Original Article

Effects of cortical bone thickness at different healing times on microscrew stability

Xing Wei^a; Lixing Zhao^b; Zhenrui Xu^a; Tian Tang^b; Zhihe Zhao^c

ABSTRACT

Objective: To compare the effects of different cortical bone thicknesses on the stability of microscrews at different healing times.

Materials: Sixty-four microscrews were inserted into the femurs of eight beagles, with four microscrews for one femur of one beagle dog. The dogs were sacrificed at 0, 3, 6, and 9 weeks after microscrew placement, respectively. All specimens were prepared for pullout testing. Cortical bone thickness was measured. Statistical analyses were conducted with analysis of variance (ANOVA) and Student-Neuman-Keuls (SNK) tests.

Results: Pullout forces in thick cortical bone sites are significantly higher than those in thin sites at 0 week and 3 weeks. For both thick and thin cortical bone thickness sites, the highest pullout forces were seen in the 0 week group and the lowest in the 3 week group. In the thin cortical bone thickness sites, the pullout force of the 3 week group was statistically different from those of the 6 week group and the 9 week group; however, no such differences were noted in thick cortical bone thickness sites.

Conclusion: Microscrews inserted into thick cortical bone thickness sites had better stability than those inserted into thin cortical bone thickness sites at early healing time. The difference diminished and became insignificant as healing time got longer. Longer healing time may be necessary if microscrews are inserted into thin cortical bone thickness sites. (*Angle Orthod.* 2011;81:760–766.)

KEY WORDS: Microscrews; Stability; Cortical bone thickness; Healing time

INTRODUCTION

Anchorage may be the most important factor that influences the plan and the result of orthodontic treatment without exaggeration. Teeth can be moved in an appropriate way if anchorage is strong enough to

^b Instructor, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Stomatological Hospital, Sichuan University, Sichuan, PR China.

° Professor and Chair, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Stomatological Hospital, Sichuan University, Sichuan, PR China.

Corresponding author: Dr Zhihe Zhao, Professor and Chair, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Stomatological Hospital, Sichuan University, #14, 3rd section of Renmin South Road, Chengdu 610041, PR China

(e-mail: zhaozhihe1963@yahoo.com.cn)

Accepted: February 2011. Submitted: November 2010.

resist orthodontic force. Various methods can be used to control anchorage in clinical practice. Recently, microscrews (MI) providing absolute anchorage have attracted the attention of orthodontists.^{1–3} Microscrews performed better than traditional appliances because of their versatility of placement, ease of removal, and lower cost.⁴ Although microscrews bring many advantages to orthodontists, they sometimes loosen during orthodontic treatment.^{5,6}

The stability of microscrews may be associated with many factors.^{7–10} However, many studies adhere to the generally accepted protocol that the stability of microscrews has a close relationship to the quality and quantity of cortical bone, the design of the microscrew, and the degree of peri-implant tissue inflammation and applied load^{11–13}; the firmness of cortical bone is generally thought to be a principal factor controlling the stability of microscrews.^{14,15} Miyawaki et al.¹⁶ stated that a high mandibular plane angle with thin cortical bone was associated with failure of the screws. Moreover, many studies have investigated cortical bone thickness (CBT) and the relationship between it and the success rate of microscrews placed with

^a PhD student-graduate, State Key Laboratory of Oral Diseases, Department of Orthodontics, West China Stomatological Hospital, Sichuan University, Sichuan, PR China.

Published Online: May 2, 2011

 $^{{\}scriptstyle \circledcirc}$ 2011 by The EH Angle Education and Research Foundation, Inc.

different CBT; many results imply that thick CBT increases implant stability.^{17–19} Salmória²⁰ has found that pullout strength is greater immediately after placement of MI, and cortical bone thickness decreases because of bone resorption. Also, a regular correlation has been observed between pullout strength and periimplant cortical bone thickness at the time immediately after placement of MI (r = 0.44). However, this study did not compare the effects of different initial CBTs on pullout force (POF) of microscrews. Stahl²¹ found highest loads in the bone in all models when cortical thickness measured 1 mm but not 2 mm and with a Young's modulus of cancellous bone of 100 MPa. Therefore, no conclusion has yet been reached about the relationship between CBT and POF.

The pullout test is the method used most often in orthopedics and oral and maxillofacial surgery when the biomechanical performance of microscrews placed into bone is evaluated.^{22,23} Although many studies have reported a close relationship between CBT and the stability of microscrews, few studies have focused on the stability of microscrews with different CBT at different healing times, and no determinate result can be found in the literature about the ideal healing time that should be allowed.^{24–26} Therefore the purposes of this study were to record the pullout strengths of microscrews placed at various locations in the femurs, where CBT increased gradually for beagles at different healing times.

MATERIALS AND METHODS

Sixty-four microscrews (6 mm height, 1.6 mm diameter, Aarhus screw system, Medicon Company, Tuttlingen, Germany) were placed in eight skeletally mature beagles (aged 24 months, weight 12.5 kg on average). They were supplied by the Experimental Animal Center of Sichuan University as left from an unrelated study. This study was approved by the Bioethics Committee of Sichuan University, China. Veterinary records indicated that the dogs were healthy. Using a computer-generated randomization method, eight beagles were divided into four groups (T0, T3, T6, and T9 groups). They were sacrificed at 0 week (T0), 3 weeks (T3), 6 weeks (T6), and 9 weeks (T9), respectively, after microscrew placement. In every group, implants were inserted at two different CBT sites that included thick cortical bone sites and thin cortical bone sites (Figure 1).

All surgical procedures were done with systemic anesthesia (1 mg/kg ketamine and 2 mg/kg intramuscular xylazine; North China Pharmaceutical Company, Hong Kong, China) and local anesthesia (2% lidocaine with 1:80,000 epinephrine). We inserted four microscrews into the mesial and distal metaphyses of one



Figure 1. Illustration for experiment design.

femur of one beagle dog, with the surface of the experimental site exposed by blunt dissection; therefore, each beagle received eight microscrews. This means that two microscrews were implanted at one end of the metaphysis (Figure 2), with CBT gradually increasing from the end to the center of the femur.

Then we used a guide drill to locate the microscrew insertion sites and made sure that the microscrews had been inserted perpendicular to the cortical bone surface of the femurs. Microscrews were placed manually with a screwdriver until the beginning of the cylindrical part reached the surface of the femur. Monocortical anchorages were intended. Microscrews were not loaded throughout the experiment.

After the beagles had been killed, their femurs were surgically removed, dissected, and sectioned into small blocks with a band saw. Each microscrew was surrounded by approximately 4 mm of bone tissue without soft tissue (Figure 3).

Given that the CBT of femurs was continuous (Figure 4), CBT around the microscrews can be calculated as the mean value of the two ends of bone blocks. Because of obvious borders between cortical bone and cancellous bone, we can measure CBT of the distal and mesial ends at the upper side of every bone block with Vernier calipers.

The bone blocks were frozen in saline-soaked gauze at -15° C until testing. On the day of testing, specimens were thawed to room temperature. Then the bone specimens were embedded in polymethylmethacrylate (PMMA; Dental Products, Heraeus, Germany), vertical to the longitudinal axis of the microscrews, and microscrews had to be aligned with the axis of the testing machine to prevent a bending moment during the test; axial pullout strengths were recorded correctly without disturbance. The testing machine could tightly clamp the block and pull the head of the microscrews by using a grip with the microscrew heads exposed. All acrylic resin blocks were made in the same shape and size.



Figure 2. Two microscrews were implanted at one end of the metaphysis of a femur, 2 cm and 4 cm away from the metaphyses, respectively.

The axial pullout test was carried out with a Materials Test Systems (Instron 5565, Instron Corporation, Norwood, Mass) (Figure 5), and a crosshead speed of 0.05 mm per second was applied. The applied load was monitored, and the POF was obtained from the data file.

Normal data distribution and homogeneity of group variances of POF were tested before analysis with a repeated measures analysis of variance (ANOVA); this detected statistically significant differences (P < .05) among time periods with the use of SigmaStat software (Statistical Package for the Social Sciences [SPSS] Inc., Chicago, III). Variables with statistically significant differences were submitted for multiple



Figure 3. Every bone block, measuring approximately 4 mm, without soft tissue, contained one microscrew, respectively.

comparisons using the Student-Newman-Keuls (SNK) method (P < .05).

RESULTS

The success rate of microscrews was 100% for all groups, and the microscrews did not loosen throughout the study. The results of pullout tests on 64 specimens were completely recorded. Because all prepared specimens were tested in groups and all microscrews from the same group were tested on the same day, an unexpected disturbance could be excluded to some extent. Means and standard deviations for POF and CBT are shown in Table 1 and Figure 6. Results of comparisons are provided in Table 2. These data had normal data distribution and homogeneity of group variances, thus ANOVA was suitable for analyzing them.

Results showed that the T0 group had the highest POF, and T3 had the lowest. Then, the POF for T6 and T9 groups increased gradually. In the T0 and T3 groups, the POF for different CBT sites showed significant differences. However, for T6 and T9 groups, POF showed no such statistical differences. In thin or thick CBT sites, the POF demonstrated a statistically significant difference between T0 and T3 groups. The POF for the T3 group indicated significant differences compared with T6 and T9 groups in thin CBT sites, but not in thick CBT sites.

DISCUSSION

To assess the biomechanical influence of CBT, we used the pullout test. The POF is the result of bone



Figure 4. The cortical bone thickness of femurs was continuous, increasing gradually from the end to the middle part.

failure¹⁰ and reflects the magnitude of POF that the microscrew will bear before bone rupture.²⁷

In this study, we chose femurs as placement sites for microscrews because the shape of the femurs was



Figure 5. The pullout test for a specimen with Materials Test Systems.

regular, and CBT increased gradually from metaphases to the middle part of the femurs; boundaries between cortical and cancellous bone were very clear. Thus we can measure and calculate the CBT very precisely and conveniently without the use of complex equipment. Second, microscrews in femurs will not be affected by bad oral hygiene or eating. Third, microscrews inserted into the femurs will not be approximate to roots of teeth or inserted into some dangerous zones such as the maxillary sinus. Finally, we chose the insert location close to the metaphases, but far from the middle parts of the femurs, which contacted too much bone marrow and might be harmful to the initial stability of microscrews. On the contrary, placing microscrews in jaws leads to greater risk of failure because of increased occurrence of peri-implant inflammation or damage to dental roots.28 Based on these reasons, we chose femurs as our experimental sites to test the effects of CBT.

Roberts²⁹ compared the bone repair time of dogs, rabbits, and humans, dividing the healing time into four periods that were respectively called acceleration, active resorption, latency, and bone formation phase. As for the dogs, in the first days of microscrew insertion, osteoclasts began to be active, and cortical bone was about to absorb. Then the osteoclasts became more active and resorption of cortical bone was accelerating; this would last for about 2 to 3 weeks. After this, bone resorption got to the latency phase gradually. After 6 weeks of microscrew placement, osteoblasts were more activated than osteoclasts, and osteoid matrix formed, beginning a new phase called bone neoformation. Finally, at 9 weeks, bone formation and filling were mostly completed. Based on these

Healing Time	Site	CBT Mean \pm SD, mm	POF Mean \pm SD, N	P Value
0 week	Thin CBT Thick CBT	1.74 ± 0.56 2.62 ± 0.47	310.21 ± 59.63 370.59 ± 32.56	< .05
3 weeks	Thin CBT Thick CBT	1.75 ± 0.44 2.65 ± 0.39	226.11 ± 45.63 293.18 ± 75.36	< .05
6 weeks	Thin CBT Thick CBT	1.69 ± 0.51 2.61 ± 0.29	289.85 ± 49.78 328.96 ± 39.21	> .05
9 weeks	Thin CBT Thick CBT	1.76 ± 0.35 2.69 ± 0.59	$\begin{array}{r} 296.32 \pm 47.25 \\ 331.68 \pm 65.21 \end{array}$	> .05

 Table 1.
 CBT and POF in Each Group of Samples

parameters, the time periods chosen for this study were 0, 3, 6, and 9 weeks after microscrew placement. T0 was elected for ascertaining the primary stability of the microscrews. T3 represented the beginning of the latency phase of the bone remodeling cycle, and T6 corresponded to the osteoid matrix deposit phase in dogs. T9 connected with the final bone formation phase.

At T0, peripheral microscrew thread portions were in intimate contact with surrounding bone (mechanical engagement), ensuring the primary stability that accounted for the POF. Owing to solid mechanical engagement, the POF at T0 was very high. Decreased POF at T3 can be associated with the previously mentioned healing circle of bone. Between T0 and T3, the bone repair cycle seen in the dogs was at accelerating and resorption phases. Therefore, osteoclastic bone resorption had already occurred, whereas at T6, bone formation was proceeding with the osteoid matrix deposit, beginning a new phase called bone neoformation. This may explain why at T3 both thin and thick CBT sites had the lowest POF and at T6 the POF increased. As healing time goes by, at about 9 to 10 weeks, increasing amounts of bone are formed and a resorption cavity becomes filled with bone; thus the POF continues to be higher.

At T0 and T3, significant differences were noted between thin and thick CBT sites, and thick CBT sites had a higher POF. We may infer that at T0, microscrews had intimate contact with surrounding bone





through mechanical engagement, but not osseointegration. Cortical bone can supply a more intimate contact than cancellous bone because of its denser bone quality. Therefore, thick CBT sites had a higher POF. At T3, the POF was statistically significantly different between thin and thick CBT. Berglundh³⁰ supposed that the stability of microscrews was decided by mechanical extrusion in the first phases, and then instead of biological attachment, gradually. As we mentioned previously, after about 3 weeks, bone resorption got to a latency phase and osteoclasts were replaced by osteoblasts. Thus before 3 weeks, the stability of microscrews may be dominated mainly by mechanical extrusion; therefore, a significant difference was noted between thin and thick CBT sites at T3. We recommend that longer healing time may be necessary if microscrews are inserted into thin cortical bone thickness sites.

At T6 and T9, no significant differences were seen between thin and thick CBT sites. We consider that with longer healing time, more osseointegration occurs and biological attachment becomes increasingly important. On the one hand, it is demonstrated that bone remodeling changes as healing time goes by. On the other, as bone remodeling and osseointegration proceed, both thin and thick CBT sites can get good biological attachment, and significant differences between the two diminish. Thus we may infer that at thin CBT sites, longer healing time is necessary.

Our results show that thicker CBT had a higher POF—a finding that is consistent with those of other studies. $^{\rm 14,19}$

Salmória et al.²⁰ demonstrated significantly greater strength at 0 days compared with after 15 days and 60 days. Investigators reported decreased POF at 15 days and 60 days as healing phases of bone and peri-implant inflammation were caused by dental plaque accumulation. In our study, POF at T0 was also highest, but at T6 and T9, POF gradually increased. This may be associated with the different insertion sites. As we inserted microscrews into the femurs of dogs, not into the jaws, less peri-implant inflammation was noted without dental plaque. Therefore, the phase of bone absorption may be shorter.

Table 2.	Summary of the	SNK Test for	Comparison of	of POF in Each	Group of Samples
----------	----------------	--------------	---------------	----------------	------------------

Healing Time	CBT	0 Week		3 Weeks		6 Weeks		9 Weeks	
		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
0 week	Thin		*	*					
	Thick	*		*	*	*		*	
3 weeks	Thin	*	*		*	*	*	*	*
	Thick		*	*					
6 weeks	Thin		*	*					
	Thick			*					
9 weeks	Thin		*	*					
	Thick			*					

* *P* < .05.

Because the force necessary for tooth movement in orthodontics varies from 0.3 to 4 N,³¹ which is much lower than the POF found in this study at T0, T3, T6, T9, we believe that microscrews can be loaded at any of these phases. One study suggests that microscrews tested in the axial mode have 34% higher POF than the same microscrews tested in the tangential (cantilever) mode.³² Correcting our results downward by 34% still showed enough strength to bear an orthodontic force. Therefore, to achieve more reliable parameters, we suggest that future studies should examine qualitatively bone tissue at sites of microscrew placement, and that investigators should apply loads to the microscrews at different times.

CONCLUSIONS

- The value of pullout force in thick CBT sites is significantly greater than that in thin CBT sites at T0 and T3, but not at T6 and T9.
- For thick CBT sites and thin CBT sites, the value of the POF is highest in the T0 group and lowest in the T3 group. Then, with prolongation of healing time, the stability of microscrews increases gradually.
- Microscrews inserted into thick CBT sites have stronger stability than those inserted into thin CBT sites at early healing time. However, differences diminish and become insignificant with longer healing time.

ACKNOWLEDGMENT

This work was supported by a grant from the National Nature Science Foundation of China (30470436).

REFERENCES

- 1. Park HS. Orthodontic Treatment Using Micro-implants: The Clinical Application of MIA (Micro-Implant Anchorage). Seoul, Korea: Narae Publishing; 2001.
- 2. Ohnishi H, Yagi T, Yasuda Y, Takada K. A mini-implant for orthodontic anchorage in a deep overbite case. *Angle Orthod*. 2005;75:444–452.

- Takano-Yamamoto T, Miyawaki S, Koyama I. Can implant orthodontics change the conventional orthodontic treatment? *Dental Diamond*. 2002;27:26–47.
- Kanomi R, Takada K. Application of titanium mini-implant system for orthodontic anchorage. In: Mah J, Davidovitch Z, eds. *Biological Mechanisms of Tooth Movement and Craniofacial Adaptation*. Birmingham, Ala: EBSCO Media; 2000:253–258.
- Costa A, Raffaini M, Melsen B. Mini-screws as orthodontic anchorage: a preliminary report. *Int J Adult Orthod Orthognath Surg.* 1998;13:201–209.
- Sawa Y, Goto K, Suzuki N, Kamo N, Kamo K. The new method for the maxillary retraction of the anterior teeth using a titanium microscrew as anchorage. *Orthod Waves*. 2001; 60:328–331.
- Wang Z, Zhao Z, Xue J, et al. Pullout strength of miniscrews placed in anterior mandibles of adult and adolescent dogs: a microcomputed tomographic analysis. *Am J Orthod Dentofacial Orthop.* 2010;137:100–107.
- Zhang L, Zhao Z, Lia Y. Osseointegration of orthodontic micro-screws after immediate and early loading. *Angle Orthod.* 2010;80:354–360.
- Baek S-H, Kim B-M, Kyung S-H, et al. Success rate and risk factors associated with mini-implants reinstalled in the maxilla. *Angle Orthod*. 2008;78:895–901.
- Kim J-W, Baek S-H, Kim T-W, Chang Y-I. Comparison of stability between cylindrical and conical type mini-implants. *Angle Orthod.* 2008;78:692–698.
- Holmgren EP, Seckinger RJ, Kilgren LM, Mante F. Evaluating parameters of osseointegrated dental implants using finite element analysis—a two-dimensional comparative study examining the effects of implant diameter, implant shape, and load direction. J Oral Implantol. 1998;24:80–88.
- 12. Motoyoshi M, Yoshida T, Ono A, Shi-Mizu N. Effect of cortical bone thickness and implant placement torque on stability of orthodontic mini-implant. *Int J Oral Maxillofac Implants.* 2007;22:779–784.
- 13. Mesa F, Munoz R, Noguerol B, et al. Multivariate study of factors influencing primary dental implant stability. *Clin Oral Implants Res.* 2008;19:196–200.
- 14. Huja SS, Litsky AS, Beck FM, Johnson KA, Larsen PE. Pullout strength of monocortical screws placed in the maxillae and mandibles of dogs. *Am J Orthod Dentofac Orthop.* 2005;127:307–313.
- 15. Motoyoshi M, Hirabayashi M, Uemura M, Shimizu N. Recommended placement torque when tightening an orthodontic mini-implant. *Clin Oral Implants Res.* 2006;17: 109–114.

- 16. Miyawaki S, Koyama I, Inoue M, et al. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. *Am J Orthod Dentofacial Orthop.* 2003;124:373–378.
- Ono A, Motoyoshi M, Shimizu N. Cortical bone thickness in the buccal posterior region for orthodontic mini-implants. *Int J Oral Maxillofac Surg.* 2008;37:334–340.
- Miyamoto I, Tsuboi Y, Wada E, et al. Influence of cortical bone thickness and implant length on implant stability at the time of surgery—clinical, prospective, biomechanical, and imaging study. *Bone.* 2005;37:776–780.
- 19. Motoyoshi M, Inaba M, Ono A, et al. 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.
- Salmória KK, Tanaka OM, Filho OG, et al. Insertional torque and axial pull-out strength of mini-implants in mandibles of dogs. *Am J Orthod Dentofacial Orthop.* 2008;133: 790.e15–e22.
- Stahl E, Keilig L, Abdelgader I, et al. Numerical analyses of biomechanical behavior of various orthodontic anchorage implants. *J Orofac Orthop.* 2009;70:115–127.
- 22. Inceoglu S, Ferrara L, McLain RF. Pedicle screw fixation strength: pullout versus insertional torque. *Spine J.* 2004;4: 513–518.
- Struckhoff JA, Huja SS, Beck FM, Litsky AS. Pull-out strength of monocortical screws at 6 weeks postinsertion [thesis abstract]. *Am J Orthod Dentofacial Orthop.* 2006; 129:82–83.

- 24. Ohashi E, Pecho OE, Moron M, Lagravere MO. Implant vs. screw loading protocols in orthodontics: a systematic review. *Angle Orthod*. 2006;76:721–727.
- 25. Chen Y, Kyung HM, Zhao WT, et al. Critical factors for the success of orthodontic mini-implants: a systematic review. *Am J Orthod Dentofacial Orthop.* 2009;135:284–291.
- Huang LH, Shotwell JL, Wang HL. Dental implants for orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2005;127:713–722.
- 27. McLain RF, Fry MF, Sharkey NA. Lumbar pedicle screw salvage: pullout testing of three different pedicle screw designs. *J Spinal Disord.* 1995;8:62–68.
- Kang Y-G, Kim J-Y, Lee Y-J, Chung K-R, Park Y-G. Stability of mini-screws invading the dental roots and their impact on the paradental tissues in beagles. *Angle Orthod.* 2009;79: 248–255.
- 29. Roberts WE, Turley PK, Brezniak N, et al. Bone physiology and metabolism. *J Calif Dent Assoc.* 1987;15:54–61.
- Berglundh T, Abrahamsson I, Lang NP, et al. De novo alveolar bone formation adjacent to endosseous implant. *Clin Oral Implants Res.* 2003;14:251–262.
- 31. Ren Y, Maltha JC, Kuijpers-Jagtman AM. Optimum force magnitude for orthodontic tooth movement: a systematic literature review. *Angle Orthod*. 2003;73:86–92.
- 32. Pierce WA, Sucato DJ, Young S, Picetti G, Morgan DM. Axial and tangential pullout strength of uni-cortical and bicortical anterior instrumentation screws. Proceedings of the 49th Annual Meeting of the Orthopaedic Research Society; February 2–5, 2003; New Orleans, La.