

## Insertion Torque of Orthodontic Miniscrews According to Changes in Shape, Diameter and Length

Seon-A Lim<sup>a</sup>; Jung-Yul Cha<sup>b</sup>; Chung-Ju Hwang<sup>c</sup>

### ABSTRACT

**Objective:** To determine the variation in the insertion torque of orthodontic miniscrews according to the screw length, diameter, and shape.

**Materials and Methods:** The maximum insertion torque (MIT) was measured using a torque tester at a constant speed of 3 rotations per minute. Cylindrical and taper type of miniscrews (Biomaterials Korea Inc, Seoul, Korea) with different lengths, diameters, and pitches were tested.

**Results:** The results showed that the insertion torque significantly increased with increasing screw length ( $P < .01$ ). In particular, there was a significant increase in torque with increasing screw length and diameter ( $P < .01$ ). An analysis of the serial insertion torque of miniscrews revealed the cylindrical type screw to have much higher insertion torque at the incomplete screw thread, while the taper type screw showed a much higher insertion torque at the final inclination part of the screw thread. The insertion torque was affected by the outer diameter, length, and shape in that order.

**Conclusions:** An increase in screw diameter can efficiently reinforce the initial stability of the miniscrew, but the proximity of the root at the implanted site should be considered.

**KEY WORDS:** Miniscrew; Insertion torque; Diameter; Length

### INTRODUCTION

Securing appropriate anchorage is one of the important factors in achieving the objectives of orthodontic treatment. Therefore, many osseointegrated implants have been used with relative success as stable orthodontic anchorages.<sup>1-6</sup> However, there are some limitations with an osseointegrated implant. It is expensive, it requires extensive surgery, it needs considerable time for osseointegration, and there is limited area for insertion due to the size of the implant.

Many studies on the possibility of using miniscrews as orthodontic anchorage have been carried out with some success.<sup>7-11</sup> It was reported that a miniscrew

type implant is useful because it is easy to insert and remove, and can be used for various purposes because it can be inserted in a wide range of areas. However, miniscrews have occasionally been removed due their mobility before or during orthodontic treatment. It was reported that miniscrews have a lower success rate (80%–85% lower) than osseointegrated implants.<sup>11-14</sup> Therefore, there is a need to improve the stability of miniscrews in order to achieve reproducible treatment results.

The initial stability of a miniscrew is important because most incidences of orthodontic miniscrew failure occur at the early stage.<sup>15</sup> The displacement of a screw can occur due to inflammation as a result of a poor bone-screw interface,<sup>12</sup> but screw factors such as the screw diameter, length, pilot hole diameter, and screw thread form are also believed to be important for their initial stability.<sup>16-18</sup>

One of the methods used to predict the initial stability of a miniscrew is to measure the insertion torque. The insertion torque is commonly used to evaluate the mechanical stability of implants including miniscrews.<sup>19-24</sup> Previous studies have shown that a certain level of insertion torque is necessary in order to achieve the initial anchorage at the screw and the bone interface, and that the insertion torque of mini-

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Cylindrical Type

Taper Type

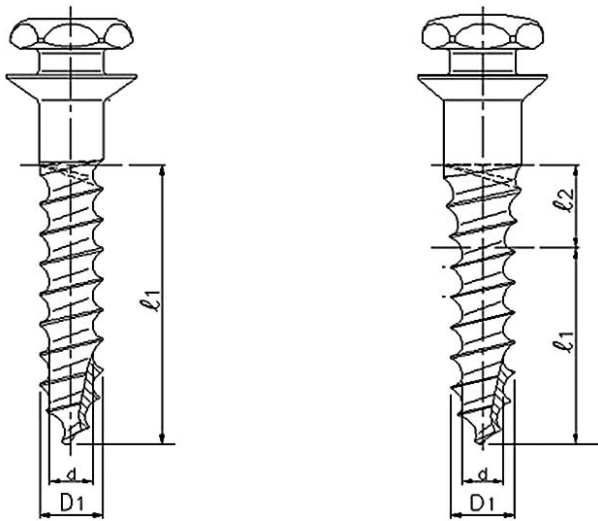


Figure 1. Drawing of 1508C and 1508T miniscrews.

screws is an important factor in determining the appropriate initial stability of a screw.<sup>22,25</sup> Furthermore, it was suggested that excessive insertion torque, heat at the border between the screw and bone, and mechanical injury can cause degeneration of the bone at the implant-tissue interface.<sup>26</sup>

Orthodontic miniscrews are used generally to secure anchorage in contemporary orthodontic treatments. Therefore, there is a need for an objective method for examining the influences of the morphologic characteristics of miniscrews on the screw stability. In this study, a driving torque tester (Biomaterials Korea Inc, Seoul, Korea), which provides a constant rotational speed and vertical force to increase the reproducibility of the experiment, was used to measure the serial torque from the initial phase of implantation to the end phase. The changes of maximum insertion torque (MIT) for different screw design factor, ie, the

length, outer diameter, and shape of the screw, were examined.

MATERIALS AND METHODS

Experimental Materials

The Ti-6Al-4V ELI miniscrews (Biomaterials) were used, and the samples were divided into cylindrical and taper types. The cylindrical type was composed of a parallel thread along the whole length of tread part showing different inner and outer diameters and pitch for each subgroup. The taper type had different ranges of increasing inner and outer diameter at the end of the thread part. The prescription of the subgroups was measured using hyperscope (MF-A1010H; Mitutoyo Corp, Japan) from 10 samples, and the error range during the manufacturing procedure was determined to be within 25 μm (Figure 1, Table 1).

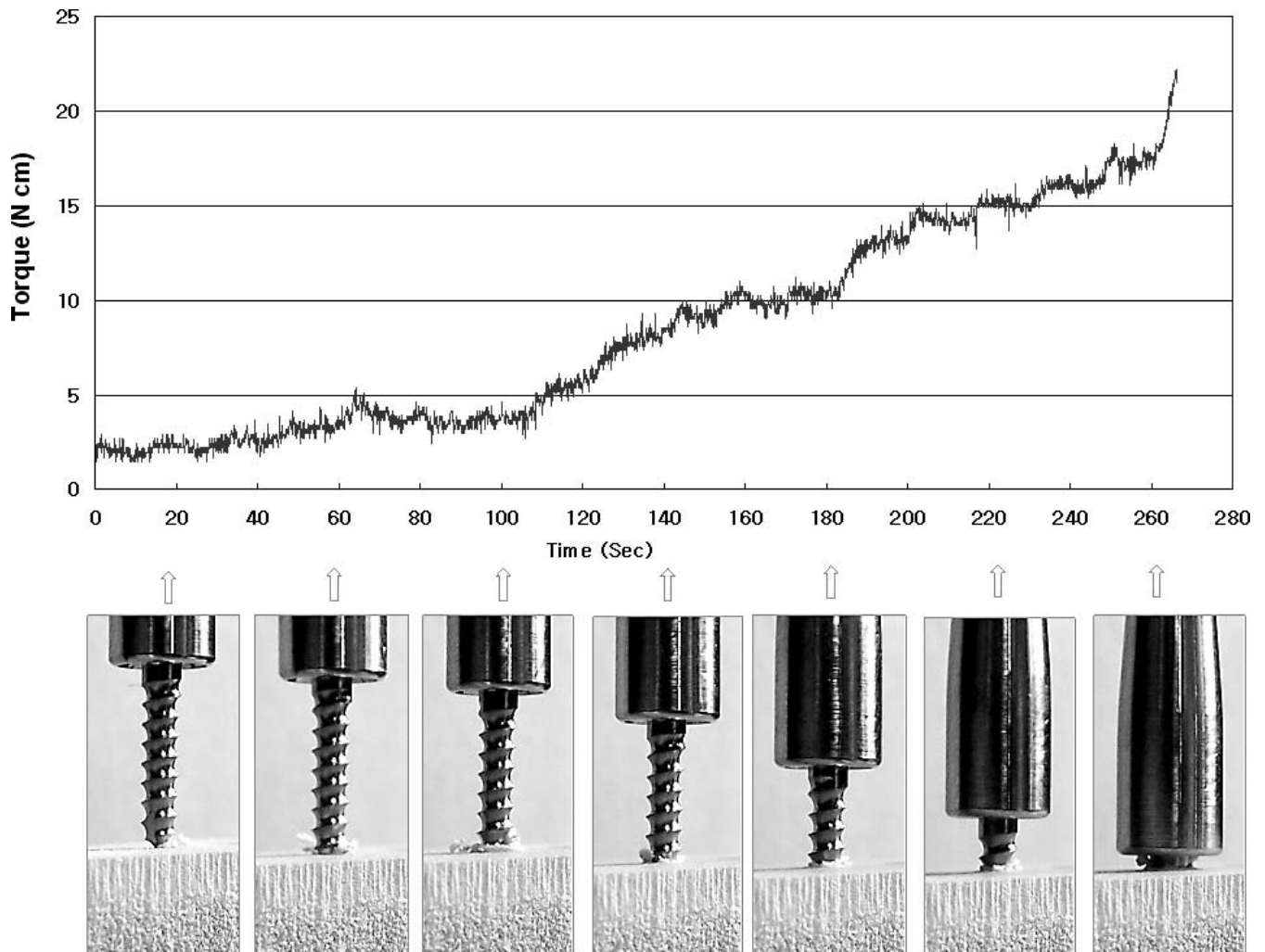
In this study, an experimental artificial bone block (Sawbones; Pacific Research Laboratories Inc, Wash) was fabricated and used to measure the insertion torque, as reported by Song et al.<sup>27</sup> The E-Glass-filled epoxy sheets were cut into 1 mm, 1.5 mm, and 2 mm sizes using a milling machine (NSM-A; Nam Sun Machine Tools Co Ltd, Seoul, Korea), and attached to solid rigid polyurethane foam using an acrylate bond (Automix; 3M, St Paul, Minn). The dimensions of the blocks (L × W × H) were 110 × 10 × 10 mm.

Insertion Torque Test

After setting the miniscrew tip to contact the artificial bone sample perpendicularly, the rotational axis of the torque tester was rotated clockwise at a speed of 3 rotations per minute, and the torque values were recorded every 0.1 second using a computer program (QuickDataAcq, SDK Developer, London, UK) (Figure 2). To allow sufficient vertical force for the miniscrew to perforate the cortical bone, a weight of 470 g was attached to the rotational axis of the torque tester, and

Table 1. The Prescription of Screws Tested in This Study (unit: mm)

Type	Subgroup	Measurements				
		External Diameter (d <sub>e</sub> )	Internal Diameter (d)	Total Length (l <sub>1</sub> )	Pitch (P)	Taper Length (l <sub>2</sub> )
Cylindrical	1208C	1.15	0.80	8.0	0.50	—
	1507C	1.45	1.00	7.0	0.70	—
	1508C	1.45	1.00	8.0	0.70	—
	1509C	1.45	1.00	9.0	0.70	—
	1808C	1.75	1.20	8.0	0.75	—
	2008C	2.00	1.20	8.0	0.80	—
	2508C	2.50	1.65	8.0	1.00	—
	Taper	1506T	1.45	1.00	6.0	0.70
1507T		1.45	1.00	7.0	0.70	1.94
1508T		1.45	1.00	8.0	0.70	1.94



**Figure 2.** Graph with diagram of torque tester of 1508C screw on the 1.5 mm cortical bone. Photos show the amount of screw insertion at each time point.

a dial indicator depth gauge with 1/100 mm of accuracy was used for precise insertion depth of the miniscrew. Among the serial values of the insertion torque, the maximum value was recognized as the MIT.

To test the two types of miniscrews, miniscrews with an identical width of 1.5 mm (1507C, 1508C, 1509C, 1506T, 1507T, 1508T) were used to measure the MIT according to the length. The MIT according to the outer diameter was measured by testing cylindrical type screws with a length of 8 mm (1208C, 1508C, 1808C, 2008C, 2508C). A multiple regression equation on the MIT was acquired from the variables of shape, external diameter, internal diameter, length, taper length, and pitch. The MIT according to the cortical bone thickness was measured while implanting cylindrical type screws (1508C, 2008C, 2508C) and taper type screws (1506T, 1507T, 1508T) into a cortical bone block, 1.0 mm, 1.5 mm, and 2.0 mm in thickness. Five

miniscrews were implanted into the artificial bone for each screw design, making a total of 115 miniscrews.

A Kruskal-Wallis significance test using SPSS for Windows (version 12.0) was performed at  $\alpha = .05$  level of significance to determine the changes in MIT according to the length and width of the miniscrew.

## RESULTS

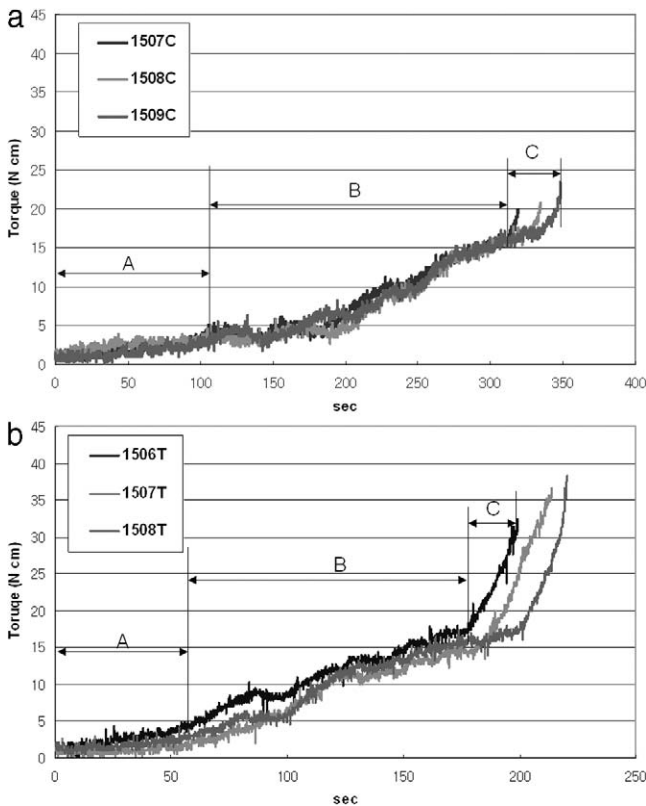
### The Measurement of MIT According to Length of the Screw

In the 1.5-mm thick cortical bone, the MIT value increased with increasing screw length for both the cylindrical and taper type screws (Table 2). The serial insertion torque graph was acquired and matched with the expected screw position at the artificial bone using real time video capture during the installation of the miniscrew (Figure 3). Part A shows where the screw

**Table 2.** Maximum Insertion Torque Depending on Screw Length on the 1.5 mm Cortical Bone<sup>a</sup>

Subgroup	Length (mm)	Max. Insertion Torque (Ncm)		
		Mean	SD	P-value
1507C	7.0	19.5	0.4	0.021*
1508C	8.0	20.9	0.7	
1509C	9.0	23.0	0.8	
1506T	6.0	32.6	0.6	NS
1507T	7.0	35.6	0.9	
1508T	8.0	37.3	0.9	

<sup>a</sup> Sample number = 5; SD, Standard deviation; Significance determined by Kruskal-Walis test.  
\*  $P < .01$ .



**Figure 3.** The change of torque depending on the length of screw type on the 1.5 mm cortical bone. (A) Cylindrical type screw. (B) Taper type screw.

was drilled into cortical bone in the initial phase. Part B shows where the middle cylindrical part of the screw was implanted. Part C indicates the results of a suddenly changing inclination where the tapered part of the screw was implanted (Figure 3). The changes in torque according to length were significant in the cylindrical type ( $P < .01$ ).

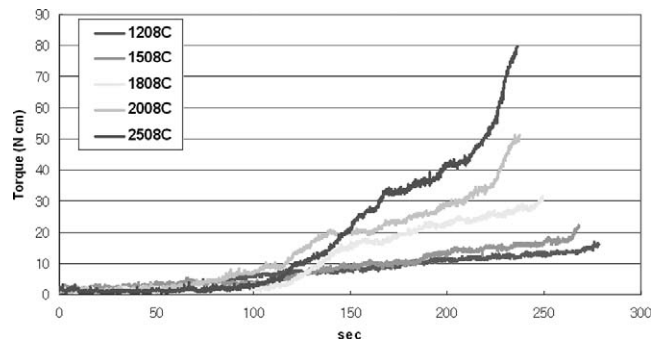
**The Measurement of MIT According to Outer Diameter of the Screw**

The MIT increased with increasing diameter as shown on Table 3 and Figure 4. In addition, the gra-

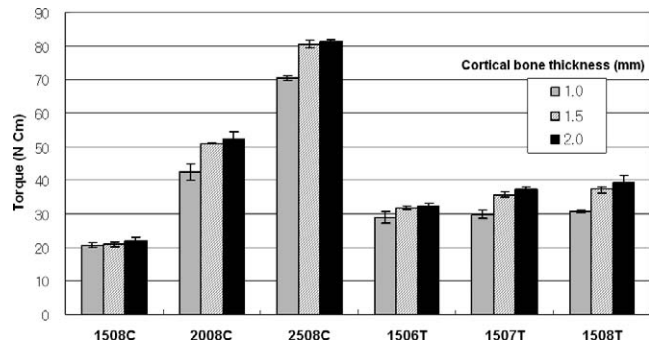
**Table 3.** Maximum Insertion Torque Depending on the External Diameter of Screws

Subgroup	Length (mm)	Max. Insertion Torque (Ncm)		
		Mean	SD	P-value
1208C	1.2	16.5	0.4	0.001*
1508C	1.5	20.9	0.7	
1808C	1.8	31.3	0.2	
2008C	2.0	51.1	0.3	
2508C	2.5	80.6	1.1	

<sup>a</sup> Sample number = 5; SD, Standard deviation; Significance determined by Kruskal-Walis test.  
\*  $P < .01$ .



**Figure 4.** The change of torque depending on the external diameter of cylindrical type screw on the 1.5 mm cortical bone.



**Figure 5.** Maximum insertion torque depending on the thickness of cortical bone.

dent of the continuous graph increased suddenly as the outer diameter was increased. The changes in MIT according to the outer diameter were statistically significant ( $P < .001$ ).

**Multiple Regression Analysis**

Multiple regression analysis showed that among all the variables, external diameter, length, and shape had a significant influence on the MIT (Table 4).

**The Measurement of MIT According to Cortical Bone Thickness**

With all the screws, the MIT increased with increasing cortical bone thickness (Table 5, Figure 5). How-

**Table 4.** Multiple Regression Analysis Between Insertion Torque and Shape, Length, and Diameter of Screws

	Unstandardized Coefficients		Standardized Coefficients		P-value
	Beta	SE	Beta	t	
Shape	16.58	13.17	0.41	1.26	0.04*
External diameter	70.26	8.98	1.38	7.83	0.00***
Internal diameter	19.79	16.64	0.24	1.19	0.24
Length	3.21	1.18	0.13	2.73	0.01**
Taper length	1.70	6.97	0.08	0.24	0.81
Pitch	-97.01	21.00	-0.61	-4.62	0.09

SE indicates standard error.

\*  $P < .05$ ; \*\*  $P < .01$ ; \*\*\*  $P < .001$ .

**Table 5.** Maximum Insertion Torque (Mean  $\pm$  SD in Ncm) Depending on the Thickness of Cortical Bone

Subgroup	Cortical Bone Thickness, mm			P value <sup>a</sup>
	1.0	1.5	2.0	
1508C	20.50 $\pm$ 0.65	20.91 $\pm$ 0.74	22.14 $\pm$ 0.76	.088
2008C	42.56 $\pm$ 2.60	51.10 $\pm$ 0.27	52.41 $\pm$ 1.86	.054
2508C	70.47 $\pm$ 0.56	80.56 $\pm$ 1.11	81.38 $\pm$ 0.50	.049*
1506T	29.05 $\pm$ 1.71	31.90 $\pm$ 0.37	32.55 $\pm$ 0.61	.044*
1507T	29.78 $\pm$ 1.11	35.64 $\pm$ 0.88	37.43 $\pm$ 0.50	.027*
1508T	30.68 $\pm$ 03.7	37.27 $\pm$ 0.92	39.38 $\pm$ 1.99	.039*

<sup>a</sup> Significance determined by Kruskal-Wallis test.

\*  $P < .05$ .

ever, with the exception of 1508C, there were some differences between the cortical bone thickness of 1.0 mm and 1.5 mm, but not between the cortical bone thickness of 1.5 mm and 2.0 mm.

There were significant differences in torque between the 2508C and taper type screw according to the changes in the cortical bone thickness. As cortical bone thickened, the MIT also increased. In particular, there were larger differences in the MIT between 1.0 mm and 1.5 mm than between 1.5 mm and 2.0 mm.

## DISCUSSION

The experimental method applied in this study was based on the ASTM (American Standard Specification and Test Methods) F543-02 regulation. The ASTM F543-02 is a general evaluation of the metallic medical bone screw. Therefore, a stretch needs to be applied in evaluating the characteristics of the miniscrew in the field of orthodontics. For a more relevant orthodontic standard for the miniscrew, this evaluation was carried out using a 470-g weight connected to the rotational axis, which was fixed with a rotational speed of 3 rotations per minute.

Biomechanical test blocks, which are E-Glass-filled epoxy sheets, a mixture of short E-Glass fibers and epoxy resin, were used as artificial bone, and solid polyurethane foam was used as a substitute for human cancellous bone. It is difficult to test the torque in vivo, and it was problematic when it comes to extract-

ing the sample from human cadavers. This challenge occurs because of the variations in thickness and density of the cortical bone from the site of extraction. Hence, the amount of torque cannot be compared.

The cortical bone sample used in this study had a density of 1.7 g/cL and 0.64 for cancellous bone. Based on the research by Misch et al,<sup>28</sup> the density of the mandible ranges from 0.85~1.53 g/cL, with an average of 1.14 g/cL, which is similar to the density of the bone samples used in this study.

Various lengths of cylindrical and taper screw implants were tested in a 1.5-mm block of bone with various levels of MIT. The results showed that the MIT of the implant increased with increasing screw length (Figure 3). In particular, in the cylindrical type, there was a significant difference in MIT according to the change in length.

The cylindrical type required a longer period of time to penetrate the bone than the tapered type screw (Figure 3). This is particularly true when penetrating the cortical bone. Although the number of screw threads and the shape of the tips were the same in both types, the reason for the difference might be due to the morphologic characteristics of the screw that are related to the driver generating a change in torque in the same side. However, more research will be needed.

The graph shows that the torque of the screw implant increased rapidly in the last part of the incom-

plete thread region of the cylindrical type and the sloped region for the tapered type. The reason for this is that the outside diameter remains constant in the cylindrical type, while the upper portion of the incomplete part (0.5–1 pitch) of the thread widens. The structure of the tapered type, which consists of a dual core diameter, an inside and outside diameter, gradually increases, and consists of a sloped portion that continues to the soft tissue.

The changes in diameter were applied only to examine the cylindrical type screw. This is because in the case of the taper type, the outside diameter, which contacts the soft tissue, runs parallel and coexists with the region that gradually increases in size. Therefore, it is difficult to control both outside factors simultaneously.

The change in the outer diameter had the most significant effect on the torque. From this result, it can be concluded that the outer diameter of the screw is the most influential factor in determining the torque. This corresponds to the results from finite element analysis of the difference in a bone's stress and distribution according to the screw design. Previous studies reported that among the various miniscrew designs, the change in diameter caused the greatest change in stress.<sup>28–30</sup> All the screws showed that the amount of maximum implant torque increased with increasing cortical bone thickness.

With the exception of 1508C, there was a larger difference in the amount of maximum insertion torque when the cortical bone thickness was changed from 1.0 mm to 1.5 mm, than when the thickness was changed from 1.5 mm to 2.0 mm. This is due to the incomplete thread region of the cylindrical type and the sloped region of the tapered screw being <1.8 mm. The depressing effect of the tapered part increased with increasing cortical bone thickness from 1.0 mm to 1.5 mm, which is in contrast to the one partially contacting the cancellous bone, showing a rapid increase in insertion torque. However, when the thickness was increased from 1.5 mm to 2.0 mm, the contact between the taper part and the cortical bone did not increase as dramatically, rather the contact area of the parallel part increased.

Clinically, the MIT increases when the tapered part of the screw is long and the cortical bone is thick. However, there is increased risk of fracture of the cortical bone or bone necrosis. Therefore, a miniscrew design with adequate torque and the lowest likelihood of unwanted side effects to the cortical bone is needed.

The level of torque (20–80 Ncm) in this study was higher than that reported previously, which was obtained in human subjects. Motoyoshi et al<sup>31</sup> suggested that 5–10 Ncm of insertion torque is acceptable for the stability of self-tapping miniscrews and reported that

excessive insertion torque results in screw breakage or instability caused by bone necrosis at the bone-implant interface. However, the high MIT value in this study was related to the type of screw insertion (non-drilling type) and the physical characteristics of the artificial bone, which is different from fresh bone.

The removal torque can be used to evaluate the miniscrew stability and insertion torque. Chen<sup>32</sup> reported removal torques >0.89 kg cm (8.7 Ncm). The removal torque was significantly higher in the mandible than in the maxilla. In addition, the insertion and removal torque was found to be strongly associated with the implant used.<sup>33</sup> In this study, the insertion torque was used as a factor to evaluate the screw stability because the initial stability plays an important role in the clinical application of a miniscrew.

These results showed that an increase in screw diameter can efficiently reinforce the initial stability of the miniscrew, but the proximity of the root at the implanted site should be considered. In addition, the comparison of MIT with fresh bone is necessary for the validation of experimental design using artificial bone block, and the clinical trial of long-term stability for different screw design, as well as the histological analysis from bone-implant interface, are essential for further research, which make it possible to select a more suitable screw for clinical use.

## CONCLUSIONS

- In both types of screws, the maximum implant torque increased with increasing screw length.
- The maximum implant torque increased with increasing outer diameter.
- As the thickness of cortical bone increased the maximum insertion torque increased. A significant increase of MIT was observed mainly in the taper type miniscrew.
- These results show that the maximum insertion torque increased with increasing diameter and length of the orthodontic miniscrews as well as increasing cortical bone thickness.
- An increase in screw diameter can efficiently reinforce the initial stability of miniscrews, but the proximity of the root at the implanted site should be considered.

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