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Bone response to orthodontic loading of endosseous implants in the rabbit calvaria: early continuous distalizing forces

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SUMMARY The purpose of this experimental study was to evaluate the effect of early orthodontic loading on the stability and bone-implant interface of titanium implants in a rabbit model. Twenty-four short threaded titanium fixtures were inserted in the calvarial mid-sagittal suture of 10 rabbits. Two weeks following insertion, 20 implants (test group) were subjected to continuous distalization forces of 150 g for a period of 8 weeks. The remaining four implants (control group) were left unloaded for the same follow-up interval. Clinically, all implants except for one test fixture were stable, and exhibited no mobility or displacement throughout the experimental loading period. Histologically, all stable implants were well-integrated into bone. No differences could be found between the pressure and tension surfaces of the test implants relative to bone quality and density within a range of 1000 μm from the fixture surface. Similarly, qualitative differences were not observed between the apical and coronal portions of test fixtures. Morphometrically, a mean percentage bone-to-implant contact of 76.00 ± 18.73 per cent was found at the test pressure sides, 75.00 ± 11.54 per cent at the test tension sides, and 68.00 ± 15.55 per cent at the control unloaded surfaces. No statistically significant differences in the percentage of bone-to-metal contact length fraction were found between test pressure surfaces, test tension surfaces, and unloaded control surfaces. Marginal bone resorption around the implant collar or immediately beneath it was found in roughly the same percentage of analysed sites in the test and control fixtures. In contrast, slight bone apposition was demonstrated at the implant collar of the test pressure surfaces, while no apposition or resorption were observed in the test tension zones. This study suggests that short endosseous implants can be used as anchoring units for orthodontic tooth movement early in the post-insertion healing period.

Introduction

The successful use of osseo-integrated implants as anchorage elements for orthodontic force application has been reported in several experimental studies (Smalley *et al*., 1988; Turley *et al*., 1988; Linder-Aronson *et al*., 1990; Wehrbein and Diedrich, 1993; Asikainen *et al*., 1997; Wehrbein *et al*., 1997) and clinical case reports (Roberts *et al*., 1989, 1990; Haanæs *et al*., 1991; Higuchi and Slack, 1991; Ödman *et al*., 1994; Wehrbein *et al*., 1996). Comparison of the orthodontic implant loading protocol in these studies revealed significant differences relative to implant size, implant location, quantity and quality of bone in the implant site, magnitude, direction and duration of orthodontic forces, and duration of the unloaded implant healing period. However, most of these studies have in common long healing periods following implant insertion and prior to orthodontic loading. In a recent

experimental study in a dog model, Wehrbein *et al.* (1997) demonstrated that short titanium screw implants retained their stability during 26 weeks of orthodontic force application following a relatively short unloaded implant healing period (8 weeks). It is evident that the use of implants for orthodontic purposes as soon as possible following insertion is appealing both in orthodontic and orthodontic-prosthetic patients. It was the purpose of the present study to histologically characterize osseous changes associated with early orthodontic loading of short titanium threaded implants inserted in the rabbit calvaria.

Material and methods

Experimental design

Ten adult New Zealand white rabbits weighing 3.5–4 kg were used in this study. The animals were anaesthetized using intramuscular injections of ketamine (Ketalar®, Parke Davis, S.p.A., Italy) 44 mg/kg of body weight, and xylazine (Rompun®, Bayer AG, Leverkusen, Germany) 6–8 mg/kg of body weight.

Immediately prior to surgery, the scalp was carefully shaved, and cleaned with a mixture of iodine and 70 per cent ethanol, and 1 ml of lidocaine 2 per cent (Xylocaine®, Astra, Södertälte, Sweden) was injected locally into the surgical site. A midline incision from the nasofrontal area to the external occipital protuberance was made sub-periosteally and a skin-periosteal flap was raised to expose the calvarial surface on both sides of the midline. By intermittent drilling, fixture sites were sequentially enlarged to 3.5 mm using a slow-speed handpiece running at 2500 rpm under profuse saline solution irrigation. Two custom-made threaded commercially pure titanium fixtures, 3.25 mm in length, 5 mm in diameter at the shoulder area, and 4 mm at the threaded portion (Figure 1), were inserted in the calvarial mid-sagittal suture of all 10 rabbits at a distance of approximately 11 mm. These two fixtures served as reciprocal anchoring elements for distalizing orthodontic forces (test implants). In four of the 10 animals, a third fixture of the same type was placed along the mid-sagittal plane, about 8 mm posteriorly to the test sites and served as an unloaded control implant. The control fixture also provided a reference point throughout the experimental period to assess implant dislocation by providing the distance to the two anterior loaded implants. All implants had the inferior aspect of the collar levelled with the bone surface.

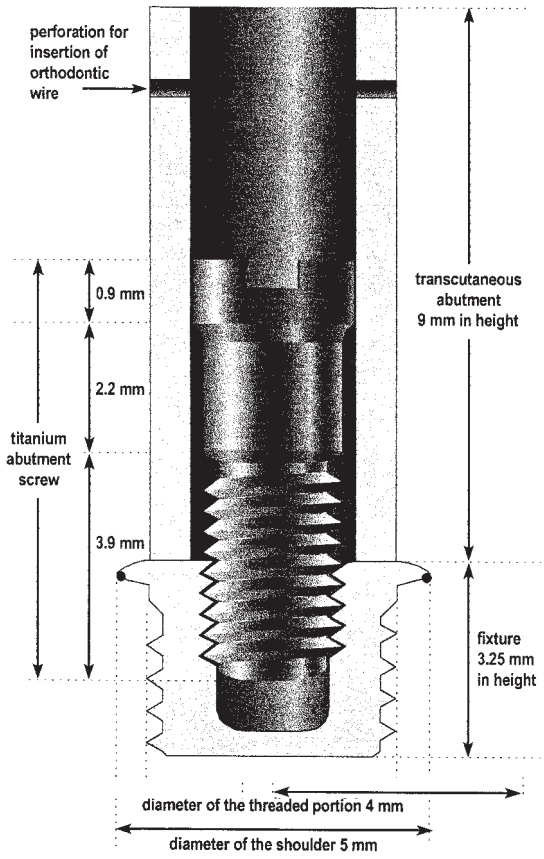

Figure 1 Schematic drawing illustrating the implant with its transcutaneous abutment. The inferior aspect of the fixture collar (dot) was levelled with the cortical bony surface at the time of implant insertion.

At the same session, 9-mm-high custom-made hollow cylindrical transcutaneous abutments with small perforations along the cylinder walls were connected to all fixtures using titanium screws (Figure 1). The skin-periosteal flaps were then repositioned and sutured using interrupted resorbable sutures (Vicryl®, 4-0, Johnson & Johnson, Sollentuna, Sweden). Post-operatively, the animals received antibiotics (Penovet®,

Figure 2 The transcutaneous abutments were connected with a rectangular wire and spring creating a reciprocal load of approximately 150 g on each of the test implants.

Boeringer, Denmark) at a dose of 0.3 ml per animal and analgesics (Temgesic®, Reckitt and Coleman, Hull, UK) at 0.05 mg/kg of body weight for 3 days.

Two weeks post-operatively, the anterior fixtures were subjected to orthodontic loading for an 8-week period. The animals were killed 8 weeks after initiation of orthodontic loading using an overdose of carbon dioxide, and block specimens were obtained.

Orthodontic force application

Orthodontic loading of the test implants was achieved by connecting the transcutaneous abutments with a 0.018×0.022-inch rectangular stainless steel wire (3M Unitek, Monrovia, CA, USA). Passing through the abutment perforations and bent at both ends was a stainless steel open coil spring (Hi-T™ II, 3M Unitek, Monrovia, CA, USA) which created a continuous constant reciprocal load of approximately 150 g on each of the test implants (Figure 2). To ascertain that loading exerted on the implants was constant throughout the experimental period, activation force of the springs was evaluated before insertion and then at 8 weeks using a precision spring scale (Dontrix Orthodontic Stress and Tension Gauge, Ormco®, Glendora, CA, USA).

Clinical examination criteria

Mobility of the fixtures was recorded using two instrument grips at 4 and 8 weeks after the initiation of orthodontic loading. For this purpose, the wire and spring were removed from the test implants and reattached directly after evaluation at each control session. For the assessment of implant dislocation, the distance between the uppermost anterior perforation of the control abutment to the corresponding perforations on the test abutments was measured at the start and end of the force application period using a digital caliper [Mitutoyo (UK) Ltd, Andover, UK]. In addition, the distance between the two test implants was recorded using the same protocol.

Tissue processing

At 8 weeks after initiation of orthodontic loading, the skull bone was retrieved *en bloc* with the implants, abutments, and orthodontic

appliances *in situ*, and fixed by immersion in 4 per cent buffered paraformaldehyde. The specimens were further dehydrated in ascending concentrations of alcohol rinses and infiltrated with methylmethacrylate resin (Sigma Chemical Co., St Louis, MD, USA). After polymerization, the specimens were sectioned along a plane perpendicular to the bone surface and parallel to the long axis of the implants to yield sections of approximately 80 μm thick (Leica 1600, Leica spa, Milano, Italy). The two most central sections were selected for each implant and stained with toluidine blue and fast green for light microscopic evaluation.

Histometric evaluation

Histological examination, photography, and morphometric measurements of the sections were carried out using a Axioskop microscope (Carl Zeiss GmbH, Jena, Germay) interfaced with a computerized morphometric system (Kontron Elektronic Image Analysis System KS 300, Kontron Electronic GmbH, Eiching bei Munchen, Germany). The histomorphometric measurements included the assessment of bone-to-metal contact length on the anterior and posterior aspects of each implant, expressed as a percentage of the total length of the implant. An average percentage value was determined for the two pressure and two tension sides of the test implants in each rabbit. In addition, the mean percentage bone-to-metal contact was calculated for both sides of the control unloaded implants. The quantitative differences between test pressure zones, test tension zones, and control implants were assessed using the ANOVA of Friedman test. Statistical testing was carried out at the 5 per cent significance level.

Results

Clinical findings

Two rabbits died at various intervals post-operatively for reasons unrelated to the surgical procedures. In the remaining eight rabbits, one test implant demonstrated good initial stability at insertion, but was mobile 4 weeks following orthodontic loading. The same implant showed a displacement of 0.5 mm in the direction of the orthodontic force. The remaining 15 test and four control implants had good primary stability directly after insertion and exhibited no mobility throughout the experimental loading period. No changes in implant position were recorded for these implants throughout the force application period as demonstrated by the invariable distance control–test and test–test abutments.

Histological findings

Microscopically, all stable implants were well integrated into bone. The test implant which exhibited mobility and displacement 4 weeks following orthodontic loading demonstrated fibrous encapsulation throughout most of the fixture length.

The thickness of bone at the implantation sites varied between 3.5 and 4 mm. In a few cases, the implants perforated the inner cortex of the calvarial bone. In these sections, new bone formation was evidenced along the implant surfaces at the perforation sites.

No differences could be found between the pressure and tension surfaces of the test implants relative to bone quality and density within a range of 1000 μm from the fixture surface. Similarly, qualitative differences could not be observed between the apical and coronal portions of the test fixtures (Figure 3). However, density of bone directly at the implant surface and within the peri-implant hard tissue was higher at the loaded surfaces when compared with the unloaded control implants.

Marginal bone resorption around the implant collar or immediately beneath it was demonstrated in roughly the same percentage of analysed sites in the test and control fixtures. In contrast, slight bone apposition was found at the implant collar of the test pressure surfaces while no apposition or resorption was observed in the test tension zones (Figures 4 and 5).

Morphometric analysis

A mean percentage bone-to-implant contact of 76.00 ± 18.73 per cent was found at the test

Figure 3 High percentage direct bone-to-implant contact is evident on both pressure (left side) and tension (right side) surfaces of an orthodontically loaded implant (fast green, magnification ×1).

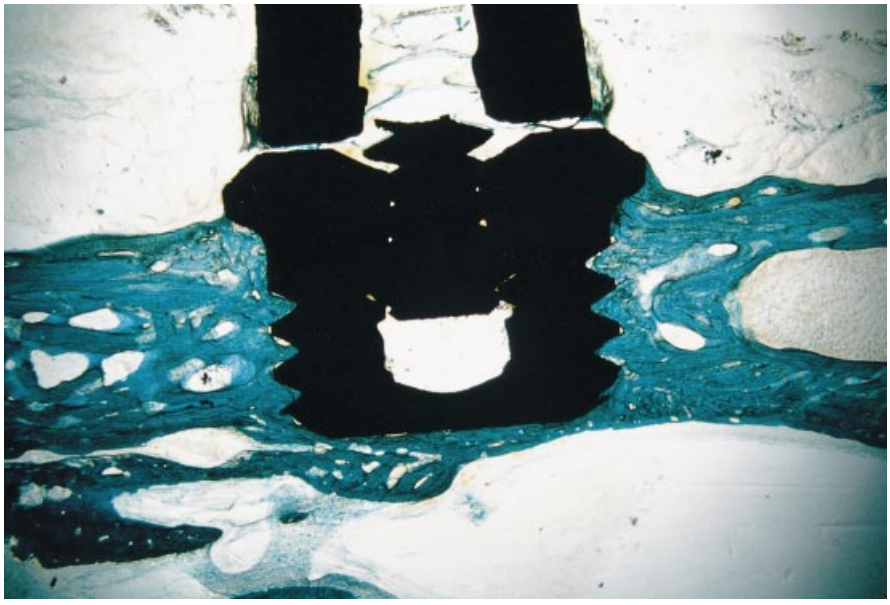

Figure 4 A test fixture showing slight bone apposition over the implant collar at the pressure surface (right side), while none is observed at the opposite tension surface (left side) (fast green, magnification ×1).

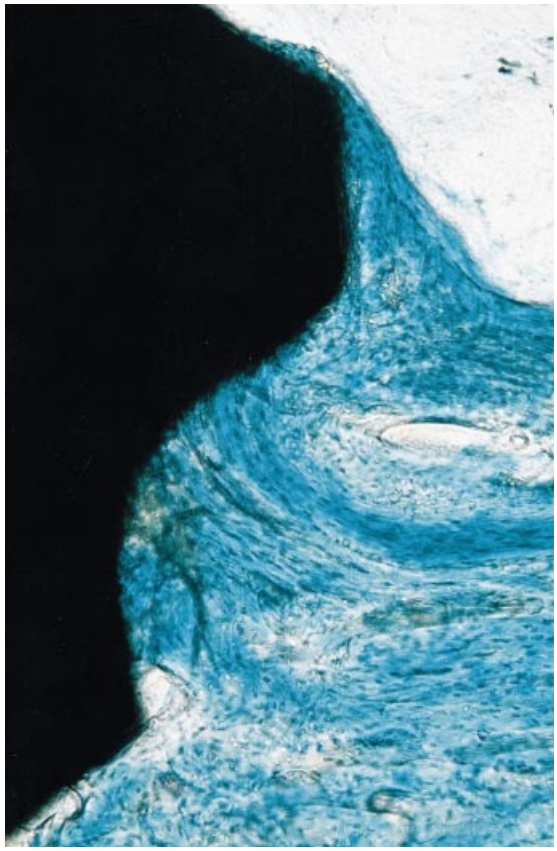

Figure 5 Higher magnification of a fixture's marginal aspect showing bone formation over the implant collar at the pressure surface (fast green, magnification ×7.1).

pressure sides, 75.00 ± 11.54 per cent at the test tension sides, and 68.00 ± 15.55 per cent at the control unloaded surfaces (Table 1). The analysis of histomorphometric data revealed no statistically significant differences in the percentage bone-to-metal contact length fraction between test pressure surfaces, test tension surfaces, and control surfaces.

Discussion

The most significant finding in this experimental study is that all orthodontically loaded implants except for one showed no clinical mobility or displacement throughout the 8-week force application period after a very short unloaded healing interval. These results, together with the histological observation that a high bone-to-implant contact was maintained under load, suggest that implant movement towards bone did not occur. This finding is in agreement with the results of previous reports that confirmed implant stability under orthodontic loading (Smalley *et al*., 1988; Turley *et al*., 1988; Roberts *et al*., 1989; Asikainen *et al*., 1997; Wehrbein *et al*., 1997). The major differences with the previous studies are: (1) the small dimensions of the implants; and (2) the extremely short unloaded healing period following implant insertion. Smalley *et al*. (1988) used cylindrical titanium fixtures 3.75 mm in diameter and 5 mm in length, while Wehrbein *et al*. (1997) applied screw-shaped implants with a submersion depth of 6 mm and a diameter of 4 mm. The endosseous portion of the fixtures used in the present study had a height of 2.85 mm and a diameter of 4 mm at the threaded portion. When considering the unloaded post-insertion healing interval, most of the previous studies have in common long healing periods following implant insertion. In a recent experimental study in the dog model, Wehrbein *et al*. (1997) demonstrated that short titanium screw implants retained their stability during 26 weeks of orthodontic force application following a relatively short unloaded implant healing period of 8 weeks. The present study allowed only a 2-week period prior to orthodontic loading of the implants. Despite these methodological conditions, all test implants but

Table 1 Percentage bone-to-implant contact at loaded and unloaded surfaces. Statistically significant differences in the percentage of bone-to-implant contact were not found between test pressure surfaces, test tension surfaces, and control surfaces.

	Test pressure surfaces	Test tension surfaces	Control unloaded implants
Mean percentage of bone-to-implant contact	76.00 ± 18.73	75.00 ± 11.54	68.00 ± 15.55

one maintained their stability and position throughout the experimental period. In addition, previous experimental studies have applied orthodontic forces varying between 2 and 6 N (Smalley *et al*., 1988; Wehrbein *et al*., 1997). In this investigation, forces of approximately 150 g were used. This value is within the range of orthodontic forces normally utilized to move natural teeth. The clinical significance of the data reported in this investigation is the potential application of small size implants using the one-stage approach and initiating orthodontic loading early in the healing period to reduce treatment duration.

It is obvious that orthodontic anchorage is required over long time periods in most clinical situations. Although the present investigation protocol limited the duration of orthodontic force application to an 8-week period, it is improbable that loss of osseo-integration could occur at longer evaluation periods. However, further assessment of possible changes in the marginal areas of the peri-implant hard tissue after long-term sustained orthodontic movement is required.

The osteodynamic changes at the pressure and tension sides were not evaluated with bone labelling fluorochromes in this study. However, extrapolation from findings of previous experimental investigations (Wehrbein and Diedrich, 1993) would indicate that extensive remodelling processes probably occurred in the peri-implant hard tissues without loss of bone structural integrity. The observation of a higher bone density at the implant surface and within the peri-implant hard tissues at the loaded surfaces when compared with the unloaded control implants was not confirmed by direct histomorphometric measurements and statistical evaluation due to the limited number of control sites. It may be suggested that the internal remodelling of mechanically loaded bone in the biomechanical force system applied in this study resulted in bone apposition within the endosteal spaces leading to a denser bone in the peri-implant area.

The observation of slight bone apposition at the pressure surfaces of orthodontically loaded implants in this study is in agreement with the results of previous experimental investigations (Wehrbein and Diedrich, 1993; Wehrbein *et al*., 1997). Roberts *et al*. (1984) reported that such orthodontically induced marginal bone apposition depends on the magnitude of the applied force and deformation of the loaded bone. It seems that the combination of force range–biomechanical force system–calvarial bone structure used in this study is compatible with marginal osteogenetic activity.

New bone formation was demonstrated at the implant surfaces where the fixtures had perforated the inner cortex of the calvarial bone. Similar findings were reported by Asikainen *et al*. (1997) in a sheep model, where implants had penetrated through the wall of the frontal sinus. Whether this bone formation was initiated during the first 2 weeks post-operatively or was stimulated later during the orthodontic phase can not be ascertained.

Conclusions

The results of the present study indicate that short titanium-threaded implants inserted in the mid-sagittal suture of the rabbit calvarial bone withstand orthodontic force application after a short 2-week unloaded implant healing period. The potential clinical applications of these findings include the possibility of minimizing the orthodontic treatment duration, using very short fixtures as orthodontic anchoring units in areas lacking sufficient bone height, and the post-orthodontic use of these implants as abutments for definitive prosthetic reconstruction.

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