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Bone-to-implant contact of orthodontic implants in humans—a histomorphometric investigation

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SUMMARY The purpose of the present study was to evaluate the percentage of direct bone-to-implant contact (BIC) of orthodontic anchorage implants (Orthosystem) after active orthodontic treatment.

Twenty orthodontic implants (diameter, 3.3 mm; length, 4 or 6 mm) were inserted for orthodontic anchorage in different anatomical regions of 18 adult patients (nine males, nine females) aged 18–63 years. Fifteen implants (one per patient) were placed in the mid-palatal area, one implant (one patient) in the retromolar area of the mandible, one in the retromolar area and the mid-palatal area (one patient), and two (bilaterally, one patient) in the zygomatic area. The duration of the unloaded healing period was 3 months while that of the loading period ranged from 9 to 22 months. Subsequently, the implants were removed with a bone drill and prepared for histological and histomorphometric evaluation. Histological analysis was performed using the ground thin-section technology. Outcome variables were clinical implant survival and BIC rates. Statistical evaluation included analysis of the measured values, minimum, maximum, means, and standard deviations of the means.

The mean percentage of direct BIC at the endosseous implant body was 68.22 per cent for the palatal implants [n = 16, standard deviation (SD): 14.35], 64.85 per cent (SD: 2.89) for the retromolar implants (n = 2), and 60.45 per cent (SD: 0.49) for the zygomatic implants (n = 2). A relatively high BIC was registered at the surfaces of the loaded implants. This finding might favour the maintenance of osseointegration during orthodontic loading of length-reduced implants.

Introduction

Anchorage is the primary problem in the treatment of dental and skeletal dysgnathia. Depending on the goal of therapy in the individual patient, orthodontic treatment is first orientated to the biological anchorage quality of the teeth (Diedrich, 1993; Bernhart *et al.*, 2001). Particularly in subjects with complex anchorage conditions, such as those with partially edentulous jaws or impaired quality of dental anchorage (Ödman *et al.*, 1991, 1994; Diedrich, 1993; Wehrbein *et al.*, 1998), additional conventional intra- and/or extra-oral anchorage aids are needed. The use of these appliances is frequently associated with poorly defined magnitudes and moments of force.

Temporary skeletal orthodontic anchorage elements such as palatal implants were developed to achieve stable and maximal anchorage in complex anchorage situations. A prerequisite for the sustained success of such implants is bony anchorage of the implant body by immediate contact between the implant surface and peri-implant bone at the cellular level. Osseous anchorage should be ensured not only at the beginning but also during the entire course of orthodontic treatment with orthodontic forces (Shapiro and Kokich, 1988; Schweizer *et al.*, 1996; Melsen and Costa, 2000; Aldikaçti *et al.*, 2004). Unstable connective tissue healing (Wehrbein and Diedrich, 1993; Wehrbein, 1994, 2003) is undesirable and may lead to dislocation or premature loss of the anchored implant under functional loads. Data from clinical studies and animal experiments have confirmed the reliability and success potential of these implants (Turley *et al.*, 1988; Roberts *et al.*, 1989; Haanæs *et al.*, 1991; De Pauw *et al.*, 1999; Melsen and Lang, 2001; Borbély *et al.*, 2008).

However, histological studies concerning the success rate of osseointegration in humans of enossal implants for orthodontic anchorage are scarce (Wehrbein *et al.*, 1998).

The aim of the present histological and histomorphometric study was to analyse the percentage of direct bone-to-implant contact (BIC) of 20 human palatal implants (Orthosytem, Straumann, Basel, Switzerland) with a sandblasted and acid-etched (SLA) surface, retrieved from patients who had undergone active orthodontic treatment. A further aim was to determine the quantity of bone contact required to maintain osseointegration.

Subjects and methods

Subjects

The study comprised 18 healthy patients aged 18–63 years (nine females and nine males) who had undergone orthodontic treatment for correction of a Class I (n = 2), Class II (n = 13), or Class III (n = 3) malocclusion. In all patients, the proposed orthodontic treatment required

maximal anchorage conditions. The orthodontic indication for implant placement was established according to the existing anchorage situation (Table 1).

The study was approved by the Ethics Committee of Rhineland-Palatinate.

Ortho-implant

The Orthosystem developed by Wehrbein *et al.* (1996a,b) was used for implantation. Fifteen palatal implants (one per patient) were inserted in a mid-palatal location, one implant (one patient) in the retromolar area of the mandible, one in the retromolar area and mid-palatal area (one patient), and two implants (bilaterally, one patient) in the zygomatic area. Figure 1a–c provides a summary of the various sites of insertion. The endosseous section (diameter, 3.3 mm) has a self-tapping thread with a SLA surface. It is available in lengths of 4 and 6 mm, depending on the volume of available vertical bone.

Surgical insertion and removal

The implants, either 4 or 6 mm, were inserted by the same surgeon in the above anatomical locations according to the manufacturer's instructions. In the region of the proposed site of insertion, such as the palate, the mucosa was removed with a punch. The compact bone in the palate was granulated with a round bur and the length of the implant site (4 or 6 mm) was prepared with a profile drill. All procedures were carried out under copious irrigation with sterile physiological saline; the implants were inserted using the appropriate ratchet.

After completion of orthodontic treatment, the implants were explanted using a trephine bur accompanied by continuous cooling with physiological saline. This was performed in alignment with a cylinder which was screwed onto the implant, down to two-thirds of the implant length. The implant and a small layer of osseointegrated bone were removed by rotational movements.

Orthodontic treatment

The duration of the unloaded healing period was 12 weeks. The implant was fitted with a rotationally secure steel abutment coping (length, 3.6 mm; diameter, 5.0 mm) onto which orthodontic arches were fixed in position by laser welding. Depending on the individual anchorage situation, the implants were loaded with orthodontic forces of 2–6 N during active treatment. Direct (force system between the palatal implant and the desmodontal unit) as well as indirect (a rigid connection such as orthodontic wire, between the palatal implant and the anchor teeth) forms of anchorage were used.

Table 1 Distribution of patients with regard to type of malocclusion, anchorage, and orthodontic treatment.

Patient initials	Indication	Orthodontic treatment	Implant anchorage
AC	Maxillary retrognathism, Angle Class III	Maxillary protraction	Direct
AChr	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
AL	Angle Class II, impacted canine	Distalization of posterior teeth (bilateral, upper jaw), control of vertical dimension, cantilever mechanics for elongation of canine	Indirect
HB	Angle Class I (unilateral), mesiomigration of posterior teeth	Distalization of posterior teeth (unilateral, upper jaw, pre-operative)	Indirect
HE	Angle Class III	Mesialization of posterior teeth (unilateral), protraction of anterior teeth (upper jaw)	Indirect
HF	Angle Class II	Distalization of posterior teeth (bilateral, upper jaw)	Direct
HM	Angle Class I, tilted second molar	Uprighting of second molar (left, lower jaw)	Indirect
HN	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
KA	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
KS	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
KW	Angle Class II	Distalization of posterior teeth (bilateral, upper jaw)	Direct
LW	Angle Class II, extraction of 16, 26	Retraction of upper anterior teeth and premolars	Indirect
PG	Angle Class II	Distalization of posterior teeth (bilateral, upper jaw)	Indirect
PH	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
SA	Angle Class III, maxillary retrognathism	Maxillary protraction	Direct
SB	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth	Indirect
SM	Angle Class II	Distalization of posterior teeth (bilateral, upper jaw)	Indirect
TY	Angle Class II, extraction of 14, 24	Retraction of upper anterior teeth/distalization of posterior teeth (right, lower jaw)	Indirect implant anchorage

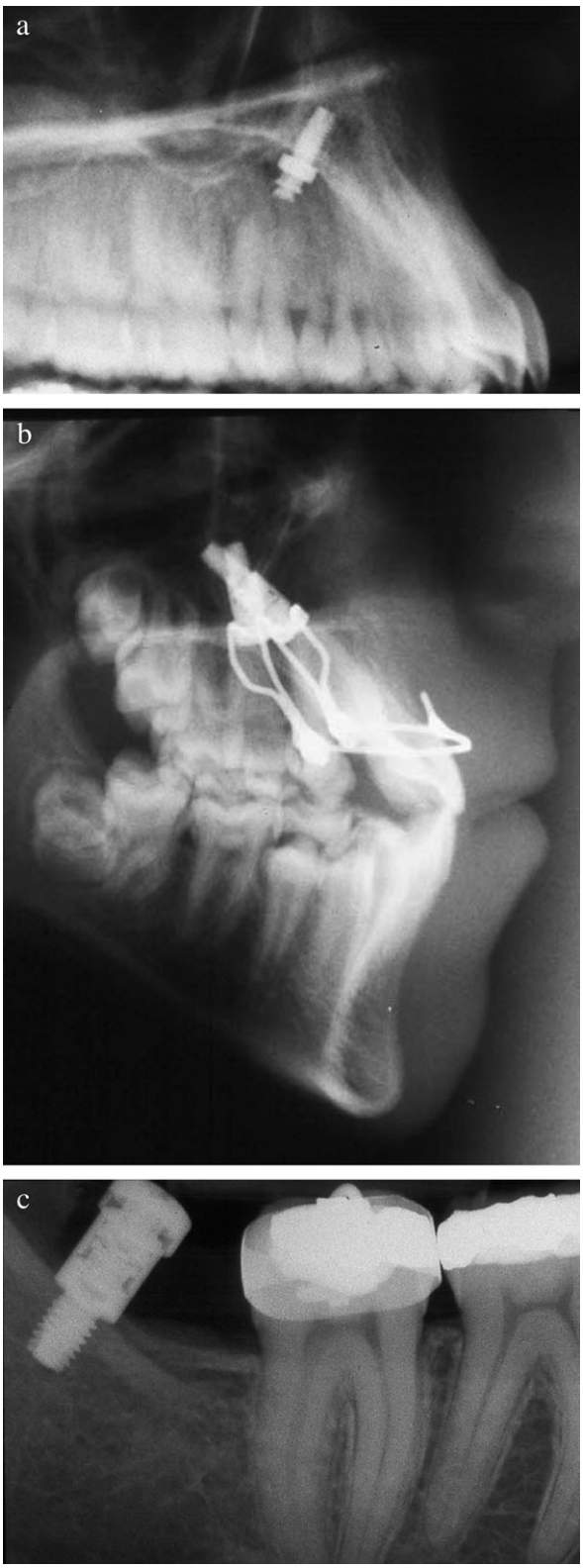

Figure 1 Various insertion sites. Lateral cephalograms (a) after median placement of a palatal implant and (b) after bilateral implant placement in the zygomatic area for maxillary protraction (patient SA); (c) radiograph after implant placement in the retromolar area for unilateral distalization of posterior teeth.

Specimens and histological processing

Depending on the size and thickness of the surrounding bone, the retrieved palatal implants were first placed in 10 per cent pH7 formaldehyde solution (Merck, Darmstadt, Germany), at room temperature, for 2–5 days. After thorough rinsing in isotonic buffer solution, the specimens were dehydrated in an ascending series of ethanol (70–100 per cent) and embedded in methyl methacrylate resin (K-Plast, Medium, Giessen, Germany). Polymerization was achieved by light curing with a light source with a 450 nm wavelength. The implants were then cut vertically along the longitudinal axis, using a high-precision 150 μm diamond disk. This was followed by grinding and polishing on a Microgrinding System (Exact, Norderstedt, Germany) according to the ground thin-section technology of Donath and Breuner (1982). From the centres of each implant, a separate thin section (with a final thickness of 20 μm) was selected for histomorphometric investigation. The sections were stained with toluidine blue for transmission light microscopy.

Histomorphometric assessment

Histomorphometric investigation of BIC was performed with a microscope (DMRX, Leica, Wetzlar, Germany) connected to an adapted colour video camera (Sony, Tokyo, Japan) interfaced with a computer-assisted morphometry system (Quantimed 600 S®, Leica, Cambridge, UK). Quantimed 600 S offers the possibility of viewing histological specimens through a microscope and visualize the selected portion of the image on a monitor. The software allows measurements to be undertaken, by simply moving the mouse, of the entire length of the thread profile and the part of the thread profile directly adjacent to bone visualized on the monitor. The ratio between BIC and the total length of the thread profile was expressed in percentage values. All specimens were measured a second time after 1 week by one investigator (FY).

Statistical analysis

Entry, assessment, and statistical analysis of data were performed using the Statistical Package for Social Science for Windows, version 12 (SPSS Inc., Chicago, Illinois, USA). Statistical analysis included the measured values, minimum, maximum, means, and standard deviations of the means. As the data concerning the investigated histological parameters were collected in a purely descriptive fashion, the evaluation was performed on the basis of absolute and relative frequencies.

Method error evaluation

In order to evaluate the method error, the BIC of all specimens was measured twice by the same operator. Based on the difference between the first and second measurement, the formula:

$$S = \sqrt{\Sigma(x_1 - x_2)^2 / 2n}$$

was used to assess the precision of the measurements. In general, the smaller the calculated value, the more exact the measurement. According to Dahlberg (1940), the method error should lie under the reference value of 1.0 in order to achieve sufficient accuracy. The method error was 0.21 per cent below this reference value.

Results

Implant survival and morphometric results of osseointegration (BIC)

All palatal implants were clinically stable and no mobility was registered during active orthodontic treatment. No complications were encountered during surgical insertion or removal.

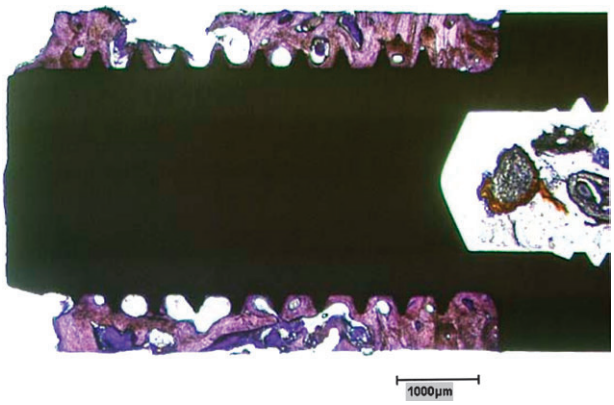

Figure 2 Histological presentation of bone-to-implant contact of an orthodontic implant inserted in the mid-palatal area (patient SM; dimensions: 3.3 × 6 mm) used in the present study. Toluidine blue, original magnification ×4.

The percentage of direct BIC (Figure 2, Table 2) was, on average, 68.22 per cent [standard deviation (SD), 14.35] for the mid-palatal implants (n = 16; range, 42–91.5 per cent; median 67.45 per cent).

Retromolar implants in the mandible (n = 2) showed a slightly lower percentage of direct BIC (range, 62.8–66.9 per cent; median and mean value, 64.85 per cent; SD 2.89).

Specimens of the zygomatic implants (n = 2) revealed a direct implant-bone interface of 60.1 (minimum) to 60.8 (maximum) per cent (mean and median value, 60.45 per cent; SD 0.49).

Bone contact to the implant shoulder

On histological investigation, the mid-palatal implants occasionally revealed no contact between the implant shoulder and the bony surface, resulting in a gap of 0–2.11 mm; the mean value was 0.91 mm (SD, 0.60) and the median value 0.83 mm.

In contrast, this distance for the zygomatic implants (n = 2) in the upper jaw as well as for those in the lower jaw was 0 mm (Figure 3).

Discussion

Palatal implants used for orthodontic anchorage are subject to specific requirements (Wehrbein *et al.*, 1996b; Wehrbein, 2003). Osseointegration offers sufficient stability not only at the beginning of insertion but also when loaded with orthodontic forces and subjected to the biomechanics of active orthodontic tooth movement (Roberts *et al.*, 1989; Ödman *et al.*, 1991; Wehrbein, 2003). Osseointegration is defined as the 'direct structural and functional connection

Table 2 Bone-to-implant contact (BIC) rates of orthodontic implants in the palate, zygomatic and retromolar areas. 'Distance' refers to the distance between the implant shoulder and the bony surface.

Patient, initials and gender	Site of implantation, aspect of section (right/left)	Implant insertion depth in mm	BIC fraction (%)	Distance in mm
AC, female	Palate	6	59.2	0.7
AChr, male	Palate	6	68.1	0.85
AL, male	Palate	6	64.5	2.03
HB, female	Palate	6	87.3	0.83
HE, male	Palate	6	55.9	0.72
HF, male	Palate	4	80.3	0.62
HM, female	Retromolar, left	4	66.9	0
HN, male	Palate	6	42.0	2.11
KA, female	Palate	6	66.8	1.51
KS, female	Palate	4	68.2	0
KW, male	Palate	6	77.1	0.84
LW, male	Palate	6	89.6	0.51
PG, female	Palate	6	62.4	0.62
PH, female	Palate	6	51.7	1.2
SA, male	Zygomatic area (right/left)	4/6	60.8/60.1	0/0
SB, female	Palate	6	53.1	1.25
SM, male	Palate	6	91.5	0
TY, female	Palate, retromolar, right	4	73.9 (retromolar: 62.8)	0.85 (retromolar: 0)

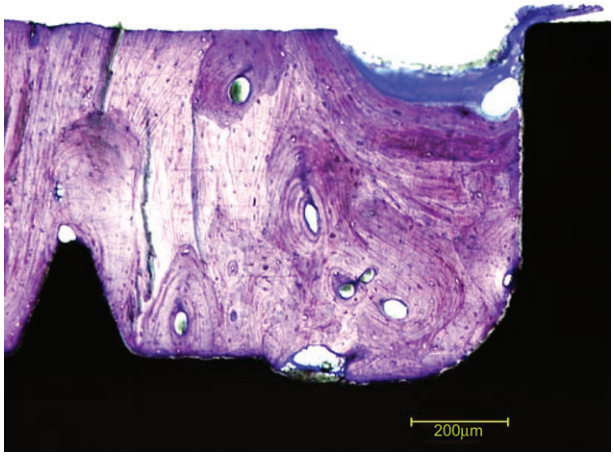

Figure 3 An orthodontic implant inserted in the retromolar area of the mandible (patient HM; dimensions: 3.3 × 4 mm). Tight contact between the implant shoulder and crestal bone can be observed. Toluidine blue, original magnification ×25.6.

between organized, living bones, and the surface of the loaded implant' (Brånemark *et al.*, 1977). In an ideal scenario, complete coverage of the implant surface with bone tissue is desirable. However, because the orthodontic anchoring element is temporary, such complete coverage is clinically not an absolute precondition. Incomplete endosseous integration is sufficient for clinical purposes as long as rigid anchorage is guaranteed (Ohmae *et al.*, 2001). The histological results of the present investigation show that all palatal implants were well integrated into bone although they had been subjected to orthodontic loads (2–6 N) for a longer period of time and 100 per cent bone coverage was lacking. These findings are in agreement with those of Roberts *et al.* (1989), Wehrbein and Diedrich (1993), Melsen and Lang (2001), Ohmae *et al.* (2001), and Aldikaçti *et al.* (2004). Based on clinical and mainly experimental investigations, these studies provide histological evidence of osseointegration for endosseous titanium implants as orthodontic anchorage elements.

However, the design of palatal implants in combination with a self-tapping thread and SLA surface appears to provide sufficient stability under orthodontic loading conditions when inserted in the palatal, zygomatic, or retromolar regions. Furthermore, the shorter length of the palatal implants compared with conventional implants permits their application in regions with limited bone (such as the palate). The integrity of the adjacent anatomical structures is not compromised.

Particularly, the SLA surface has been shown to integrate more in conventional implantology studies. Buser *et al.* (1991) found that, compared with other titanium surfaces (such as sprayed titanium plasma), the SLA surface showed the highest BIC contact after 3–6 weeks of healing. Cochran *et al.* (1998) confirmed these results and suggested that the healing period for implants with a SLA surface could be shortened because of the significantly greater percentage of BIC observed for this implant. These findings were based on experimental animal studies and histological evaluation. An unloaded healing period of 12 weeks may be recommended for palatal implants.

In the present study, direct BIC of 68.22 per cent (SD, 14.35) was registered for the palatal implant group and 64.85 per cent (SD, 2.89) for implants in the retromolar area of the lower jaw. Comparable, yet slightly higher BIC rates were reported by Wehrbein *et al.* (1998) in a clinical study on humans, based on histological evaluation of retrieved Orthosystem palatal implants after orthodontic treatment. The percentage of direct BIC ranged from 34 to 93 per cent (mean, 75.5 per cent). For implants in the palatal area, Wehrbein *et al.* (1998) reported a mean BIC of 79.3 per cent. The BIC for implants in the retromolar area of the lower jaw was 68 per cent under loading conditions with orthodontic forces (2–6 N) after an unloaded healing period of 3 months. The BIC values in the present study for the palatal implant group and for implants in the retromolar area of the lower jaw were somewhat lower than those found by Wehrbein *et al.* (1998). Nevertheless, higher percentages of direct implant-bone interface for the palatal implant group was observed compared with implants in the retromolar area of the lower jaw.

Between the implant shoulder and the marginal bone surface, Wehrbein *et al.* (1998) also registered a mean gap of 0.94 mm for implants in the mid-palatal suture area. Implants inserted in the maxilla (median palatine suture) showed an average distance of 0.91 mm. With regard to bone contact of the implant shoulder, the distance between the implant shoulder and the bony surface resulted in a less accurate insertion technique in the palatal than the retromolar area of the mandible. Thus, comparison of surgical insertion in the mandible revealed a reduced insertion depth in the region of the palate. The extent to which poor bone resorption contributed to the histological findings cannot be accurately stated. However, bone integration was sufficient for orthodontic anchorage in the palatal region. All 16 implants inserted in that area, including the implant with 42 per cent BIC, were clinically stable. None were lost before completion of active orthodontic treatment.

Conclusions

The following conclusions may be drawn from the present study comprising 20 orthodontic anchorage implants:

1. Implants measuring 4 or 6 mm in length, used for orthodontic anchorage, are suitable to establish and maintain osseointegration and thus stabilize their position.
2. A BIC of 42 per cent would be sufficient to establish and maintain osseointegration.
3. Incomplete bone coverage of the implant in the marginal area (contact of the implant shoulder to the bony surface) does not lead to loss of osseointegration.

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