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Comparison of Stability between Cylindrical and Conical Type Mini-Implants

Mechanical and Histologic Properties

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ABSTRACT

Objective: To investigate the mechanical and histologic properties of conical compared with cylindrical shaped mini-implants in terms of the success rate.

Materials and Methods: The samples consisted of cylindrical and conical groups, and commonly had 1.6 mm diameter and 6.0 mm length (Jeil Medical Corporation, Seoul, Korea) placed in beagle dogs. The mechanical study for analyzing maximum insertion torque (MIT), maximum removal torque (MRT), and torque ratio (TR; MRT/MIT) in Sawbones (Pacific Research Laboratories Inc, Vashon, Wash), and the animal study for resonance frequency analysis (RFA) and histomorphometric analysis (bone-to-implant contact and bone area) in two beagle dogs were done. All measurements were statistically evaluated using independent *t*-tests to determine any difference in MIT, MRT, TR, RFA, bone-to-implant contact (BIC), and bone area (BA) between the cylindrical group and conical group. A *P* value less than 0.05 was considered significant.

Results: The conical group showed significantly higher MIT and MRT than the cylindrical group in the mechanical study. However, there was no significant difference in RFA, BIC, and BA between the two groups in the animal and histomorphometric studies.

Conclusions: Although the conical shaped mini-implant could induce tight contact to the adjacent bone tissue and might produce good primary stability, the conical shape may need modification of the thread structure and insertion technique to reduce the excessive insertion torque while maintaining the high resistance to removal.

KEY WORDS: Mini-implant, Cylindrical, Conical, Stability, Mechanical, Histomorphometric.

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INTRODUCTION Return to TOC

Recently, implants,[1] onplants,[2] and orthodontic mini-implants[3,4] were introduced as effective tools for anchorage reinforcement. Prosthodontic implants and onplants have some disadvantages such as the need for surgical procedures, limitations of site selection and a waiting time for osseointegration.

Orthodontic mini-implants can be easily inserted into various sites and can be loaded at a relatively early stage compared with prosthodontic implants and onplants.[5,6] However, mini-implants with a small diameter can be easily loosened by low removal torque[7,8] and mini-implants with short length show a lower success rate.[9] Therefore, it is necessary to consider how to increase the success rate.

The conical shaped mini-implants are known to be more stable because a conical shape is able to provide a tighter contact between the mini-implant and tissue than the cylindrical ones due to the different diameters between the upper and lower parts.[10,11] Although the conical shape could provide mechanical retention between the implant and bone, the tapered or conical mini-implants produced higher crestal stresses as compared with cylindrical ones of the same dimensions.[12] Additionally, the taper shaped mini-implant has a 20%–30% smaller surface areas than a cylindrical one.[13] The small surface area of the conical implant decreases the contact surface with the bone and may reduce stability. Evaluation of the mechanical stability and biocompatibilty of the conical shaped mini-implants is needed.

To study the stability of mini-implants, a mobility test, resonance frequency analysis, and torque analysis can be applied.[14] Although insertion torque can be measured to evaluate the stability of mini-implants,[15] insertion torque is known to have a low relationship to stability.[16] Since removal torque is more related to the resistance and the removal moment than insertion torque,[17] removal torque can be used to test the mechanical stability of implants. For torque analysis of implant or surgical screw, a polyurethane foam with homogenous density like Sawbones (Sawbones, Pacific Research Laboratories Inc, Vashon, Wash) as artificial bone is often used for mechanical studies.[18] Resonance frequency analysis (RFA) is used to evaluate implant stability.[19] RF analyzer measures the flexural resonance frequency which is determined by the stiffness of the bone-implant interface, bone density, and implant design.[20,21]

However, there are few mechanical and histologic studies evaluating the effect of the conical shape on the stability of mini-implants. The purpose of this study was to investigate the mechanical and histologic properties of the conical shaped mini-implants in terms of success rate compared with cylindrical mini-implants through a mechanical study using Sawbones and histomorphometric analysis in beagle dogs.

MATERIAL AND METHODS Return to TOC

Mini-implants (diameter: 1.6 mm; length: 6.0 mm; Dual Top, Jeil Medical Corporation, Seoul, Korea) were made with Ti-6Al-4V alloy[22] (Table 1). According to the shape of the mini-implants, the samples consisted of a cylindrical group and a conical group (Figure 1A).

Insertion and Removal Torque Analysis

For torque analysis, each group, consisting of 10 mini-implants, was inserted to the solid rigid polyurethane foam (Sawbones), in which the density was homogeneously 30 pcf (Table 2 and Figure 1B). To avoid the variations of density, stiffness and rigidity in natural bone, a polyurethane Sawbone-based test setup was used.

The mini-implants were inserted and removed with a surgical engine (Elcomed SA200C, W&H, Bürmoos, Austria) (Figure 1C), which could measure and record the torque at 1/8 second intervals. It was calibrated at each time for the exact measurement. The rotation speed of the surgical engine was set as 30 rpm.

To analyze torque change patterns between groups, insertion torques were compared at 8 seconds (4 turns), 4 seconds (2 turns), and 0 second before maximum insertion torque (MIT); and removal torques were compared at 0 second, 2 seconds (1 turn) and 4 seconds (2 turns) after maximum removal torque (MRT). The torque ratio (TR) of MRT to MIT was calculated.

All measurements were statistically evaluated using an independent *t*-test to determine any difference in MIT, MRT, and TR between the cylindrical and conical groups. A P value less than 0.05 was considered significant.

RFA and Histomorphometric Analysis Insertion and Loading

For animal experiments, a male and a female beagle dog (11 kg and 13 kg, respectively) were used as the experimental subjects. Each group, which consisted of 16 mini-implants, was inserted to the buccal and palatal side of the maxilla and the buccal side of the mandible (Figure 2). The cylindrical shaped mini-implants were inserted on the right side of the maxilla and mandible, and the conical shaped mini-implants on the left side under saline irrigation. In both groups a force of 200–300 g was applied 1 week after insertion using a Ni-Ti coil spring (Ormco, Orange, Calif). The force continued for 17 weeks after insertion.

Measurement of Stability

Immediately (T0), 1 week (T1), and 17 weeks (T2) after mini-implant insertion, the resonance frequency analyzer (Osstell, Integration Diagnostic Ltd, Gothenburg, Sweden) was used for direct measurement of mini-implant stability. An intermediate jig between the transducer of Osstell and the mini-implants was used to apply the Osstell to the mini-implant.

The resonance frequency values, calculated from the peak amplitude, are represented in a quantitative unit called implant stability quotient (ISQ) on a scale from 1 to 100. ISQ values are derived from the stiffness (N/μm) of the transducer/implant/bone system and the calibration parameters of the transducer. A high ISQ value indicates high stability, whereas a low value indicates low stability.

Specimen Preparation

The dogs were sacrificed 17 weeks after insertion. The specimens of each mini-implant with the adjacent bone tissue were prepared in the axial plane using an Exakt cutting and grinding system (Exakt Apparatebau, Nordstedt, Germany). The resin-embedded mini-implant specimens were sliced and ground using the Exakt cutting and grinding system according to the method reported by Donath and Breuner.[23] The thickness of the specimens was about 40–50 μm. The specimens were stained with hematoxylin and eosin.

Histomorphometric Analysis

The histologic observation was performed using an Olympus BX51 microscope (Olympus Co, Toyko, Japan) which was connected to a computer. The following parameters of the three best consecutive mini-implant threads of each mini-implant were measured using image analyzing software (KAPPA, opto-electronics GmbH, Gleichen, Germany): (1) the bone-to-implant contact (BIC), the percentage of osseointegration on the thread; and (2) the bone area (BA), the percentage of mineralized tissue within the threads.[24]

Statistical Method

All measurements were statistically evaluated using an independent *t*-test to determine any difference in the ISQ, the bone-to-implant contact, and the bone area between the cylindrical and conical groups. A $P < .05$ was considered significant.

RESULTS Return to TOC

Insertion torque was gradually increased in all groups (Figure 3). MIT and MRT were higher in the conical group than the cylindrical group (Table 3).

Failure of Mini-Implant

Seven mini-implants (21.88%) failed in this study (Table 4). The failure rates of both groups were the same. The most common site of failure was the palate (31.25%), while there were no failures in the mandible (0.00%).

Resonance Frequency Analysis (RFA)

There was no significant difference in the ISQ between each group ($P > .05$). The ISQ of the mandible was highest at T0 and T1. Although the ISQ of the palate was highest at T2, the range for the standard deviation was broad. The ISQs of all the groups had a tendency to decrease with time (Table 5).

Histologic Findings

Generally, most of the mini-implants showed osseointegration with the adjacent bone tissue similar to other studies.[10,25] All mini-implants did not show good bone contact and bone area between the threads. However, all mini-implants which remained stable until the end of the study were resistant to orthodontic force.

There were the Harversian systems with the lamella bone and new bone around the mini-implants (Figure 4). The new bone was found close to the mini-implants, while the Harversian systems were located in various sites around the mini-implants.

Histomorphometric Analysis

There were no significant differences between each group in BIC and BA (Table 6). The BIC of each group was over 40%, and BA, over 55%. There was no significant difference in the BA according to location.

DISCUSSION Return to TOC

Insertion torque is known to have a correlation with mechanical stability.[13] However, despite high insertion torque, the clinical success rate may be low in cases with cancellous bone.[14] Removal torque is more related to the mechanical stability of the mini-implants than the insertion torque.[15] Therefore, torque itself and torque change patterns during insertion and removal need to be studied.

To evaluate insertion torque change pattern, the torque of each group was compared at 8 seconds (4 turns), 4 seconds (2 turns), and 0 second before MIT (Table 3, Figure 3A). There were no significant differences between each group at 8 seconds (4 turns) before MIT (Table 3). However, the insertion torque of the conical group was significantly higher than the cylindrical group at 4 seconds (2 turns). These findings mean that the difference between the cylindrical and conical shaped groups gradually increased from the middle of insertion. A continuous increase of insertion torque in the conical group was probably due to a tighter contact to the surroundings than the cylindrical group due to difference in diameter between the upper and lower parts.[26] Good primary stability may reduce the risk of micromotion and negative tissue responses such as the formation of the fibrous scar tissue at the bone-implant interface during healing and loading.[27] Therefore, primary stability is considered to play an essential role in successful osseointegration,[28] and insertion torque is used to evaluate the initial stability.[15]

However, some studies reported that the insertion torque had a low relationship to stability.[16] Therefore, removal torque was used to test the mechanical stability of implants because the removal torque was more related to the resistance to the removal moment than the insertion torque.[17]

The results of this study showed that the removal torque was much lower than the insertion torque. Both groups showed a sudden decrease of removal torque after MRT. To analyze removal torque change patterns, the removal torque of each group was compared at 2 seconds (1 turn) and 4 seconds (2 turns) after MRT. Although the conical group showed a higher torque 2 seconds after MRT than the cylindrical group, both groups showed lower MRT than MIT. The torque ratio of MRT to MIT was 26.05% ± 5.19% in the cylindrical group and 31.10% ± 5.28% in the conical group. This means that the resistance to the insertion may not indicate primary stability, and the primary stability may be more related to removal torque than insertion torque.

A conical shape has been applied to the implant to decrease failure of implants.[17] A conical shape is able to provide a tight contact between the implant and tissue as it is deeply inserted because the upper part of the taper shape has a larger diameter than the lower part.[10] Some clinical studies have shown favorable results for tapered implants.[28,29] The conical shape was considered to enhance the initial stability of the mini-implant.[30] However, excessive insertion torque may produce microfracture and ischemia of the surrounding bone, delay bone healing, and induce implant failure.[31]

Although the higher MRT of the conical group seemed to relate to high mechanical stability, excessive MIT of the conical group might be harmful to the tissue adjacent the mini-implant. Therefore, clinical stability of the conical shaped mini-implant is controversial.

The conical shaped mini-implant may have some advantages such as mechanical retention and good primary stability.[10] The results from this study with Sawbones were similar to the characteristics of the conical shaped mini-implant from other studies. However, the conical shape may induce negative bone tissue reaction because of over-compression to the bone tissue on insertion.[11] What is needed is a reduction in the compression to the bone without a decrease of mechanical retention by high removal torque.

From the results of this animal study there were no significant differences in the success rate and the histomorphometric analysis between the cylindrical and conical groups. The success rate was lower in the conical group than the cylindrical group. The histomorphometric analysis showed that the two groups in this study had no difference in the BIC and BA. This means that the conical shape would not be better in clinical applications because of over-compression to the surrounding tissue[12] and a smaller size of the surface area[13] than cylindrical shapes, although it may provide the mechanical stability when being removed. To reduce the damage to the surrounding tissue, relatively low insertion torque and high removal torque would be beneficial to the stability of the mini-implant.

Clinically, the conical shape may provide good initial stability because of high removal torque. However, high insertion torque may induce the over-compression to the bone tissue and decrease the stability of the mini-implant. Therefore, efforts to reduce the insertion torque as in modification of the thread shape may be better for tissue healing. Additionally, a drilling procedure before insertion of a conical shaped or thick diameter mini-implant could decrease the insertion torque, although a drill-free technique may enhance the stability of the thin mini-implant.[10]

Stability of the orthodontic mini-implant might be affected by various biologic and mechanical factors such as the bone density, soft tissue condition, oral hygiene, insertion method, surface treatment, and various shapes, diameters, and lengths of the mini-implants. These factors must be considered and evaluated in future studies.

CONCLUSIONS Return to TOC

- Although the conical group required high removal torque, which means good initial stability, it also showed high insertion torque which could affect adjacent tissue healing.
- The success rate, RFA, and histomorphometric analysis showed no significant difference between the cylindrical and conical groups.
- The conical shape may need modification of the thread structure and insertion technique to reduce the excessive insertion torque while maintaining the high resistance to removal.

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TABLES Return to TOC

Table 1. Chemical Composition and Mechanical Properties of Ti-6Al-4V Alloy

	Chemical Composition, %								Mechanical Properties		
Alloy:	N	C	H	Fe	O	Al	V	Ti	Tensile Strength (MPa)	Young's Modulus (GPa)	Yield Strength, 0.2% Offset (MPa)
Ti-6Al-4V	0.05	0.08	0.012	0.25	0.13	5.5–6.5	3.5–4.5	Balance	860–896	110	795–827

Table 2. Mechanical Properties of the Solid Rigid Polyurethane Foam (Sawbones) for Insertion of the Orthodontic Mini-Implants

Density		Compressive		Tensile		Shear	
pcf	g/cc	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa
30	0.48	20	553	11	640	8.9	122

Table 3. Torque (Mean Ncm ± SD) at 8, 4, and 0 Seconds Before the Maximum Insertion Torque and 0, 2, and 4 Seconds After the Maximum Removal Torque of Each Group

		Torque (Ncm)				
		Cylindrical Group		Conical Group		
	Time[a] (turn)	Mean	SD	Mean	SD	Sig[b]
Insertion	−8 sec (−4 turns)	4.84	0.50	5.38	0.67	NS
	−4 sec (−2 turns)	7.12	0.42	9.67	0.89	***
	0 sec (0 turn)	13.32	0.60	16.61	0.42	***
Removal	0 sec (0 turn)	3.47	0.71	5.16	0.85	***
	+2 sec (1 turn)	2.19	0.35	2.83	0.57	NS
	+4 sec (2 turns)	1.63	0.30	1.57	0.36	NS

[a] Insertion time was calibrated to the time (0 sec) of the maximum insertion torque of each group. Removal time was calibrated to the time (0 sec) of the maximum removal torque of each group. One second corresponds to a half turn of mini-implant.

[b] Sig indicates significance by independent *t*-test; NS, not significant.

*** $P < .001$.

Table 4. Mini-Implant Loss Rate (%) of Each Group of Each Area

	Failure Rate of Mini-Implant					
	Cylindrical Group		Conical Group		Total	
Area	%	Number of Failures/ Total Number	%	Number of Failures/ Total Number	%	Number of Failures/ Total Number
Palate	25.00%	2/8	37.50%	3/8	31.25%	5/16
Maxilla	25.00%	1/4	25.00%	1/4	25.00%	2/8
Mandible	0.00%	0/4	0.00%	0/4	0.00%	0/8
Total	18.75%	3/16	25.00%	4/16	21.88%	7/32

Table 5. The Resonance Frequency Value (ISQ) of Each Group for Each Time

	Resonance Frequency Value (ISQ)[a]				
	Cylindrical Group		Conical Group		
Time	Mean	SD	Mean	SD	Sig[b]
T0: 0 Week (insertion)	46.88	21.87	43.56	16.53	NS
T1: 1 Week (loading)	38.19	25.88	36.25	7.13	NS
T2: 17 Weeks	31.63	29.33	35.81	35.96	NS

[a] ISQ indicates in implant stability quotient.

[b] Sig indicates significance by independent *t*-test; NS, not significant.

Table 6. Bone-to-Implant Contact (BIC) and Bone Area (BA) of Each Group

	Cylindrical Group		Conical Group		
Measurement	Mean	SD	Mean	SD	Sig[a]
BIC, %	40.33	15.77	45.35	22.35	NS
BA, %	58.99	12.96	56.39	12.52	NS

[a] Sig indicates significance by independent *t*-test; NS, not significant.

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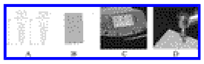

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Figure 1. Materials and equipment for insertion and removal of the orthodontic mini-implants. (A) Groups of the orthodontic mini-implants: cylindrical (left) and conical types (right). (B) Polyurethane foam (Sawbones) with homogeneous density (30 pcf). (C) Surgical engine (Elcomed SA200C) which can control the torque and speed (rpm), and measure the torque at an interval of 1/8 second. (D) Insertion of the orthodontic mini-implant into the polyurethane foam using the surgical engine

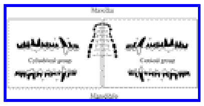

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Figure 2. Locations of the orthodontic mini-implants. The gray points indicate the locations of insertion. Cylindrical group was inserted in the right side of the maxilla and mandible; conical group, in the left side of the maxilla and mandible

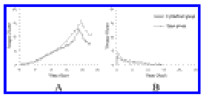

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Figure 3. Insertion and removal torques according to the elapsed time in each group. (A) Insertion torque. (B) Removal torque

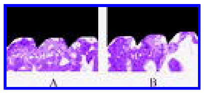

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Figure 4. Microscopic views of mini-implant in the mandible. There is the lamella bone (L) and the Harversian systems (H) in the cylindrical (A) and conical groups (B)

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