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Alveolar bone preservation subsequent to miniscrew implant placement in a canine model

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Structured Abstract

Objective – To assess the effects of transcortical screws on alveolar (bone) ridge preservation following extraction.

Design – Four adult beagle dogs had mandibular premolars extracted bilaterally. After 6 weeks, using a split-mouth design, two transcortical screws were inserted unilaterally below the alveolar crest on the experimental side in the region of the extraction. The dogs were killed after 12 weeks. The bone at the extraction sites was analyzed using μCT and 3D analysis. A cylindrical core was placed around the actual and a virtual screw placed in the identical location on the control side. The bone volume within the cylinders was quantified. An insertion of a dental implant was simulated bilaterally at the insertion site. The height of the clinical crown and the alveolar crest were determined on both sides. The bone turnover was assessed histomorphometrically on un-decalcified buccolingual sections stained with basic fuchsine and toluidine blue.

Results – Comparison of the two sides revealed a significant difference both with regard to the bone volume and morphology. The transcortical screw caused an increase in bone density and less ridge atrophy. When simulating a dental implant placement on both sides, the bone preservation on the experimental side led to a need for a shorter clinical crown compared to the control side. A higher activity level of the bone in the experimental side was demonstrated histologically.

Conclusion – In this dog model the insertion of a mini-implant across the healing alveolar process results in increased density not only adjacent to the screws, but also in the region where a potential dental implant would be inserted. In humans, the insertion of transcortical screws may maintain bone when for various reasons insertion of a permanent dental implant has to be postponed.

Key words: alveolar bone; atrophy; implants; TADs

Introduction

The tissue reaction adjacent to temporary anchorage devices (TADs) has been subject to a number of studies. Many of the studies have been conducted on animals to assess the bone density and bone-to-implant contact using histomorphometric analyses (1). Most of these studies have been performed to identify factors of importance for the long-term stability of TADs under loading (2). It has, however, also been suggested that TADs could be used as support for temporary restorations until growth has ceased thus allowing for the delay in placement of the final restorative implant in patients with remaining growth (3, 4). The delay in placement of the restorative implant is based on the observation that implants inserted in growing individuals do not follow the continuous eruption of the adjacent teeth and thus appear submerged (5, 6). While the TADs are not osseointegrated on a microscopic level, they cannot follow the development of the alveolar process during eruption of the adjacent teeth either. Thus, such TAD-borne pontic as a temporary replacement cannot be recommended. While 'successful' short-term treatments have been published, it is obvious from the published images (7) that even in these cases the bone surrounding the implant does not follow the vertical bone development of the adjacent teeth. The vertical development is very variable, and there may still be cases where such a use of the TAD will be successful, but there are no objective data on long-term effects of using TAD supported temporary restorations, and there is currently disagreement on whether or when they should be used. The influence of the presence of loaded and unloaded mini-implants on the alveolar bone has been studied by means of both histomorphometry and micro-tomography in several animal experiments (1, 8).

TADs are typically removed after having served as orthodontic anchorage. In a patient with agenesis of 6 premolars, treated at the Orthodontic Department at Aarhus University, one of two transcortical screws in the lower premolar region, used as anchorage for protraction of the molars, was inadvertently left following treatment (Fig. 1) (5). At an observation recall of 1 year, it was observed that on the side where the mini-implant was left in place both the height and the width of the alveolar process in the edentulous area was larger than in the contralateral side where the screw had been removed. The same tendency was seen in another patient with bilateral agenesis of upper lateral incisors. As there was a need for a

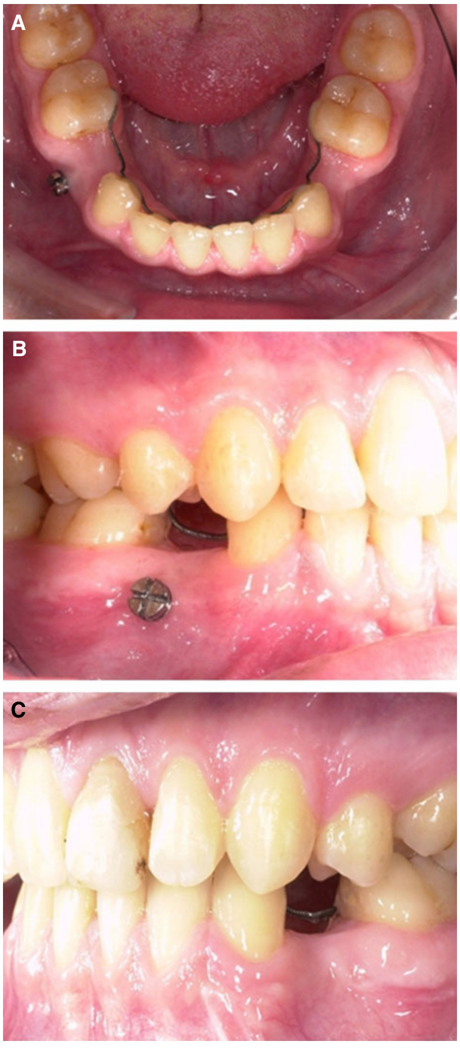

Fig. 1. Clinical pictures (A–C) of a patient suffering from agenesis of 6 premolars. The spaces were closed in the upper arch with temporary anchorage devices (TADs) as anchorage, and in the lower arch, the molars were displaced mesially with TADs placed transcortically in the region of the first premolar as anchorage. Following the space closure, the TAD was removed on one side, but for unknown reasons, it was forgotten in the opposite side. At a 6-month control, it was clear that the alveolar process where the screw had been removed was atrophic, whereas both height and width were retained where the screw was still present.

C-anchorage on one side, only one transcortical mini-implant was inserted, whereas on the other side traditional non-skeletal anchorage was used. CBCT images indicated a higher density of bone on the side where the TAD had been inserted and served as anchorage for a mesial movement of the posterior segment. Based on these observations, it was decided to test the hypothesis that the presence of a screw would maintain bone following extraction. This was carried out in a split-mouth study on dogs assessing how the presence of an unloaded implant or transcortical screw would influence the modeling of the alveolar bone following extraction.

Material and method

Animal husbandry and experimental design

Institutional animal care and use committee approval was obtained for all protocols. Four 1- to 2-year-old male beagle dogs were obtained. One week after acclimatization, the animals were scheduled for extractions. Two premolars, P2 and P3, were extracted bilaterally in the mandible. All surgeries were conducted at the University Laboratory Animal Resources at the Ohio State University Surgery Suite utilizing aseptic technique. A muco-periosteal flap was reflected on the buccal aspect to expose the coronal 1/3 of the root, the tooth was elevated, the crown was hemi-sectioned and each root was extracted separately. Absorbable 4–0 sutures (Ethicon, Somerville, NJ, USA) were placed across the incision and extraction site. At the time of surgery, each dog was sedated with acepromazine (2 mg), anesthetized with ketamine (100 mg)/diazepam (5 mg) I.V., intubated, and maintained on isoflurane (2.0–2.5%). Lidocaine HCl 2% with 1:50 000 epinephrine (0.5 cc) was infiltrated at each surgical site for hemostasis. After surgery, all dogs received buprenorphine (0.12 mg) prior to recovery from anesthesia or had a transdermal fentanyl patch placed the day prior to surgery. Oral amoxicillin (250 mg) was administered at 12 h pre-surgery and then every 12 h post-surgery for 5 days. Six weeks post-extraction, two self-drilling surgical screws with a diameter of 1.5 mm and an intra-osseous length of 6.5 mm (Medicon eG, Tuttlingen, Germany) were placed unilaterally with the side being randomized by dog. A 1 mm pilot hole was drilled approximately 3–4 mm from the anticipated crest of the healing ridge followed by the insertion of a self-drilling mini-screw perpendicular to the monocortical plate (Fig. 2).

At the end of the observation period of 12 weeks, the dogs were killed by means of intravenous sodium pentobarbitone overdose. Both jaws were excised and after removal of the soft tissues cut into separate blocks of bone tissue around the mini-implants. After fixation in 70% ethanol, the specimens were sequentially dehydrated and embedded in methyl methacrylate and subsequently processed for micro-computed tomography (micro-CT).

Micro-CT and virtual probing

Micro-CT-scans (uCT40, Scanco Medical AG, Brüttisellen, Switzerland) of each tissue block were made with a pixel size and interslice distance of 36 μm. The single-slice images were exported in DICOM format and read into image analysis software (Mimics 15.0, Materialise®, Leuven, Belgium).

For the jaw section samples containing mini-screws, first a global segmentation was performed to select the hard tissues (bone and teeth) and the mini-screws by creating so-called overlay masks, thereby identifying these materials in the single-slice images. From these masks,

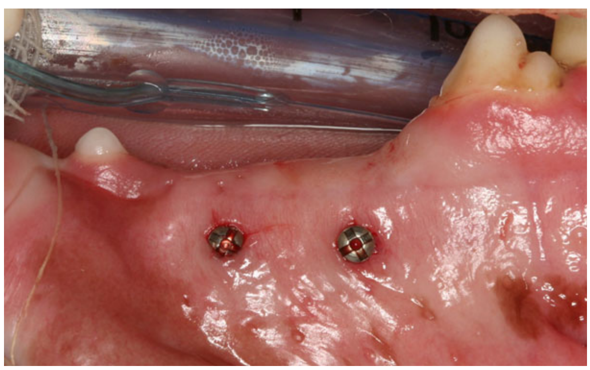

Fig. 2. Miniscrew implants (MSIs) placed at 2–3 mm under the alveolar crest. The implants are placed in movable mucosa. The screws did not have an orthodontic attachment.

3D surface objects were generated, one representing the hard tissues and the other the mini-screw. To delineate the region of interest (ROI_s), a virtual cylinder with a diameter of 3.5 mm thus comprising a ring with a width of 1 mm around the mini-screw's outer diameter was created. The length of the ROI_s was chosen to be equal to the mini-screw's intra-osseous length. Using a Boolean intersection operation with the hard tissue object, the bone tissue inside the ROI_s could be isolated and its volume automatically calculated by the above mentioned software (Fig. 3). In order to be able to perform a paired comparison of the experimental and the control side, digital copies of the 3D mini-screw and ROI_s objects were virtually inserted into the 3D models of the jaw segments of the contra-lateral (control) side. To position and orientate the screw copy (and corresponding ROI_s) as close as possible to the location as the actual screw, a set of three reference planes were constructed. The first plane was defined by three points on the 3D model of the jaw segment: 1) the apex of the crown present in the section (Pnt. 1); 2) the lowest point of the mandible in the same single-slice image, which featured Pnt. 1 (Pnt. 2); and 3) the most prominent point on the crown of the tooth in the direction of the screw (Pnt. 3). This plane was defined as a sagittal plane. The second plane was perpendicular to the first plane through Pnts. 1 & 2, and defined as the frontal plane. The third plane was perpendicular to both previous planes through Pnt. 3 and would thus represent the occlusal plane (Fig. 4). By indicating the center of the tip and head of the screw and automatic determination of the

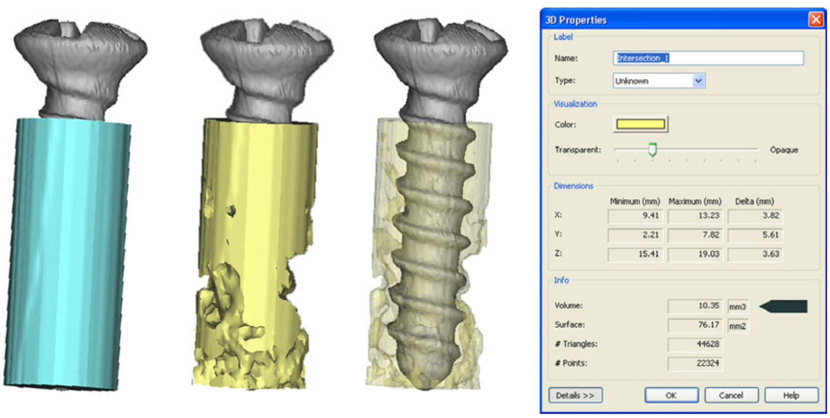

Fig. 3. The principle of the virtual probe. Using a Boolean intersection operation between the cylindrical ROI (left) and the jaw bone results in the bone present inside the ROI (middle). A subsequent Boolean subtraction operation with the MSI itself (right) results in a 3D object representing the amount of bone present around the screw inside the ROI. The image analysis software provides the properties of this 3D object, of which the volume (black arrow) is used for further analysis.

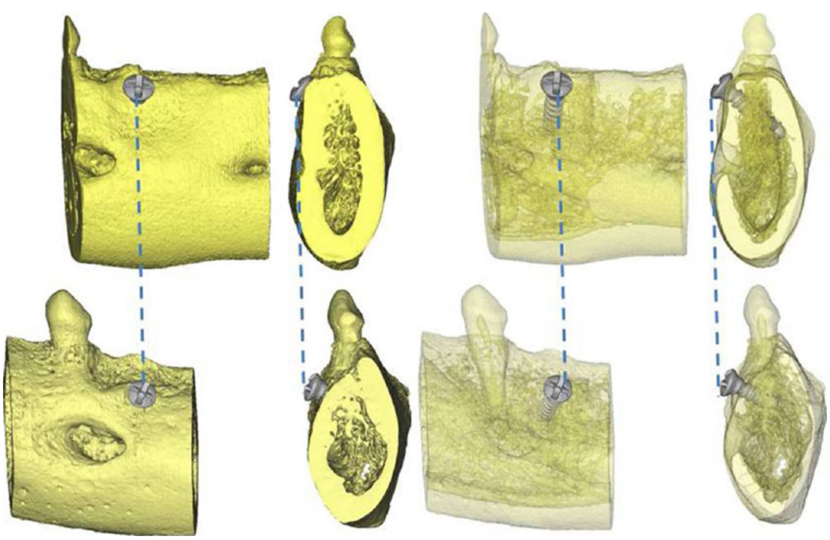

Fig. 4. Overview of the three reference planes used to ensure that the placement of virtual MSI closely approximates the contralateral position of the actual MSI: the sagittal plane (green), the frontal plane (blue), and the occlusal plane (red). The distances of the head and tip of the actual and virtual MSI to these three planes are within 1 mm of each other.

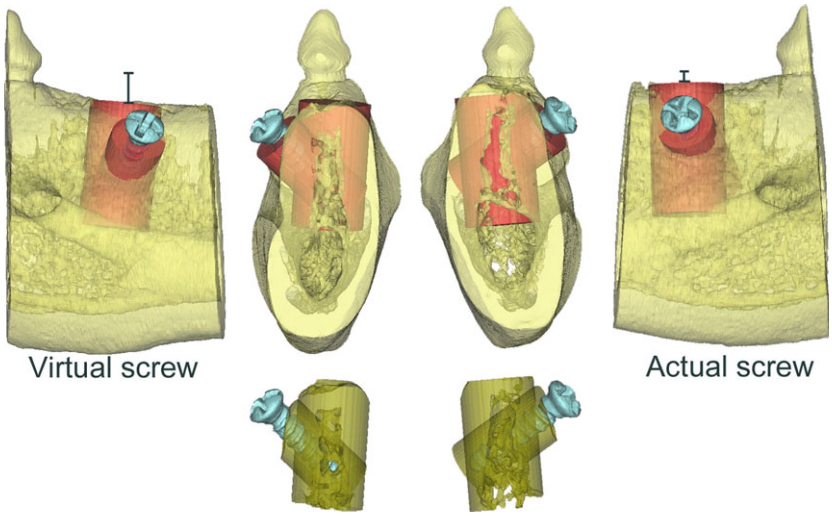

Fig. 5. 3D reconstructions of a jaw segment containing an MSI (right) and the contralateral segment containing a virtual MSI (left). In both the screw, ROI (red) and the implant ROI (orange) are shown. The black bars denote the height difference between the levels at which the implant ROIs were placed relative to the cement/enamel junction of the tooth. At the bottom, the amounts of bone present in the ROIs are shown.

distances of these two points to the three planes, the virtual screws could be positioned to within 0.5 mm of the original location at the contralateral side. The corresponding amount of bone inside the ROI_s on the control side was determined.

A second cylindrical region of interest (Ø 4.5 mm, length 8 mm) was constructed to represent the region where a possible future dental/restorative implant might be inserted (ROI_i). The ROI_i was virtually positioned in the mesio-distal aspect at the site of an inserted mini-screw and vertically at a level that allowed the full bone coverage of the implant. A digital copy of the ROI_i was virtually inserted with the same orientation at the control side (where now a virtual screw was inserted). The amount of bone in this ROI_i was also calculated after a Boolean subtraction of the screw and a subsequent Boolean intersection with the hard tissue object. Finally, the cervical level of the ROI_i both on the screw side and the corresponding control side was measured as the distance to a plane parallel to the occlusal plane (third of the three planes mentioned above), indicating the height of a future implant-borne crown (Fig. 5). Also the height of the alveolar crest at the level of the ROI_i was measured at the screw and control sides.

As the validity of the findings could be influenced by the threshold level, the reproducibility of the findings was assessed by applying both higher and lower threshold values.

Histological examination

Following the micro-CT scanning, 70 μm thick bucco-lingual un-decalcified bone sections, parallel to the long axis of the mini-implant, were produced from each embedded specimen by means of a Leiden saw (KDG-95, Meprotech BV, Heerhugowaard, The Netherlands) and stained with toluidine blue and basic fuchsine (Fig. 6). The total bucco-lingual area of the alveolar process was computed using software (cellSens, Olympus Danmark A/S, Ballerup, Denmark) for

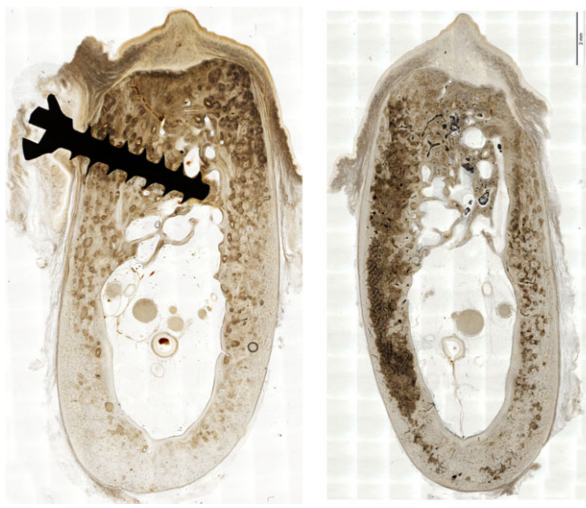

Fig. 6. Comparison of a un-decalcified basic fuchsine stained histological section of the mandible containing an MSI (left) and the corresponding contralateral control (right) side (without implant). Bone surrounding the screw is observed along the entire length of the implant. The implants are placed 2–3 mm away from the alveolar crest.

measurements of areas, and the maximum height of the mandibular corpus was determined using the same software. Histomorphometric analyses of the stained sections were performed using an Olympus BX51 microscope (Olympus) equipped with an integrating reticle (Carl Zeiss, GmbH, Oberkochen, Germany) at a magnification of $\times 100$, under visible light. As a reflection of the bone dynamics, the relative extension of osteoid and osteoclast covered surfaces were determined at identical sites.

Statistics

The measurements obtained from the 3D virtual probing and the histomorphometric analysis on the screw and control sides were compared using a nonparametric 2-related samples Wilcoxon signed ranks test, assuming statistical significance at a level of $p \leq 0.05$.

When the error of the measurement on the virtual images was assessed by changing the threshold level, the significance levels did not change.

Results

Clinical

The healing of the miniscrew implants (MSIs) was uneventful. All screws in the mandibles were retained to the end of the study. Soft tissue overgrowth had occurred over many of the MSI's.

Micro-CT

Micro-CT scanning and 3D image analysis revealed that the tissue reaction was influenced by the presence of the screw in the region (Table 1). There was a significantly larger amount of bone present in the ROI_s around the actual screw compared to the virtual screw on the control side ($p = 0.012$). A similar result was found for the ROI_i representing the location for a future dental implant ($p = 0.012$), although the relative increase in volume fraction when comparing the screw and control sides was less than for the ROI_s.

We evaluated whether the level of the threshold for the mineralized tissue had an influence on the results above. The measurements were repeated by applying both an upper and lower limit of the threshold value. The representation of the hard tissue for these extreme threshold values was clearly not optimal, albeit that the artifactual holes (in case of the upper limit) and excessive noise (in case of the lower limit) were still not overly disturbing, when creating the 3D objects. The influence of the chosen threshold value was maximally 2.4 mm^3 for the amount of bone present in the ROI_s and 6.3 mm^3 for the amount of bone in the ROI_i. Both for the upper and lower threshold values, there was significantly more bone present in both ROI_s and ROI_i on the screw side compared to the control side. For the lower threshold, the significance values both were $p = 0.012$. For the upper threshold, these values were 0.017 and 0.012, respectively (Table 1).

When comparing the level at which a dental implant would have had to be positioned, it was generally found to be lower on the control side than on the screw side due to the developing atrophy of the alveolar process of the extraction site on the control side. This applied in particular to the mesial ROI_i, for which differences in height approximated 1.5 mm. For the distal ROI_i, this was less clear. The height on the alveolar crest, on the other hand, was significantly larger on the screw side compared to the control side (Table 1).

Histomorphometry

The parameters obtained by histomorphometry demonstrated a significant difference in the total bucco-lingual area of the alveolar process with the screw side being significantly larger than the control side ($p = 0.028$) (Table 2). Also there was a tendency, albeit not significant, for a higher turnover of the bone on the screw side than on the contralateral side (Table 3) (Fig. 7).

Discussion

The present study was following the classical format for scientific progress: observe, hypothe-

Table 1. **Bone volumes for the individual animals at the screw and control side in the different regions of interest and at different threshold values, together with the implant and crest heights for the mesial and distal ROI_i**

	Animal ID	3605		3606		3607		3608		
	Threshold	Screw	Control	Screw	Control	Screw	Control	Screw	Control	*p*-Value
Bone volume	Low	46.6	43.1	49.8	46.7	46.1	40.5	46.1	40.7	0.012
Mesial screw ROI_s (mm^3)	Optimal	44.9	40.8	48.2	43.3	42.9	37.1	42.3	37.5	0.012
	High	42.4	37.9	43.1	40.3	38.5	33.2	37.0	34.3	0.017
Bone volume	Low	47.6	37.4	43.4	41.8	39.1	36.6	44.8	36.7	
Distal screw ROI_s (mm^3)	Optimal	44.5	34.3	41.1	39.4	36.3	35.1	41.9	35.2	
	High	41.7	29.9	39.8	37.0	31.5	33.7	39.4	34.1	
Bone volume	Low	92.4	79.4	107.0	105.2	89.4	86.4	96.0	90.9	0.012
Mesial screw ROI_i (mm^3)	Optimal	85.8	71.9	101.2	96.8	79.2	75.6	87.1	81.7	0.012
	High	78.4	62.6	90.4	88.2	65.3	64.2	75.7	74.6	0.012
Bone volume	Low	96.5	86.8	97.6	94.3	76.2	68.5	99.3	91.9	
Distal screw ROI_i (mm^3)	Optimal	88.7	81.5	89.6	85.2	72.0	66.1	92.9	88.4	
	High	83.6	73.9	79.6	76.7	64.5	63.7	86.0	85.1	
Implant height mesial ROI_i (mm)	–	3.9	4.6	3.3	4.6	5.6	6.4	3.2	4.6	0.292
Implant height distal ROI_i (mm)	–	4.9	4.8	2.5	3.4	5.6	4.4	4.0	3.2	
Crest height mesial ROI_i (mm)	–	15.3	15.2	15.3	14.9	15.5	14.7	15.4	14.7	0.012
Crest height distal ROI_i (mm)	–	15.9	15.8	15.8	15.0	14.1	13.8	14.8	14.6	

The last column shows the *p*-values for the nonparametric comparisons (Wilcoxon signed ranks test) of screw vs. control side for the bone volumes in the different regions of interest and at different threshold values, together with the implant and crest heights for the mesial and distal ROI_i. Note that the *p*-values are given for the pooled mesial and distal data.

Table 2. **Total surface area of the histomorphological sections for the individual animals at the screw and control side for the mesially and distally placed screws**

	Animal ID	3605		3606		3607		3608		
	Position	Screw	Control	Screw	Control	Screw	Control	Screw	Control	*p*-Value
Bone area	Mesial	105.31	98.07	105.07	88.04	97.20	82.04	98.90	94.85	0.028
(mm^2)	Distal	100.66	97.95	95.09	95.69	*	92.95	84.23	81.26	

The last column shows the p-value for the nonparametric comparison (Wilcoxon signed ranks test) of screw vs. control side for the surface area. Note that this p-value is given for the pooled mesial and distal data. * Value could not be provided due to a cutting phenomenon.

size and certify. In this study an observation of a forgotten screw led to the hypothesis that a screw could maintain bone. The reaction to insertion of transcortical screws in the alveolar process following extraction in the mandibular arch was assessed in a canine model. The advantage of a split-mouth study design is that differences between individual dogs are taken into consideration (6). Although there was a clear difference between the two sides in all four dogs, there were limitations of sampling, which are inherent in clinical practice. One bias related to the parameters obtained was the change in the external morphology. Not all screws were inserted at exactly the same height or the same angle and, as alveolar ridge reduction on the control side had already taken place, a simulated insertion of the screw conducted at the same height in relation to the inferior border of the mandible was undertaken.

Multiple studies on the tissue reaction adjacent to screws used as anchorage in relation to

Table 3. **The relative formation and resorption surfaces on the bone in percent**

	Screw		Control	
	Average	Range	Average	Range
Relative formation surfaces	45	20–57	35	14–44
Relative resorption surfaces	16	4–32	12	4–17

Although there was a tendency toward a larger activity on the screw side, a large variation existed and no statistical significance between the screw and the control side could be shown.

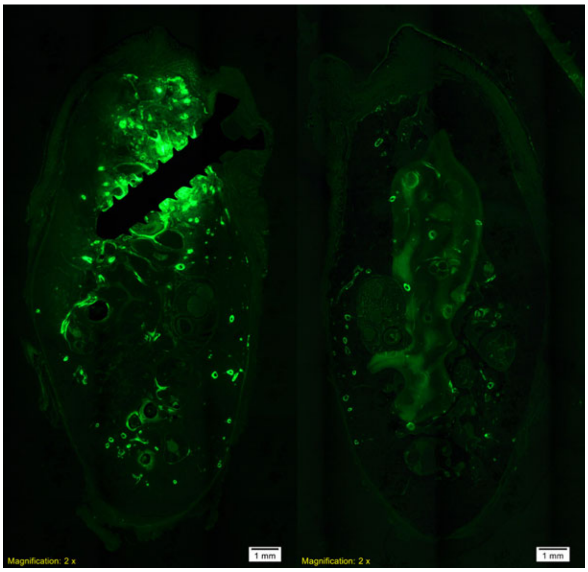

Fig. 7. Composite of the two sides, screw and control observed in fluorescent light. Note the increased active remodeling of the bone adjacent to the MSI.

orthodontic treatment have been performed (1). The mini-implants were in all these reports inserted into areas considered suitable based on the type and density of bone. The problem addressed in the present study differed significantly as the screws were inserted into areas which for stability reasons would be contra-indicated. Normally when TADs are to be used as anchorage, it is important to insert them into bone where the remodeling is low. In this case, the screws were inserted in bone characterized by high turnover due to the healing occurring following extraction. It has been mentioned earlier that high remodeling either in relation to resorption of deciduous teeth or replacement close to a mini-implant will lead to loosening and eventually loss (9). The concept presented in this paper is entirely different as the screw is on purpose inserted in an area where an active healing is taking place and no external loading occurs. Even in a situation of no external loading, it has been demonstrated that loading caused by normal function in combination with difference in stiffness of the screw and bone would lead to an increased turnover adjacent to the screw as an attempt of bone to generate a stress-relieve zone between the two materials of different physical properties (10, 11). The tissue reaction is most frequently assessed by histomorphometry. The validity of this method is however also problematic, as the results are confounded by the marked interindividual variation, and the sections are the representations of 3D tissues. In the present study, only few parameters could be applied. The application of micro-CT and the computer possibilities were obviously the methods that would provide the most information. The simulation of the virtual screw on the control side made it possible to compare both the cortical and the trabecular bone quantity and density, both of which were clearly influenced by the presence of the screw. The results did generally confirm the tissue reaction observed adjacent to dental implants, where it is well known that the presence of implants will maintain bone and prevent further atrophy of alveolar bone provided peri-implantitis can be prevented (12).

As the MSIs are not placed in the same location (transcortical vs. the alveolar crest), as the dental implants would occupy later, a simulation of the insertion of the dental implants was performed. When simulating the insertion of a dental implant to establish the influence of the presence of the screw, the implant was inserted in the same mesio-distal distance from the adjacent tooth, but at the height that would render satisfactory bone at both sides. This made it obvious that the crown height on the control side was larger than on the screw side. As the bone density was also higher, the study seems to indicate that insertion of a transcortical screw can contribute to the maintenance of alveolar bone; in other words, it could prevent or reduce the atrophy occurring of edentulous area following extraction. As the tissue reaction to insertion of implants in dogs and humans are comparable, it could be anticipated that a transcortical screw would also maintain bone in humans who for various reasons, for example, growth or economy, cannot have implants inserted immediately when the extraction space is healed.

Conclusions

In a dog model, the insertion of a mini-implant across the healing alveolar process results in increased density not only adjacent to the screws, but also in the region where a potential dental implant would be inserted. In humans, the insertion of transcortical screws may maintain bone when for various reasons insertion of a permanent dental implant has to be postponed.

Clinical relevance

Atrophy of the alveolar process following loss of teeth is well known. This generates a problem whether dental implants are to replace the lost teeth later. This study indicates that the insertion of transcortical screws may contribute to the maintenance of both quantity and quality of the alveolar process thereby reducing the need for reconstruction surgery before the insertion of implants.

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