Original Article

Effects of predrilling depth and implant shape on the mechanical properties of orthodontic mini-implants during the insertion procedure

Keun-Chul Cho[a]; Seung-Hak Baek[b]

ABSTRACT

Objective: To investigate the effects of orthodontic mini-implant (OMI) shape and predrilling depth on the mechanical properties of OMIs during the insertion procedure.

Materials and Methods: A total of 30 OMIs (self-drilling type, 7 mm in length; Biomaterials Korea Inc) were allocated into six groups according to OMI shape (cylindrical and tapered type) and predrilling depth (control, 1.5-mm and 3.0-mm predrilling; predrilled with a drill-bit [1 mm in diameter]): C-con, C-1.5, C-3.0, T-con, T-1.5, and T-3.0 groups (N = 5 per group). The OMIs were installed in artificial bone blocks with two layers that simulated the cortical and cancellous bone (Sawbone®, Pacific Research Laboratories Inc). Total insertion time (TIT), maximum insertion torque (MIT), total insertion energy (TIE), and inclination of the time-torque graph (INC) were measured.

Results: Within the same shape group, although predrilling groups exhibited shorter TIT than control groups (control vs 1.5; control vs 3.0; all $P < .05$), there was no difference in TIT between 1.5-mm and 3.0-mm predrilling groups. MIT and TIE decreased in the order of control, 1.5-mm predrilling, and 3.0-mm predrilling (control vs 1.5; 1.5 vs 3.0; all $P < .05$), but INC revealed a pattern of increase from control to 1.5-mm predrilling and of decrease from 1.5-mm predrilling to 3.0-mm predrilling within the same shape group (control vs 1.5, 1.5 vs 3.0, all $P < .05$). The MIT and INC of C-con were smaller and less steep than those of T-con ($P < .01$ and $P < .05$, respectively). In the same predrilling depth, no differences were observed in MIT, INC, and TIE between cylindrical and tapered groups.

Conclusion: In cases of thick cortical bone, predrilling might be an effective tool for reducing microdamage without compromising OMI stability. (*Angle Orthod.* 2012;82:618–624.)

KEY WORDS: Mechanical properties; Orthodontic mini-implants; Predrilling depth; Mini-implant shape

INTRODUCTION

The stability of orthodontic mini-implants (OMIs) is influenced by mechanical retention and biological reactions. Primary stability is a mechanical phenomenon related to the quality and quantity of the bone, OMI type, and placement technique.[1] Secondary stability is a consequence of bone modeling and remodeling at the OMI-bone interface.[1,2] Although high insertion torque can increase primary stability,[3] it might have a negative effect on secondary stability due to the excessive compression stress, microdamage, and peri-implant bone resorption.[4,5] Therefore, Motoyoshi et al.[6,7] and Suzuki and Suzuki[8] insisted that it is necessary to bring the insertion torque into a proper range that can satisfy the primary and secondary stability of OMIs simultaneously.

According to studies about the success rate of OMIs, a wide range of overall success rates have been reported,[6,7,9–12] ranging from 83.3% to 91.6%. The failure rate is known to be more increased in the mandible compared to the maxilla.[9–12] Baumgaertel and Hans[13] and Lim et al.[14] reported that the buccal cortical bone was thicker in the mandible than in the maxilla and that the buccal cortical bone thickness in the mandibular posterior area ranged from 1.50 mm to 3.65 mm. Implant site preparation, such as that

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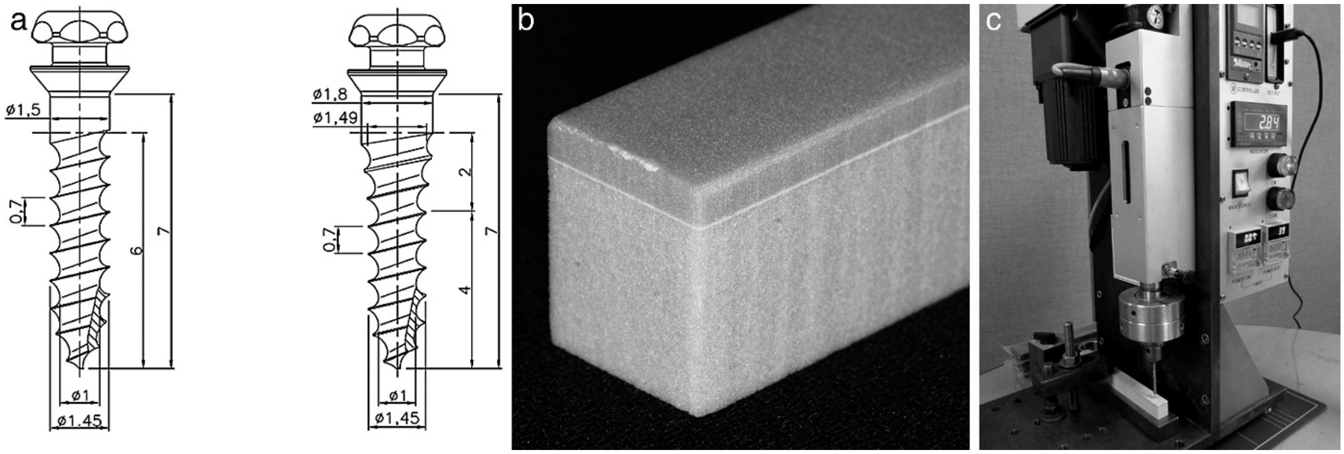

Figure 1. a. Schematic diagram of the orthodontic mini-implants (OMIs, Cylindrical shape, OAS-T1507; Tapered shape, OAS-T1507T; Biomaterials Korea Inc). b. Custom-made polyurethane foam artificial bone blocks with two layers that simulate the cortical and cancellous bone (Sawbone®, Pacific Research Laboratories Inc). c. The driving torque tester (Biomaterials Korea Inc).

associated with predrilling of the thick buccal cortical bone in the mandibular posterior area, can lower the insertion torque into the appropriate range. Kim et al.[15] reported that the non-predrilling group exhibited less mobility and greater bone-to-implant contact than did the predrilling group. However, their study had some limitations since there was no explanation about the predrilling depth and because the combined data from both the maxilla and mandible were used.

Since OMI stability can be influenced by the degree of compression stress in the bone, it is reasonable to consider both maximum insertion torque (MIT) and total insertion energy (TIE) as reference values for predicting the OMI stability because TIE is the sum of the insertion torque values from the beginning to the end of OMI installation.[16]

If the entire thickness of the cortical bone is predrilled in the mandibular posterior area, root damage of the posterior teeth and/or failure of the OMIs can occasionally occur by the predetermined direction of OMI installation. In order to weaken the cortical bone without predetermining the direction of OMI installation, a partial predrilling technique can be used. Although there have been numerous studies on the effects of predrilling diameter on OMI stability,[2,17–20] studies about the effects of predrilling depth on mechanical properties such as MIT and TIE of OMIs are insufficient. Therefore, it is necessary to perform OMI insertion experiments with diverse predrilling depths. Also, in the in vitro study, it is important to use artificial bone blocks with two layers, the mechanical properties of which are similar to the cortical and cancellous bone in humans.[20] If an artificial bone block with two layers that have different mechanical properties from those of humans is used, improper interpretation of the mechanical results might potentially occur.

To the authors' knowledge, a few studies[2,21] have simultaneously investigated the effects of OMI shape and predrilling depth on the mechanical properties of OMIs during the insertion procedure. Therefore, the purpose of this study was to investigate the effects of OMI shape and predrilling depth on the mechanical properties of OMIs during the insertion procedure in artificial bone blocks with two layers that simulate the cortical and cancellous bone in humans.

MATERIALS AND METHODS

OMIs and Allocation of the Groups

A total of 30 OMIs (self-drilling type, 7 mm in length; Biomaterials Korea Inc, Seoul, Korea) were allocated into six groups according to the OMI shape (cylindrical and tapered shape, Figure 1a) and predrilling depth (control, 1.5-mm predrilling, and 3.0-mm predrilling), as follows: C-con, C-1.5, C-3.0, T-con, T-1.5, and T-3.0 groups ($N = 5$ per group). Cylindrical OMIs had an external diameter of 1.45 mm and an internal diameter of 1.0 mm. Tapered OMIs consisted of two parts. The configuration of the lower 4 mm was identical to that of the cylindrical OMI, while the upper 2 mm had an increase of taper from 1.45 mm to 1.8 mm for the external diameter and from 1.0 mm to 1.49 mm for the internal diameter.

Artificial Bone Block

The custom-made polyurethane foam artificial bone blocks with two layers that simulate the cortical and cancellous bone (180 mm in length, 15 mm in width, and 18 mm in height; the upper layer with a density of 0.80 g/cc [50 pcf] and a height of 3 mm; the lower layer with a density of 0.48 g/cc [30 pcf] and a height of 15 mm; Sawbone®, Pacific Research Laboratories Inc,

Table 1. Mechanical Properties of the Polyurethane Foam (Sawbones®, Pacific Research Laboratories Inc) Used in the Artificial Bone Blocks

	Density		Compressive, MPa		Tensile, MPa		Shear, MPa	
Medium	pcf	g/cc	Strength	Modulus	Strength	Modulus	Strength	Modulus
Cortical bone	50	0.80	58	1400	32	2000	20	262
Cancellous bone	30	0.48	19	520	12	427	10	146

Vashon, Wash; Table 1; Figure 1b) were fixed with a metal clamp.

Predrilling and Installation of OMIs

The OMIs were installed in the artificial bone blocks using a driving torque tester (Biomaterials Korea Inc; Figure 1c). The tester was set to a uniform speed of 3 rpm, which corresponds to American Society for Testing and Materials regulation F543-02. A 500-g weight was added on the tester's rotational axis to mimic the perpendicular force in a clinical situation.

After a drill-bit (1.0 mm in diameter; Jeil Medical Corp, Seoul, Korea) was attached to the chuck of the torque tester's rotational axis, the predrilling depth (1.5 mm or 3.0 mm) was set using digital vernier calipers (Mitutoyo Corp, Tokyo, Japan). When the predrilling was completed, a drill-bit was replaced with an OMI. Six groups of OMIs were randomly installed with a distance of 10 mm.

The OMIs used in this study consisted of a threaded portion (bottom 6 mm) and a nonthreaded portion (top 1 mm) (Figure 1a). In order to prevent the over-insertion of the OMIs, only the threaded portion of the OMIs was inserted into the artificial bone block using a 1-mm–diameter metal bar stop.

Measurements and Statistical Analysis of the Insertion Variables

The insertion variables were total insertion time (TIT), maximum insertion torque (MIT), total insertion energy (TIE), and inclination of the time-torque graph (INC). The definitions for these variables are provided in Figure 2. The Kruskal-Wallis test and the Mann-Whitney *U*-test with a Bonferroni correction were performed for statistical analysis.

RESULTS

Total Insertion Time (TIT; Tables 2 and 3; Figure 3)

Since TIT represents the number of turns for OMI installation, a speed of 3 rpm means that 20 seconds produce one turn (360°). Although the cylindrical

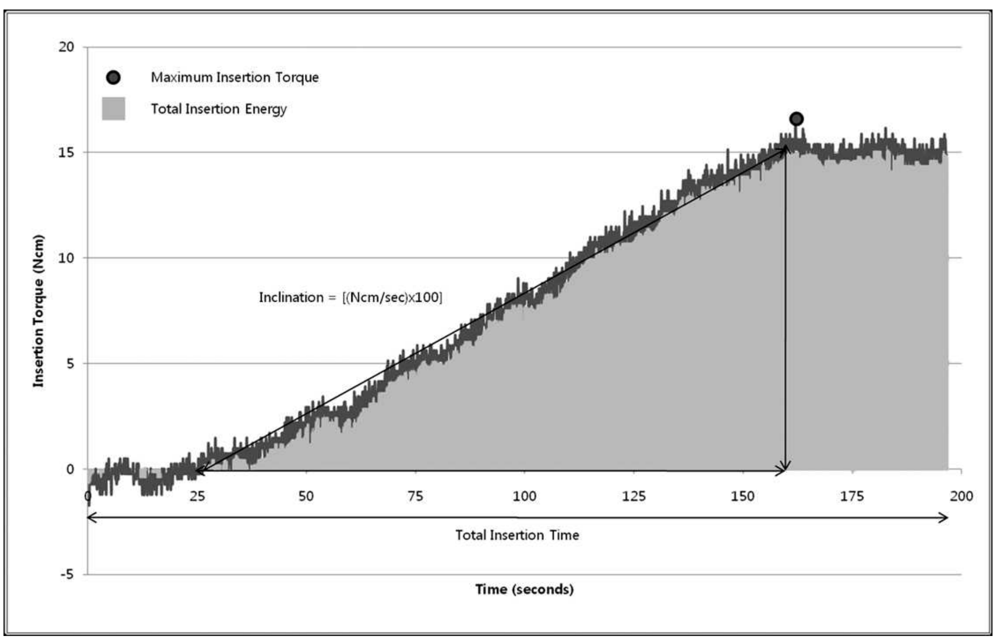

Figure 2. Definitions of the insertion variables. Total insertion time (seconds) is the time from the beginning to the end of orthodontic mini-implant (OMI) insertion. Maximum insertion torque (Ncm) is the maximum torque value during OMI insertion. Total insertion energy (J) is calculated by the area under the graph from the beginning to the end of OMI insertion. Inclination [(Ncm/second) × 100] is calculated by the graph from the zero point of the torque value to the start of the plateau.

Table 2. Comparison of the Mechanical Properties During the Insertion of the Mini-Implants in the Artificial Bone Blocks Between the Cylindrical and Tapered Shape in the Control, 1.5-mm, and 3.0-mm Predrilling Groups[a]

Variables		Control (non-predrilling)			1.5-mm Predrilling			3.0-mm Predrilling		
		Cylindrical (N = 5)	Tapered (N = 5)	*P*-Value	Cylindrical (N = 5)	Tapered (N = 5)	*P*-Value	Cylindrical (N = 5)	Tapered (N = 5)	*P*-Value
Total insertion time, s	Mean	195.52	183.20	.0160*	140.52	136.72	.0090**	138.56	133.74	.0090**
	SD	8.91	1.40		1.12	1.95		1.44	1.37	
Maximum insertion torque, Ncm	Mean	16.31	17.82	.0074**	15.09	14.94	.5245	11.33	11.67	.1653
	SD	0.32	0.17		0.53	0.76		0.41	0.32	
Total insertion energy, J	Mean	48.11	48.66	.4647	36.46	34.65	.1172	25.28	23.63	.0283*
	SD	1.80	0.82		0.63	1.70		1.82	0.20	
Inclination, (Ncm/s) × 100	Mean	11.95	13.33	.0163*	15.63	16.14	.0758	11.87	11.24	.0758
	SD	0.79	0.45		0.52	0.48		0.54	0.28	

[a] Mann-Whitney *U*-test was performed. SD indicates standard deviation; * $P < .05$; ** $P < .01$.

groups exhibited longer TIT than the tapered groups (C-con vs T-con, $P < .05$; C-1.5 vs T-1.5, $P < .01$; C-3.0 vs T-3.0, $P < .01$), there was no difference in the number of turns between the two groups (difference between C-con and T-con, 221.8° and 0.6 turn; difference between C-1.5 and T-1.5, 68.4° and 0.2 turn; and difference between C-3.0 and T-3.0, 86.8° and 0.2 turn).

However, within the same shape group, the control groups exhibited a longer TIT and more rotation than the predrilling groups (difference between C-con and C-1.5, 990.0° and 2.8 turn; difference between C-con and C-3.0, 1025.3° and 2.9 turn; difference between T-con and T-1.5, 836.6° and 2.3 turn; and difference between T-con and T-3.0, 890.3° and 2.5 turn, all $P < .05$). In addition, there was no difference in TIT between the 1.5-mm predrilling and 3.0-mm predrilling within the same shape group (C-1.5 vs C-3.0 and T-1.5 vs T-3.0; all $P > .05$).

Maximum Insertion Torque

Although the MIT of T-con was larger than that of C-con ($P < .01$), there was no difference in MIT for the same predrilling depth between the cylindrical and tapered groups (C-1.5 vs T-1.5 and C-3.0 vs T-3.0; all $P > .05$). Within the same shape group, MIT decreased in the order of control, 1.5-mm predrilling, and 3.0-mm predrilling (C-con vs C-1.5, C-1.5 vs C-3.0, C-con vs C-3.0, T-con vs T-1.5, T-1.5 vs T-3.0, and T-con vs T-3.0; all $P < .05$).

Total Insertion Energy (TIE; Tables 2 and 3, Figure 3)

Within the same shape groups, TIE decreased in the order of control, 1.5-mm predrilling, and 3.0-mm predrilling (C-con vs C-1.5, C-1.5 vs C-3.0, C-con vs C-3.0, T-con vs T-1.5, T-1.5 vs T-3.0, and T-con vs T-3.0; all $P < .05$; Tables 2 and 3; Figure 3). There was no difference in TIE of the control group and of the 1.5-mm predrilling group between the cylindrical and tapered groups (C-con vs T-con and C-1.5 vs T-1.5; all $P > .05$). In addition, there was a statistically significant but numerically insignificant difference in TIE between C-3.0 and T-3.0 (difference of 1.7J, $P < .05$).

Inclination of the Time-Torque Graph (INC; Tables 2 and 3, Figure 3)

Although INC of T-con was steeper than that of C-con (13.3 vs 12.0, $P < .05$), there was no difference in INC between the cylindrical and tapered groups with the same predrilling depth (C-1.5 vs T-1.5 and C-3.0

Table 3. Comparison of the Mechanical Properties During the Insertion of the Mini-Implants in the Artificial Bone Blocks Between the Cylindrical Shape Groups, Between the Tapered Shape Groups, and Among All Groups[a]

Variables	Kruskal-Wallis Test[b]			Mann-Whitney *U*-Test With a Bonferroni Correction[c]					
				Cylindrical			Tapered		
	Cylindrical	Tapered	All	Control vs 1.5	1.5 vs 3.0	Control vs 3.0	Control vs 1.5	1.5 vs 3.0	Control vs 3.0
Total insertion time, s	.0037**	.0030**	.0000***	.0090*	.0472	.0090*	.0088*	.0283	.0088*
Maximum insertion torque, Ncm	.0018**	.0018**	.0000***	.0080*	.0086*	.0080*	.0082*	.0088*	.0080*
Total insertion energy, J	.0019**	.0019**	.0000***	.0090*	.0090*	.0090*	.0090*	.0090*	.0090*
Inclination, (Ncm/s) × 100	.0092**	.0019**	.0000***	.0090*	.0090*	.9168	.0090*	.0090*	.0090*

[a] Control, non-predrilling; 1.5, 1.5-mm predrilling; and 3.0, 3.0-mm predrilling.

[b] Kruskal-Wallis test was performed. * $P < .05$; ** $P < .01$; *** $P < .001$.

[c] Mann-Whitney *U*-test with a Bonferroni correction was performed. * $P < .0166$; ** $P < .0033$; *** $P < .0003$.

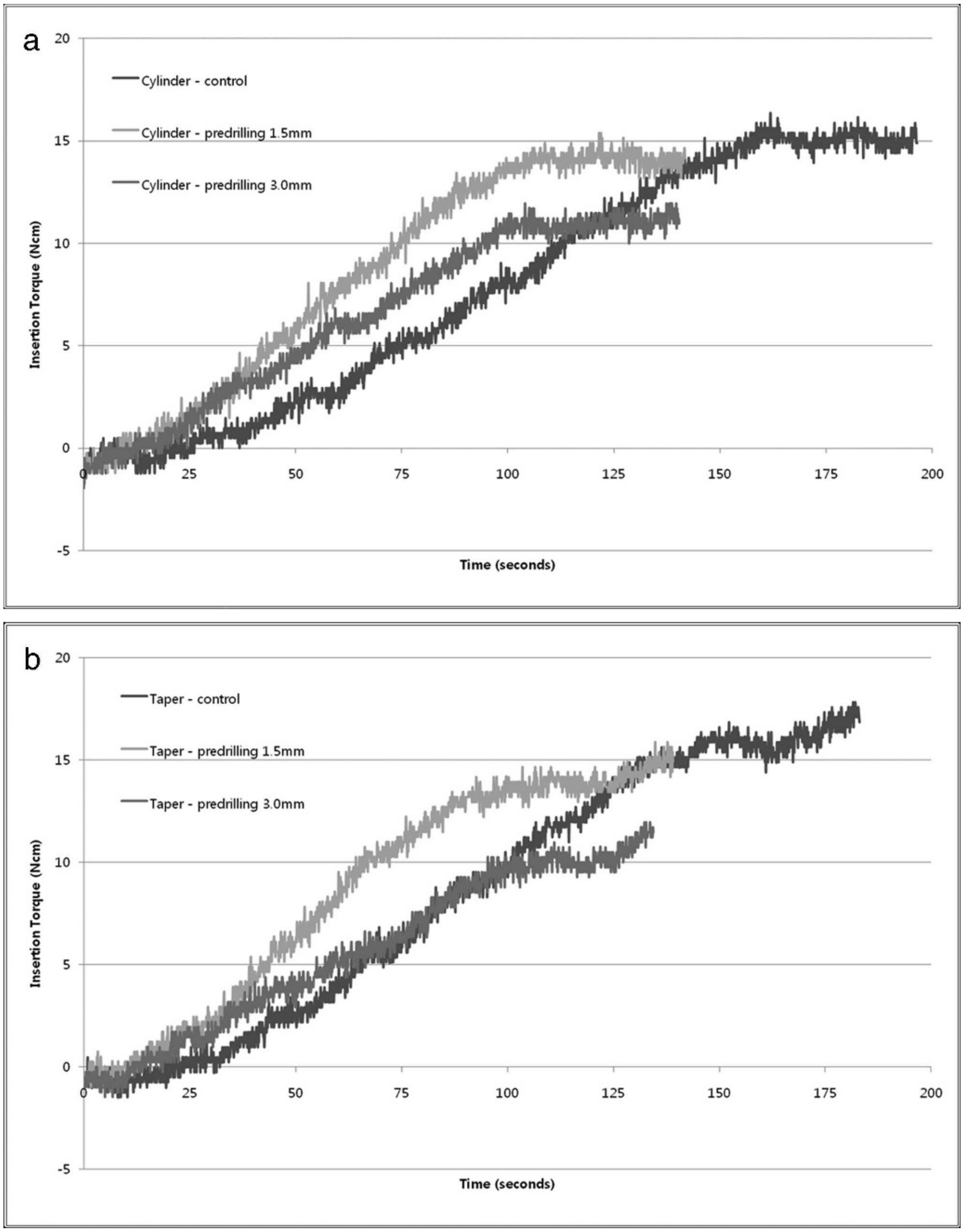

Figure 3. Superimposition of the time-insertion torque graphs between the control, 1.5-mm predrilling, and 3.0-mm predrilling groups. a. Cylindrical orthodontic mini-implants (OMIs); b. Tapered OMIs.

vs T-3.0; all $P > .05$). Regardless of shape, the values of INC exhibited an increasing pattern from control to 1.5-mm predrilling and a decreasing pattern from 1.5-mm predrilling to 3.0-mm predrilling (C-con vs C-1.5, C-1.5 vs C-3.0, T-con vs T-1.5, and T-1.5 vs T-3.0; all $P < .05$).

DISCUSSION

Gantous and Phillips[17] and Heidemann et al.[18] reported that the predrilling hole size could be increased by as much as 82% to 85% of the external diameter of the screw without resulting in a significant decrease in holding power in the pull-out test. However, these studies did not include the internal diameter of the screws. If the predrilling hole size is larger than the internal diameter of OMI, there will be a dead space between the OMI and bone interface, which can have a negative effect on OMI stability. Oktenoğlu et al.[19] suggested the use of a drill-bit with a smaller diameter than the internal diameter of the screw in order to fasten the screw to the bone. Therefore, in the present study, a drill-bit with the same diameter as the internal diameter of the cylindrical and tapered OMIs (1.0 mm, 66.7% of the external diameter) was used (Figure 1a).

The finding that the control groups presented with a longer TIT and more rotation than did the predrilling groups within the same shape group (Tables 2 and 3) implies that the control groups required some time to create a hole in the cortical bone during the first part of OMI installation. After the predrilling hole was formed, the cutting flute of OMI could be completely fitted into the predrilling hole. Therefore, regardless of the predrilling depth, no time was wasted in making a hole in the cortical bone in the predrilling groups. As a result of the constant installation speed of the driving torque tester (3 rpm), there was no significant difference in TIT between the 1.5-mm and 3.0-mm predrilling groups (C-1.5 vs C-3.0 and T-1.5 vs T-3.0; all $P >$ .05; Table 3).

During installation of the self-drilling type OMI, some portion of the bone was removed through the flute of OMI, and the other portion of the bone was compressed laterally by as much as the volume of OMI. This lateral compressive force was measured as the insertion torque. Therefore, the amount of bone removed by predrilling can be inversely related to the amount of insertion torque. The finding that MIT decreased in the order of control, 1.5-mm predrilling, and 3.0-mm predrilling within the same shape group (C-con vs C-1.5, C-1.5 vs C-3.0, T-con vs T-1.5, and T-1.5 vs T-3.0; all $P <$ .05; Tables 2 and 3) was in accordance with the results of Wilmes et al.[2] They observed that deep or complete predrilling of the cortical bone could reduce the insertion torque value compared to shallow or partial predrilling.

Since the tapered OMI had an increase of taper from 1.0 mm to 1.49 mm for the internal diameter and from 1.45 mm to 1.8 mm for the outer diameter in the top–2 mm portion (Figure 1a), T-con generated greater MIT by lateral compressive forces than did C-con ($P <$ .01; Table 2), which was consistent with the results of previous studies.[21–24] However, in the predrilling groups, these compressive forces had a minimal effect because the bone equivalent to the volume of OMI was already removed. Therefore, there was no difference in MIT between the cylindrical and tapered groups in the same predrilling depth (C-1.5 vs T-1.5 and C-3.0 vs T-3.0; all $P >$ .05; Table 3).

Since TIE is the sum of the real-time insertion torque values during the insertion procedure, TIE is correlated with TIT and MIT. Since the control groups had higher MIT and longer TIT than the predrilling groups (Table 3), the TIE of the control group was greater than that of the predrilling groups (C-con vs C-1.5, C-con vs C-3.0, T-con vs T-1.5, and T-con vs T-3.0; all $P <$ .05; Table 3). Within the predrilling groups, the TIE of the 1.5-mm predrilling group was greater than that of the 3.0-mm predrilling group (C-1.5 vs C-3.0 and T-1.5 vs T-3.0, all $P <$ .05; Table 3) because MIT of the 1.5-mm predrilling group was more increased than that of the 3.0-mm predrilling group (C-1.5 vs C-3.0 and T-1.5 vs T-3.0; all $P <$ .05; Table 3).

The increase of INC from the control group to the 1.5-mm predrilling group (C-con vs C-1.5 and T-con vs T-1.5; all $P <$ .05; Table 3) can be explained by the shortening of the TIT (C-con vs C-1.5, 195.5 seconds to 140.5 seconds and T-con vs T-1.5, 183.2 seconds to 136.7 seconds; all $P <$ .05; Tables 2 and 3). Moreover, the decrease of INC from the 1.5-mm predrilling group to the 3.0-mm predrilling group (C-1.5 vs C-3.0 and T-1.5 vs T-3.0; all $P <$ .05; Table 3) may have resulted from a decrease in the insertion torque (C-1.5 vs C-3.0, 15.1 Ncm to 11.3 Ncm and T-1.5 vs T-3.0, 14.9 Ncm to 11.7 Ncm; all $P <$ .05; Tables 2 and 3). These findings imply that the 1.5-mm predrilling group reached the MIT faster than the other groups.

Wawrzinek et al.[4] and Lee and Baek[5] reported that there was greater microdamage in cases involving larger diameter, tapered shape, and overtightening of OMIs. Since extensive microdamage can reduce secondary stability, Wilmes et al.[2] insisted that the cortical bone must be weakened to avoid extreme insertion torques and to prevent the consequent risk of a screw fracture. Kim et al.[15] reported that the average periotest value of the predrilling group in the mandible was less than that of the non-predrilling group in the maxilla. This means that predrilling does not critically reduce primary stability in the mandible, which has thicker cortical bone than the maxilla. Therefore, the partial predrilling procedure could satisfy the requirements for primary and secondary stability by means of effectively reducing the values of MIT and TIE.

Since this study was an in vitro test in artificial bone blocks, it has some limitations with regard to understanding the biologic response and effect on the long-term success rate of OMIs. Therefore, further in vivo studies conducted via animal testing and clinical research will be needed to investigate the effects of partial predrilling on MIT, TIE, bone-implant contact, microdamage, and primary and secondary stability.

CONCLUSION

- In cases of thick cortical bone, predrilling might be an effective tool for reducing microdamage without compromising OMI stability.

REFERENCES

1. Meredith N. Assessment of implant stability as a prognostic determinant. *Int J Prosthodont*. 1998;11:491–501.
2. Wilmes B, Rademacher C, Olthoff G, Drescher D. Parameters affecting primary stability of orthodontic mini-implants. *J Orofac Orthop*. 2006;67:162–174.

3. Suzuki EY, Suzuki B, Aramrattana A, Harnsiriwattanakit K, Kowanich N. Assessment of miniscrew implant stability by resonance frequency analysis: a study in human cadavers. *J Oral Maxillofac Surg*. 2010;68:2682–2689.
4. 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.
5. 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.
6. Motoyoshi M, Hirabayashi M, Uemura M, Shimizu N. Recommended placement torque when tightening an orthodontic mini-implant. *Clin Oral Implants Res*. 2006;17: 109–114.
7. Motoyoshi M, Yoshida T, Ono A, 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.
8. Suzuki EY, Suzuki B. Placement and removal torque values of orthodontic miniscrew implants. *Am J Orthod Dentofacial Orthop*. 2011;139:669–678.
9. 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.
10. 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.
11. 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.
12. 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.
13. Baumgaertel S, Hans MG. Buccal cortical bone thickness for mini-implant placement. *Am J Orthod Dentofacial Orthop*. 2009;136:230–235.
14. Lim JE, Lee SJ, Kim YJ, Lim WH, Chun YS. Comparison of cortical bone thickness and root proximity at maxillary and mandibular interradicular sites for orthodontic mini-implant placement. *Orthod Craniofac Res*. 2009;12:299–304.
15. 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.
16. Kim SH, Lee SJ, Cho IS, Kim SK, Kim TW. Rotational resistance of surface-treated mini-implants. *Angle Orthod*. 2009;79:899–907.
17. Gantous A, Phillips JH. The effects of varying pilot hole size on the holding power of miniscrews and microscrews. *Plast Reconstr Surg*. 1995;95:1165–1169.
18. Heidemann W, Gerlach KL, Gröbel KH, Köllner HG. Influence of different pilot hole sizes on torque measurements and pullout analysis of osteosynthesis screws. *J Craniomaxillofac Surg*. 1998;26:50–55.
19. Oktenoğlu BT, Ferrara LA, Andalkar N, Ozer AF, Sarioğlu AC, Benzel EC. Effects of hole preparation on screw pullout resistance and insertional torque: a biomechanical study. *J Neurosurg*. 2001;94(1 suppl):91–96.
20. Hung E, Oliver D, Kim KB, Kyung HM, Buschang PH. Effects of pilot hole size and bone density on miniscrew implants' stability. *Clin Implant Dent Relat Res*. 2010 Mar 12. [Epub ahead of print].
21. 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.
22. 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.
23. 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.
24. Kim YK, Kim YJ, Yun PY, Kim JW. Effects of the taper shape, dual-thread, and length on the mechanical properties of mini-implants. *Angle Orthod*. 2009;79:908–914.