Osseointegration of miniscrews: a histomorphometric evaluation

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SUMMARY Mini-implants and miniscrews are commonly used in orthodontics to provide additional temporary intraoral anchorage. Partial osseointegration represents a distinct advantage in orthodontic applications, allowing effective anchorage to be combined with easy insertion and removal. This article reports the histomorphometric findings of the osseointegration of bracket screw bone anchors (BSBAs).

In an experimental animal study, four BSBAs were inserted in the alveolar process of the lower jaw in each of five male beagle dogs, aged 6.5 months from the same mother.

Eleven screws were lost during the study, nine of them due to lack of primary stability. One screw was removed at the end of the examination period for evaluation of ease of removal. After 6 months, histological evaluation of the eight remaining screws was performed to evaluate the extent of osseointegration. All eight screws showed partial osseointegration (mean 74.48 per cent, standard deviation \pm 15.33 per cent). The amount of osseointegration was independent of loading time and location (anterior or posterior), as tested with an independent samples *t*-test (*P* > 0.05).

Analysis of the data indicated that small titanium screws were able to function as rigid osseous anchors against an orthodontic load of 200 cN for 6, 12, 18, or 24 weeks after a minimal healing period or no healing period. These findings show that miniscrews, used for temporary anchorage in orthodontics, partially osseointegrate.

Introduction

Since the introduction of fixed appliances, the question of anchorage has always been a challenging problem to orthodontists. According to the third law of Newton, when two units of teeth are connected by an active appliance, they are subjected to equal and opposite forces. It is, however, not desirable in most orthodontic cases to perform equal and opposite tooth movements. Various methods have been introduced to provide additional anchorage, a number of which depend on patient compliance (Egolf *et al.*, 1990). Implant-like devices were introduced to provide absolute anchorage, as they show no movement to the applied forces (Higuchi and Slack, 1991; Block and Hoffman, 1995; Bousquet *et al.*, 1996; Glatzmaier *et al.*, 1996; Wehrbein *et al.*, 1996a,b, 1999; Kanomi, 1997; Costa *et al.*, 1998; Bae *et al.*, 2002; Park *et al.*, 2002).

Osseointegrated implants provide excellent anchorage, but also have disadvantages. There is a delay of several months between placement and loading, they are expensive, and the different bone morphology in the palatal region imposes some restrictions to implant geometry compared with conventional dental implants (Turley *et al.*, 1988; Bernhart *et al.*, 2000) and removal may be difficult (Fritz *et al.*, 2004). Miniscrews were introduced in an attempt to solve these problems, with ease of insertion and removal, low cost, and no delay in loading (Costa *et al.*, 1998; Melsen, 2000; Park *et al.*, 2001, 2002; Melsen and Garbo, 2004; Carano *et al.*, 2005). One of these is the bracket screw bone anchor (BSBA, Asscherickx *et al.*, 2005). Histological studies have shown that osseointegration of titanium miniscrews is less then half that of conventional dental implants (Costa *et al.*, 1998). The aim of the present study was to evaluate histomorphometrically osseointegration of the BSBA in the mandible, and to determine if loading time has an influence on osseointegration.

Materials and methods

The research was approved by the Ethics Committee for Research on Animals (Ethical Board VUB 2002/109). Five male beagle dogs (6.5 months old) from the same mother were used in this study and all five dogs remained in good health throughout the experimental period. Four of the five dogs gained weight in the first 18 weeks of the experimental period.

The BSBA consists of a titanium (Ti_6Al_4V alloy) bone screw with a cross-slot, which is semi-self-tapping, with a diameter of 1.7 mm and a length of 6 mm (Leibinger-Stryker[®] GmbH & Co, Freiburg, Germany, ref. 52-17206). It was laser welded on a 0.018-inch slot titanium bracket (Ormco[®] Orange, California, USA, ref. 448-6610).

Apical radiographs were taken prior to the insertion of the screws in order to determine the appropriate insertion site. The insertion site was identified with a periodontal probe and the attached gingiva punched. A small hole (diameter 1.6 mm) was drilled through the cortex with a slow speed counter handpiece under continuous water irrigation and the BSBAs were inserted manually with a screwdriver that fitted the 0.018-inch bracket slot. Insertion of the screws was performed by an experienced surgeon under local anaesthesia.

Each of the five dogs received two BSBAs in the right and two in the left side of the lower jaw (n = 20). The screws were inserted in a horizontal direction between the roots of the second and third (P2/P3), and third and fourth premolars (P3/ P4; Figure 1). The different pairs of screws were loaded in a mesial and distal direction with a 200 cN Nitinol open coil spring (GAC International Inc., Bohemia, New York, USA; Figure 2). Four screws were left unloaded and served as the controls, eight screws were loaded immediately after insertion (100 cN), and eight screws were loaded after 6 or 12 weeks.

All animals were subjected to sequential point labelling with single intravenous injections of 7 mg/kg calcein green (Fluka Chemie A.G, Buchs, Switzerland) at 6 and 24 weeks, an intravenous injection of 30 mg/kg tetracycline hydrochloride (Fluka Chemie A.G) after 12 weeks, and an intravenous injection of 90 mg/kg of xylenol orange (Fluka Chemie A.G) after 18 weeks. The dogs were killed after a period of 25 weeks and a number of specimens obtained from the insertion sites. The specimens were fixed in 10 per cent buffered formalin for 2 weeks and dehydrated with a graded series of ethanol (Donath, 1988). The specimens were then embedded in histological resin and, from these resin blocks, 70 μ m vertical sections were obtained.

For histomorphometric analysis, the sections were initially examined under a fluorescence microscope (Leica, DMR[®], Wetzlar, Germany) and then subsequently stained with toluidine blue/McNeal (Schenk *et al.*, 1984) and examined with a light microscope (Leica, DMR[®]). The outlines of the miniscrews and the osseointegrated parts of the miniscrews were measured (in mm) directly under the microscope using Diskus software (Diskus v 4.30.539, Hilgers, Königswinter, Germany) linked to the optical microscope. Measurements were calculated as the 'percentage of osseointegration'.

Statistical analysis

Statistical calculations were carried out using the Statistical Package for Social Sciences (Windows v 12.0, SPSS, Inc,



Chicago, Illinois, USA). The differences in osseointegration between the different categories (loading time) and insertion sites (anterior/posterior) were analysed using the independent samples *t*-test. The normality of the residuals was analysed with a Kolmogorov–Smirnov test, and homogeneity of the variances with the Levene's test.

Results

Eight screws were lost within the first 6 weeks and three between 6 and 12 weeks (Table 1). Therefore, a success rate of 50 per cent was obtained. At the end of the examination period, only nine of the 20 screws were still *in situ*. One of these was removed with the screwdriver used at the time of insertion to establish whether the screw could be removed easily. No problems were encountered. The remaining eight screws were retrieved from three animals (H 186, H 187, and H 189) and evaluated in three categories according to the time of loading: 1—not loaded (H 189), 2—immediately loaded (H 187), and 3—loaded after 6 or 12 weeks (H 186).

Despite minimal bone defects, bony islands were present in close contact with the miniscrew surface in the marginal area (Figure 3). Vital staining showed a normal deposition of new bone around the BSBAs with calcein green, tetracycline, and xylenol orange present around the BSBA (Figure 4).

The results of the histomorphometric measurements are shown in Table 2. No statistical differences were found between the measurements at the buccal or lingual site (P > 0.05). The osseointegration values for categories 1, 2, and 3 were 76.66 (±16.48), 76.27 (±15.52), and 71.83 (±15.63) per cent, respectively. The osseointegration of anterior and posterior screws was measured at 73.88 (±7.71) and 72.38 (± 9.29) per cent, respectively. This difference was not statistically significant (P > 0.05). The overall mean osseointegration was 74.48 per cent (±15.33 per cent, Figure 5).

Discussion

The screws used in this research, on which the brackets were laser welded, are normally designed for miniplate fixation in reconstructive surgery. They have a small diameter (1.7 mm) and are semi-self tapping. For alveolar dental implants, it has been shown that bone inside, and adjacent to, the screw threads is under a state of increased loading, which results in higher remodelling rates (Chen *et al.*, 1995; Garetto *et al.*, 1995). Under low-cycle fatigue loads orthogonal to their axis, normal dental implants have been demonstrated to be susceptible to failure within the working range (Genna, 2003). In the present study, the direction of loading (mesial or distal) appeared to have no influence. The open coil spring generated two moments of force which could have caused a convergence of the screws at the top and a divergence at the base. However, this was



Figure 2 Loading of the bracket screw bone support anchors with a 200 cN coil spring force between the miniscrews inserted in the mandible.

 Table 1
 General overview of insertion and loss of the screws.

	Start		6 weeks		12 weeks		18 weeks		24 weeks		25 weeks	
	А	Р	А	Р	А	Р	А	Р	А	Р	А	Р
Dog 186												
Ř	+	+	+	+	+	+	+	+	+	+	+	+
L	+	+	+	+	+	+	+	+	+	+	+	+
Dog 187												
Ř	+	+	+	+	+	+	+	+	+	+	+	+
L	+	+	+	+	+	_	+	_	+	_	S	_
Dog 188												
Ř	+	+	_	+	_	_	_	_	_	_	_	_
L	+	+	_	_	_	_	_	_	_	_	_	_
Dog 189												
Ř	+	+	+	?	+	_	+	_	+	_	+	_
L	+	+	+	_	+	_	+	_	+	_	+	_
Dog 190												
Ř	+	$^+$	_	_	_	_	_	_	_	_	_	_
L	+	$^+$	_	_	_	_	_	_	_	_	_	_

A, anterior insertion; P, posterior insertion; ?, loose screw; and S, unscrewed to check for ease of screw removal.

not observed clinically. In this study, the BSBAs were placed in the mandible between P2/P3 and P3/P4 in an area of good bone quality (Figure 1) and no differences in osseointegration were found between anterior or posterior sites.

Recently Huja *et al.* (2005), in an experimental animal study in beagle dogs, reported that screws placed in the anterior mandibular region were easier to remove but this was not confirmed in the present study. A full bonded interface can transfer both compressive and tensile stress as well as shear stress. It was shown that if the BSBA was inserted in a mandible with normal bone quality, but insufficient height for normal implant insertion and loaded with orthodontic forces, partial osseointegration was present. The overall mean osseointegration of all screws was calculated at 74.48 per cent (\pm 15.63 per cent).



Figure 3 Histological scan coloured with toluidine blue under light microscopy (\times 40). Ideal insertion of the bracket screw anchorage is shown with 100 per cent osseointegration indicated by arrows (C: cementum, R: root, B: bone, PDL: periodontal ligament, HC: haversian canals). The red arrow indicates a small bone defect where no osseointegration was achieved. The distance between the screw and intact periodontal ligament is depicted by a ruler (2.66 mm).



Figure 4 Scan under a fluorescence microscope. The calcein green staining is clearly visible round the bracket screw bone anchor (BSBA). Xylenol orange staining surrounds the BSBA further away. Note the intact periodontal ligament associated with central insertion of the screw in the alveolar process (B: bone, S: miniscrew, PDL: periodontal ligament).

Calculation of the mean osseointegration for all screws was possible as there were no significant differences with respect to loading time or site (P > 0.05). The findings of bone-to-implant contact are comparable with previous animal studies (Zubery *et al.*, 1999; Nkenke *et al.*, 2003). No significant differences (P > 0.05) were seen in the percentage of bone-to-metal contact between the loaded and unloaded BSBAs. In an experimental study using rabbits to compare the amount of bone in the immediate surroundings of the marginal part of implants, Duyck *et al.* (2001) found a significantly lower bone volume (density)

	Category 1	Category 2	Category 3 (a)	Category 3 (b)
RA2	76 71		69.16	47 34
RA3	68.07		69 99	72.65
RA4	42.28		81.05	90.83
RA5	80.28		79.05	89.96
RA6	88.72		19:00	07.70
LA2	84.08	74 23		
LA3	97 44	60.45		
LA4	75.69	66.3		
LAS	83.46	76.91		
LAG	05.10	89.81		
RP2		09.01	38 11	78 91
RP3			60.67	59.32
RP4			84 23	95.11
RP5			64 58	68 31
LP2		52 34	01.00	00.51
LP3		92.13		
I P4		100		
LP5		74 33		
Mean	76.66	76.27	71.83	

Category 1, no loading; category 2, immediate loading; and category 3, loading after (a) 6 and (b) 12 weeks, and localization of insertion: RA, right anterior; LA, left anterior; LP, left posterior and RP, right posterior.



Figure 5 Mean osseointegration relative to loading time and insertion sites. Category 1: no loading, category 2: immediately loaded, and category 3: loaded after 6 or 12 weeks.

around the dynamically loaded implants compared with those which were statically loaded or controls (not loaded).

Loss of the BSBAs was partly due to the study set up and partly to the design of the screw. Ten screws were lost in this research, eight of them due to lack of primary stability. Primary stability seems to be a key issue for success. A loss of 20 to 30 per cent has been reported in the literature depending on whether the screws were sited in the upper or lower jaw (Miyawaki *et al.*, 2003; Cheng *et al.*, 2004; Buchter *et al.*, 2005). It was found that the BSBAs were easily removed 6 months after insertion and this is important for patient comfort (Wehrbein et al., 1996b). A possible explanation for this is the small diameter of the screw and the fact that the screw is present in bone which exhibits a spongy texture. These findings indicate that the resistance to unscrewing is dependent on the amount of compact bone surrounding a titanium implant and are in accordance with those from the literature where the influence of diameter on the integration of titanium screw-shaped implants was studied in the rabbit tibia by means of removal torque measurements and histomorphometry (Duyck et al., 2001). The relationship between implant diameter and removal torque has been investigated in several studies (Albrektsson and Sennerby, 1991; Sennerby et al., 1992; Ivanoff et al., 1997). Biomechanical tests showed a statistically significant increase in the removal torque with increasing implant diameter. The resistance to shear seems to be determined by the implant surface in supportive cortical bone, whereas the newly formed bone at the periosteal and endosteal surfaces does not seem to have any supportive properties after 12 weeks. It has been suggested that wide diameter implants might be used clinically to increase implant stability (Albrektsson and Sennerby, 1991).

BSBAs are not intended to remain permanently in the bone and should be relatively easy to remove, which was confirmed in the present study. The extent of osseointegration was investigated microscopically by studying the appearance of the bone which was in close proximity to the screw. Microscopic evaluation also showed crater-shaped defects lateral to the osseointegrated screws. Biocompatibility, design, surface conditions of the screw, the status of the host site, the surgical technique at insertion, and the loading conditions were favourable for bone development around the screw. Analysis of these data indicated that small titanium screws were able to function as rigid osseous anchorage against orthodontic load for 12-24 weeks with a minimal healing period in the mandible of beagle dogs. However, the individual situation has to be examined carefully as, even with immediate loading, osseointegration was observed.

Conclusion

The following conclusions may be drawn:

- 1. The BSBAs which were analysed microscopically showed osseointegration in the mandible of beagle dogs.
- 2. There was no difference in the extent of osseointegration between the buccal or lingual side or at the top or base of the screw (P > 0.05).
- Osseointegration of BSBAs is independent of whether loading was immediate or delayed.
- 4. Orthodontic loading of BSBAs appears to have no influence on osseointegration.

- 5. Osseointegration appears to be independent of the location of the screw.
- 6. The screws were easy to remove after 6 months of loading with orthodontic forces.
- Early loss of BSBAs (within 6 weeks) was due to lack of primary stability.

Further histological and biometrical studies, in a larger set-up, are needed to support the present findings.

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