Article

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

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Abstract

This study evaluated the mechanical strengths of three types of orthodontic micro-implants by analyzing their structural configurations. 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. Intergroup comparisons and intragroup correlation were investigated by statistical analysis. 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 (p = 0.868). The GV of Type A (9.7 mm^3) was significant ($p < 0.01$) greater than Type C (8.4 mm^3). Type C was significant ($p < 0.01$) greater than Type B (7.2 mm^3). Spearman's rho rank correlation test showed that PS of Type B was correlated significantly with GV. In conclusion, the design of thread and its GV were the important factors on the mechanical strengths of micro-implant.

Keywords: Insertion torque; Pullout strength; Gripping volume; Micro-implant

1. Introduction

Stable and reliable control is the most crucial factor for the design of 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) [8,9], removal torque [10,11], and pullout strength (PS) [12,13].

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 hypothesis was that no significant correlation among the mechanical strengths of individual types would exist.

2. **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 (Figure 1). A scanning electron microscope (SEM) analysis (Hitachi SU8010, Japan) was performed to determine the surface features of threads (Figure 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).

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).

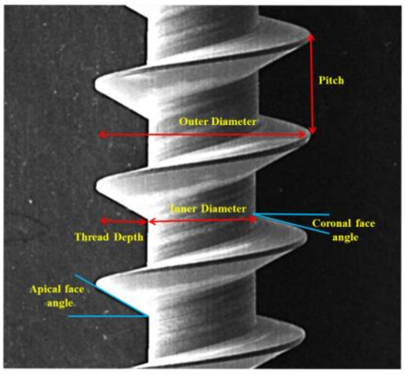

Figure 2. The dimensions of the micro-implant as determined using Scanning electron microscope (SEM) analysis (15 kV × 30, Hitachi SU8010, Japan).

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, Taiwan) was used to perform both vertical pullout test (Figure 3). The block Sawbones (20 pcf) was designed for GV test (Figure 4). After insertion 8 mm, micro-implants were vertical pullout by manually. The analytical balances (AS 220/C1, Radwag, Poland) was used to weight the mass of Sawbones anchoring on micro-implant. The GV was calculated by mass-density conversion.

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

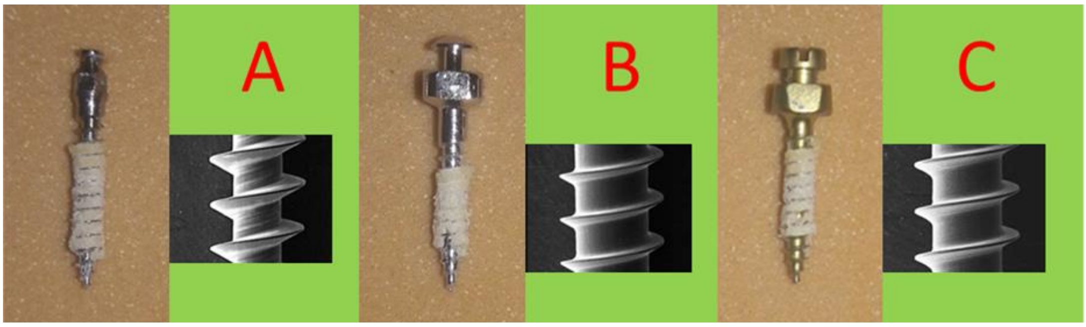

Figure 4. Gripping volume (GV) and middle portions (SEM) of micro-implants.
From left to right: Types A, B, and C.

Statistical analysis of present study used the SPSS software (IBM Corporation, Armonk, NY, USA) and a *p* values less than 0.05 was considered statistically significant. A basic analysis was performed on the collected data, and with a significant difference LSD post hoc comparison was performed to compare the IT and PS values among the types. The Spearman's rho correlation coefficient was used to examine the relationship between the IT and PS values within an individual type. The null hypothesis was that no statistically significant correlation in the intragroup comparisons existed.

3. **Results**

The dimensions of micro-implants are presented in the 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 (0.26m). 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 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

In the Table 2 and Table 3, intergroup comparisons included IT, GV and PS values (Figure 5). The IT of Type A (5.3 Ncm) was significantly (p = 0.038) 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 ($p = 0.868$). The GV of Type A (9.7 mm^3) was significant ($p < 0.01$) greater than Type C (8.4 mm^3). Type C was significant ($p < 0.01$) greater than Type B (7.2 mm^3). The PS / IT ratio (Figure 6) was in order: Type A (38) > Type B (24.5) > Type C (20.5). The PS / GV ratio (Figure 6) was in order: Type B (26.5) > Type A (24.1) > Type C (23).

Table 2 The insertion torque (N cm), pullout strength (N cm), gripping volume (mm^3) and relative ratios

Micro-implant	A		B		C	
	Mean	SD	Mean	SD	Mean	SD
IT	5.3	0.97	8.4	2.56	8.8	2.52
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
PS / IT	38.0	5.46	24.5	5.96	20.2	1.51
PS / GV	24.1	7.15	26.5	0.56	23.0	0.81
GV / IT	1.9	0.29	0.9	0.23	1.0	0.31

Insertion torque: IT; pullout strength: PS; gripping volume: GV

Table 3 Statistical significance of intergroup in the LSD post comparisons

Variables		*p* - value
Insertion torque	C > A	0.038*
Pullout strength	—	0.868
Gripping volume	A > C > B	< 0.01*

* : Significant; $p < 0.05$

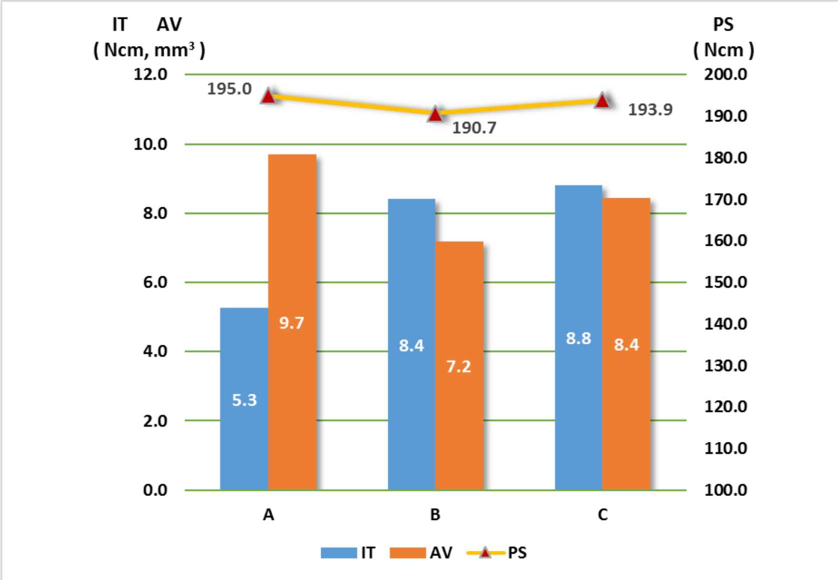

Figure 5. Insertion torque (IT), gripping volume (GV), and pullout strength (PS) of micro-implants. From left to right: Type A, B, and C.

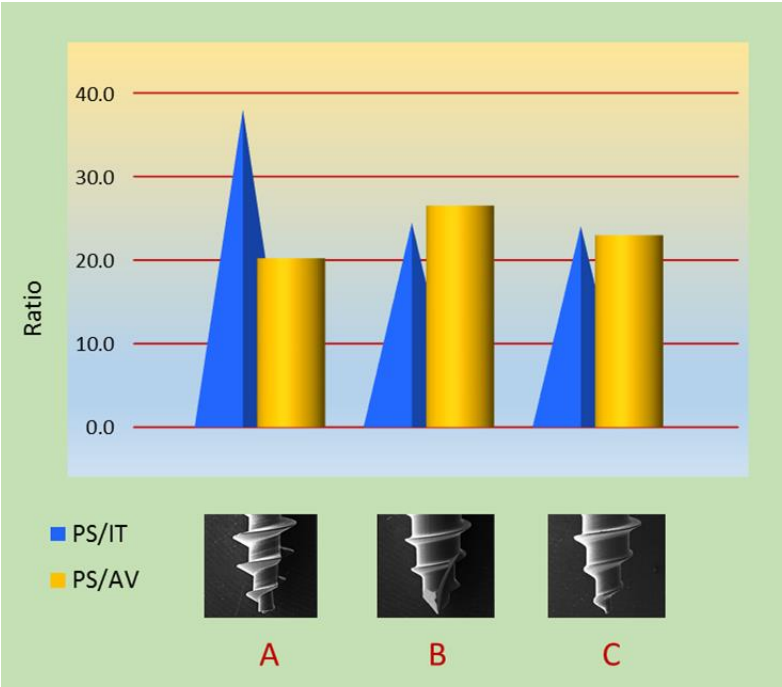

Figure 6. Threads in apical portions of microimplants were magnified using SEM analysis. From left to right: Types A, B, and C. The ratio of pullout strength (PS) / insertion torque (IT) and PS / gripping volume (GV)

In the Table 4, type B only 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. Therefore, the null hypothesis was accepted.

Table 4 Intragroup comparison by Spearman's rho rank correlation coefficient test

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

* Statistical significance was set at $p < 0.05$.

4. 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 he success rate of micro-implants. Alrbata et al. [15] investigated the biomechanical effect 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 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 (3.75 N, 4.1 N, 4.3 N, and 4.45 N) could be applied safely with the cortical bone thicknesses (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 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 (37^0). Therefore, Type A required the least effort during insertion, and had the lowest IT (5.26 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.

Is the material of orthodontic implant affected 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. Is the shape of orthodontic implant affected 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 significant 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 mm^3) > Type C (8.4 mm^3) > Type B (7.2 mm^3). 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 2 times effect GV than Type B and Type C.

Even 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 (23^0), which resulted in the smallest PS. In addition, because the three types 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 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.

Investigating PS / IT ratio, Type A had the greatest ratio (38) and Type B (24.5) was similar to Type C (20.2). It means that Type A was least IT and got 1.6 times relative effect PS than Type B and Type C. Is the material and shape of orthodontic implant affected 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. Therefore, there is no correlation among the mechanical forces of individual types and the null hypothesis was accepted.

5. Conclusion

The design of thread and its GV were the important factors on the mechanical strengths of micro-implant.

Author Contributions: Tseng Y.C. and Chen C.M. contributed to the design of the study, the collection and analysis of data and drafted the manuscript. Hsu KJ. and Tseng Y.C. performed the experiments. Hsu K.J. and Hsiao SY. performed analysis and interpretation of data. Tseng Y.C., Hsiao S.Y. and Chen C.M. provided critical revision. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kanomi R. Mini-implant for orthodontic anchorage. *J. Clin. Orthod.* **1997**, *31*,763-767.

2. Park, H.S. The skeletal cortical anchorage using titanium microscrew implants. *Kor. J. Orthod.*, **1999**, *29*, 699-706.

3. Tseng, Y.C.; Hsieh C.H.; Chen, C.H.; Shen, Y.S.; Huang, I.Y.; Chen, C.M. The application of mini-implants for orthodontic anchorage. *Int J Oral Maxillofac.* Surg. **2006**, *35*, 704-707.

4. Chen, Y.J.; Chang, H.H.; Lin, H.Y.; Lai, E.H.; Hung, H.C.; Yao, C.C. Stability of miniplates and miniscrews used for orthodontic anchorage: experience with 492 temporary anchorage devices. *Clin. Oral Implants. Res*. **2008**, *19*, 1188-1196.

5. Wu, T.Y.; Kuang, S.H.; Wu, C.H. Factors associated with the stability of mini-implants for orthodontic anchorage: a study of 414 samples in Taiwan. *J Oral Maxillofac Surg.* **2009**, *67*, 1595-1599.

6. Cheng, S.J.; Tseng, I.Y.; Lee, J.J.; Kok, S.H. 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.

7. Rodriguez, J.C.; Suarez, F.; Chan, H.L.; Padial-Molina, M.; Wang, H.L. Implants for orthodontic anchorage: success rates and reasons of failures. *Implant Dent.* **2014**, *23*, 155-161.

8. Meursinge Reynders, R.A.; Ronchi, L.; Ladu, L.; van Etten-Jamaludin, F.; Bipat, S. Insertion torque and success of orthodontic mini-implants: a systematic review. *Am. J. Orthod. Dentofacial Orthop.* **2012**, *142*, 596-614.

9. Wilmes, B., Drescher, D. Impact of bone quality, implant type, and implantation site preparation on insertion torques of mini-implants used for orthodontic anchorage. *Int. J. Oral Maxillofac. Surg.* 2011, *40*, 697-703.

10. Pithon, M.M.; Nojima, M.G.; Nojima, L.I. In vitro evaluation of insertion and removal torques of orthodontic mini-implants. *Int. J. Oral Maxillofac. Surg.* **2011**, *40*, 80-85

11. Okazaki, J,; Komasa, Y.; Sakai, D.; Kamada, A.; Ikeo, T.; Toda, I.; Suwa, F.; Inoue, M.; Etoh, T. A torque removal study on the primary stability of orthodontic titanium screw mini-implants in the cortical bone of dog femurs. *Int. J. Oral Maxillofac. Surg.* **2008**, *37*, 647-650.

12. Meira, T.M.; Tanaka, M.; Ronsani, M.M.; Maruo, I.T.; Guariza-Filho, O.;

Camargo, E.S.; Maruo, H. Insertion torque, pull-out strength and cortical bone thickness in contact with orthodontic mini-implants at different insertion angles. *Eur. J. Orthod.* **2013**, *35*, 766-771.

13. Chen, C.M.; Wu, J.H.; Lu, P.C.; Wang, H.C.; Lee, H.E.; Wang, C.H.; Du, J.K. Horizontal pull-out strength of orthodontic infrazygomatic mini-implant: an in vitro study. *Implant Dent.* **2011**, 20, 139-145.
14. Motoyoshi, M.; Inaba, M.; Ono, A.; Ueno, S.; Shimizu, N. The effect of cortical bone thickness on the stability of orthodontic mini-implants and on the stress distribution in surrounding bone. *Int. J. Oral Maxillofac. Surg.* **2009**, *38*, 13-18.
15. Alrbata, R.H.; Yu, W.; Kyung, H.M. Biomechanical effectiveness of cortical bone thickness on orthodontic micro-implant stability: an evaluation based on the load share between cortical and cancellous bone. *Am. J. Orthod. Dentofacial Orthop.* **2014**, *146*, 175-182.
16. Alrbata, R.H.; Momani, M.Q.; Al-Tarawneh, A.M.; Ihyasat, A. Optimal force magnitude loaded to orthodontic micro-implants: A finite element analysis. *Angle Orthod.* **2016**, *86*, 221-226.
17. Brown, R.N.; Sexton, B.E.; Gabriel Chu, T.M.; Katona, T.R.; Stewart, K.T.; Kyung, H.M.; Liu, S.S. Comparison of stainless steel and titanium alloy

orthodontic miniscrew implants: a mechanical and histologic analysis. *Am J Orthod Dentofacial Orthop*. **2014**, 145, 496-504.

18. Yoo, S.H.; Park, Y.C.; Hwang, C.J.; Kim, J.Y.; Choi, E.H.; Cha, J.Y. A comparison of tapered and cylindrical miniscrew stability. *Eur J Orthod.* **2014**, 36, 557-562.