European Journal of Orthodontics 34 (2012) 52–56
doi:10.1093/ejo/cjq157
Advance Access Publication 10 March 2011

Orthodontic mini-implant stability and the ratio of pilot hole implant diameter

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SUMMARY One notable complication of mini-implants that are used to provide anchorage in orthodontic treatment is loosening. The aim of this study was to evaluate the relationship between mini-implant mobility during the healing phase and the prognosis for implant stability.

Twenty male Wistar rats (aged 20 weeks) were used. Drills with diameters of 0.8, 0.9, 1.0, and 1.1 mm were used to make pilot holes in the rat tibiae. The inserted mini-implants (diameter 1.4 mm; spearhead 1.2 mm; halfway between maximum and minimum 1.3 mm; length 4.0 mm) were subjected to an experimental traction of force for 3 weeks. Bone-to-implant contact (BIC) was observed histologically. Another 20 male rats (aged 20 weeks) underwent an identical procedure, and the stability of the mini-implants was measured using the Periotest before and after traction. The data were statistically analysed using Scheffé's test.

The BIC ratios of the 0.9 and 1.0 mm groups were significantly greater than those of the other groups. The Periotest values measured 3 weeks after implant insertion were significantly lower ($P < 0.05$) than those measured at insertion, except in the 1.1 mm group. To obtain mini-implant stability, the hole diameter should be between 69 and 77 per cent of the diameter of the mini-implant. A significant decrease in the mobility of the mini-implants 3 weeks post-insertion implies a good prognosis for the subsequent mini-implant stability.

Introduction

Mini-implants are used to provide anchorage in orthodontic treatment (Tseng *et al.*, 2006). Because they are small and cause less trauma, they can be used in a variety of host sites and can be subjected to traction soon after placement. One notable complication is loosening of the mini-implant.

Miyawaki *et al.* (2003) used three types of titanium mini-implants with different diameters and lengths as anchors for orthodontic tooth movement and reported that with a diameter of 1.0 mm or less, inflammation of the peri-implant tissue and a high mandibular plane angle, which often exist with thin cortical bone, were associated with mobility of the mini-implant. To obtain stable mini-implants, favourable bone-to-implant contact (BIC) is important. Ikeda (2005) stated that the initial stability of mini-implants is related to cohesion between bone and implant and reported that a hole diameter that was 80 per cent of the implant diameter (diameter 1.4 mm; spearhead 1.2 mm; halfway between maximum and minimum 1.3 mm) afforded the best initial implant stability using a test that involved drawing implants from pig ribs. That author also found mechanical effects on the initial stability of the mini-implants, but the biological response during traction was not examined.

Akimoto *et al.* (1999) placed dental implants in simulated extraction sockets with varying gaps between the bone and dental implant in dogs and evaluated the effect of gap width on bone healing around the implants. They reported that when the implants were placed in wide defects with large gaps, initial stability was compromised. Conversely, Yano *et al.* (2006) found that when mini-implants were fixed rigidly to bone, both initial and delayed stability after loading were acquired. In addition, Wijaya *et al.* (2004) found that one of the parameters affecting the success of implantation was implant mobility, and decreased mobility resulted in more stable implants. These studies suggest that close contact at the bone-to-implant interface and less implant mobility at the time of placement are important for obtaining maximum stability after healing and that BIC and implant mobility are fundamental criteria for evaluating the stability of mini-implants.

Based on clinical studies, Motoyoshi *et al.* (2006, 2007) concluded that the cortical bone thickness in the vicinity of the implant should be 1.0 mm or greater and an adequate implant placement torque should be within the range of 5–10 Ncm when mini-implants are placed in the posterior alveolar bone.

However, a more objective evaluation method would be to improve success and to provide an accurate prognosis for mini-implants. Given this background, this study investigated which bone hole and mini-implant diameters resulted in stable mini-implants under traction, and evaluated the relationship between mini-implant stability and mobility morphometrically and mechanically in rat tibiae in an attempt to determine the prognosis for mini-implants.

Materials and methods

This study was approved by the Animal Experimentation Committee of Nihon University School of Dentistry.

Morphometric measurements

Twenty male Wistar rats (aged 20 weeks; body weight 500 ± 20 g) were used and 40 mini-implants (diameter 1.4 mm; spearhead 1.2 mm; halfway between maximum and minimum 1.3 mm; length 4.0 mm: Figure 1) were placed in the rat tibiae.

After anaesthesia with an intra-peritoneal injection of sodium pentobarbital (100 mg/kg body weight, Nembutal; Dainippon Pharmaceutical, Osaka, Japan), an incision was made along the tibial crest, and the surface of the tibia was exposed, as described by Yano *et al.* (2006). A hole was then drilled with a bone drill 5.0 mm inferior to the knee joint perpendicular to the medial surface of the tibia under physiological saline flow. Drills with a length of 4.0 mm and diameters of 0.8, 0.9, 1.0, and 1.1 mm (Dentsply-Sankin, Tokyo, Japan) were used to make a pilot hole in five rats. A mini-implant was inserted into each hole using a hand driver and a traction force of 2 N was applied using a NiTi coil spring and fine stainless steel wires (Figure 2). The mini-implants in the right tibiae were subject to traction for 3 weeks, whereas those in the left tibiae were used as controls without traction. To prevent post-operative infection, tetracycline hydrochloride paste (Showa Yakuhin Kako, Tokyo, Japan) was applied to the surgical site.

After 3 weeks, the rats were killed with pentobarbital, the tibiae were resected at the knee joint, fixed in 10 per cent neutral buffered formalin (Wako Pure Chemical Industries, Osaka, Japan) for 48 hours and then washed in clear water with ethanol dehydration and acetone degreasing. The tibiae were embedded in polyester resin (Rigolac 2004; Showa Highpolymer, Tokyo, Japan) at a constant temperature of 60°C for 8 hours, and the resulting 10.0 × 10.0 × 6.0 mm blocks were cut in the mesiodistal direction using a crystal cutter (Maruto Instrument Co., Ltd, Tokyo, Japan) at the centre of the bone including the long axis of the mini-implant. The surface of the specimen was ground with waterproof 800, 1200, and 2000 grinding papers and a hard grinding cloth with a liquid containing 1 m of diamond particles.

The BIC surrounding the cortical bone was observed using field-emission scanning electron microscopy (FE-SEM; S-4300 type; Hitachi Science Systems, Ibaraki, Japan) after osmium coating (HPC-1S type osmium coater; Shinkuu Device, Ibaraki, Japan), and photographs were taken at ×25 magnification. After tracing the photographs, the BIC ratio was calculated as the length of BIC at the cortical bone divided by the mini-implant surface at the cortical bone ×100 (Figure 3).

One examiner (MU) traced and measured all the photographs to eliminate inter-examiner error. All the tracings and measurements were performed twice, 1 month apart, to reduce intra-examiner errors. When a difference greater than 5 per cent between the mean values of the BIC ratio occurred, the measurements were repeated and the mean value of the measurements was used. Scheffé's test was used to compare the BIC ratio in each group using the Statistical Package for Social Sciences version 8.0 for Windows (SPSS, Chicago, Illinois, USA).

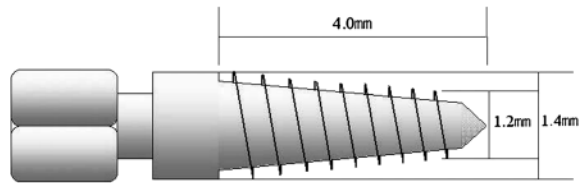

Figure 1 The mini-implant used in this study.

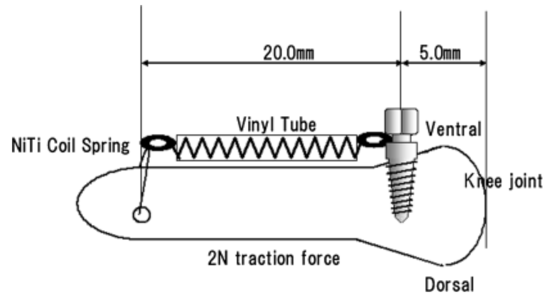

Figure 2 Insertion of the mini-implants and traction.

Mobility measurement

A further 20 male Wistar rats (aged 20 weeks; body weight 500 ± 20 g) were prepared. The initial experimental method was the same. After the mini-implants were inserted into the different sized holes using a hand driver, the mobility of all the mini-implants was measured at T1 using the Periotest (Siemens AG, Bensheim, Germany). In accordance with the manufacturer's instructions, the measurement was performed by holding the Periotest handpiece parallel to the long axis of the tibia and the head of the mini-implant was struck with the tip of the handpiece from 2.0 to 3.0 mm from the mini-implant head. The measurement was repeated five times and the average the value at T1 was determined.

The mini-implants in the right tibiae were then subjected to 2 N traction using a NiTi coil spring for 3 weeks, while the mini-implants in the left tibiae were left as non-traction controls. After the experiment, the rats were killed with sodium pentobarbital and the NiTi coil springs were removed from the mini-implant (T2). The mobility of all the mini-implants was measured again using the Periotest. The measurement was repeated five times. All measurements were carried out by the same examiner (MU). Scheffé's test was used to compare the Periotest values (PTVs) in each group using the Statistical Package for Social Sciences version 8.0 for Windows.

Results

Figure 4A shows the FE-SEM images of the control holes from each group. For the 0.8 and 1.1 mm diameter groups, less bone contact with the mini-implant surface was evident than for the 0.9 and 1.0 mm groups, and some spaces between the mini-implant and cortical bone were observed (Figure 4A). The BIC ratio averaged 66.3 ± 5.0, 82.6 ± 6.0, 88.6 ± 5.3, and 27.9 ± 17.4 per cent in the 0.8, 0.9, 1.0, and

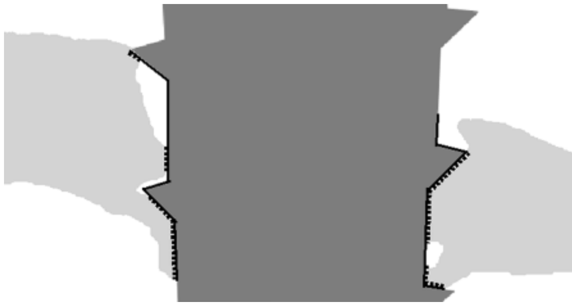

Figure 3 Method used to measure the bone–implant contact ratio. The bone-to-implant contact ratio equals the length of bone contact with cortical bone (dashed line) divided by the length of the mini-implant surface at the cortical bone ×100.

1.1 mm groups, respectively. The BIC ratio of the 1.1 mm group was significantly less than in the other groups and that of the 0.8 mm group was significantly less than that of the 1.0 mm group ($P < 0.05$; Figure 5).

Figure 4B shows the FE-SEM images of the traction holes for each group. The bone contact with the mini-implant surface was similar to that in the control groups, and some spaces between the mini-implant and cortical bone were observed in the 0.8 and 1.1 mm groups. The BIC ratio averaged 68.5 ± 4.0, 88.3 ± 2.4, 86.9 ± 5.3, and 25.0 ± 9.2 per cent in the 0.8, 0.9, 1.0, and 1.1 mm groups, respectively. The BIC ratio of the 1.1 mm group was significantly less than in the other groups ($P < 0.05$; Figure 5).

The PTVs for each hole at T1 are compared in Figure 6A. For each group, the PTVs were around 20. There was no significant difference in the PTVs among the diameters in the control and traction groups. Comparisons of the PTVs for each hole at T2 are shown in Figure 6B. For the control group, the PTV in the 1.1 mm group was significantly greater than that in the other groups ($P < 0.05$) and that of the 0.8 mm group was also significantly higher than for the 0.9 and 1.0 mm groups. In the traction group, similar results were found. The PTV in the 1.1 mm group was significantly higher than that in the other groups, and the value for the 0.8 mm group was also significantly higher than that of the 0.9 mm group ($P < 0.05$).

Table 1 shows the comparison of the PTVs at T1 and T2. The PTVs at T2 were significantly lower than at T1, except for the 1.1 mm group, in both the control and the traction groups.

The correlation coefficient of the BIC ratio and PTVs at T2 was then calculated. The correlation coefficient was −0.95 in the control group ($P < 0.01$), −0.93 in the traction group ($P < 0.01$), and −0.93 overall ($P < 0.01$).

Discussion

Currently, a great deal of research on mini-implants is being performed (Miyawaki *et al.*, 2003; Cheng *et al.*, 2004; Kim *et al.*, 2005; Motoyoshi *et al.*, 2006, 2007; Tseng *et al.*, 2006; Ono *et al.*, 2008). This has shown that the stability of

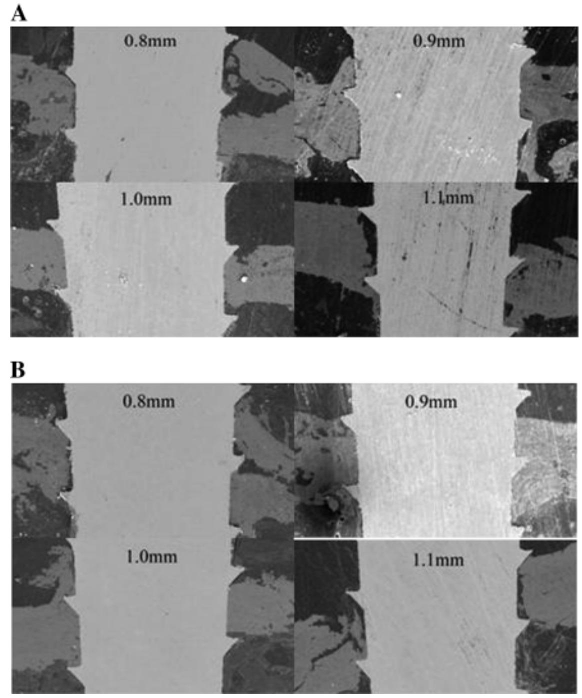

Figure 4 Field-emission scanning electron microscope images of (A) control and (B) traction groups. The black is the resin and white the cortical bone.

the implant is affected by mini-implant placement torque, cortical bone thickness in the implant area, diameter of the mini-implant, inflammation of the peri-implant tissue, and a high mandibular plane angle (Miyawaki *et al.*, 2003; Ono *et al.*, 2008). Nevertheless, no objective method is available for making a prognosis with regard to probable success after inserting a mini-implant. This study investigated the relationship between pilot hole and mini-implant diameters and estimated the success of mini-implants by measuring the change in mobility over time.

The principal finding of this study was that the PTV, which reflects the mobility of the mini-implant measured immediately after insertion, was largely independent of the size of the pilot hole. However, the PTV decreased significantly after 3 weeks in the groups with the correct size pilot hole. Conversely, the PTV did not decrease in the groups with incorrect size pilot hole. This may be important for estimating the outcome of mini-implant stability. It is desirable to have a quantitative method for establishing the stability of a mini-implant at the time of placement because no appropriate method for determining the prognosis of mini-implant stability exists (Dilek *et al.*, 2008).

In an investigation of dental implants, Olive and Aparicio (1990) stated that the quantitative and reproducible attributes of the Periotest method allow objective clinical follow-up of the stability of bone-implant anchorage, and the Periotest is an objective easy-to-apply method for judging successful integration of implants (Olive and Aparicio 1990; Nakago *et al.*, 1994; May *et al.*, 1998; Wijaya *et al.*, 2004).

In the present study, 3 weeks after inserting the mini-implants, the PTV was significantly reduced, with or without traction, except for the 1.1 mm diameter pilot holes. Therefore, a 1.1 mm diameter hole does not confer initial stability to facilitate rigid support when using 1.3 mm diameter mini-implants. With the 1.1 mm diameter holes, less bone support was observed around the mini-implant and many gaps were present between the bone and mini-implant, resulting in insufficient anchorage (Akin-Nergiz *et al.*, 1998). The improved PTV with the 0.8 mm hole group was lower than that for the 0.9 and 1.0 mm groups, reflecting the reduced BIC ratio. This might be related to the delayed healing caused by excessive stress or pressure on the bone by surrounding tissues during insertion when the hole is too small compared with the implant diameter (Sumikawa *et al.*, 2004). However, bone healing in the 0.8 mm group might simply require more time compared with that for the 0.9 and 1.0 mm groups to obtain similar stability.

The PTVs at T2 in the 0.9 and 1.0 mm hole groups were 4.6–6.4 in both the control and the traction groups, whereas they were 11.4–12.2 in the 0.8 mm group and 19.8–21.4 in the 1.1 mm group. Mini-implants with a diameter of 1.3 mm were more stable in the 0.9 and 1.0 mm holes than in the 0.8 and 1.1 mm holes and were able to provide rigid support. Therefore, 1.3 mm diameter mini-implants inserted in 0.9 and 1.0 mm holes have reduced mobility, and this is highly recommended for mini-implant stability. Comparing the PTVs at T1 and T2, the values fell by more than one-third in the 0.9 and 1.0 mm groups. This reflects a good prognosis for subsequent stability of the mini-implant. Although these findings cannot be directly applied to clinical applications because this was an animal experiment, measurement of mini-implant mobility 3 weeks after insertion may predict the subsequent stability of mini-implants.

Yano *et al.* (2006) found that the BIC ratio was 82.3 ± 15.0 per cent after immediate traction for 2 weeks with 1.2–1.4 mm diameter (halfway: 1.3 mm) mini-implants in 1.0 mm implant holes. The BIC ratio with 1.0 mm implant holes was greater in the present study. This could be due to the longer treatment period (3 versus 2 weeks), suggesting that the BIC ratio increases over time. It is generally considered that a sufficient healing period improves implant stability. However, because the mini-implant mobility in the 0.9 and 1.0 mm groups decreased significantly after 3 weeks, independent of immediate traction, correctly sized pilot holes are more important for stability than a sufficient healing period before traction. By contrast, the BIC ratio in the 1.1 mm group was less than that for the other diameters in both the control and the traction groups. Therefore, it is likely that when the hole size is adequate, a mini-implant inserted in the hole becomes progressively more stable over 3 weeks, independent of whether or not traction is applied.

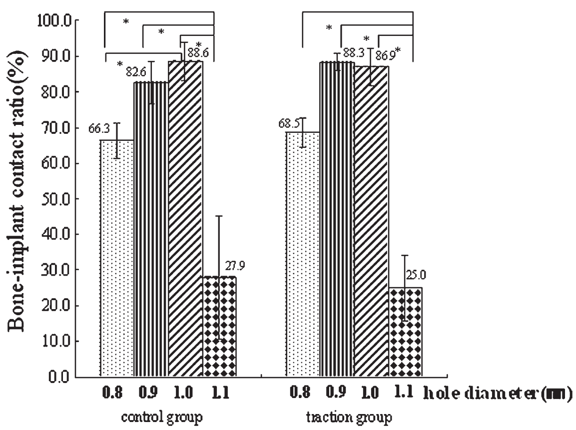

Figure 5 The bone-to-implant contact ratio in the traction and control groups. *$P < 0.05$.

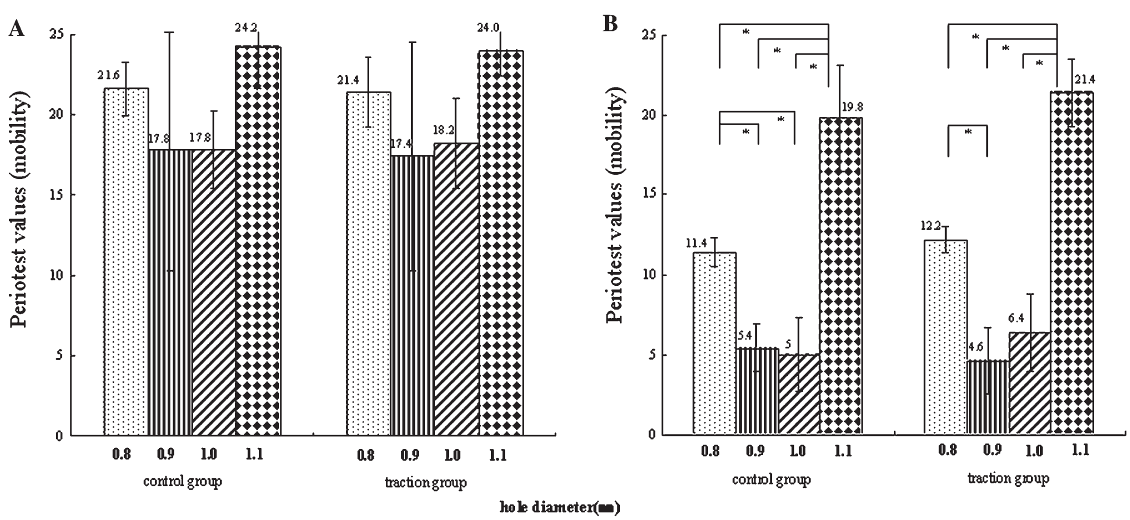

Figure 6 The Periotest values (A) immediately after insertion and (B) after 3 weeks, indicating the mobility of the mini-implants. *$P < 0.05$.

Table 1 Periotest values change of the mini-implant mobility before (T1) and after (T2) traction.

	Hole diameter (mm)	T1		T2		Significance
		Mean	SD	Mean	SD	
Control group	0.8	21.6	1.7	11.4	0.9	*
	0.9	17.8	7.5	5.4	1.5	*
	1.0	17.8	2.4	5	2.3	*
	1.1	24.2	2.6	19.8	3.3	
Traction group	0.8	21.4	2.2	12.2	0.8	*
	0.9	17.4	7.1	4.6	2.1	*
	1.0	18.2	2.8	6.4	2.4	*
	1.1	24	1.6	21.4	2.1	

*$P < 0.05$.

Ikeda (2005) examined the pull-out force of 1.2–1.4 mm diameter (halfway: 1.3 mm) mini-implants using pig ribs and found that 0.9 and 1.0 mm holes were suitable. That author concluded that the diameter of the implant hole should be 75–83 per cent (69–77 per cent when the diameter of 1.3 mm was assumed) that of the mini-implant to facilitate initial stability. Although Ikeda (2005) did not investigate the biological response of bone during traction, the data were similar to the current findings. In the present study, the BIC ratio was larger for the 0.9 and 1.0 mm groups than for the 1.1 mm group. The implant/hole diameter ratio in the 1.1 mm group was 84.61 per cent when the diameter of 1.3 mm was assumed halfway between the maximum and minimum size of the mini-implant, which might result in insufficient bone formation and an unstable mini-implant. Therefore, the best diameter/mini-implant ratio should be between 69 and 77 per cent, the poorest values were 62 and 84 per cent for the mini-implants with a diameter of 1.3 mm. Moreover, the deepest location in the range of the attached gingival might be recommended as a placement site in accordance with the greater thickness of cortical bone. Slanting a mini-implant increases the apparent cortical bone thickness and might enhance stability, particularly in maxillary alveolar bone.

An inverse relationship ($P < 0.01$) was found between the BIC ratio and PTV. The Periotest appears to be useful for determining the stability of mini-implants in clinical practice, instead of morphometric measurements, which can only be undertaken in animal experiments.

Conclusions

To obtain mini-implant stability, the hole diameter should be between 69 and 77 per cent of the diameter of the mini-implant for 1.3 mm diameter mini-implant. A significant decrease in the mobility of the mini-implant after 3 weeks, tested using the Periotest, implies a good prognosis for subsequent stability.

Funding

Grant-in-Aid for Scientific Research (21592613) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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