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Hard palate deformation in an animal model following quasi-static loading to stimulate that of orthodontic anchorage implants

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SUMMARY The aim of the present investigation was to identify adequate implant treatment for young patients. In an animal model palate deformation was investigated by acute quasi-static loading. Three series of tests (with newborn, young and adult pigs) were performed, each with two groups (one or two-point stress) and 5–7 animals per group. Discs with a diameter of 3 and 5 mm were placed in group 1 in the suture area, and in group 2 at both the right and left sides of the suture. Deformation was analysed by a computerized three-dimensional (3D) photo-imaging evaluation system.

In young animals the one-point load at a significantly lower force level led to fractures in comparison with the two-point load ($P < 0.001$). Similar results were measured by an increase in the size of one disc from 3 to 5 mm ($P < 0.001$). In contrast, adult pigs showed stable results with both methods. In general, a larger disc diameter led to less instability.

The one-point load seems to be suitable for adult animals, whereas a two-point load might be favourable during ossification. The advantage of the two-point load is the generation of a higher stress and therefore improved control of dental fixation. However, further tests are necessary to investigate the long-term effects.

Introduction

Maximum anchorage of molars may be required for orthodontic space closure after anterior tooth extraction. In those cases the desmodontal anchorage of molars must be strengthened by blocking and by further forces acting on anchorage teeth in a posterior direction (Diedrich, 1993).

Application of headgear and Class II elastics depends on compliance, whereas negative side-effects may be manifested after long-term use of a Nance appliance (Fuhrmann *et al.*, 1994). A compliance-independent alternative is provided by temporary osseointegration of implants in or beside the medial palatal suture area (Triaca *et al.*, 1992; Wehrbein, 1994; Block and Hoffmann, 1995). Until now, temporary palatal screws have been placed in the nasal spine (Creekmore and Eklund, 1983). The problem inherent in this type of anchorage in growing patients is the difficulty in maintaining still available germ tissue undamaged, thus avoiding potential implant-induced growth retardation in the palatal suture. This is dependent on the age of the patient, the number and form of implants, and the insertion site in the palatal vault (Wehrbein *et al.*, 1996).

Implant forces may deform the palatal bone, which can lead to reduction of the goal-directed anchorage support. Forces of approximately 200 N occur during chewing and maximal intercuspation on the first molars (Skalak, 1983; Paphangkorakit and Osborn, 1998). These forces by far exceed those required for orthodontic anchorage purposes. The anchorage load and occlusal forces are reproduced from the teeth on the implant due to rigid connection of the transpalatal arch (TPA). The implant transmitted the load to the bone tissue and palatal vault (Rieger *et al*., 1990).

The occlusal forces are not transmitted to the implant entirely because of the deformation of the TPA. Load intensity of the implants is caused by the wire diameter of the TPA. Additionally, mesial movement of the teeth and occlusal forces together with tongue pressure act on the implant.

In children with lower calcification levels a deformation of the palatal bone is greater than in juveniles or adults, because the growing bone has not yet sufficiently mineralized and hardened. Due to ankylotic connection between implant and bone, the occurring forces are introduced directly into the surrounding tissue (Skalak, 1983; Rieger *et al*., 1990; Weinberg, 1993). From the biomechanical analysis of axially-occurring occlusal forces, the peri-implant bone is claimed to be most strongly stressed at the margin (Rieger *et al*., 1990; Weinberg, 1993). However, this view is not shared by all authors (Wehrbein *et al*., 1999).

The nasomaxillary complex can be regarded as a vibrating system, which transfers mechanical energy. In orthodontics the load force acts directly on the implant, which in turn defines the load point on the hard palate. When the resistance limit is exceeded, fractures and irreversible bone deformation will occur.

Biological tissue reactions and the mechanical qualities typical of the nasomaxillary complex, as well as resistance limits, can be assessed after implantation only in an animal model. The pig skull is particularly suitable for investigations with regard to anatomical structure and deformation under stress, since the pressure occurring at the palate is derived at lateral trajectories as in humans.

Experience with osseointegrated implants in adult patients exists and the peri-implant tissue can be assumed to have sufficient stability. However, further investigations are needed to determine the resistance limit of young immature bone tissue (Wehrbein, 1994).

The aim of the present investigation was to determine the resistance of juvenile and young bone under application of one- or two-point force. For this purpose the following parameters were investigated in the animal experiment dependent of age: size, number, and position of implant-like discs, and resistance of palatal bone towards maximum forces applied.

Materials and methods

Seventy-five pig skulls were used for the resistance examination. These pig skulls were stored for less than 6 hours after death so that the liquid content of the native bone, which has a substantial influence on its elastic qualities, was maintained. The skulls were subdivided into 12 groups. Each group contained five to seven skulls depending on the disc diameter (3 and 5 mm), the number of onplant-like discs (one or two onplants) and the age of the animals (newborn, young, or adult).

The experiments were carried out on 75 'Deutsches Landedelschwein' pigs. The evaluation of the palatal suture of this species is similar to that of humans. For evaluation, comparison of the palatal suture of pigs and humans, undecalcified sections of the nasomaxillary complex were prepared and analysed (Enlow, 1989). Thin, undecalcified sections were used, following the method of Donath (1988).

Bone quality and tightness of the palatal suture of newborn animals corresponded to 5–7-year-old children, and that of 6–8-week-old pigs to the maturity stage of 9–12-year-old patients. The osseous strength of 16-week-old animals corresponded to that of 17-year-old adolescents (Figure 1a,b,c).

Measurements of samples were carried out at a constant temperature of 27°C. The nasomaxillary complex was embedded into hard plaster after removal of the mucoperiosteal tissue in order to prevent the skull from distorting under pressure. The palate deformation was measured on the bone surface after soft tissue removal. The bone preparations were kept adequately moist throughout the experiment. The duration of the quasi-static load was 30 minutes.

Submucous onplants and most endosseous implants are inserted into the mid-palatal suture area of adult patients (Triaca *et al*., 1992; Block and Hoffman, 1995). In the present experiment

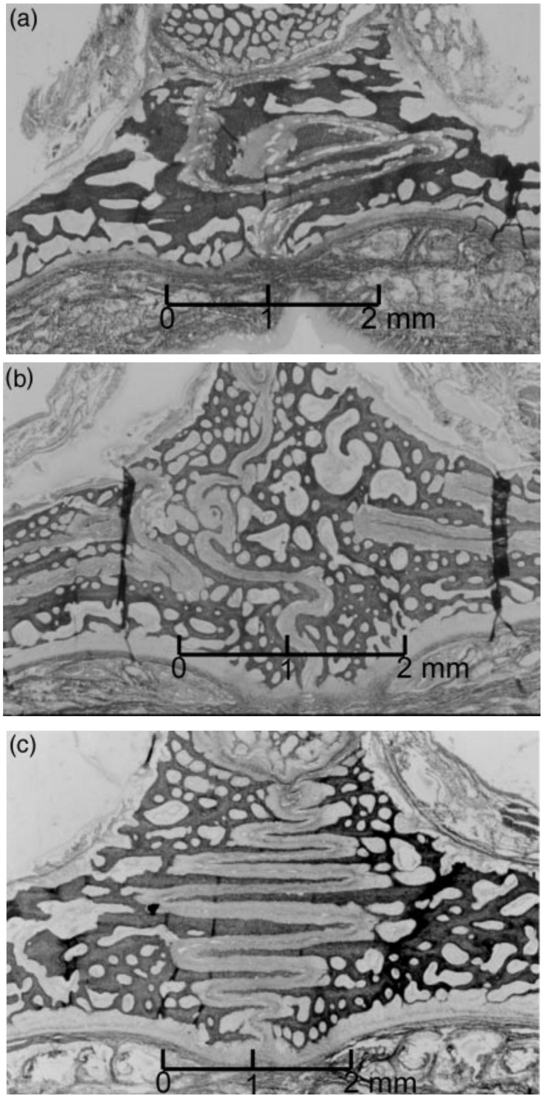

Figure 1 Thin, undecalcified sections were used, following the method of Donath (1988). The van Gieson reaction was used to stain the palate cross-sections. Histological investigations of quality and strength of the palatal suture area of pigs in different age groups were carried out: (a) newborn animals comparable with 5–7-year-old children; (b) 6-week-old pigs comparable with maturity stage of 9–12-year-old patients; (c) 16-week-old animals comparable with the maturity stage of 17-year-old patients. Bar = 0–2 mm of palate.

stainless steel plates of 3 and 5 mm diameter corresponding to onplants were used for the testing of mechanical stress. The stress was applied directly to the bone either in the palatal suture area or paramedially by two implants at the first premolar level (Triaca *et al*., 1992; Figure 2a,b). By means of a swivel arm, a static force on the implant was applied until damage occurred to the hard palate. This gradual increased force was measured by a strain gauge connected to the swivel arm and linked to a computer device. During measurement the hard palate was scanned in order to investigate its deformation and fracture.

The evaluation of the scanned pictures was carried out (without direct contact) by beams of light according to the so-called principle of light cut triangulation.

The ODKM (optical digitizer of small objects) gauge (Fraunhofer Institute of Applied Optics and Precision Mechanics, Jena, Germany) produces, by means of strip projector (50 W halogen lamp) on the palatal bone, a linear grid that has to be measured. A CCD camera registers sectional lines of the grid images on the surface of the object and transforms them into phase-modulated intensity signals. The image size can be zoom-modified steplessly between 0.5 and 10 mm without recalibration or a change of image scale. The pig skull was fixed on a swivel plate for measurement purposes and after vertical positioning, the table and camera were rigidly connected to each other and could be turned around the axis.

At least three different geniometric adjustments were determined for coordinate calculation of the phase measurements. The measuring system was calibrated and optimized with regard to the fault repetition rate. Control of the measuring device and the following three-dimensional (3D) reconstruction were computer-assisted, using the Argus 5.8 3D-visualization programme (Fraunhofer Institute). Measuring and recording were performed up to a maximum force of 110 N or to the first disrupting phenomena. Deformation measurements were carried out in the disc positioned region, as well as on the complete hard palate. Palatal deformation caused by the various pressures and implant sizes was visualized by means of pseudo-colours for the deformation lines. Holographic evaluation of palate deformation also permitted precise

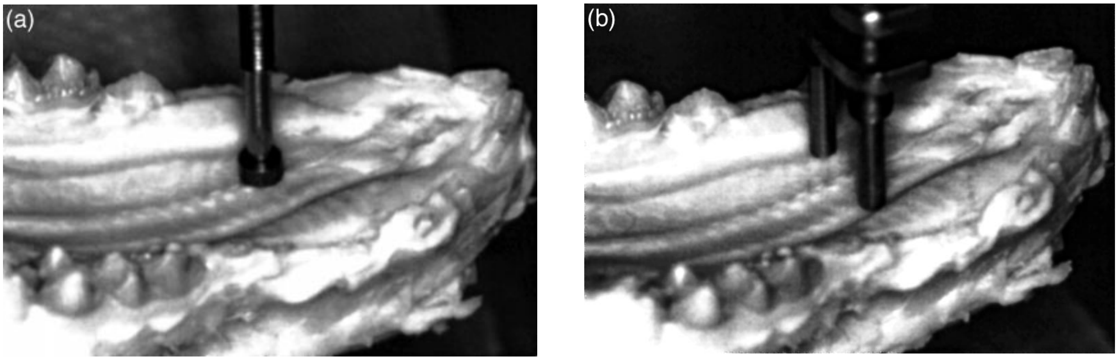

Figure 2 Placement of discs on prepared palatal bone of experimental animals. (a) One disc in the medial palatal suture area. (b) Two discs paramedial of the medial palatal suture area.

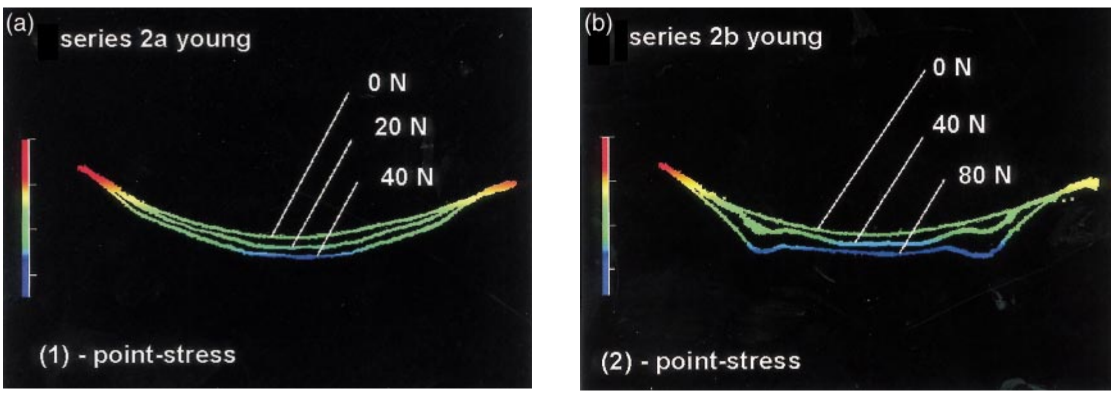

Figure 3 Palate deformation in young animals with an implant diameter of 5 mm. Colour imaging representation with respective stress results. (a) Application of one-disc method in the medial palatal suture area. (b) Application of two-disc method paramedially of the palatal suture.

determination of the time when fractures occurred as a result of excessive stress (Figure 3a,b).

Statistical analyses

The results are given as arithmetic means ± standard deviation (SD). The Student's *t*-test (Cavalli-Sforza, 1969) was applied to evaluate differences for bone comparisons within the groups and with each other. Two by two comparisons were used in the same animal group. The total number of experimental animals was $n = 75$. The number of animals with one-point stress was $n = 37$ and with two-point stress $n = 38$. Five to seven animals per group (with newborn, young and adult pigs) and type of treatment were used.

Results

Implant-induced stress in the medial palatal suture

Using the one-point method with a pressure stamp diameter of 3 mm, bone destruction occurred in the medial palatal suture of newborn and juvenile animals even at relatively low forces (Table 1). Both the palatal bone and the nasal septum were damaged, whereas the nasomaxillary complex of the fully-grown animals showed a similar phenotype after a force application of

Table 1 First signs of fracture with one- and two-point methods (3 and 5 mm diameter).

	1-point stress		2-point stress	
	3 mm (SD)	5 mm (SD)	2 × 3 mm (SD)	2 × 5 mm (SD)
Newborn	21.17 (± 3.43)†	33.71 (± 2.93)‡	47.29 (± 4.85)†	77.17 (± 7.88)
Young	27.20 (± 4.14)**	54.33 (± 6.02)	53.67 (± 4.50)**	79.71 (± 2.75)**
Adult	44.71 (± 2.21)	58.80 (± 1.64)	80.00 (± 1.87)	110.00 (0.00)

Significant differences between newborn and young animals †$P \leq 0.05$, ‡$P \leq 0.001$. Significant differences between young and adult animals *$P \leq 0.05$, **$P \leq 0.001$. The number of animals with one-point stress was $n = 37$ and two-point stress $n = 38$. Five to seven animals per group (with newborn, young and adult pigs) were used.

45 ± 2 N. The difference between the resistance of newborn and juvenile bone and mature bone was significant.

A significant increase of resistance in the palatal suture area was measured when the pressure stamp diameter was increased to 5 mm (Table 1). This increased resistance was registered mostly in juvenile animals where the strength limit almost reached that of adult animals (59 ± 2 N).

Stress by two implants paramedially to the medial palatal suture

The risk of bone fracture induced by one implant stress in the medial palatal bone can be avoided by paramedial placement. A maximum force of 47 ± 5 N in newborn animals and 54 ± 4 N in juvenile animals may be applied without causing recognisable damage by distributing the force over two stamps, each 3 mm in diameter (Table 1). Extension of stimulated implant areas up to a diameter of 5 mm and application of pressure paramedially on both sides led to increased stress in newborn and juvenile animals (Table 1). As expected, comparison of one- and two-disc methods with respect to palatal deformation showed less deformation with the latter.

Discussion

The present investigation has clearly shown the limited stress resistance capacity and higher risk of damage to palatal bone resulting from loading of a one-point implant in the medial palatal suture area. Preservation of tissue elasticity in the nasomaxillary complex is a prerequisite for optimal growth, independent of mechanical stress by foreign element in a sensitive growth zone (Hansson *et al*., 1983).

In newborn and juvenile animals, forces leading to bone destruction are approximately 10 times greater than those inducing molar retrusion. The far stronger chewing and occlusal strengths may lead to distinctive palate deformation, and may contribute to mechanical trauma. To reduce the risk of bone deformation in younger individuals the two-point method seems to be more favourable (Wehrbein, 1994).

Alternatives are submucosal placement of a disc-like implant with a diameter of at least 5 mm (Block and Hoffman, 1995) positioned in the medial palatal area or paramedial anchorage of two endosseous implants. Insertion of two implants, however, has the disadvantage of greater operative trauma resulting from two-fold surgery, but the advantage of less palatal deformation. Therefore, initial experiences with a broad implant should be gained in a clinical setting, since the disadvantages of the different methods can most likely be minimized by these means.

Direct peri-implant damage after insertion, as well as manifestation of bone deformations and consequent growth impairment, must be taken into consideration (Glatzmaier *et al*., 1995). The applied light cut measuring method permitted this to be identified and the limiting placement areas to be determined. Thus, the complexity of the punctiform force application induced by one implant and its transmission to the complete palatal vault could also be proved.

Despite the limits of the results of animal experiments on their application to humans, it can be deduced from the present investigation that implant anchorage for orthodontic purposes in children and adolescents is subject to compliance, with measures aimed at protecting the medial palatal suture.

Conditions for both the pros and cons of different locations of disc-like implants for orthodontic anchorage can be represented experimentally in the animal model by means of the applied force method and computer-assisted non-contact measurement of the resulting bone deformation.

Conclusions

For insertion of implants for intra-oral anchorage purposes in the medial palatal suture area, bone should have a degree of maturity and strength, which is attained in humans at 16 years of age (completed growth).

During the earlier developmental period, either one submucous onplant with a diameter of 5 mm or two implants with a diameter of 3 mm should be used with paramedial localization for stress distribution in the palatal suture.

Onplants with a diameter of 5 mm permit sufficient anchorage and can be used in young patients.

The presented non-contact computer-assisted measuring method for the recording of palatal deformation under various load applications in the animal model is also suitable for other investigations.

Further analysis is necessary to determine the strength of the intra-oral anchorage between implants in the hard palate and teeth.

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