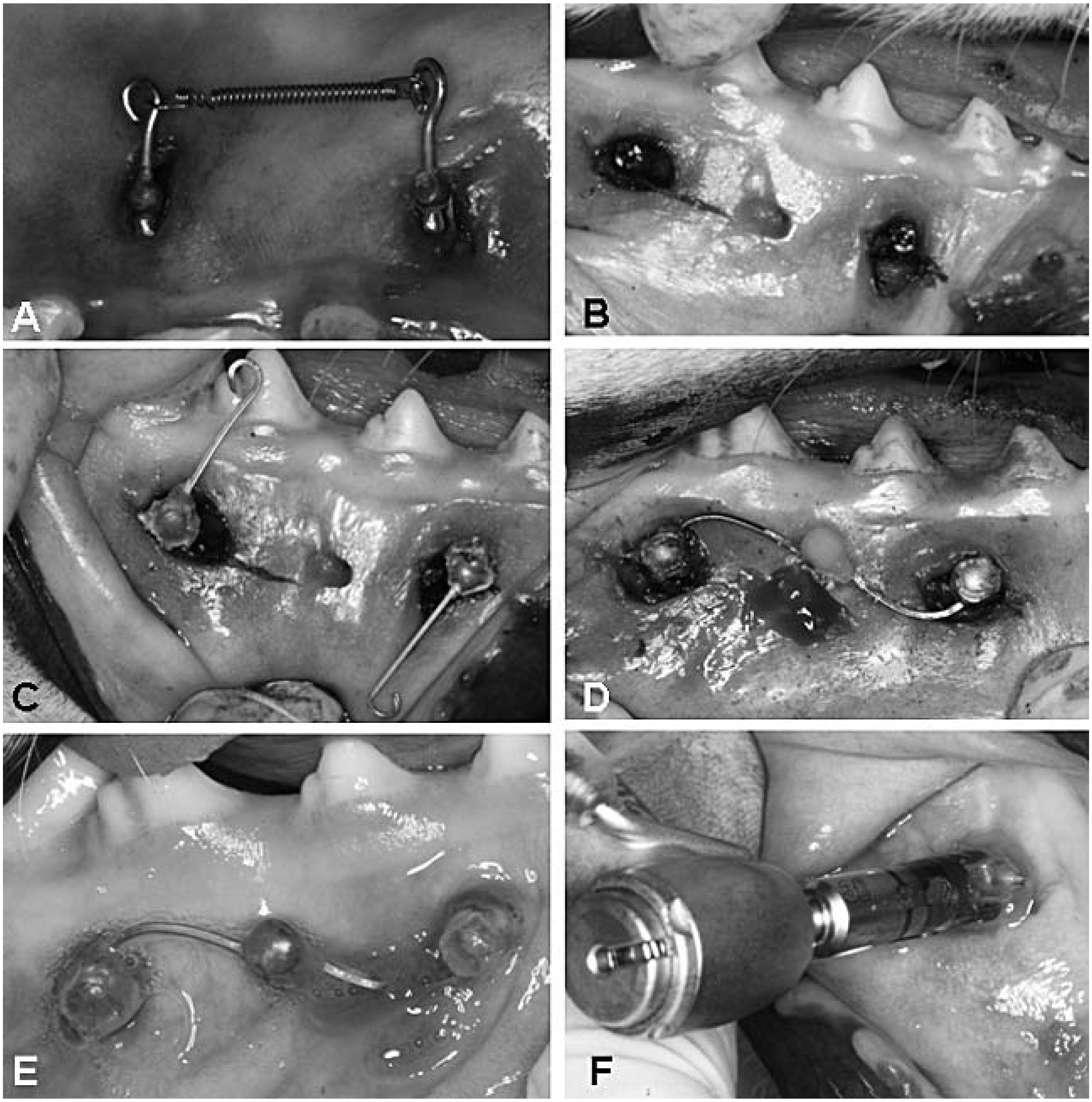

Figure 4. (A) Rotational moment application using stainless steel lever arm and Ni-Ti closed-coil spring. This design was not suitable for the beagle dog experiment. (B) Screw parts of mini-implants exposed to the intraoral cavity. (C) Custom-made rotational moment application tool (composed of titanium head part of mini-implant, 0.016- × 0.022-inch Ni-Ti wire, and acrylic resin) cemented to the screw part. (D) Rotational moment application through bending the arch wire and resin curing. (E) After 5 weeks of rotational moment application. (F) Removal of mini-implant using a custom-made driver tip and surgical engine.

quires rotational moments, the typical tactic is to apply the rotational force to a tooth that is somehow attached to the mini-implant (indirect anchorage).[8] Cho evaluated the influence of an immediate rotational moment on the stability of machined-surface mini-implants in a beagle study and showed that counterclockwise rotational moments have a detrimental effect on the stability of orthodontic mini-implants.[7] In animal experiments comparing machined mini-implants to surface-treated mini-implants, SLA implants had a higher mean removal torque value and exhibited new bone formation around the SLA surface.[13,14] In a study on the success rates of surface-treated mini-implants, surface characteristics did not appear to influence survival rates of immediately loaded mini-implants.[22] In contrast, Lee et al showed that SLA surface treatment

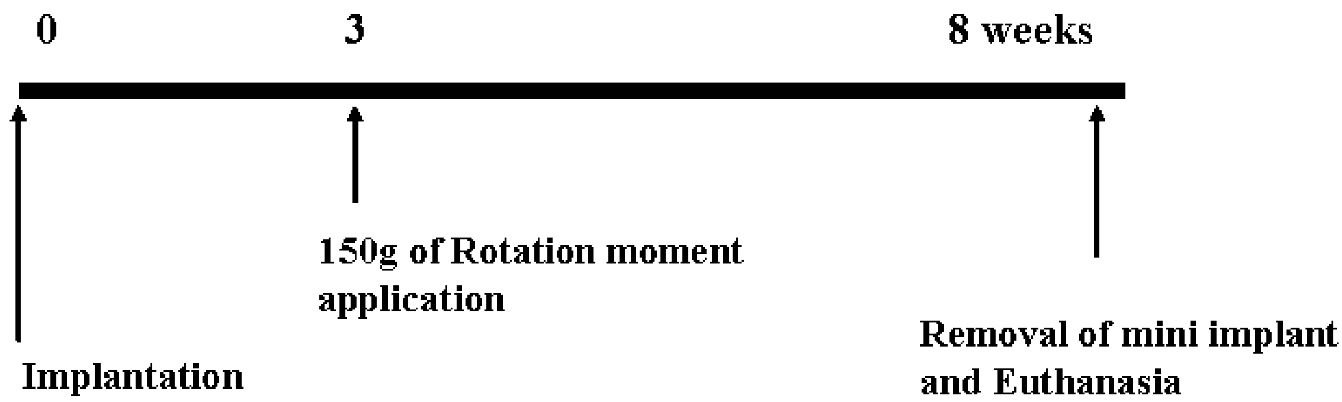

Figure 5. Timetable for placing implants.

Table 1. Measurement Values and Definitions Used

Measurement Values	Unit	Definition
Maximum insertion torque	N/cm	Maximum torque value from beginning to end of insertion of mini-implants
Insertion angular momentum	N·cm·s	Load developed to implant during initial insertion to the maximum insertion torque value[25]; angular momentum values are assessed by plotting insertion torque graph into the program
Total insertion energy	J	Energy absorbed by bone from the beginning to the maximum torque value of mini-implant insertion
Maximum removal torque	N/cm	Maximum torque value from beginning to end of removal of mini-implants
Removal angular momentum	N·cm·s	Load developed to implant during the maximum torque value to the end of removal of mini-implants; angular momentum values are assessed by plotting removal torque graph into the program
Total removal energy	J	Energy absorbed by bone during the maximum torque value to the end of removal of mini-implants

increased the stability of mini-implants both initially and after osseointegration, allowing various orthodontic forces to be applied.[18]

Counterclockwise stability of osseointegrated mini-implants offers the benefit of applying moments one could not apply with smooth-surface mini-implants. This includes such biomechanics as the dynamic forces of intermaxillary elastics and lever arms for incisor intrusion or torque control.[16,17] The orthodontist can benefit from rotational stability of the surface-treated mini-implant, so long as removal is not made difficult or risky. The degree of osseointegration is probably important. Partial osseointegration represents a distinct advantage in orthodontic applications, because rotational stability can offer support for lever arm mechanics, but the implant is still easy to remove.[23,24] The human study of Kim et al[15] showed that surface-treated mini-implants can be removed safely and easily without fracture after use for skeletal anchorage. As stated earlier, the SLA mini-implant has been used clinically as a posterior anchorage device in place of bands and brackets for en masse retraction. This demonstrates its resistance to heavy and dynamic forces and rotational moments produced by the intrusive moment of the retraction biomechanics.[15–18] In spite of a large amount of osseointegration, the coherence would be relatively low, since active remodeling and less mineralized bone formation takes place in the bone around the loaded screw part.[25,26] Also, a guide drill was used to penetrate the cortical bone in this study. This means that the SLA mini-implant, which has a modified cylindric profile with blunt pitches and apices, will not cause any difficulties during removal despite strong osseointegration, nor will it have harmful effects on adjacent periodontal ligament or root.

This study had a 50% retention rate of the mini-implants, which in humans would be unacceptable. The dogs tended to interfere with the mini-implant with their paws or tongue, causing micromotion that can loosen the screw. The bone quality in dogs clearly provides less stability to these devices than human bone. In humans, the failure rate decreases as time elapses and osseointegration proceeds. In animals, this is less evident. A beagle dog study by Vande Vannet et al[24] measured a success rate of 50% in 20 mini-implants. Failure was not associated with jaw location, placement on the right or left side, mesiodistal position, rotational direction, or quality of the surface treatment.

While other studies on mini-implant in beagles used only a static lateral force, the mini-implants in this

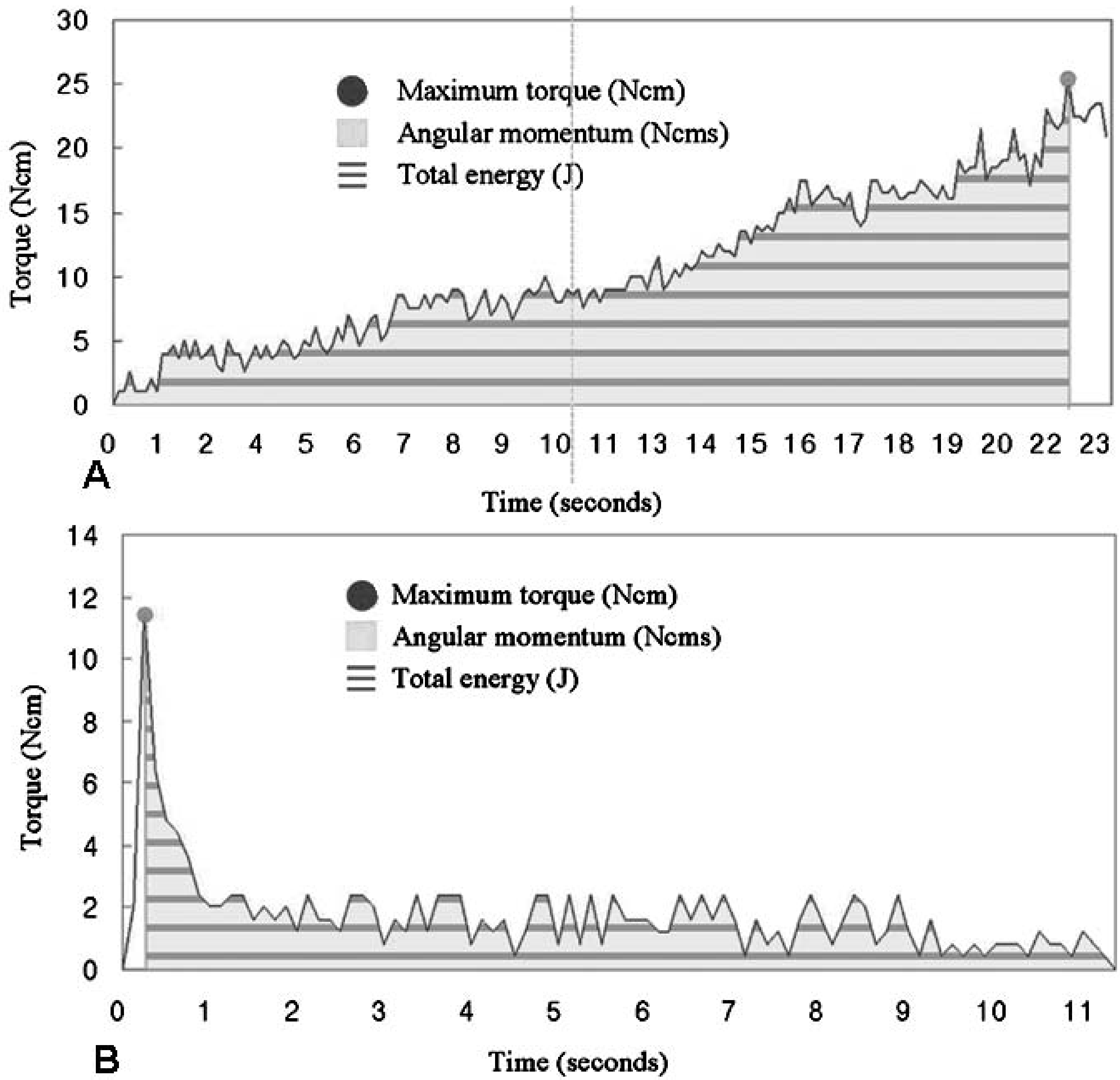

Figure 6. Graph and variables used during insertion (A) and removal (B) of mini-implants.

study were subjected to complex rotational moments, which might have increased the failure rate. To evaluate the effect of osseointegration on the stability of the mini-implants, the maximum torque value, angular momentum, and total energy were measured. Insertion torque is a standard to evaluate the mechanical stability of the mini-implant at insertion, and the removal torque value is a measure of osseointegration and stability of mini-implants.[15,20] However, measurement of only the difference between insertion and removal torque value is subject to error because the value might be affected by the position and posture of the clinician. In this study the use of a torque-measuring device minimized this risk of error since the device could measure consecutive torques every 0.125 seconds during insertion and removal, and it was possible to make corrections to the torque.[19,20]

Clinically, the maximum insertion torque (MIT) increases when the tapered part of the screw is long and the cortical bone is thick. High values of MIT will increase the risk of fracture of the cortical bone or the incidence of bone necrosis.[27] The screw design of the mini-implants used in this study is a modified cylinder in which the body tapers to the apex, and the apex

Table 2. Distribution of Mini-Implant Failures According to Various Conditions

Variables	N (%)		Significance[a]
	Surface Treatment		
	Machined	SLA	.914
Success	25 (52.1%)	23 (47.9%)	
Failure 0–3 weeks	16 (48.5%)	17 (51.5%)	
Failure 3–8 weeks	7 (46.7%)	8 (53.3%)	
	Rotational Direction		
	Clockwise	Counterclockwise	.953
Success	24 (50.0%)	24 (50.0%)	
Failure 0–3 weeks	16 (48.5%)	17 (51.5%)	
Failure 3–8 weeks	8 (53.3%)	7 (46.7%)	
	Maxilla vs Mandible		
	Maxilla	Mandible	.362
Success	22 (45.8%)	26 (54.2%)	
Failure 0–3 weeks	16 (48.5%)	17 (51.5%)	
Failure 3–8 weeks	10 (66.7%)	5 (33.3%)	
	Right vs Left		
	Left	Right	.809
Success	23 (47.9%)	25 (52.1%)	
Failure 0–3 weeks	18 (54.5%)	15 (45.5%)	
Failure 3–8 weeks	7 (46.7%)	8 (53.3%)	
	Mesiodistal Position		
	Mesial	Distal	.298
Success	26 (54.2%)	22 (45.8%)	
Failure 0–3 weeks	13 (39.4%)	20 (60.6%)	
Failure 3–8 weeks	9 (60.0%)	6 (40.0%)	

[a] Statistical significance (Fisher's exact test).

and pitch were blunt, making it easy to remove even when well ossointegrated.[15]

At insertion of the mini-implants, the machined group showed a higher MIT and angular momentum than the SLA group in this study. This result agrees with Cho's mini-implant study in beagle tibiae that the uniformly rough surface of SLA mini-implants provides the passage for blood to flow away, reducing friction against the adjacent bone.[28] At removal, the maximum removal torque value and angular momentum of the SLA implants were higher than those of the machined implants, although this was without statistical significance. The total energy at removal was significantly higher in the SLA group than in the machined group. Since the energy is the stress applied to the bone, low stress at insertion and high stress at removal have a favorable influence on bone tissues.[21] In this study, the SLA group showed lower torque value and angular momentum but higher total removal energy than the machined group, indicating that the surface treatment had influenced the osseointegration potential. SLA mini-implants were predicted to have higher resistance to counterclockwise rotation than the machined mini-implants. However, neither group showed statistically significant differences in torque values. Early loading was applied after 3 weeks of healing in this study, which might be enough time for early bone fixation in dogs, and the implants showed stable resistance against a rotational moment of 150 g regardless of the surface treatment.[21] Further studies are needed to evaluate osseointegration in relation to surface treatment when a rotational moment is applied immediately after implant insertion.

Table 3. Maximum Torque (N/cm), Angular Momentum (N·cm·s), and Total Energy (J) During Insertion and Removal for Both Machined and SLA Surface-Treated Orthodontic Mini-Implants

Rotational Direction	Type of Surface Treatment		Significance	
	Machined	SLA	Machined vs SLA	CW vs CCW
Maximum insertion torque (N/cm)				
CW	19.25 ± 8.34	15.27 ± 6.65	*	NS
CCW	16.52 ± 7.26	15.33 ± 8.80		
Insertion angular momentum (N·cm·s)				
CW	128.99 ± 64.74	103.79 ± 51.25	*	NS
CCW	113.68 ± 52.07	102.02 ± 57.58		
Total insertion energy (J)				
CW	3.98 ± 2.11	3.31 ± 1.57	NS	NS
CCW	3.43 ± 1.79	3.17 ± 1.84		
Maximum removal torque (N/cm)				
CW	7.45 ± 2.18	10.74 ± 8.53	NS	NS
CCW	6.18 ± 1.73	8.43 ± 1.62		
Removal angular momentum (N·cm·s)				
CW	30.96 ± 23.96	41.28 ± 44.99	NS	NS
CCW	23.20 ± 19.98	48.79 ± 38.85		
Total removal energy (J)				
CW	0.88 ± 0.61	1.31 ± 1.43	*	NS

CONCLUSIONS

- SLA mini-implants showed relatively lower insertion torque value and angular momentum but higher total energy during removal than machined-surface mini-implants, indicating higher osseointegration shortly after insertion.
- SLA implants show resistance to counterclockwise rotational forces, a quality that offers valuable biomechanical possibilities in orthodontics.
- With a sufficient healing period, partial osseointegration appears extensive enough to resist applied biomechanical forces without regard to surface treatment, jaw location, or rotational direction.

ACKNOWLEDGMENT

This study is based on all the theses referenced in this article. The rotation moment study using one component mini implant is from Dr Cho's[28] thesis and the mechanical analyses idea is from Drs Cho[28] and Park[21] and was partly supported by the Korean Society of Speedy Orthodontics, and Uijeongbu St Mary's Hospital. We also give special thanks to Dr Gerald Nelson, the Division of Orthodontics, Department of Orofacial Science, University of California at San Francisco, for manuscript editing.

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