Effects of insertion angle and implant thread type on the fracture properties of orthodontic mini-implants during insertion

Il-Sik Cho[a]; Tae-Woo Kim[b]; Sug-Joon Ahn[c]; Il-Hyung Yang[d]; Seung-Hak Baek[b]

ABSTRACT

Objective: To determine the effects of insertion angle (IA) and thread type on the fracture properties of orthodontic mini-implants (OMIs) during insertion.

Materials and Methods: A total of 100 OMIs (self-drilling cylindrical; 11 mm in length) were allocated into 10 groups according to thread type (dual or single) and IA (0°, 8°, 13°, 18°, and 23°) (n = 10 per group). The OMIs were placed into artificial materials simulating human tissues: two-layer bone blocks (Sawbones), root (polymethylmethacrylate stick), and periodontal ligament (Imprint-II Garant light-body). Maximum insertion torque (MIT), total insertion energy (TIE), and peak time (PT) were measured and analyzed statistically.

Results: There were significant differences in MIT, TIE, and PT among the different IAs and threads (all $P < .001$). When IA increased, MIT increased in both thread groups. However, TIE and PT did not show significant differences among 0°, 8°, and 13° IAs in the dual-thread group or 8°, 13°, and 18° IAs in the single-thread group. The dual-thread groups showed higher MIT at all IAs, higher TIE at 0° and 23° IAs, and longer PT at a 23° IA than the single-thread groups. In the 0°, 8°, and 13° IA groups, none of the OMIs fractured or became deformed. However, in the 18° IA group, all the OMIs were fractured or deformed. Dual-thread OMIs showed more fracturing than deformation compared to single-thread OMIs ($P < .01$). In the 23° IA group, all OMIs penetrated the artificial root without fracturing and deformation.

Conclusions: When OMIs contact artificial root at a critical contact angle, the deformation or fracture of OMIs can occur at lower MIT values than those of penetration. (*Angle Orthod.* 2013;83:698–704.)

KEY WORDS: Fracture properties; Mini-implant; Insertion angle; Implant thread type

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INTRODUCTION

The use of orthodontic mini-implants (OMIs) for anchorage purposes has greatly broadened the treatment scope of orthodontics during the last 10 years. Although OMIs have advantages, such as a reduced necessity for patient compliance and the simplification of treatment mechanics, they may fail for a variety of reasons, including age, sex, inflammation, mobility, fracture, root proximity, and root contact.[1–4]

If an OMI is placed in the area of the narrow interdental space, iatrogenic root injury may occur. Potential complications of root injury mentioned in the literature include loss of tooth vitality, osteosclerosis, and dento-alveolar ankylosis.[5–7] Asscherickx et al.[3] suggested that proximity or contact between an OMI and a root might be a major risk factor for OMI failure. In their animal studies, Kim and Kim[8] observed that when OMIs were left in situ, the root surface mostly resorbed away from the OMI thread, and partial repair began at 8 weeks. They also
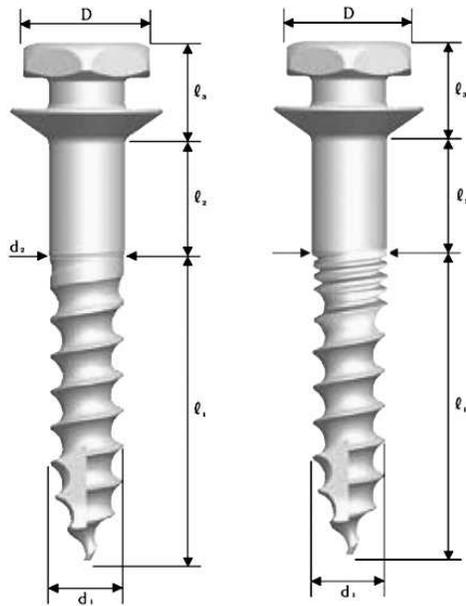
Size(mm)	d1	d2	l1	l2	l3	D
OAS-T1511	1.45	1.50	7.00	4.00	2.10	2.20
Mplant U3-11	1.45	1.50	7.00	4.00	2.10	2.20

Figure 1. Dimensions of the OMIs used in the study. The single-thread type (OAS-T1511) is shown on the left and the dual-thread type (Mplant U3-11) is shown on the right side (Biomaterials Korea Inc, Seoul, Korea).

found that when the OMI thread was left touching the root, the normal healing response did not occur.[8]

OMI fracture might be a more severe clinical complication than root contact.[9] To reduce the risk of fracture of OMIs, their diameter can be increased, which increases the fracture torque.[10,11] OMI insertion angle (IA) and/or thread type seem to be important factors in fracture properties when an OMI contacts a root. However, no studies have yet evaluated the effects of OMI IA and thread type on OMI fracture properties. Therefore, the purpose of this in vitro study was to investigate the effects of IA and thread type on the fracture properties of OMI during the insertion procedure in artificial materials that simulated the cortical and cancellous bone, root, and periodontal ligament space in humans.

MATERIALS AND METHODS

OMIs and Allocation of the Groups

A total of 100 OMIs (self-drilling type, cylindrical shape, 11 mm in length; Biomaterials Korea Inc,

Seoul, Korea) were allocated into 10 groups according to thread type (dual or single; Figure 1) and IA (0°, 8°, 13°, 18°, and 23°) (n = 10 per group). All of the OMIs had an external diameter of 1.45 mm and an internal diameter of 1.0 mm. Dual-thread OMIs had the dual thread on the upper coronal of the thread (Figure 1).

Artificial Bone Block

The custom-made polyurethane foam artificial bone blocks consisted of two layers that simulated cortical and cancellous bone. The blocks were 180 mm long × 15 mm wide × 18 mm high. The 3-mm-high upper layer had a density of 0.80 g/cc (50 pcf), and the 15-mm-high lower layer had a density of 0.48 g/cc (30 pcf) (Sawbone, Pacific Research Laboratories Inc, Vashon, Wash; Table 1; Figure 2).

The artificial root was simulated with a transparent round polymethylmethacrylate stick (density 1.19 g/cc, tensile strength 72 MPa, compressive strength 123 MPa) with a diameter of 10 mm. To simulate the periodontal ligament space, a 10.5-mm-diameter hole was drilled into the artificial bone blocks. The polymethylmethacrylate stick was then inserted into the artificial bone blocks with silicone impression materials (Imprint II Garant light body, 3M ESPE, St Paul, Minn).[12,13]

Placement of OMIs

We used an artificial bone block with 3 mm of cortical bone to simulate the mandibular molar area. The sum of the cortical bone (3 mm), cancellous bone (1 mm), and radius of the artificial root (5 mm) in the midline was 9 mm (Figure 2). Therefore, to clearly determine the effect of root contact with the OMI, 11-mm OMIs were used.

After the artificial bone block was fixed with a metal clamp, the OMIs were placed in the block with a torque device (Biomaterials Korea Inc) (Figure 3) set to a uniform speed of 28 rpm. A 500-g weight was added to the torque device's rotational axis to mimic the perpendicular force in a clinical situation.

Pilot tests were performed to determine the specific IA at which the OMI would touch the periodontal ligament space made by the silicone impression materials in the given dimension (Figure 2). This was determined as an 8° IA; the IA was then increased in 5°

Table 1. Mechanical Properties of the Polyurethane Foam Used for the Artificial Bone Block

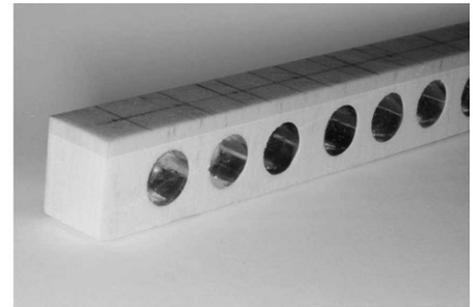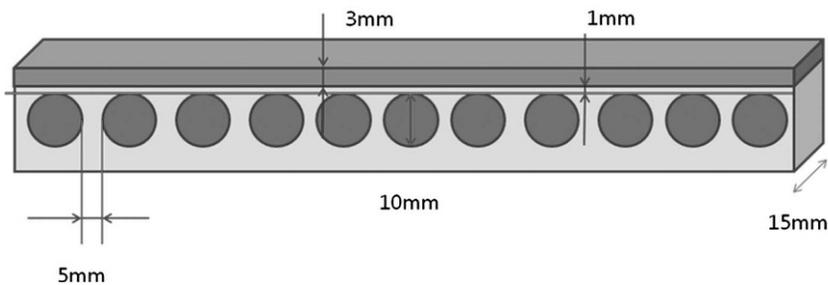|	Density		Compressive		Tensile	
Type of Bone	(pcf)	(g/cc)	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)
Cortical layer	50	0.80	58	1400	32	2000
Cancellous layer	30	0.48	19	520	12	427

Figure 2. Diagram (left) and photograph (right) of the artificial bone block with two layers that was used to simulate cortical and cancellous bone (Sawbone, Pacific Research Laboratories Inc, Vashon, Wash). A transparent polymethylmethacrylate stick was placed into the artificial bone block with silicone impression material (Imprint II Garant light body, 3M ESPE, St Paul, Minn) to simulate the root and periodontal ligaments.

intervals, from 8° to 23°. The control was set as a 0° IA. These different IAs (0°, 8°, 13°, 18°, and 23°) were applied using a custom-made vise (Figure 3).

Measurements of the Insertion Variables and Grinding Procedure of the Samples

The insertion variables analyzed were maximum insertion torque, total insertion energy, and peak time. The definitions of these variables are given in Figure 4. After the variables were measured, all samples were ground with a model trimmer to evaluate the status of the OMIs.

Statistical Analysis of the Insertion Variables

The sample size determination was performed by a power analysis using the Sample Size Determination Program version 2.0.1 (Seoul National University Dental Hospital, #2007-01-122-004453, Seoul, Korea). Welch variance weighted analysis of variance, Duncan's multiple comparison test, and the χ^2 test were performed for statistical analyses. The level of significance for all the tests was set at $P < .05$.

RESULTS

Comparison of the Mechanical Properties of OMIs During Insertion

There were significant differences in maximum insertion torque, total insertion energy, and peak time among the IA and thread groups (all $P < .001$, Table 2).

Dual-thread groups showed higher maximum insertion torque values than single-thread groups for all IAs. Although the 8° and 13° IA groups did not show significant differences within each thread group, maximum insertion torque showed a tendency to increase according to increases in the IA in both single- and dual-thread groups, respectively (Figure 5A).

In terms of total insertion energy, the dual-thread groups showed a significant increase at 18° and 23° IAs, and the single-thread groups showed significant increases at 8° and 23° IAs. In other words, total insertion energy did not show a significant difference among the 0°, 8°, and 13° IAs in the dual-thread groups and among the 8°, 13°, and 18° IAs in the
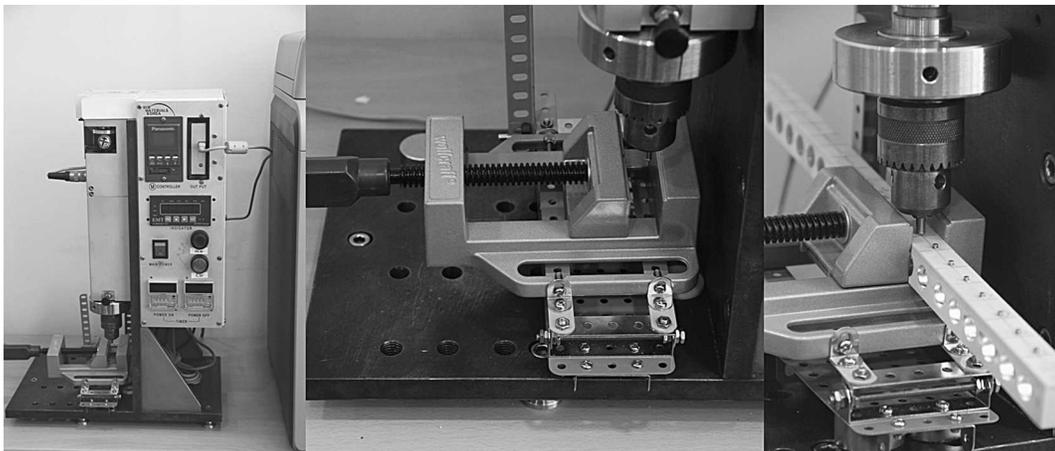

Figure 3. Torque driver (Biomaterials Korea Inc, Seoul, South Korea) and custom-made vise.
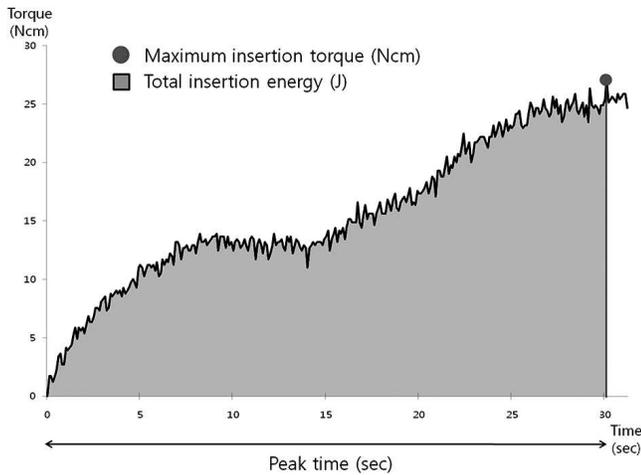
Figure 4. Definitions of insertion variables. Peak time (seconds) is the time from the beginning of OMI insertion to the maximum insertion torque. Maximum insertion torque (Ncm) is the maximum torque value reached during OMI insertion. Total insertion energy (J) is calculated by the area under the graph from the beginning of OMI insertion to the maximum insertion torque.

single-thread groups. The total insertion energy values of dual-thread groups were significantly higher for 0° and 23° IAs than the single-thread groups (Figure 5B).

In terms of peak time, the 0°, 8°, and 13° IA groups did not show a significant difference within the dual-thread groups. Within the single-thread groups, the 8°, 13°, and 18° IAs did not show a significant difference. The peak time in single-thread groups was significantly higher only in the 13° IA than in the dual-thread groups, but the peak time within the dual-thread groups was significantly higher only for the 23° IA than the single-thread groups (Figure 5C).

Fracture Ratio According to Thread Type

In the 0°, 8°, and 13° IA groups, none of the OMIs fractured or were deformed. In the 23° IA group, all of the OMIs penetrated the polymethylmethacrylate stick without fracturing or deformation (Figure 6). However, in the 18° IA group, there was a significant difference in

the occurrence of fracture and deformation according to the thread type ($P < .01$; Table 3). Eighty percent of the dual-thread OMIs fractured, and 90% of the single-thread OMIs were bent. In the dual-thread OMIs, the fracture sites were located at the dual-thread site, while in single-thread OMIs, the fracture sites were located at the end of the thread (Figure 6).

Interestingly, maximum insertion torque values in the 18° IA groups (deformation/fracture of OMIs) were lower than those in the 23° IA groups (root penetration) (30.6 Ncm vs 34.8 Ncm for the dual-thread type and 28.2 Ncm vs 30.7 Ncm for the single-thread type; Table 2). These findings indicate that OMIs can be deformed or broken at lower values compared to the values of penetration.

Time and Torque Graph

Irrespective of the IA and OMI thread type, nearly identical patterns were observed among the groups until 24 seconds after insertion, which was just before contact with the artificial root (polymethylmethacrylate stick). After contact with the artificial roots, higher IA and dual-thread OMIs showed higher insertion torque values than lower IA and single-thread OMIs (Figure 7). Especially in the 18° IA group, dual-thread OMIs showed higher insertion torque values than single-thread OMIs (Figure 8).

DISCUSSION

In this study, the same artificial bone that had been used in previous studies[14,15] was used to simulate cortical and cancellous bone. A transparent polymethylmethacrylate stick was used as an artificial root to simulate the human counterpart and to help identify root contact or penetration by OMIs. Although the density of the polymethylmethacrylate stick (1.19 g/cc) was slightly lower than that reported in previous studies (1.27~1.50 g/cc),[16,17] its tensile strength was similar to the results of previous studies.[18,19]

Table 2. Comparison of Maximum Insertion Torque, Total Insertion Energy, and Peak Time Between Groups

IA	Thread Type (n = 10 Per Group)	Maximum Insertion Torque (Ncm)	Total Insertion Energy (J)	Peak Time (s)
0°	Dual	26.03 ± 1.16	13.98 ± 0.99	32.67 ± 0.83
	Single	23.44 ± 0.83	12.70 ± 0.72	31.01 ± 0.89
8°	Dual	28.34 ± 1.01	14.54 ± 0.81	32.23 ± 1.41
	Single	26.93 ± 1.48	14.62 ± 0.75	33.19 ± 1.78
13°	Dual	28.52 ± 0.73	14.33 ± 1.57	31.64 ± 2.14
	Single	26.07 ± 1.10	14.69 ± 0.69	33.45 ± 1.20
18°	Dual	30.59 ± 1.94	16.41 ± 0.93	34.37 ± 1.66
	Single	28.20 ± 0.91	15.90 ± 1.53	34.32 ± 1.35
23°	Dual	34.77 ± 1.37	22.68 ± 3.04	40.06 ± 3.37
	Single	30.74 ± 1.00	19.93 ± 1.53	38.38 ± 2.13
Significance		$< .001$***	$< .001$***	$< .001$***

*** P-value $< .001$; Welch variance weighted analysis of variance.

A
Maximum insertion torque
(Ncm)

B
Total insertion energy
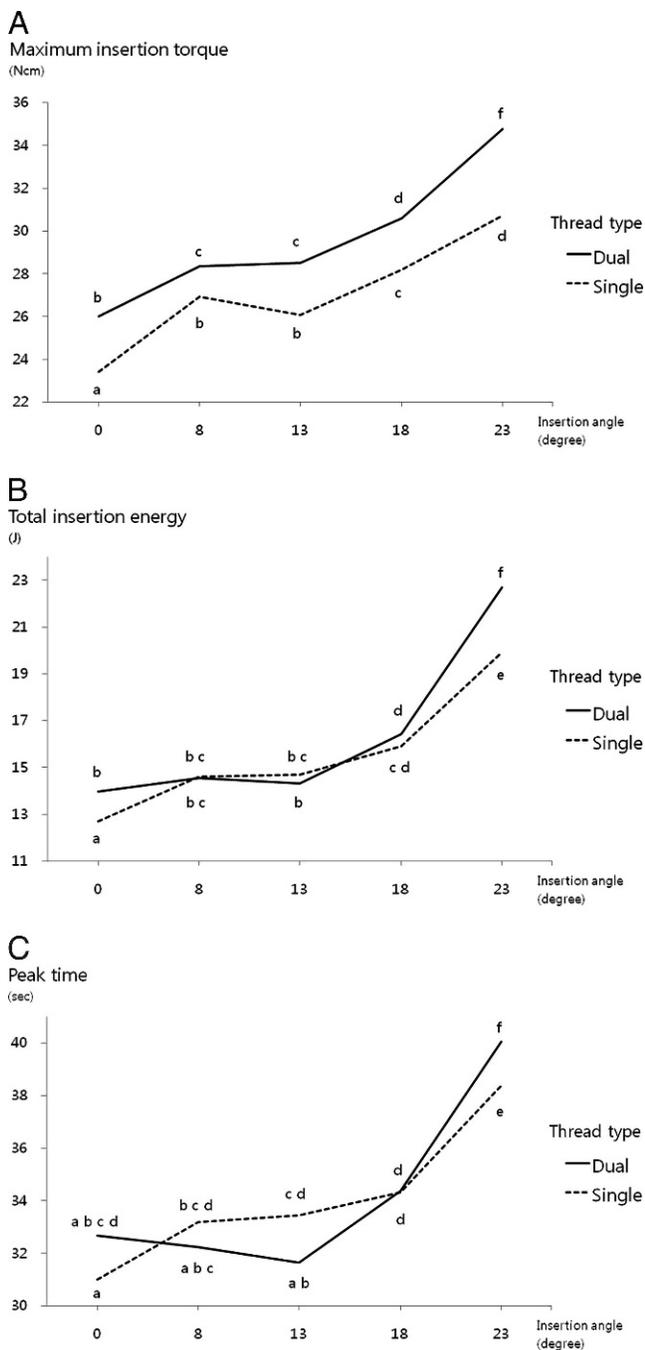(J)

C
Peak time
(sec)

Figure 5. The results of the Duncan multiple comparison test between IA and thread type. (A) Maximum insertion torque. (B) Total insertion energy. (C) Peak time. The same letters indicate groups that were not statistically significantly different ($P > .05$).

Cho and Baek[14] reported that the maximum insertion torque value measured in the same artificial bone block was 16.31 ± 0.32 Ncm, which was lower than that of the present study. This difference seems to have originated from the difference in the lengths of OMIs studied (7 mm in Cho and Baek[14] vs 11 mm in the present study). Kim et al.[20] also reported that longer OMIs showed higher maximum insertion torque values.
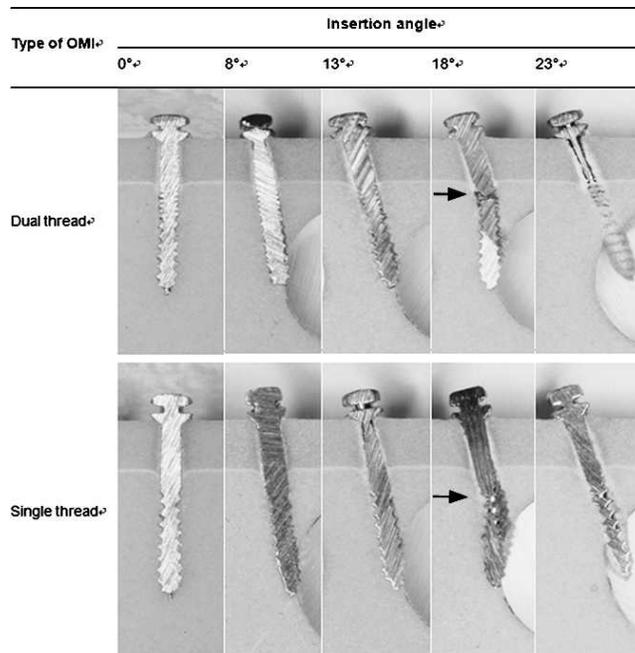
Figure 6. Cross-sectional view of placed OMIs according to IA and thread type. The arrow shows the site of the OMI fracture or deformation.

In the 8° and 13° IA groups, there were no significant differences in the values for maximum insertion torque, total insertion energy, and peak time because there were no deformations or fractures of OMIs at the point of contact with the polymethylmethacrylate stick (Figure 5). However, these findings do not mean that slight root contact is safe. Previous studies suggested that proximity or contact between an OMI and the root is a major risk factor for the failure of the OMI.[21,22] In addition, Lee et al.[23] reported that the incidence of root resorption increased when the distance between the OMI and the root was less than 0.6 mm, and that the incidence of bone resorption and ankylosis was increased when OMIs came close to the root surfaces, even without root contact.

Since all the OMIs showed deformations or fractures in the 18° IA group, regardless of thread type, an IA of 18° seemed to be a critical angle for slippage or

Table 3. Fracture Ratio According to Thread Type of the OMIs at an 18° IA[a]

Type of Mini-implant	Fracture Ratio (%)	Bending Ratio (%)	P
Dual thread (n = 10)	80	20	.005**
Single thread (n = 10)	10	90	

** $P < .01$; χ^2 test.
[a] In the 8° and 13° IA groups, none of the OMIs fractured or were deformed. In the 23° IA group, all of the OMIs penetrated the artificial root (transparent polymethylmethacrylate stick).
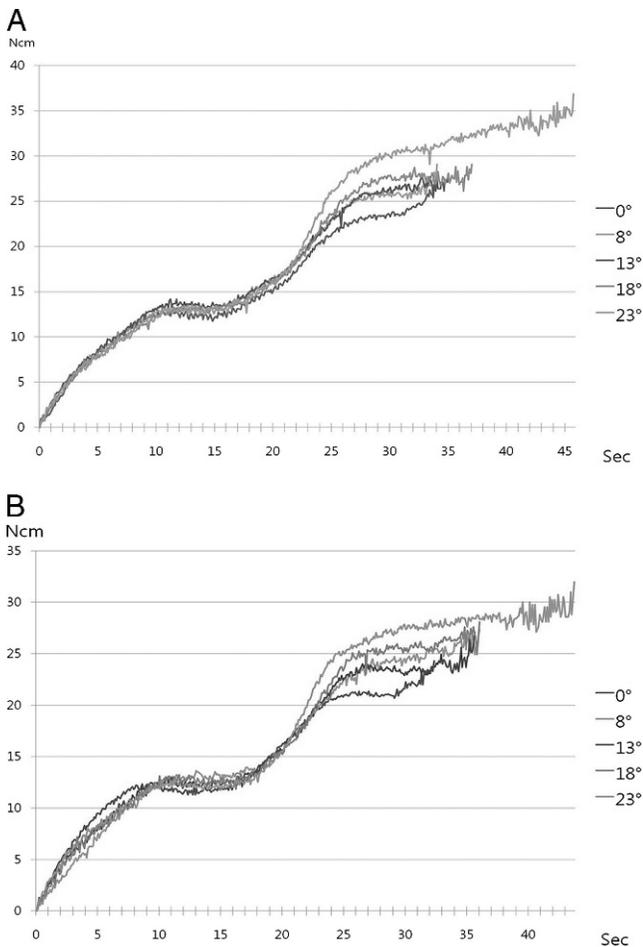
A

B

Figure 7. Superimposition of time/insertion torque graphs between the 0°, 8°, 13°, 18°, and 23° IA groups. (A) Dual-thread OMIs. (B) Single-thread OMIs.

Figure 8. Superimposition of the time-insertion torque graph between the 18° dual- and single-thread OMI groups.

penetration at the root contact site in this study. Interestingly, the thread type influenced the fracture ratio in the 18° IA group (80% fracture and 20% bending in the dual-thread group vs 10% fracture and 90% bending in the single-thread group, $P < .01$; Table 3). The reason for this result seems to originate from the differences in the structural and physical properties of the thread types. Dual-thread OMIs exhibited a significant increase in total insertion energy at an 18° IA compared to a 13° IA (Table 2, Figure 5B). However, single-thread OMIs did not show a significant increase in total insertion energy at 18° IA compared to 13° IA (Table 2, Figure 5B). In other words, there were differences in stress concentrations between dual- and single-thread OMIs. However, this result does not imply that single-thread OMIs are superior to dual-thread OMIs, because deformed OMIs also carry a risk of fracturing during removal.

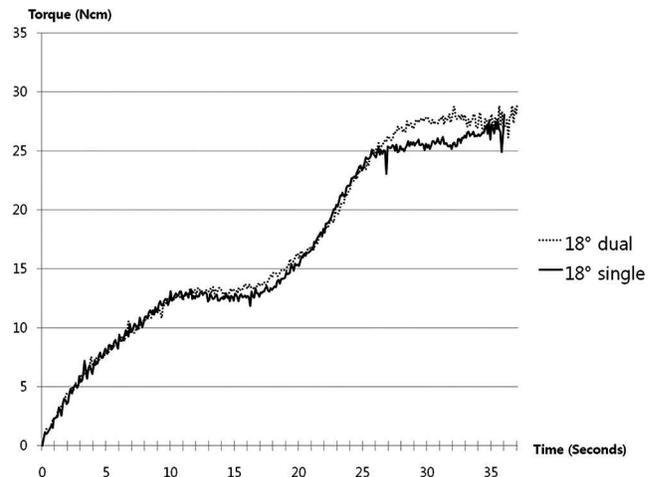At the beginning of root contact, the time/insertion torque graph showed higher values irrespective of the presence of deformation or penetration, which was in agreement with a previous study.[24] Therefore, an abrupt increase in resistance or insertion torque during OMI placement can be used as an indicator of possible root contact with the OMI.

Lima et al.[25] reported that fractures occurring at the moment of insertion, which have an incidence of around 4% in the literature, are principally caused by excessive force and the inability of the implant to resist rotational forces. In the present study, deformation/fracture torque was lower than penetration torque (30.6 Ncm vs 34.8 Ncm for dual-thread OMIs and 28.2 Ncm vs 30.7 Ncm for single-thread OMIs; Table 2). The reason seems to be the presence of a lateral force at the critical contact angle. When OMIs are in contact with the tooth root at the critical contact angle, the deformation or fracture of OMIs can occur at lower-than-expected maximum insertion torque values. There is also a possibility that fracture will occur, similar to the effect during clinical insertion of OMIs.

This study was an in vitro test performed with artificial bone, root, and periodontal ligament space. Because this experimental system has some limitations with regard to the understanding of the effects of the complex root surface, further studies are required to take into consideration the three-dimensional morphology of the root.

CONCLUSIONS

- When an OMI comes into contact with artificial root at the critical contact angle, deformation or fracture of the OMI can occur at lower maximum insertion torque values than those of penetration.
- Although this is an in vitro study of the effects of OMI contact with artificial root and periodontal ligament space on the fracture properties of OMIs, the results of this study might provide a guideline for further studies or clinical situations.

ACKNOWLEDGMENT

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