European Journal of Orthodontics 28 (2006) 541–546
doi:10.1093/ejo/cjl044

Tapered orthodontic miniscrews induce bone–screw cohesion following immediate loading

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SUMMARY The aim of this study was to investigate the initial stability of tapered orthodontic miniscrews (T-type screws) after placement, the necessity of a healing period, and the propriety of immediate loading. Twenty male Wistar rats with a mean age of 20 weeks were divided into two groups. In the immediate-loading groups, straight orthodontic miniscrews (S-type screws) and T-type screws (five rats each) underwent experimental traction force for 2 weeks (W) immediately after placement. In the healing groups (S- and T-type, five rats each), force was applied for 2 W after a 6-W healing period. The right tibia in each rat was identified as the test limb, while the left tibia in each rat was used as the control group, and underwent no experimental force during the experimental period. The screw-to-bone contact was observed histologically and the bone–screw contact ratio was calculated. Scheffe's test was performed to compare the bone–screw contact ratio in each group using statistical software package (SPSS 8.0 for Windows).

In the control group, the bone–screw contact ratio improved from 34.8 ± 16.0 to 74.8 ± 12.0 per cent with S-type screws in proportion to the experimental period (2 to 8 W, respectively). With the T-type screws in the test group, there was no significant difference between the immediate-loading and healing groups. In the immediate-loading group, the bone–screw contact ratio with T-type screws was significantly greater (82.3 ± 15.0 per cent) than with the S-type screws (33.3 ± 11.8 per cent; $P < 0.05$), suggesting that T-type screws can be used for orthodontic anchorage immediately after placement.

Introduct ion

In recent years, titanium miniscrews placed into alveolar bone have been used as absolute anchorage and have led to favourable treatment outcomes (Park *et al.*, 2004, 2005; Chung *et al.*, 2005; Ohnishi *et al.*, 2005); however, some researchers have experienced loosening of the screws (Costa *et al.*, 1998; Sawa *et al.*, 2001).

Miyawaki *et al.* (2003) used three types of titanium screws with different diameters and lengths as anchors for orthodontic tooth movement, and reported that a diameter of 1.0 mm or less, inflammation of the peri-implant tissue, and a high mandibular plane angle, which often exists with thin cortical bone, were associated with mobility and failure of the screw. Cheng *et al.* (2004) assessed the risk factors associated with the failure of miniscrews used for orthodontic anchorage, and concluded that screws exposed in keratinized mucosa survived longer than those surrounded by non-keratinized tissue. They also found that screws in the posterior mandible were more susceptible to infection because less attached gingiva is available in this region. Furthermore, bone in the posterior mandible is dense and overheating is more likely to occur during implant placement, especially when screws are placed in a self-tapped manner.

Initial stability of implants is one of the fundamental criteria for obtaining osseointegration (Albrektsson *et al.*, 1981). Deguchi *et al.* (2003) reported that once an implant was rigidly fixed within supporting bone, orthodontic loads were no obstacle to osseointegration. It is therefore considered that as screws are rigidly fixed to bone, not only initial stability but also delayed stability can be acquired. However, Deguchi *et al.* (2003), Miyawaki *et al.* (2003), and Cheng *et al.* (2004) using straight orthodontic miniscrews (S-type screws) investigated screw stability after a specified healing period. Recently, tapered orthodontic miniscrews (T-type screws), which can endure immediate loading, have been developed and used clinically (Motoyoshi *et al.*, 2006); however, even these screws show mobility and failure during clinical orthodontic treatment, and their effectiveness has not been sufficiently investigated.

The aims of this study were to investigate the initial stability of T-type screws after placement, the necessity of a healing period, and the propriety of immediate loading. S-type screws were also investigated and the two screw types compared.

Materials and methods

Twenty male Wistar rats (age = 20 weeks, body weight at the beginning of the experiment = 500 ± 20 g) were prepared. Twenty S-type screws (diameter = 1.2 mm, length = 4.0 mm) and 20 T-type screws [diameter = 1.4 mm (spearhead = 1.2 mm), length = 4.0 mm (Figure 1)] were placed into the rat tibia, and traction force was then loaded using NiTi coil spring. The animals in the test group were divided into two groups (S-type or T-type screws), and each group was then subdivided into groups of immediate loading (immediate-loading group) and loading after 6 weeks (W) of healing (healing group). Screws in the right tibiae underwent experimental traction force for 2 W, while screws in the left tibiae were treated as the control (Figure 2). The experiments were approved by the AnimalExperimentation Committee of Nihon University School of Dentistry.

Surgical procedure and force application

After anaesthesia with an intra-peritoneal injection of sodium pentobarbitone (100 mg/kg body weight, Nembutal; Dainippon Pharmaceutical Co. Ltd, Osaka, Japan), an incision was made along the tibial crest, and the surface of the tibia was exposed. A hole was then formed 5.0 mm inferior to the knee joint using a bone drill with a diameter of 1.0 mm and length of 4.0 mm (Dentsply-Sankin Co. Ltd, Tokyo, Japan) perpendicular to the bone surface under physiological saline flow. S- and T-type screws were inserted into the hole using a hand driver, and traction force was applied in the test group (Figure 3). To prevent infection after surgery, tetracycline CMC paste (tetracycline hydrochloride pasta; Showa Yakuhin Kako Co., Ltd, Tokyo, Japan) was applied to the surgical site.

S- and T-type immediate-loading groups (five rats each) underwent experimental traction for 2 W immediately after placement. In the healing groups (S- and T-type, five rats each), force was applied for 2 W after a 6-W healing period according to Ohmae *et al.* (2001; Figure 4). The right tibia in each rat was used as the test group, and a hole 1.0 mm in diameter was formed 25 mm inferior to the knee joint to fix a closed NiTi coil spring (Tomy International Co. Ltd, Tokyo, Japan) to apply a traction force of approximately 2 N for 2 W. The left tibia in each rat was used as the control group, which received no experimental force during the experimental period (2 or 8 W).

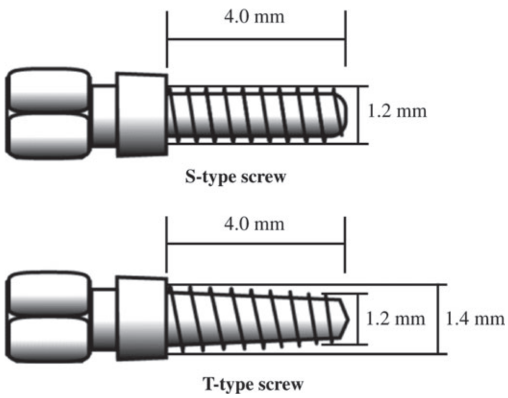

Figure 1 The S- and T-type screws used in the study.

Histological procedure

The rats were killed with pentobarbital at the end of the experiment, and the tibiae were resected at the knee joint. They were washed in clear water with ethanol dehydration and acetone degreasing after fixing in 10 per cent formalin solution (Wako Pure Chemical Industries Ltd, Osaka,

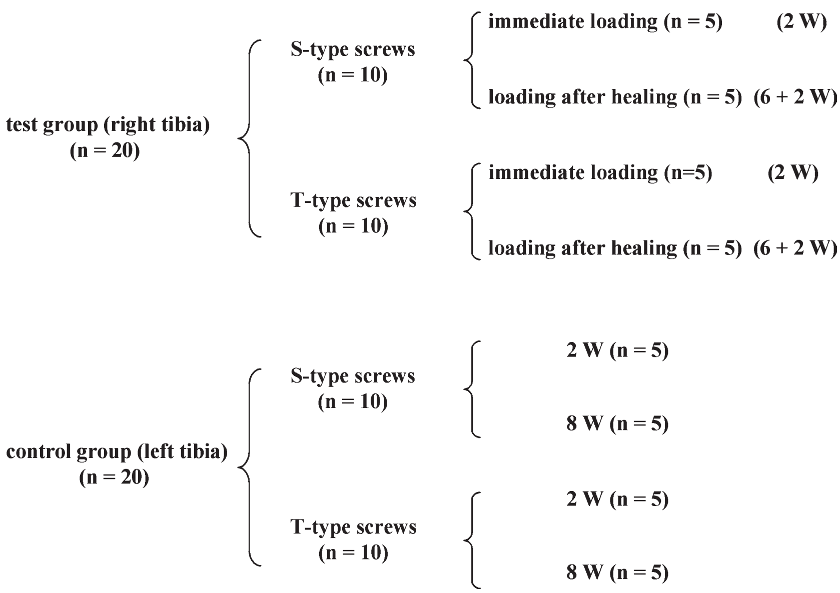

Figure 2 Classification of the experimental groups. The test group was divided into two groups using S-type or T-type screws, and each group was then subdivided into immediate-loading and healing groups.

Japan) for 48 hours. Polymerization stiffening and a Maruto cutter (Maruto Instrument Co. Ltd, Tokyo Japan) were used with polyester resin (Rigolac 2004; Showa Highpolymer Co. Ltd, Tokyo, Japan) at a constant temperature of 60°C for 8 hours, and a block (10.0 × 10.0 × 6.0 mm) was constructed. After grinding with bifid cracking and waterproof grinding paper, 800, 1200, and 2000, a crystal cutter (Maruto Instrument Co. Ltd) was used on the central side, along the axis of the screw. The block was then ground with liquid containing diamond particles of 1 μm and a hard grinding cloth. The condition of the bone-to-screw contact surrounding the cortical bone was observed using a finite element scanning electron microscope (FE-SEM, S-4300 type; Hitachi Science Systems Ltd, Ibaraki, Japan) after osmium coating (HPC-1S type osmium coater; Shinkuu Device Co. Ltd, Ibaraki, Japan) and a photograph was taken of these blocks.

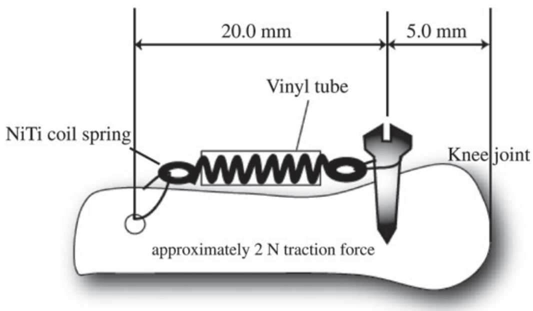

Figure 3 Insertion position of screws and methods of loading.

Evaluation of bone–screw interface and statistical analysis

The bone–screw contact ratio was calculated using ×30-enlarged micrographs derived from FE-SEM (Figure 5). After tracing the photographs, the bone–screw contact ratio was calculated using the following equation:

Bone–screw contact ratio = length of bone contact at cortical bone/length of screw surface at cortical bone×100.

One examiner (SY) traced and measured all the photographs to eliminate inter-examiner errors. All the tracings and measurements were performed at least twice to reduce intra-examiner errors, and the mean values were used. When there was more than a 5 per cent difference in the bone–screw contact ratio, they were remeasured and the mean value of the three measurements was used. Scheffe's test was carried out to compare the bone–screw contact ratio in each group using the Statistical Package for Social Scince (Version 8.0 for Windows, SPSS Inc., Chicago, Illinois, USA).

Results

Loosening of screws

In the test groups, one S-type screw in the immediate-loading group and two S-type screws in the healing group loosened, and removed by hand (Figure 6). There was no loosening of the T-type screws.

FE-SEM evaluation

Figure 7 shows FE-SEM imaging for the test group. For the S-type screws (Figure 7A,B), the bone contact to screw

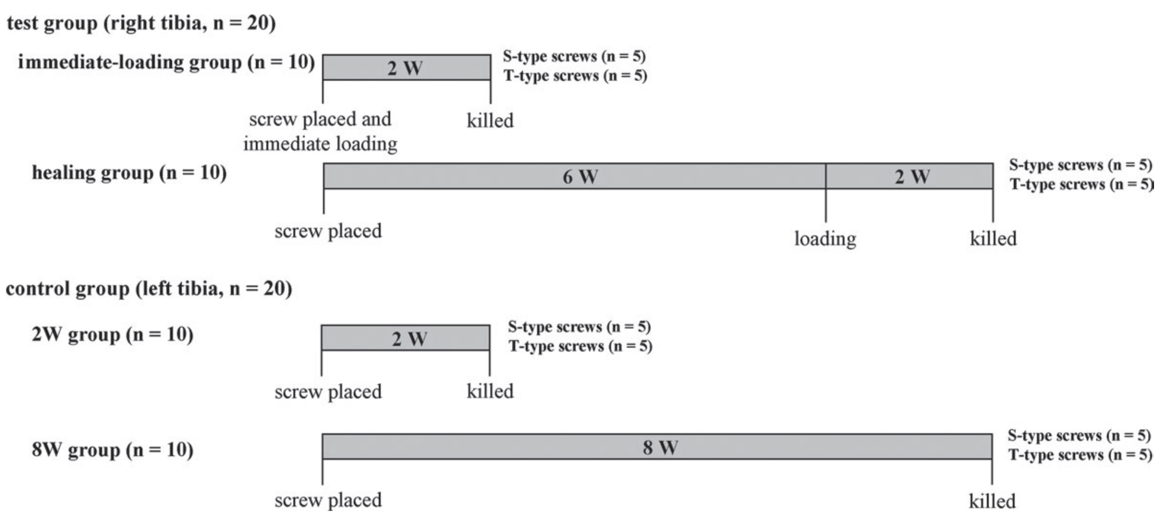

Figure 4 Flow chart showing the protocol for the test and control groups. The right tibia in each rat was used as the test group. S- and T-type immediate-loading groups underwent experimental traction force for 2 weeks (W) immediately after placement. In the healing groups, force was applied for 2 W after a 6-W healing period. The left tibia in each group underwent no experimental force during the experimental period (2 or 8 W). The number of rats is shown in parentheses.

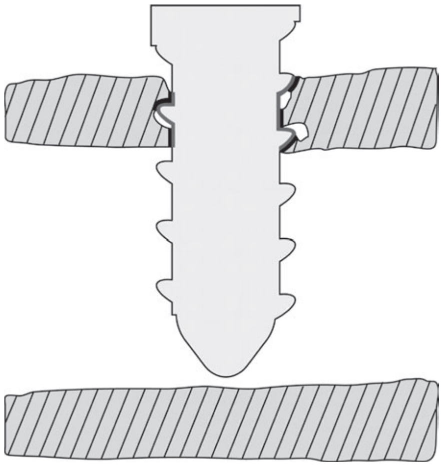

Figure 5 Method for measuring the bone–screw contact ratio. Bone–screw contact ratio = length of bone contact at cortical bone (black)/length of screw surface at cortical bone (grey) × 100.

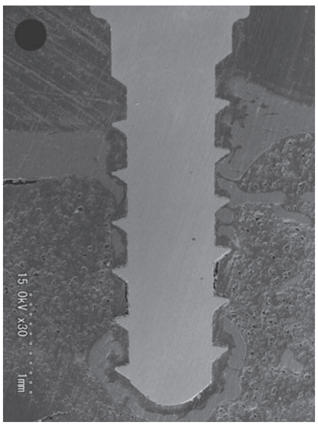

Figure 6 S-type screw with observed mobility.

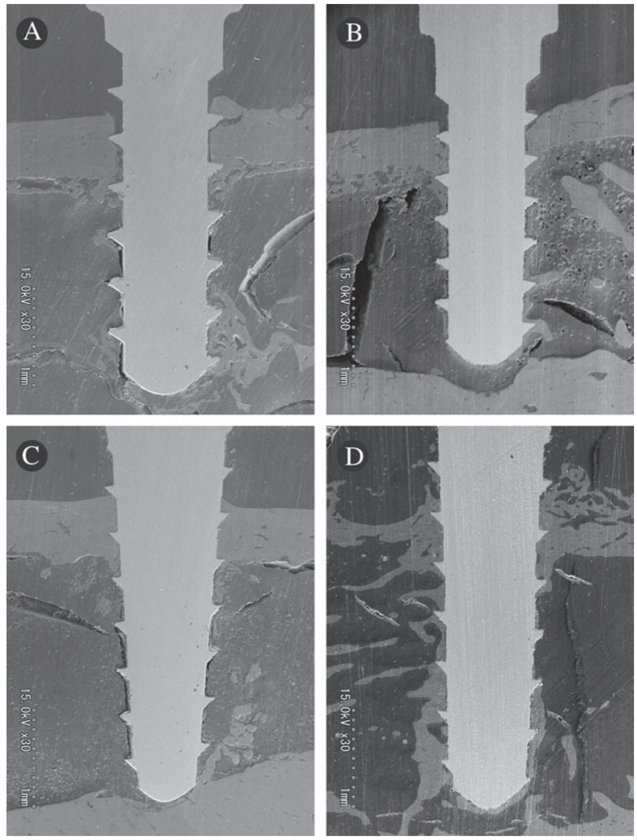

Figure 7 Finite element scanning electron images for the test group. (A) S-type screws in the immediate-loading group. (B) S-type screws in the healing group. (C) T-type screws in the immediate-loading group. (D) T-type screws in the healing group.

surface condition was insufficient, and some spaces between the screw surface and cortical bone were observed. In contrast, in the T-type screws (Figure 7C,D), cortical bone was seen in the screw threads in the immediate-loading and healing groups.

For the S-type screws of the 2-W group (Figure 8A), the bone contact to screw surface was insufficient, but in the 8-W group (Figure 8B), the cortical bone contact area was raised in the whole surface of the screw threads. In contrast, with the T-type screws (Figure 8C,D), cortical bone was seen in the screw threads for both the 2-W and 8-W groups.

Placement resistance was relatively small when tightening all S-type screws.

Bone–screw contact ratio

For the T-type screws, the bone–screw contact ratios were in the range of 81.1 ± 17.7 to 88.0 ± 11.6 per cent (Figure 9). There was no significant difference among the test, control, immediate-loading, or healing groups.

Comparing the S- and T-type screws in the test group, there were significant differences between the S-type screws in the immediate-loading group and the T-type screws in both the immediate-loading and healing groups ($P < 0.05$). In the healing groups, a significant difference was also observed between the S- and T-type screws ($P < 0.05$).

For the control group, the bone–screw contact ratio was on average 34.8 ± 16.0 per cent in the S-type 2-W group, 74.8 ± 12.0 per cent in the S-type 8-W group, 81.1 ± 17.7 per cent in the T-type 2-W group, and 86.0 ± 6.2 per cent in the T-type 8-W group. A significant difference was observed between the S-type 2-W group and the other groups ($P < 0.05$).

There was no difference in the bone–screw contact ratio between the right tibiae (test group) and left tibiae (control group) in identical matching.

Discussion

For the T-type screws in the test group, the bone–screw contact ratio was similar between the immediate-loading

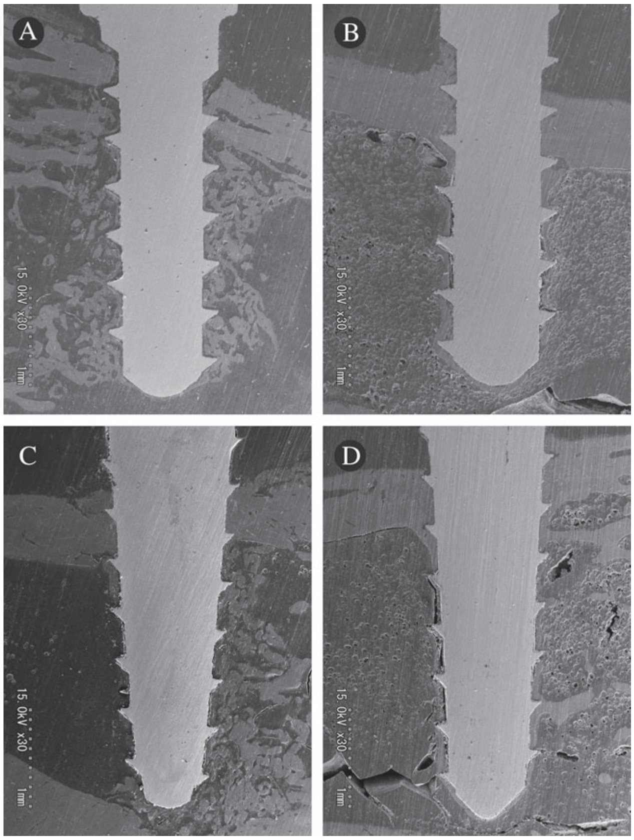

Figure 8 Finite element scanning electron images for the control group. (A) S-type screws in the 2-week (W) group. (B) S-type screws in the 8-W group. (C) T-type screws in the 2-W group. (D) T-type screws in the 8-W group.

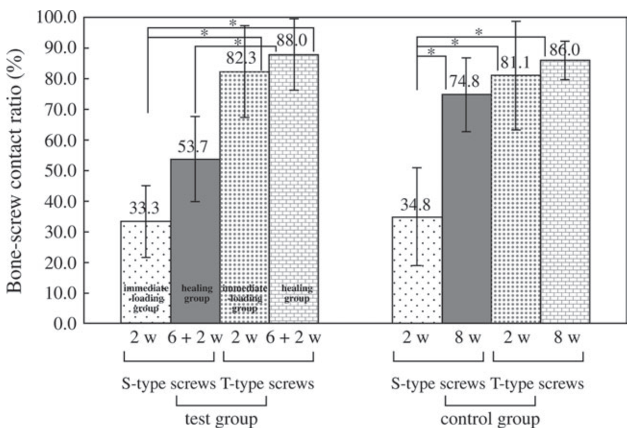

Figure 9 Comparison of the bone–screw contact ratio: 2 weeks (W) in the test group indicates the loading period, 6 W in the test group indicates the healing period, and 2 W and 8 W in the control group indicate the observation period.

and the healing groups, 82.3 ± 15.0 and 88.0 ± 11.6 per cent, respectively (Figures 7C,D and 9). According to previous studies investigating bone–screw contact ratio, the values ranged from 48 to 78 per cent (Piattelli *et al.*, 1998; Zubery *et al.*, 1999; Nkenke *et al.*, 2003; Heitz-Mayfield *et al.*, 2004). The values in this study were larger than those reported in previous investigations. This could be due to differences in measurement, the diameter of the implant, and the sharpness of tapering.

In the test group, bone–screw contact ratios in the healing group (53.7 ± 13.9 per cent) and in the immediate-loading group (33.3 ± 11.8 per cent; Figures 7A,B and 9) were significantly smaller with the S-type than with the T-type screws (Figures 7C,D and 9). It is considered that the shapes of the S- and T-types caused this difference. When tightening the T-type screw, cortical bone was seen in the screw threads and the cortical bone contact area was raised in the whole surface of the screw threads. O'Sullivan *et al.* (2004) compared tapered and straight dental implants, and reported that significantly higher insertion torque was needed to insert tapered implants, and this shape resulted in improved primary stability compared with straight implants. In a comparative clinical study using resonance frequency analysis, Glauser *et al.* (2001) found significantly higher values for tapered implants (Brånemark System, Mk IV) than for non-tapered implants (Brånemark System, Mk II and Mk III). The tapered shape could therefore improve insertion of the screw to the cortical bone and the initial mechanical cohesion of the bone to the screw threads.

On the other hand, some researchers have reported that sufficient osseointegration results in improved long-term stability of dental implants (Brånemark *et al.*, 1969, 1983; Adell *et al.*, 1981; Albrektsson, 1983; Lindquist *et al.*, 1996; Buser *et al.*, 1997). Furthermore, it is generally considered that immediate loading before acquiring osseointegration reduces the survival rate of dental implants (Becker *et al.*, 1994; Schnitman *et al.*, 1997). In this study, however, the bone–screw contact ratio with the T-type screws was 82.3 ± 15.0 per cent despite immediate loading.

Conclusions

The findings of this study show that in the controls, the T-type screw resulted in no significant difference between the 2-W and 8-W groups. In contrast, with the S-type screw in the control groups, the bone–screw contact ratio in the 8-W group was greater than in the 2-W group, indicating that as the healing period increased, the cohesion of bone-to-screw thread also increased. Straight screws can be used for orthodontic anchorage if there is a sufficient healing period.

Although the 8-W control group showed the highest bone–screw contact ratio (74.8 ± 12.0 per cent), in the groups with S-type screws, this value was lower than the ratio (81.1 ± 17.7 per cent) in the T-type immediate-loading group. It is therefore suggested that tapered screws can tolerate immediate-loading and achieve stable anchorage with a high rate of success.

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Acknowledgements

We wish to thank Professor Isokawa for his assistance. This study was supported by grants from the Promotion and Mutual Aid Corporation for Private Schools of Japan for 2003 and 2004 and grants from Nihon University Individual Research Grant for 2004.

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