Original Article

Mechanical properties of self-drilling orthodontic micro-implants with different diameters

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ABSTRACT

Objective: The hypothesis to be tested is that peak-insertion torque of self-drilling micro-implants of an appropriate diameter correlates with peak-removal torque mechanically.

Materials and Methods: A total of 360 self-drilling micro-implants composed of five different types were used. They (24 of each group) were inserted in three types of artificial bone with the use of a driving torque tester at a speed of 15 rpm. Insertion torque was measured during the placement, while the removal torque was measured within 3 days after insertion.

Results: Most of the micro-implants in type A sheared before they were completely inserted in 40–pounds per cubic foot bone. The implants in other types were successfully inserted without implant breakage and bone fracture in all bone densities. There was a statistically significant correlation between insertion torque and removal torque ($r \geq 0.43543$, $P = .0001$). There were significant differences in insertion and removal torque among the diameters of implants and bone densities with an increasing tendency. The torque loss rates reduced as the diameter of the implant and bone density increased.

Conclusions: Micro-implants with a diameter of less than 1.3 mm are unsuitable for insertion into a bone with a density greater than 40 pounds per cubic foot mechanically when one is using a self-drilling technique. (*Angle Orthod.* 2010;80:821–827.)

KEY WORDS: Micro-implants; Orthodontics; Self drilling; Mechanical property

INTRODUCTION

The high success rate of the orthodontic mini-implant under immediate and early loading is associated with the initial mechanical stability after surgical placement and, later, with stability supported by osseointegration.[1,2] Some qualitative and objective methods have been introduced to measure the initial

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stability when the implants are inserted. The measurement methods include noninvasive clinical test methods[3–5] (ie, insertion torque, radiographs, periotest and resonance frequency measurement) and invasive research test methods[6,7] (ie, Pull Out Test and removal torque). The reliability of the methods and the relationship between initial stability and bone quality has been explored.[8]

Friberg et al.[9] demonstrated a statistically significant correlation between implant placement resistance and the bone density values of the recipient site, and they indicated that insertion torque measurements for the evaluation of bone quality seemed to be reliable. When the insertion torque is large, the stability of the mini-implant may be enhanced.[10] Conversely, when the insertion torque is too small, the mini-implants will be unstable,[11] because insertion torque of implants is adjusted by increasing the ratio of the implant diameter and the diameter of the pilot hole. Even though the literature[12] has provided interesting insights into the results of the insertion torque measurement, most of the studies are of the self-tapping dental implants.[13] The investigation into the self-drilling micro-implants (SDIs) that have been thought to be the most proper fixture to insert in the thin cortical bone area is

Table 1. Five Types of Self-Drilling Micro-Implants

Types	System	Neck Diameter, mm	Tip Diameter, mm	Length, mm	Cutting Flute	Pitch, mm	Threads
A	SH1211-07	1.2	1.1	7	v	0.5	11
B	SH1312-07	1.3	1.2	7	v	0.5	11
C	SH1413-07	1.4	1.3	7	v	0.5	11
D	SH1514-07	1.5	1.4	7	v	0.7	9
E	SH1615-07	1.6	1.5	7	v	0.7	9

limited.[14] As the diameter of the self-drilling micro-implants increases, the danger of implant fracture during the installation and determination of optimal torque values for different diameters should be determined.

This study was intended to determine an adequate mechanical insertion torque for self-drilling micro-implants with different diameters and to analyze the relationship between the insertion and removal torques.

MATERIALS AND METHODS

A total of 360 self-drilling titanium (Ti)-alloy (Ti-6Al-4Va) micro-implants (Abso-anchor, Dentos Inc, Daegu, Korea) comprising five designs were inserted into three bone densities. Each implant was selected from the same series, with the same length and similar shape. The shape of the implant in the implant system was designed the same for all three sizes. The main difference was the size of the micro-implant (type A: 1211-07; type B: 1312-07; type C: 1413-07; type D: 1514-07; and type E: 1615-07). The micro-implants in types A to C had a standard 60° thread and a 0.5-mm pitch, whereas the ones in types D and E had a 45° thread and 0.7-mm pitch. However, the thread depth of

each of the five types of implants was the same (ie, 0.25 mm; Table 1; Figure 1).

Three types of solid rigid polyurethane foam (SawBones®, Pacific Research Laboratories Inc, Vashon, Wash) with homogeneous density were selected as implant receipt materials. The densities of polyurethane foam were 20 pounds per cubic foot (pcf), 30 pcf, and 40 pcf (Table 2).

Methods

To control the insertion depth, all implants were inserted with two O-rings at the neck of the implant, in line, as depicted in Figure 2. To reduce the interoperator variables, the implants were perpendicularly inserted without pre-drilling with a surgical engine implant system (SA200C, M&H ELCO Med Burmoos, Salzburg, Austria) (Figure 2), which could measure and record the torque at 1/8-second intervals during the insertion. The handpiece was calibrated at a speed of 15 rpm and a torque of 30 N cm, with a 75:1 control angle using a long rod transferred from the machine. Torque values were taken with software (ImpDat Plus, East Lansing, Michigan) installed on a digital card.

The insertion torque (IT, N cm)—that is, the force of the maximum clockwise movement that stripped bone
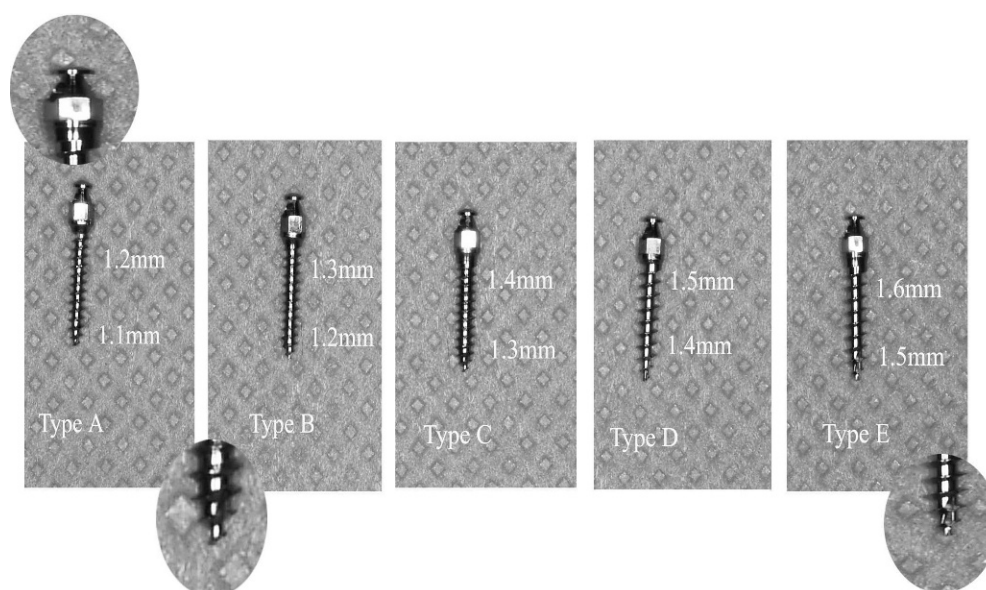
Figure 1. Photograph of the five micro-implant types tested: types A through E.

Table 2. Mechanical Properties of the Solid Rigid Polyurethane Foam (Sawbone®)

| Density		Compressive		Tensile		Shear	
pcf	g/cc	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa	Strength, MPa	Modulus, MPa
20	0.32	8.8	260	5.9	267	4.5	67
30	0.48	18.9	520	12.2	42.7	9.7	14.6
40	0.64	32.6	876	19.1	659	14.6	247

from the screw insertion to perfect fixation—was reported by the implant system with the insertion at an interval of 1/8 second (24 micro-implants in each group).

Removal torque (RT, N cm)—that is, the force of the maximum counterclockwise movement to cause micro-implants to loosen—was performed with the same machine for the same micro-implants with the IT measurement in each group (24 micro-implants in each group).

Statistical Analysis

Descriptive statistics, including the mean value and standard deviation of the IT, the RT value for different implant types, and different bone densities, were calculated with software (Version 8.0 SAS, AC ANRY, Raleigh, NC, USA). For significant differences, the data were evaluated using a one-way analysis of variance (ANOVA) test, followed by the Student-Newman-Keuls (SNK) test. Data were analyzed by t-test, χ^2 test, or Kruskal-Wallis test depending on the variances satisfying a normal distribution and homogeneities, or unequal homogeneities.

The Spearman correlation analysis was used to study the relationship between the IT and RT. Significance for all statistical tests was predetermined at $P \leq .05$.
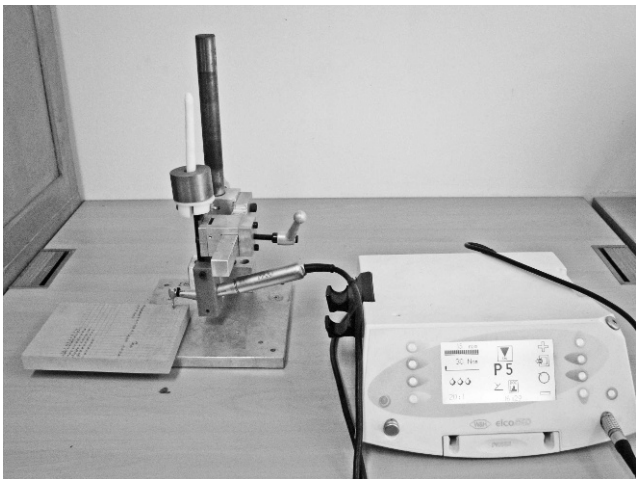
Figure 2. A surgical engine implant system (SA200C, M&H ELCO Med Burmoos, Austria) for the insertion of micro-implants and the measurement of insertion torque and removal torque.

RESULTS

Insertion and Removal Torque Measurements

For the IT and RT measurements, 360 micro-implants from the five types were inserted into three bone densities, and most were successfully recorded without micro-implant breakage and artificial bone fracture, except for type A in 40-pcf bone. Statistical analyses were performed on 24 micro-implants in each group (types A through D and type E) of various diameters (1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, and 1.5 mm) and various bone densities (20 pcf, 30 pcf, and 40 pcf).

The ANOVA test showed a significant statistical difference associated with IT among the micro-implants with different diameters and in different bone densities. The IT increased in relation to an increase in the diameter of the implant and the bone density (Table 3).

In the artificial bone with 20-pcf bone density, all five types of micro-implants were inserted completely without any problem, and they could be removed easily and reinstalled without breakage. The variance did not satisfy a normal distribution. The Kruskal-Wallis test showed a statistically significant difference in IT value among the five groups ($\chi^2 = 22.332$, $P = .001$). The SNK test showed a statistically significant difference between the implants in type A vs the other four types of implants ($P < .05$) and between the implants
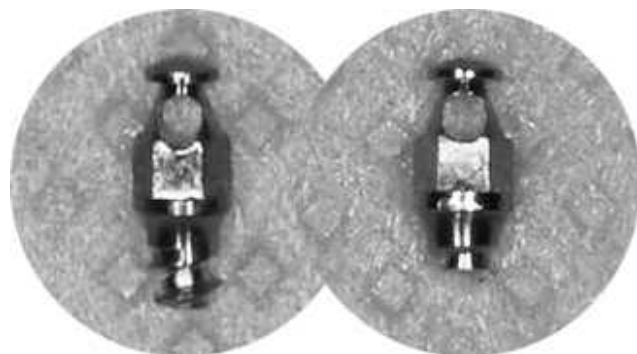
Table 3. Insertion Torque of Different Diameters of Self-Drilling Micro-Implants (SDIs) in Three Bone Densities (N cm)

Types of Implants	Mean/SD			P
	20 pcf	30 pcf	40 pcf	
Type A (SH1211-07)[a]	3.28 ± 0.59	4.69 ± 0.60		***
Type B (SH1312-07)	3.86 ± 1.02	5.21 ± 1.32	9.97 ± 2.23	***
Type C (SH1413-07)	3.86 ± 0.51	7.10 ± 0.92	13.17 ± 1.48	***
Type D (SH1514-07)	3.93 ± 1.00	7.13 ± 0.86	13.29 ± 1.76	***
Type E (SH1615-07)	4.64 ± 1.22	8.12 ± 1.44	14.65 ± 1.46	***
P	**	***	***	

[a] For the comparison of insertion torque of type A at 20–pounds per cubic foot (pcf) and 30-pcf bone density, t-test was used. For the comparison of insertion torque of other types at different bone densities, χ^2 and Kruskal-Wallis tests (χ^2 approximation) were used, respectively, depending on whether or not the samples satisfied normal distribution and homogeneity of variance or satisfied unnormal distribution and unequality of variance.

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

Figure 3. Breakage position of the micro-implants.

Table 4. Removal Torque of Different Diameters of Self-Drilling Micro-Implants (SDIs) in Three Bone Densities (N cm)

Types of Implants	Mean/SD			P
	20 pcf	30 pcf	40 pcf	
Type A[a]	2.2 ± 0.01	2.63 ± 0.48		*
Type B	3.03 ± 0.61	3.2 ± 0.47	8.28 ± 1.62	***
Type C	2.38 ± 0.31	4.75 ± 0.32	9.78 ± 1.34	***
Type D	2.33 ± 0.35	4.35 ± 0.49	10.63 ± 1.39	***
Type E	2.75 ± 0.49	4.98 ± 0.9	12.00 ± 1.37	***
P	***	***	***	

[a] For the comparison of removal torque of type A at 20–pounds per cubic foot (pcf) and 30-pcf bone density, t-test was used. For the comparison of removal torque of other types at different bone densities, χ^2 and Kruskal-Wallis tests (χ^2 approximation) were used, respectively, depending on whether or not the samples satisfied normal distribution and homogeneity of variance or satisfied unnormal distribution and unequality of variance.

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

in type E vs the other four types of implants ($P < .05$). The IT values of types B, C, and D performed similarly, and there was no significant difference in IT between two-type comparisons ($P > .05$).

In 30-pcf artificial bone, all five types of micro-implants were completely inserted, but the micro-implants in type A showed fatigue because they were removed with strong resistance. The variance did not satisfy a normal distribution. The Kruskal-Wallis test showed a statistically significant difference in IT value among the five groups ($\chi^2 = 61.898$, $P = .0001$). The SNK test showed a statistically significant difference ($P < .05$) among the five groups, except in the case of type A vs type B ($P > .05$).

In 40-pcf artificial bone, four types of micro-implants were successfully inserted, whereas nine of the micro-implants in type A were broken before being completely inserted, and others could not be removed. The broken point was subjacent to the implant head (Figure 3). If the micro-implants were inserted through that point, the fracture should not have happened, even if such implants had a very high IT value. The variance satisfied a normal distribution. The χ^2 test showed a statistically significant difference in IT value among the four groups ($F = 30.44$, $P = .0001$). The SNK test showed statistically significant differences ($P < .05$), except in the case of type E vs type D ($P > .05$).

For the comparison of the IT in different bone densities, the ANOVA test showed statistically significant differences in five different implant diameters. The IT value of the implants in type A resulted in failure in 40-pcf artificial bone, with the t-test showing a statistically significant difference in type A ($t = 4.07$, $P = .0001$). In types B, D, and E, the variance did not satisfy a normal distribution. The Kruskal-Wallis test showed a statistically significant difference in IT values among the three bone densities ($\chi^2 = 102.5$, $\chi^2 = 154.9$, and $\chi^2 = 375.39$, respectively; $P = .0001$). In type C, the variance satisfied a normal distribution, and

the χ^2 test showed a statistically significant difference ($F = 375$, $P = .0001$).

The ANOVA test showed a statistically significant difference of the mean RT in every diameter in various bone densities (for type E, $F = 375$; for types B, C, and D, $\chi^2 = 28.312$; for type A, $t = -2.4845$; $P = .0001$; Table 4).

In 20-pcf artificial bone, the variance satisfied a normal distribution. The χ^2 test showed a significant statistical difference in RT values among the five groups ($F = 17.24$, $P = .0001$). The SNK test showed a statistically significant difference between type A and types B and E ($P < .05$), between type B and types C ($P < .05$) and D ($P < .05$), and between type C and type E ($P < .05$).

In 30-pcf artificial bone, the variance did not satisfy a normal distribution. The Kruskal-Wallis test showed a statistically significant difference in RT values among the five groups ($\chi^2 = 38.906$, $P = .0001$). The SNK test showed a statistically significant difference between type A and types B ($P < .05$) and E ($P < .05$). A statistically significant difference was seen between type B and type D ($P < .05$) and between type C and type E ($P < .05$; Table 4).

In 40-pcf artificial bone, the variance satisfied a normal distribution. The χ^2 test showed a significant statistical difference in RT values among the four groups ($F = 15.31$, $P = .0001$). The SNK test showed a statistically significant difference between type B and type C ($P < .5$), between type B and type D ($P < .5$), and between type D and type E ($P < .05$).

Torque Loss

In all bone densities, IT was greater than RT. There was no significant difference in torque loss rate in type A between 20-pcf and 30-pcf bone. However, the

Table 5. Torque Loss Rate of Different Diameters of Self-Drilling Micro-Implants (SDIs) (%)

Types of Implants	Mean[a]			
	20 pcf	30 pcf	40 pcf	
Type A	32.93	43.92		30 pcf > 20 pcf
Type B	21.50	38.59	16.95	30 pcf > 20 pcf > 40 pcf
Type C	37.86	33.10	25.75	20 pcf > 30pcf > 40 pcf
Type D	40.72	38.99	20.02	20 pcf > 30pcf > 40 pcf
Type E	40.74	38.90	18.09	20 pcf > 30pcf > 40 pcf
	E > D > C > A > B	A > D > E > B > C	C > D > E > B	

[a] pcf indicates pounds per cubic foot.

Table 6. Spearman Rank Order Correlation Coefficients for Insertion and Removal Torque at Different Diameters

Spearman Correlations Between Indexes of Insertion Torque (IT) and Removal Torque (RT)	Format of Distribution	r
Type A IT vs Type A RT	Normal distribution	0.43543*
Type B IT vs type B RT	Un-normal distribution	0.81696***
Type C IT vs type C RT	Un-normal distribution	0.95669***
Type D IT vs type D RT	Un-normal distribution	0.93652***
Type E IT vs type E RT	Un-normal distribution	0.91752***

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

torque loss rates were reduced as the bone density and the implant diameter increased (Table 5).

The Spearman correlation analysis was used to investigate the effect of the IT of implants with various diameters on RT in different bone densities. There was a regular and significant statistical correlation between IT and RT ($r \geq 0.43543$ for five groups, $P = .0001$; Table 6) depending on bone density.

DISCUSSION

The experimental method applied in this study was based on the American Standard Specification and Test Methods F543-02 regulation,[3] which is a general evaluation of the metallic cortical bone screw. To reduce interoperator variation, the implants were perpendicularly inserted without pre-drilling with the M&H ELCO Med implant system, which has the advantage of objectively reflecting the mechanical properties of micro-implants and the disadvantage of unclear digital data. It is feasible to determine IT measurement of implants during placement, and this would not produce any discomfort or abnormal sensation during the test.

In numerous previous studies,[15,16] wood, polyvinyl chloride, and porcine bone were used as the test materials in in vitro tests. In the present study, the artificial bone, the biological properties of which are similar to those of natural bone, is more suitable to test the holding power of micro-implants. Artificial bone, which is composed of synthetic, homogeneous materials, has been shown to be a good substitute for jaw bone, which varies considerably and so presents difficulties in terms of the mechanical characteristics of the metallic implants.

The mean IT in the present in vitro study is associated with the diameter of the micro-implant and ranged from 3.28 N cm to 14.65 N cm without implant breakage and bone fracture in different bone

densities. A statistically significant difference in the mechanical properties of the SDIs was seen in five different types, and the SNK test showed a statistical difference between type A, type E, and other types. An increasing tendency of IT values is consistent with increased diameter and greater bone density.

In an in vitro test, You et al.[17] described similar outcomes for self-tapping micro-screws with the same diameter in 1-mm, 2-mm, and 3-mm cortical bone. Consistent with the self-tapping implants, the IT values of the self-drilling micro-implants could have provided more knowledge of a relationship between bone density and insertion resistance, since no pilot drill was given. The IT values of every micro-implant type varied dramatically in three bone densities. A relatively higher level of IT (20–80 N cm) in artificial bone was reported by Lim et al.,[10] using a self-drilling mini-implant of 1.6-mm diameter that was inserted without a pilot drill. This outcome might be explained by the difference between the implant diameter in their study and that used in this study and might further confirm that the stability of the implant is affected by the screw diameter and bone density.[18] In 40-pcf artificial bone, the micro-implants had the greatest IT for every type, and nine of the micro-implants in type A sheared before they were completely inserted, while the others were broken during removal.

In the present in vitro study, the holding power of the new type of self-drilling micro-implants was tested by RT, which has been accepted as a biomechanical method to measure mechanical anchorage or endosseous integration. The important finding in this study is that RT shows a statistically significant difference among the five implant types and that the SNK test showed a significant difference between every two-type comparison. However, in 20-pcf and 30-pcf bone, type C yields the highest RT value, whereas in 40-pcf bone, RT increases as the diameter of the implant also increases. This result seems to show that the elements that may influence unscrewing tolerance of an implant are not only the diameter but also the pitch and threads and bone density, because the micro-implants in types

D and E are characterized by small pitch, less thread, and a sharp cutting flute at the leading end of the thread portion. Heidemann et al.[15] considered that the pitch of the screw, which converts the rotational motion into a linear advance, influences the compressive force of the screw. A fine-pitched screw moves a smaller linear amount for a given angular rotation and produces greater stress on the implant itself. This study asserts that the pitch and the height of the unthreaded shank under the plate greatly affected the screw holding strength in thin bone area.[19]

The RT values of each screw type, according to the artificial bone density, tend to correlate to the IT value ($r = 0.43543$), and the correlation gets larger as an increase in the implant diameter occurs. The correlation further confirms that IT is related to initial stability. Type C has the closest correlation ($r = 0.95669$). This proves that the fine threads and pitch are useful in promoting holding power.

An interesting finding in 20-pcf artificial bone is that the torque loss rate gets higher as an increase in diameter occurs, whereas in 30-pcf and 40-pcf bone it reduces as the implant diameter increases. This phenomenon might be explained by the low bone density not maintaining holding strength mechanically. The thick bone density may maintain good retentive strength for the micro-implant, as an increase in the potential for biomechanical interlocking of bone into the implant surface in high bone density occurs.[20] This result is supported by a similar finding in an in vivo test of Chen et al.,[21] who measured RT values of 7.1 N cm in the mandible and 6.5 N cm in the maxilla after a 9-week healing period. As consideration of the density of the jaw bone is vital in selecting the optimal size of micro-implants, clinically it is suggested that small-sized micro-implants should not be used in a thick cortical bone area if they are self-drilling.

From the mechanical viewpoint, the high IT indicates that the implants will have better initial stability and a high success rate. However, an overly high IT is not necessary. If torque values are excessive and over the range the micro-implant can withstand, they will cause breakage of implants, and there will be substantial pressure on the surrounding bone, causing bone cracking or bone necrosis.[22] The success of the micro-implants is mainly determined by the secondary osseointegration caused with bone healing and remodeling.

CONCLUSIONS

- IT is an important indicator for insertion resistance and holding power.
- The ideal mechanical IT is dependent on the diameter of the micro-implants. Using a self-drilling technique, micro-implants with a diameter of less than 1.3 mm are unsuitable for insertion into a bone with a density greater than 40 pcf mechanically.

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