Original Article

Effects of the Taper Shape, Dual-Thread, and Length on the Mechanical Properties of Mini-Implants

Young-Kyun Kim[a]; Yoon-Ji Kim[b]; Pil-Young Yun[c]; Jong-Wan Kim[d]

ABSTRACT

Objective: To analyze the mechanical effects of the length and the various shapes such as cylindrical shape, taper shape, and dual-thread shape on the insertion and removal torque of mini-implants.

Materials and Methods: Mini-implants (diameter 1.6 mm and length 6 mm and 8 mm) consisting of cylindrical, taper, and dual-thread groups were inserted and removed in Sawbones while measuring the torque and time. Mechanical analysis was done of maximum insertion torque (MIT), maximum removal torque (MRT), torque ratio (TR; MRT/MIT), insertion angular momentum (IAM), removal angular momentum (RAM), and time of MIT. Measurements were statistically evaluated to analyze any differences of shapes and lengths.

Results: The cylindrical shape had the lowest MIT and MRT in each length. Although taper shape showed the highest MIT in each length, dual-thread shape showed significantly higher MRT, TR, and RAM in each length ($P < .05$). Dual-thread groups showed a gentle increase of insertion torque and a gentle decrease of removal torque in contrast to the other shape groups. However, it had higher IAM and time of MIT. The long length group showed significantly higher measurements except for TR.

Conclusions: Dual-thread shape provided better mechanical stability with high removal torque on the broad range than other shapes. However, dual-thread shape may need improvement for reducing the long insertion time to decrease the stress to the surrounding tissue. (*Angle Orthod.* 2009;79:908–914.)

KEY WORDS: Mini-implant; Shape; Dual-thread; Mechanical; Torque

INTRODUCTION

Small diameter mini-implants as temporary anchorages can be easily applied to the maxilla and mandible. However, small diameter and short length mini-implants may reduce primary stability. The primary stability of the orthodontic mini-implant might be mainly supported by mechanical retention.[1] Primary stability is determined by the bone properties, surgical technique, and implant size and design. An implant that has a large diameter and long length could be used to overcome insufficient initial stability in low quality and quantity of bone tissue.[2] However, orthodontic mini-implants, which may often be inserted between the roots, have limitation in diameter and length.[3]

The shape and texture of the implant may also have an effect on initial stability.[4] The design of the implant for primary stability may be important in soft bone.[5] Some clinical studies of taper-shaped implants have shown favorable results.[6] Although the taper shape could provide mechanical retention between the implant and bone, taper-shaped implants produced higher crestal stresses than cylindrical implants of the same dimensions.[7] Additionally, tapered implants have 20%–30% less surface area than cylindrical implants,[8]

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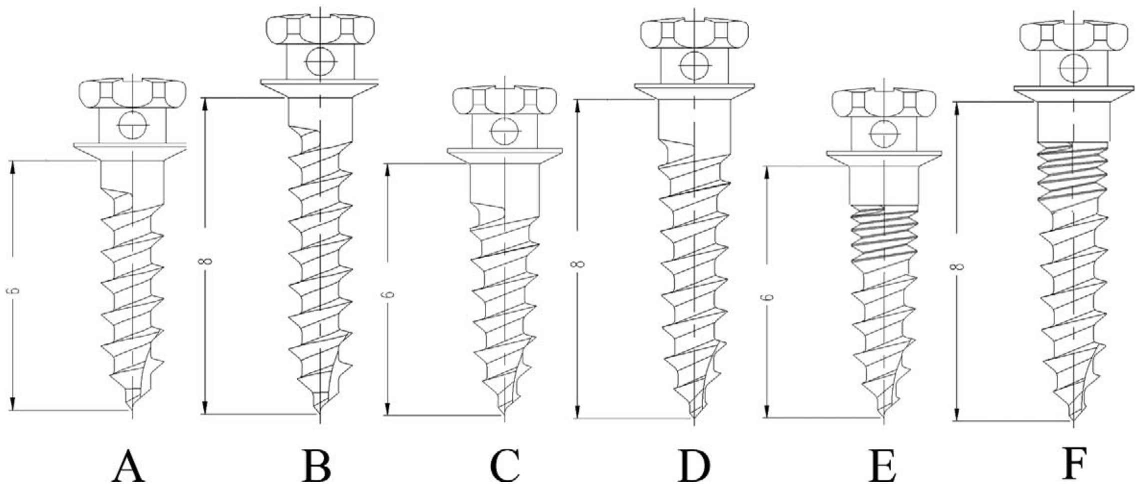

Figure 1. Tested groups of orthodontic mini-implants: (A) 6 mm cylindrical (SC) group; (B) 8 mm cylindrical (LC) group; (C) 6 mm taper (ST) group; (D) 8 mm taper (LT) group; (E) 6 mm dual-thread and taper (SD) group; and (F) 8 mm dual-thread and taper (LD) group.

and this decreases the contact surface with the bone and may reduce stability.[9]

Micro threads on the implant may be favorable for distributing stress and preserving marginal bone support because of the contact between the micro threads of the upper part of the implant and cortical bone.[10]

To evaluate the stability of implants, the mobility test, resonance frequency analysis, and torque analysis are possible.[11] Although insertion torque analysis was developed as a method to measure stability and supportive capacity of the implant,[12] insertion torque may have a low relationship to stability and removal torque can be more useful to test the mechanical stability of implants.[13] For torque analysis of an implant or surgical screw, polyurethane foam such as Sawbones with homogenous density is often used for mechanical studies as with artificial bone.[8]

Successful osseointegration of endosseous implants is the result of a favorable interaction between the surface geometry of the implant and the bone tissues.[14] The macro-design and surface structure of implants are important factors which influence the clinical outcome of an implant.[15] Although the parameters affecting the primary stability of orthodontic mini-implants were recently studied,[16,17] there are few mechanical studies about the effects of the shape and the micro threads of the mini-implants on enhancing the initial stability. The aim of this study was to evaluate the influence of taper shape, micro thread and length of mini-implants on the initial stability. For this, a mechanical study on artificial bone for evaluation of taper shape and micro thread in relation to insertion and removal torque was done.

MATERIALS AND METHODS

The mini-implants (diameter 1.6 mm, Jeil Medical Corporation, Seoul, Korea) were made with Ti-6Al-4V alloy.[15] The lengths of the mini-implants were 6 mm and 8 mm, and the shapes were cylindrical, taper, and dual-thread. According to the shape and the length, groups of the mini-implants were classified into the 6 mm cylindrical (SC), 8 mm cylindrical (LC), 6 mm taper (ST), 8 mm taper (LT), 6 mm dual-thread and taper (SD) and 8 mm dual-thread and taper (LD) (Figure 1). SD and LD groups were made with the ST and LT group modifying the upper thread which was the micro-thread to about half the pitch of the lower thread. Each group was composed of 10 mini-implants. The SD and LD groups had micro threads on the upper part of mini-implant.

The mini-implants were inserted just below the collar into artificial bone, which was solid rigid polyurethane foam (Sawbones, Pacific Research Laboratories Inc, Vashon, Wash) and had a homogeneous 30 pounds per cubic foot (pcf) density (Table 1). Although the mini-implants might be inserted too deeply because of a soft tissue layer, it needed a criterion because the thickness may be different at the different sites. Therefore, the collar of the mini-implant was used as a stop.

Table 1. Mechanical Properties of the Solid Rigid Polyurethane Foam (Sawbones) for Insertion of the Orthodontic Mini-Implants

Density		Compressive Strength		Tensile Strength		Shear Strength	
(pcf)	(g/cc)	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa
30	0.48	20	533	11	640	8.9	122

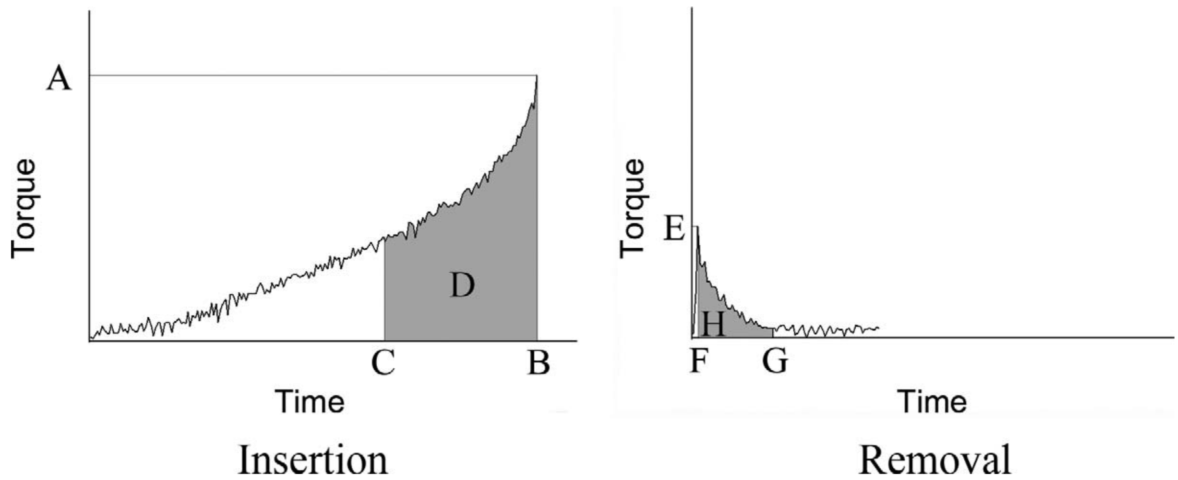

Figure 2. Measurements for analyzing mechanical characteristics of mini-implants having various shapes: (A) maximum insertion torque (MIT); (B) time of MIT; (C) time of 8 seconds before MIT; (D) insertion angular momentum (IAM), which is the integrated torques from 8 seconds to 0 seconds before MIT; (E) maximum removal torque (MRT); (F) time of MRT; (G) time of 4 seconds after MRT; and (H) removal angular momentum (RAM), which is the integrated torque from 0 seconds to 4 seconds after MRT.

The mini-implants were inserted and removed with the torque recorded by a surgical engine (Elcomed SA200C, W&H, Bürmoos, Austria), which had rotational speed of 30 rpm. Impdat software (Kea Software GmbH, Poecking, Germany) was used for the readout of the recorded torque value.

To analyze and compare the patterns of the torque changes between each group, the insertion torque was measured at 8 seconds (4 turns), 4 seconds (2 turns), and 0 seconds before the maximum insertion torque (MIT). The removal torque was measured at 0 seconds, 2 seconds (1 turn), and 4 seconds (2 turns) after the maximum removal torque (MRT). The time was converted to turns, because 1 second might correspond to a half turn of the mini-implant at 30 rpm. The torque ratio (TR) of the MRT to the MIT was calculated. The TR was used to evaluate the mechanical efficiency of the mini-implant.

To analyze the energy to insert the mini-implant to the bone, the angular momentum (Ncms) was calculated integrating the torque by time (Figure 2). The insertion angular momentum (IAM) was the integrated torque from 8 seconds to 0 seconds before MIT. The removal angular momentum (RAM) was the integrated torque from 0 seconds to 4 seconds after MRT. The time of MIT was analyzed to compare the insertion patterns between each group.

Statistical Method

Because the data were not normally distributed under the Levene variance homogeneity test, nonparametric analyses were done. Kruskal-Wallis tests were done to determine any differences between the cylindrical, taper, and dual-thread groups. All measurements were statistically evaluated using the Mann-Whitney *U*-test to determine any difference between the short and long groups in same shape groups. $P < .05$ was considered significant.

RESULTS

The insertion torque was gradually increased in all groups (Figure 3A). Torque of the taper shape groups suddenly increased during insertion and suddenly decreased during removal (Figure 3A,B). However, the dual-thread groups showed a gentle increase of insertion torque and a gentle decrease of removal torque.

The cylindrical shape had the lowest MIT and MRT in each length (Tables 2 and 3, Figure 3C,D). Although the taper shape showed the highest MIT in each length, the dual-thread shape showed significantly higher MRT, TR, and RAM in each length (Tables 2 through 6) ($P < .05$).

Although the effect of length during insertion was from the 8 seconds before MIT, during removal it was until 2 seconds after MRT (Tables 2 and 3).

The LD group showed the highest MRT although the LT group showed the highest MIT (Tables 2 and 3). The SC group showed the lowest MIT and MRT (Tables 2 and 3).

The torque ratio of the dual-thread groups was significantly higher than other groups in each length (Table 4). The torque ratio of cylindrical groups was lowest in each length. The RAM was significantly higher in the dual-thread groups than in any other shape group (Table 5). However, the dual-thread groups showed higher IAM and time of MIT, too (Tables 6 and

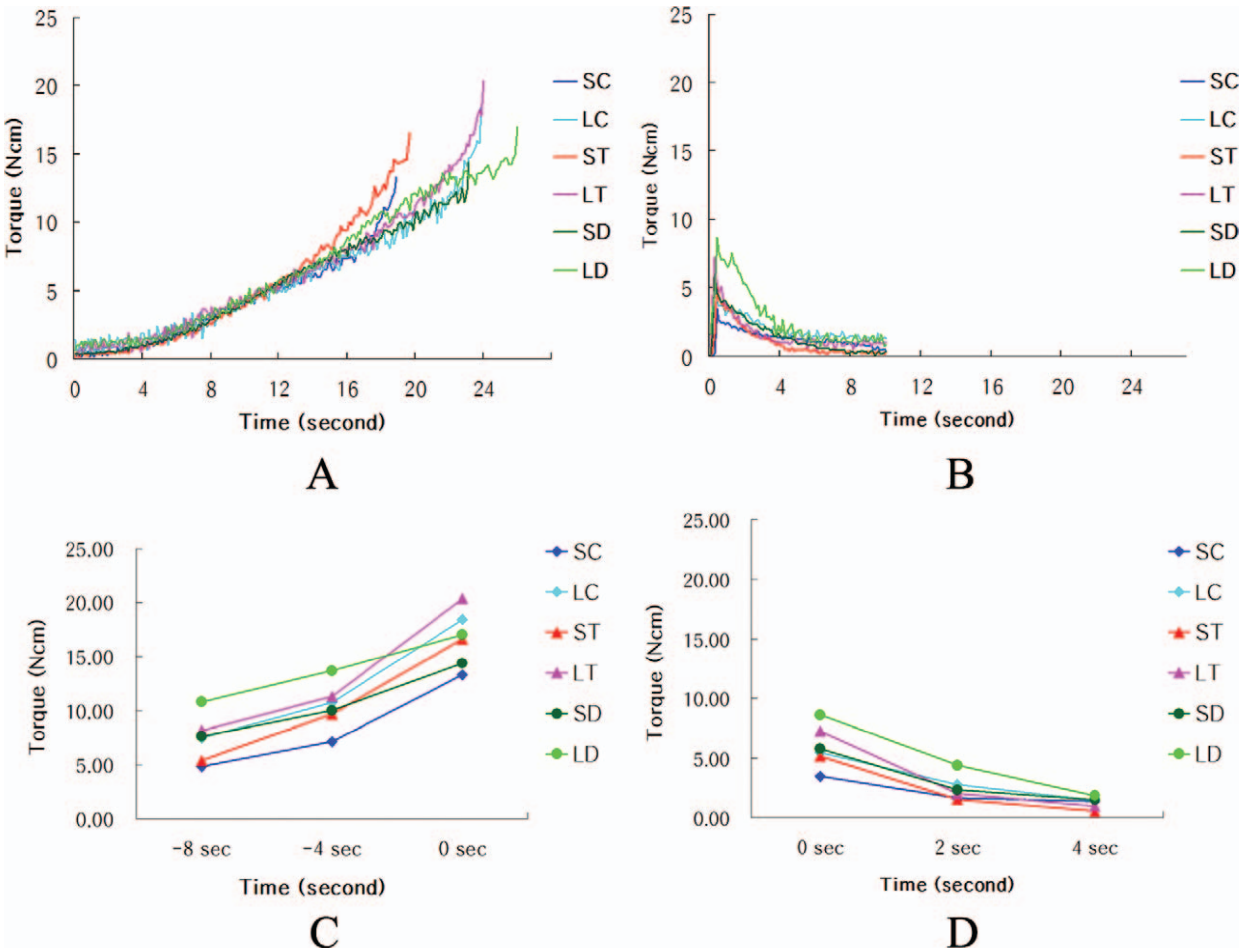

Figure 3. Insertion and removal torques in each group: (A) insertion torque according to the elapsed time; (B) removal torque according to the elapsed time; (C) insertion torque at 8, 4, and 0 seconds before the maximum insertion torque; and (D) removal torque at 0, 2, and 4 seconds after the maximum removal torque.

Table 2. Torque (Mean Ncm ± SD) at 8, 4, and 0 Seconds Before the Maximum Insertion Torque

		Insertion Torque, Ncm						
		Cylindrical		Taper		Dual-Thread		
Insertion Time[a]	Length, mm	Mean	SD	Mean	SD	Mean	SD	Sig[b]
−8 seconds	6	4.84	0.50	5.38	0.67	7.61	0.98	***
(−4 turns)	8	7.47	1.40	8.19	1.19	10.80	1.36	***
	Sig[c]	***		***		***		
−4 seconds	6	7.12	0.42	9.67	0.89	10.03	0.80	***
(−2 turns)	8	10.77	1.30	11.28	1.56	13.68	1.14	***
	Sig[c]	***		*		***		
0 seconds	6	13.32	0.60	16.61	0.42	14.39	1.22	***
(0 turns)	8	18.42	0.91	20.37	0.73	17.04	0.58	***
	Sig[c]	***		***		***		

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

[b] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[c] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; * $P < .05$; *** $P < .001$.

Table 3. Torque (Mean Ncm ± SD) at 0, 2, and 4 Seconds After the Maximum Removal Torque

Removal Time[a] (Turn)	Length, mm	Removal Torque, Ncm						
		Cylindrical		Taper		Dual-Thread		
		Mean	SD	Mean	SD	Mean	SD	Sig[b]
0 seconds	6	3.47	0.71	5.16	0.85	5.78	1.03	***
(0 turns)	8	5.46	0.98	7.23	1.56	8.64	1.08	***
	Sig[c]	***		**		***		
2 seconds	6	1.63	0.30	1.57	0.36	2.34	0.81	**
(1 turn)	8	2.79	1.23	2.04	0.68	4.41	1.01	***
	Sig[c]	*		NS		***		
4 seconds	6	1.38	0.21	0.55	0.19	1.50	0.54	***
(2 turns)	8	1.47	0.50	0.99	0.78	1.89	0.66	*
	Sig[c]	NS		NS		NS		

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

[b] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[c] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; NS, not significant; * $P < .05$; ** $P < .01$; *** $P < .001$.

7). The long length group showed significantly higher measurements except of TR.

DISCUSSION

There was no significant difference between the cylindrical group and the taper group with the same length at 8 seconds before MIT (Table 2). However, the insertion torque of the taper group was significantly higher than the cylindrical group at 4 seconds before MIT. This means that the insertion torque of the taper groups might highly increase from the middle of the insertion because of an increase of the tight contact surface resulting from the taper shape. The cylindrical and taper groups showed a sudden increase of insertion torque and a sudden decrease of removal torque. The rpm of the surgical engine was 30 turns/min. This may mean that 2 seconds corresponded to one turn. The cylindrical or taper mini-implant may show the sudden increase of insertion torque from 4–8 seconds before complete insertion, which means that these mini-implants can be easy to fracture during the last two to four turns.

However, the dual-thread groups showed a gentle increase of insertion torque by the upper micro thread, which might have an influence on the decrease of MIT (Table 2). The dual-thread groups showed a significantly lower MIT than the tapered mono-thread groups (Table 2). The decreased MIT may prevent tissue damage and mini-implant fracture. When a small diameter is needed to reduce some risks such as tooth contact, the dual-thread may be helpful to prevent fractures.

The dual-thread groups showed a gentle decrease of removal torque. The dual-thread groups showed higher removal torque than the mono-thread groups in the same length at 0 seconds, 2 seconds, and 4 seconds after MRT (Table 3). The removal torque of the dual-thread groups at 2 seconds after the MRT was over 1.5 times that of the mono-thread groups. This means that the upper micro thread in the dual-thread

Table 4. Torque Ratio (%) of Maximum Removal Torque to Maximum Insertion Torque

Length, mm	Torque Ratio, %						
	Cylindrical		Taper		Dual-Thread		
	Mean	SD	Mean	SD	Mean	SD	Sig[a]
6	26.06	5.19	31.10	5.28	40.75	10.01	***
8	29.62	4.81	35.46	7.48	50.78	6.76	***
Sig[b]	NS		NS		*		

[a] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[b] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; NS, not significant; * $P < .05$; *** $P < .001$.

Table 5. Insertion Angular Momentum, Which Was the Integrated Torques From 8 Seconds to 0 Seconds Before Maximum Insertion Torque

Length, mm	Insertion Angular Momentum, Ncms						
	Cylindrical		Taper		Dual-Thread		
	Mean	SD	Mean	SD	Mean	SD	Sig[a]
6	114.47	5.21	152.70	10.04	156.59	12.26	***
8	167.01	7.40	187.82	8.04	204.53	7.29	***
Sig[b]	***		***		***		

[a] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[b] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; *** $P < .001$.

Table 6. Removal Angular Momentum, Which Was the Integrated Torque From 0 Seconds to 4 Seconds After Maximum Removal Torque

Length, mm	Removal Angular Momentum, Ncms						
	Cylindrical		Taper		Dual-Thread		
	Mean	SD	Mean	SD	Mean	SD	Sig[a]
6	14.63	1.80	16.02	2.25	21.88	2.95	***
8	19.30	2.94	22.02	2.88	36.95	3.09	***
Sig[b]	***		***		***		

[a] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[b] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; *** $P < .001$.

Table 7. The Time to Maximum Insertion Torque (MIT) in Each Group to Compare Patterns of Insertion

Length, mm	Time to Maximum Insertion Torque, sec						
	Cylindrical		Taper		Dual-Thread		
	Mean	SD	Mean	SD	Mean	SD	Sig[a]
6	19.03	0.22	19.79	0.32	23.40	1.10	***
8	24.05	0.29	24.05	0.44	25.74	0.51	***
Sig[b]	***		***		***		

[a] Significance between the cylindrical, taper, and dual-thread groups by the Kruskal-Wallis test.

[b] Significance between the 6 mm and 8 mm groups by the Mann-Whitney *U*-test. SD indicates standard deviation; *** $P < .001$.

groups might increase the stability with resistance to the removal rotation on the broad range of a turn.

Within the same shape, the torque of the long length (8 mm) groups was higher than the short length (6 mm) groups during insertion and removal. The effects of length were more obvious on the insertion torque than the removal torque and more on the cylindrical group than other groups (Tables 2 and 3).This means that the long mini-implant may provide higher stability with high torque during removal. However, the long mini-implant can have a chance to fracture during insertion because it needs a high insertion torque.[15] Additionally, tissue damage or contact to the anatomical structures such as tooth root and nasal cavity may occur with long mini-implants.[18] Therefore, the mini-implant, which is short and needs low insertion torque and high removal torque, will be favorable.

The MRT of each group was under half of its MIT. This means that MRT is not as high as the MIT,[15] and the stability of the mini-implant might be more related to the removal torque than the insertion torque. The high torque ratio of MRT to MIT may be related to the high mechanical efficiency, which means that insertion of mini-implant may be easy, but removal may be more difficult.

TR of mono-thread groups was below 36%. However, the dual-thread groups had a high TR, over 40% regardless of their lengths. A low MIT with a gentle increase of insertion torque may reduce the tissue damage and mini-implant fracture. A high MRT with a gentle decrease of removal torque may improve the stability of the small diameter mini-implant.

However, the stress to the surrounding bone tissue might be related to not only insertion torque, but also the energy for insertion.[19] The time of MIT was longest in the dual-thread groups and shortest in the cylindrical groups. This means that the dual-thread groups might need more energy for insertion and might induce more stress to the tissue because of the long insertion time.

The results of the IAM showed this possibility. The IAM might mean the energy for insertion. The IAM of the dual-thread group was higher than other shaped groups, although the dual-thread group had the high RAM, which may be helpful to resist the removal torque. The time of the MIT was longest in the dual-thread group, too. The high IAM and the long time of MIT of the dual-thread could lead to stress in the bone tissue.

Dual-thread groups might have their low insertion torque reduced by decreasing the forward insertion velocity under the same rotational velocity because of the small pitch of the micro thread. It might cause the gentle increase of the insertion torque. The small pitch might affect the backward removal velocity and might contribute to the maintenance of a high removal torque. However, the decrease of the forward insertion velocity might prolong the time of the MIT and IAM of the dual-thread groups. It might increase the stress rather than decrease the stress to the bone tissue.

Although the micro thread could enhance the stability of a small diameter mini-implant, it needs to decrease the time of MIA and IAM for reducing the tissue stress. For this, the modifications of the micro thread design and operative procedure may be helpful.[20,21] Modifications of pitch, depth, and thread shape could enhance the cutting efficiency of the micro thread. Careful pilot drilling procedure before insertion could prevent the concentration of stress to the bone tissue by a long insertion time, although the drilling method might lead to tissue damage because of heat by the drilling procedure.[22]

The long and thick mini-implant might have some tissue damage and root contact. However, the short and thin mini-implant might be easy to fracture and less stable. Taper and dual-threads could support the short and thin mini-implant to overcome these disadvantages by decreasing the insertion torque and increasing the removal torque. However, an effort to reduce the insertion time and IAM would be needed for reducing the stress to the surrounding tissue. The results of the insertion torque in this study might differ from the results of other studies because the artificial bone used in this study might have different mechanical characteristics from human bone or animal bone.[23] Additional studies about modification of taper and dual-thread shape and development of operative procedure under clinical conditions may be needed to improve the stability and to decrease the tissue stress.

CONCLUSIONS

- The taper shape needs high insertion torque. However, the removal torque of the taper shape was lower than the removal of torque of the dual-thread shape.
- The dual-thread shape showed a low insertion torque and a gentle increase of insertion torque. The dual-thread shape also showed higher removal torque on the broad range than the cylindrical and taper shapes.
- Long mini-implants need higher insertion torque than short mini-implants, although long mini-implants showed high removal torque.
- The modification of thread, such as dual-thread, may be less harmful to the surrounding bone tissue because of the low insertion torque. The modification of thread also may provide short and small mini-implants better mechanical stability with a high removal torque. However, the dual-thread shape may need improvement for reducing the long insertion time to decrease the stress to the around tissue.

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