



Original Article

The correlation among gripping volume, insertion torque, and pullout strength of micro-implant



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KEYWORDS

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Abstract *Background/purpose:* The fixation stability is the key factor for orthodontic micro-implant to succeed. This study evaluated the mechanical properties of three types of micro-implants by analyzing their structural configurations.

Materials and methods: Thirty micro-implants of three types (diameter 1.5 mm, Types A, B, C) were assessed. All micro-implants were manually driven into artificial bones at an 8-mm depth. The insertion torque (IT), pullout strength (PS), and gripping volume (GV) of each type were measured. The indexes of mechanical properties denoted as the PS/IT, GV/IT and PS/GV ratios. Intergroup comparisons and intragroup correlation were examined using statistical analysis.

Results: Type B had the greatest inner–outer diameter ratio (0.67), and Type A had the smallest (0.53). The IT of Type A (5.26 Ncm) was significantly ($p = 0.038$) lower than that of Type C (8.8 Ncm). There was no significant difference in the pullout strength. The GV of Type A (9.7 mm³) was significantly greater than Type C (8.4 mm³). Type C was significantly greater than Type B (7.2 mm³). The ratios of mechanical properties (PS/IT, PS/GV, and GV/IT) were found significant in intergroup comparison. The PS/GV ratio was in order: Type B (26.5) > Type A (23.0) > Type C (20.2). Spearman's rho rank correlation test showed that PS of Type B was

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correlated significantly with GV.

Conclusion: The design of thread and gripping volume were the important factors that contribute to the mechanical strengths of micro-implant.

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Introduction

Stable and reliable control is the most crucial factor in designing a successful orthodontic anchorage. Recently, micro-implants have gained considerable interest as a skeletal anchorage instrument for orthodontic treatment. Micro-implant anchorage can reduce surgical time, prevent wire-stick injury, and increase the comfort levels of patients. Because of the resultant stability and reliability, micro-implant anchorage controls orthodontic forces successfully, limits undesired teeth movements, and corrects severe malocclusion. According to the related literature,^{1–7} the success rate of orthodontic micro-implants is 60%–90%; therefore, micro-implant can be a useful adjunct for orthodontic treatment.

Different parameters have been applied to measure the stability of micro-implants, including insertion torque (IT), removal torque, and pullout strength (PS).^{8–13} The purpose of our study was to evaluate the mechanical strength according to IT, PS, gripping volume (GV), and their correlations in different types of orthodontic micro-implants. The null hypothesis was that there is no significant difference in the mechanical properties (PS/IT, GV/IT and PS/GV ratios) among the different types of micro-implants.

Materials and methods

Three types [Type A (1.5 × 10 mm, titanium alloy), Type B (1.5 × 10 mm, stainless steel), and Type C (1.5 × 9 mm, titanium alloy)] of 1.5-mm micro-implants were tested with vertical and horizontal forces. Each type (5 micro-implants) had been tested in mechanical strength and GV tests; thus, a total of 30 micro-implants were employed (Fig. 1). A scanning electron microscope (SEM) analysis (Hitachi SU8010, Tokyo, Japan) was performed to determine the surface features of threads (Fig. 2). The artificial bones (Sawbones, Pacific Research Laboratories, Inc., Vashon Island, WA, USA) include 2 mm cortical bone (40 pcf) and bone marrow (20 pcf).

In consideration of the interdental alveolar bone thickness and actual operational conditions, the locking depth for direct insertion into the artificial bone with no predrilling was 8 mm. The IT values for the five micro-implants of each type were determined using a torque meter (Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) by directly locking into the artificial bone at the depth of 8 mm. The material tester (GOTECH AI-3000, Taichung, Taiwan) was used to perform vertical pullout test (Fig. 3). The block Sawbones (20 pcf) was designed for GV test (Fig. 4). After

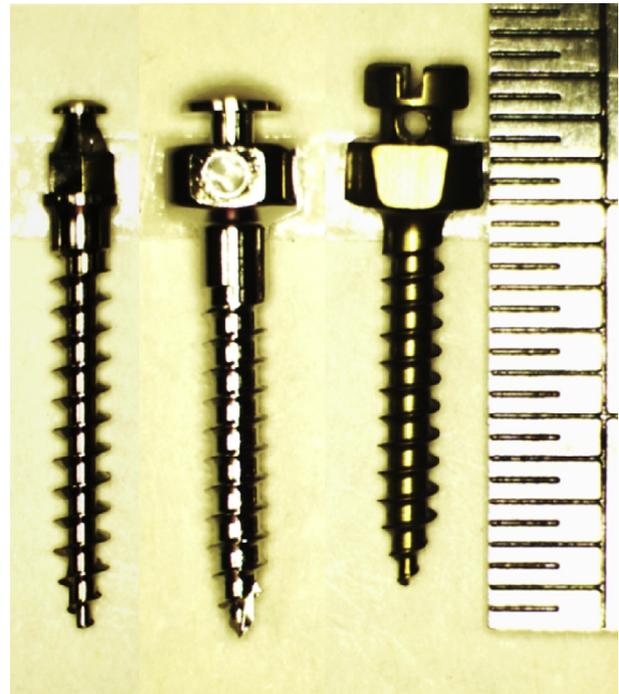


Figure 1 Three types of micro-implants, from left to right: Type A (1.5 × 10 mm), Type B (1.5 × 10 mm), and Type C (1.5 × 9 mm).

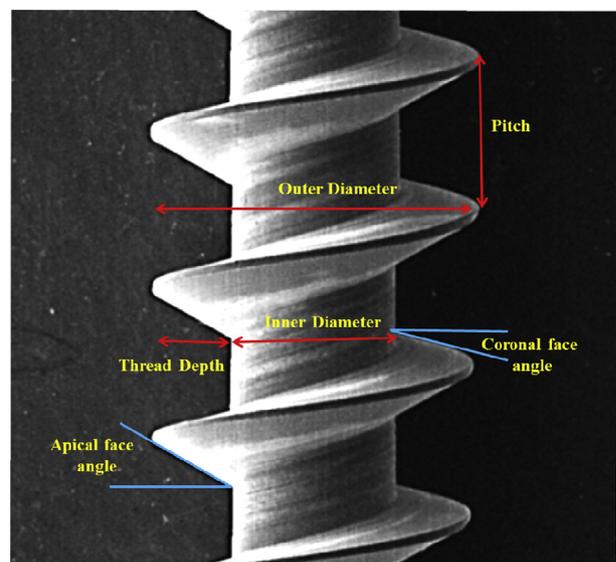


Figure 2 The dimensions of the micro-implant as determined using Scanning electron microscope (SEM) analysis (15 kV × 30, Hitachi SU8010, Japan).



Figure 3 The material testing machine (GOTECH AI-3000, Taiwan) for the pullout strength (PS) test.

insertion 8 mm, micro-implants were vertical pullout by manually. The analytical balances (AS 220/C1, Radwag, Poland) were used to weight the mass of Sawbones anchoring on micro-implant. The GV was calculated by mass-density conversion. In present study, the indexes of mechanical properties are denoted as PS/IT, GV/IT and PS/GV ratios. In order for PS/IT and GV/IT to be constant, an increased IT will result in higher PS and larger GV. Similarly, an increased GV value will lead to greater PS in order for PS/GV to be constant.

SPSS software (IBM Corporation, Armonk, NY, USA) was used to carry out statistical analysis and a p value of 0.05 was chosen. One way analysis of variance (ANOVA) was performed with LSD post hoc comparison among different micro-implants. The Spearman's rho correlation coefficient was used to examine the relationship between the IT, GV and PS values within the same type of micro-

implant. The null hypothesis was that there is no statistically significant difference in the mechanical properties (PS/IT, GV/IT and PS/GV ratios) among the different micro-implants.

Results

The dimensions of micro-implants are presented in [Table 1](#). For the inner diameter measurements, Type B (1.05 mm) was the largest and Type A (0.79 mm) was the smallest. Type A had the largest thread depth (0.35 mm) and Type B had the smallest (0.26 m). Type B had the greatest inner–outer diameter ratio (0.67) and Type A had the smallest (0.53). Type A had the greatest apical face angle (37°) and Type B had the smallest apical face angle (29.6°). Type B had the greatest coronal face angle (23°) and Type C had the smallest apical face angle (14°). [Table 2](#) and [Fig. 5](#) show intergroup comparisons using IT, GV, PS values and indexes of mechanical properties (PS/IT, PS/GV, and GV/IT). The IT of Type A (5.3 Ncm) was significantly lower than that of Type C (8.8 Ncm). The PS of micro-implants was in the order: Type A (195 Ncm) > Type C (193.9 Ncm) > Type B (190.7 Ncm). However, there is no significant difference in the PS test. The GV of Type A (9.7 mm^3) was significantly greater than Type C (8.4 mm^3). Type C was significantly greater than Type B (7.2 mm^3).

The indexes of mechanical properties (PS/IT, PS/GV, and GV/IT) were shown significant by LSD post hoc comparison. Type A (38) was found to have the greatest PS/IT ratio followed by Type B (24.5) then Type C (24.1). Type B (26.5) was found to have the greatest PS/GV ratio followed by Type A (23.0) then Type C (20.2). Type A (1.9) was found to have the greatest GV/IT ratio followed by Type C (1.0) then Type B (0.9). Therefore, the null hypothesis was rejected. In [Table 3](#), Type B presented significant correlation (0.975) between GV and PS. However, Type A and Type C showed no significant correlation among the IT, PS and GV.

Discussion

Motoyoshi et al.¹⁴ evaluated the correlation between cortical bone thickness and the success rate of orthodontic implants. They found that 1 mm cortical bone could increase the success rate of micro-implants. Alrbata et al.¹⁵ investigated the biomechanical relationship between micro-implant stability and the cortical bone thickness. The highest stress concentrations take place in the fulcrum where the micro-implant, undergoing tipping, pressed the

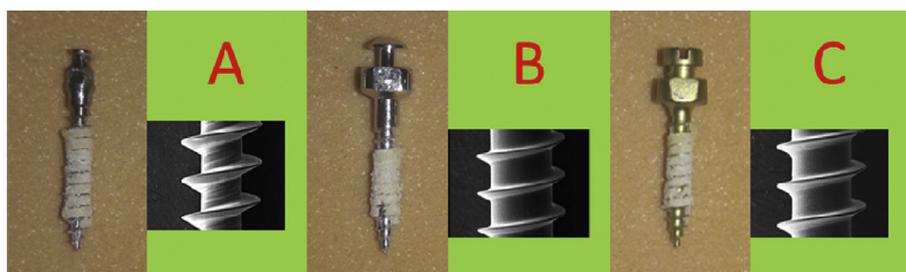


Figure 4 Gripping volume (GV) and middle portions (SEM) of micro-implants. From left to right: Types A, B, and C.

Table 1 The parameters of micro-implants.

Micro-implants	A	B	C
Inner diameter (mm)	0.79	1.05	0.98
Outer diameter (mm)	1.50	1.57	1.52
Inner diameter/ Outer diameter ratio	0.53	0.67	0.64
Thread pitch (mm)	0.76	0.73	0.69
Thread depth (mm)	0.35	0.26	0.27
Apical facing angle; Degree	37.0	29.6	35.0
Coronal face angle; Degree	15.5	23.0	14.0

cortical bone surface under loading force. They concluded that nearly all of the orthodontic force is transmitted to the cortical bone at cortical bone thickness values of 2 mm. Thus, our study designed a 2-mm cortical bone for the anchorage of interdental orthodontic micro-implants 1.5 mm in diameter. The length of 10 or 9 mm for micro-implants and insertion depth of 8 mm are consistently the most common choices of orthodontists when they intend to place micro-implants in the interdental region. Our study followed clinical rules.

Alrbata et al.¹⁶ used finite element analysis to determine an optimal force that can be loaded onto a micro-implant to fulfill the biomechanical demands of orthodontic treatment. The maximum loading force of 3.75 N, 4.1 N, 4.3 N, and 4.45 N could be applied safely to the cortical bone thicknesses of 0.5 mm, 1.2 mm, 2.0 mm, and 3.0 mm, respectively.¹⁶ Motoyoshi et al.¹⁴ also recommended that IT of micro-implant should be controlled up to 10 Ncm without having the risk of over pressure on the cortex. In our study, all ITs of micro-implants were less than 10 Ncm. In the comparisons of ITs, Type A had the smallest inner–outer diameter ratio (0.53), largest thread depth (0.35 mm) and largest apical face angle (37°). Therefore, Type A required the least effort during insertion, and had the lowest IT (5.3 Ncm). The inner–outer diameter ratios and thread depths of Types B and C were similar, and thus, their ITs were not significantly different. In the comparison among the different types, the IT of Type C was significantly greater than that of Type A. These results showed that IT correlated the most with the inner diameter, inner–outer diameter

ratio, thread depth and apical facing angle of the micro-implants. Thus, Type A required the least force during implantation because it had the lowest IT.

Dose the material of orthodontic implant affect the value of IT? Brown et al.¹⁷ reported that titanium mini-screw had significant lower IT than those made of stainless steel. In our study, Type A and Type C were made of titanium alloy and Type B was made of stainless steel. However, there is no significant difference between Type A (5.3 Ncm) and Type B (8.4 Ncm). Therefore, IT can't be only valuated according to the material compositions of the orthodontic implant. Dose the shape of orthodontic implant affect the value of IT? Yoo et al.¹⁸ found that tapered type was significantly higher than cylinder type but both types had similar success rate with no statistically significant difference. In our study, all of micro-implant was cylindrical shape. However, Type A was significantly lower than Type C (8.8 Ncm) and there is no significant difference between Type B and Type C. Therefore, IT can't be only valuated according to the shapes of the orthodontic implant. However, in our previous report, IT presented no significant difference concerning the material and shape of mini-implant.

GV is the artificial bone locked between pitches of micro-implant after vertical pullout. In present study, GV presented the significant difference in order: Type A (9.7 mm³) > Type C (8.4 mm³) > Type B (7.2 mm³). In our study, inner–outer diameter ratio of micro-implants was also in same order: Type A (0.53) < Type C (0.64) < Type B (0.67). The smaller inner–outer diameter ratio could lock deeper into artificial bone and get more GV. Therefore, there is a potential correlation between inner–outer diameter ratio and GV. From intergroup comparison, we found that GV/IT ratio was in order: Type A (1.9) > Type C (1.0) > Type B (0.9). It means that Type A was least insertion force and acquired two times effect GV than Type B and Type C.

Even with no significant difference, PS was in order: Type A (195 Ncm) > Type C (193.9 Ncm) > Type B (190.7 Ncm). Type A had the smallest inner–outer diameter ratio (0.53) and the largest PS. Type B had the largest inner–outer diameter ratio (0.67) and largest coronal facing angle (23°), which resulted in the smallest PS. In addition, due to the fact that three types of micro-implants had similar coronal facing angles, the resistance angles that affected the PS were also similar. Therefore, the PS values of Types A, B, and C did not

Table 2 The insertion torque (N cm), pullout strength (N cm), gripping volume (mm³) and indexes of mechanical properties in the ANOVA with LSD post hoc comparison.

Micro-implant	A		B		C		Intergroup comparisons
	Mean	SD	Mean	SD	Mean	SD	
IT	5.3	0.97	8.4	2.56	8.8	2.52	*C > A
PS	195.0	10.56	190.7	16.84	193.9	4.44	–
GV	9.7	0.62	7.2	0.52	8.4	0.34	*A > C > B
PS/IT	38.0	5.46	24.5	5.96	24.1	7.15	*A > C, A > B
PS/GV	20.2	1.51	26.5	0.56	23.0	0.81	*B > C > A
GV/IT	1.9	0.29	0.9	0.23	1.0	0.31	*A > C, A > B

IT: insertion torque; PS: pullout strength; GV: gripping volume.

Indexes of mechanical properties: PS/IT, PS/GV, and GV/IT.

– :Non significant; *: Significant; $p < 0.05$.

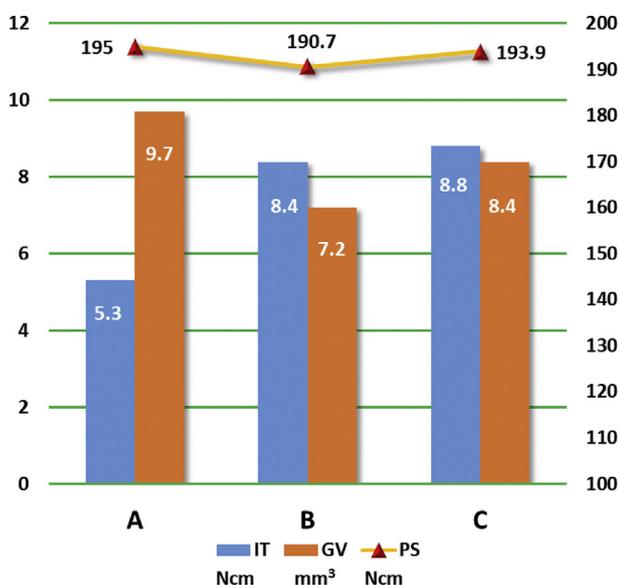


Figure 5 Insertion torque (IT), gripping volume (GV), and pullout strength (PS) of micro-implants. From left to right: Type A, B, and C.

significantly differ. We also found that the magnitude of PS was in the same order of GV. There is a potential correlation was between GV and PS. It means that more GV had more PS.

Regarding the PS/IT ratio, Type A had the greatest ratio (38) and Type B (24.5) was similar to Type C (24.1). It means that Type A was least IT and got 1.6 times relative effect PS than Type B and Type C. Dose the material and shape of orthodontic implant affect the value of PS? In our previous study, PS revealed no significant difference concerning the material and shape of mini-implant. In present study, there is also no significant difference among 3 types of micro-implant.

According to the correlation coefficient analysis, all IT values did not correlate significantly with their GV and PS values in the intragroup comparisons. These results suggested that individual IT can't be used to predict GV and PS. Type A and Type C also showed no significant correlation coefficient between GV and PS. In conclusion, the design of thread and its GV were the important factors on the mechanical strengths of micro-implant.

Table 3 Intragroup comparison by Spearman's rho rank correlation coefficient test.

Micro-implants	Correlation Coefficient		
	Type A	Type B	Type C
Insertion torque vs Pullout strength	0.700	0.410	0.300
Insertion torque vs Gripping volume	0.400	0.500	-0.211
Gripping volume vs Pullout strength	0.000	0.975*	0.527

*: Significant; $p < 0.05$.

Declaration of Competing Interest

The authors have no conflicts of interest relevant to this article.

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