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ORIGINAL ARTICLE

MA Cornelis
P Mahy
JP Devogelaer
HJ De Clerck
C Nyssen-Behets

Does orthodontic loading influence bone mineral density around titanium miniplates? An experimental study in dogs

Authors' affiliations:
M.A. Cornelis, C. Nyssen-Behets, Department of Experimental Morphology, Faculty of Medicine, Université catholique de Louvain, Brussels, Belgium
P. Mahy, Department of Oral & Maxillofacial Surgery, Cliniques Universitaires St-Luc, Brussels, Belgium
J.P. Devogelaer, Department of Rheumatology, Cliniques Universitaires St-Luc, Brussels, Belgium
H.J. De Clerck, Private practice, Brussels, Belgium

Correspondence to:
M. A. Cornelis
Department of Experimental Morphology
Université catholique de Louvain
Av. Mounier, 52/5251
1200 Brussels
Belgium
E-mail: macornel@hotmail.com

Structured Abstract

Authors – Cornelis MA, Mahy P, Devogelaer JP, De Clerck HJ, Nyssen-Behets C

Objectives – To evaluate whether orthodontic loading has an effect on miniplate stability and bone mineral density (BMD) around the screws supporting those miniplates.

Setting and Sample Population – Two miniplates were inserted in each jaw quadrant of 10 dogs.

Material and Methods – Two weeks later, coil springs were placed between the miniplates of one upper quadrant and between those of the contralateral lower quadrant. The other miniplates remained non-loaded. The dogs were sacrificed 7 or 29 weeks after surgery, and the jaws were scanned with peripheral Quantitative Computed Tomography (pQCT) to assess BMD.

Results – The success rate was not significantly different for the loaded and the non-loaded miniplates, but was significantly higher for the maxillary compared to the mandibular ones. Mobility, associated with local inflammation, most often occurred during the transition between primary and secondary stability. pQCT showed higher BMD around mandibular vs. maxillary screws, without significant difference between loaded and non-loaded ones. Furthermore, load direction did not lead to any significant difference in BMD.

Conclusion – Miniplate stability and BMD of the adjacent bone did not appear to depend significantly on orthodontic loading, but rather on the receptor site anatomy.

Key words: bone density; dog; miniplate; orthodontic anchorage procedures

Introduction

Anchorage, which is of critical importance to fulfill orthodontic treatment goals, classically relies on patient's compliance and dentition's integrity. Skeletal, 'absolute' anchorage, by contrast, goes beyond the limits of classical orthodontics. Conventional dental implants were initially placed in edentulous (1), retromolar (2) or palatal (3) regions, but recent use of smaller devices such as miniscrews (4) and miniplates (5), requiring less bone, allows wider indications while reducing surgical trauma.

Among these temporary skeletal anchorage devices (TSAD), the originality of miniplates relates to their efficiency in *en masse* distalization of

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an entire dental arch (6), maxillary protraction (7) and molar intrusion for open bite closure (8). Even though prospective clinical trials bring evidence in terms of success rate and orthodontic efficiency (9, 10), some issues such as influence of loading and time remain unanswered.

We recently assessed histomorphometrically bone-screw contact and bone volume around screws of miniplates and found no influence of orthodontic load on bone reactions (11). In the same animal experiment, we measured bone mineral density (BMD) around the screws supporting the orthodontic miniplates. Densitometry was performed with peripheral Quantitative Computed Tomography (pQCT), which is known to characterize bone with accuracy in both humans (12, 13) and animals (14, 15). In the present investigation, we aimed to determine the influence of both load and direction of load on the local bone mineral density. Our initial hypothesis was that loading would not influence bone density.

Materials and methods

As recently reported (11), ten 1-year-old male beagle dogs with similar weight, from different litters, were divided into a short-term (ST) and a long-term (LT) group of five dogs each. Eighty titanium miniplates designed for orthodontic anchorage (Bollard, Surgi-Tec, Bruges, Belgium), were placed between the dental roots: two miniplates per jaw quadrant, each with two 5-mm-long, 2.3 mm diameter titanium self-tapping screws (Surgi-Tec) (Fig. 1A–C). The screws were made of TiAl6V4, without any surface treatment, and the miniplates were made of commercially pure titanium.

Surgery was performed under general anesthesia with laryngeal intubation. After elevation of an L-shaped mucoperiosteal flap into the attached mucosa (Fig. 1C), pilot-holes were drilled in the cortical bone with a 1.6 mm-diameter bur under saline irrigation. The screws were inserted with a screw-driver through the miniplate. One layer closure was obtained with 4/0 resorbable sutures over the miniplate. The fixation units, facing mesially, were bent in order to avoid cheek irritation and each quadrant was radiographed. After surgery, the dogs were given antibiotics and anti-inflammatory drugs for 5 days as well as a soft diet for 14 days, followed by regular hard food. The miniplates were daily sprayed with chlorhexidine until loading.

Two weeks after surgery, nickel-titanium coil springs generating a 125 g force were placed under sedation between the two fixation units of one upper quadrant and between those of the controlateral lower quadrant (Fig. 1D). Fluid composite and orthodontic wax were used to avoid gingival irritation. The miniplates of the other quadrants remained non-loaded and were considered controls. The distances between the fixation units of the same quadrant were measured with a digital caliper. In order to maintain fair oral hygiene, the anchors were brushed four times a week during the loading period. During these sessions, the coil springs were controlled and replaced if necessary, and miniplate mobility was checked. The dogs were euthanatized 7 (ST) or 29 weeks (LT) after miniplate placement. The distances between the fixation units were measured again after sacrifice. The experimental procedure was approved by the Animal Experimentation Ethics Committee of the Université catholique de Louvain.

Jaw samples supporting the miniplates were dissected, dehydrated and embedded in methylmeth-

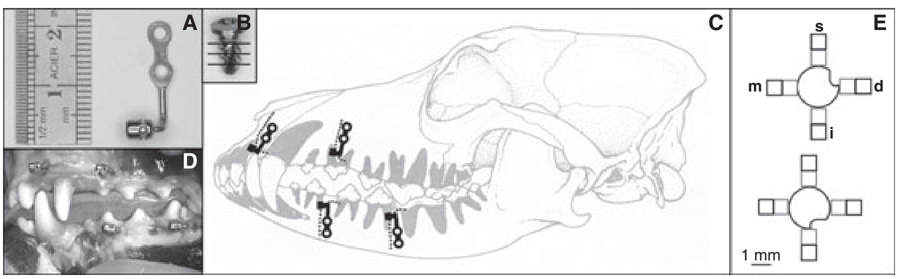

Fig. 1. Titanium miniplate, composed of a two-hole bone plate, a round connection bar and a cylindrical orthodontic fixation unit (A), screw with the levels of the three pQCT transversal slices (B), schematic drawing of a dog skull with surgical incisions and miniplates localization [adapted from Emily P, Penman S (1992). Dentisterie du chien et du chat. Maisons-Alfort (France): Ed. Du Point Vétérinaire] (C), upper loaded miniplates and lower control ones on the left side of one dog (D), schematic representation of the four tangential (grey) and the four external (black) ROI around two screws sections, in the superior (s), inferior (i), mesial (m) and distal (d) directions (E).

acrylate. Each quadrant sample was scanned with a pQCT Research SA+ (Stratec, Pforzheim, Germany) in the sagittal plane in order to acquire 10 transversal, 0.5 mm apart, slices through the screws. With a slice thickness of 150 μm and a pixel size of 0.070×0.070 mm, the translation of the X-ray source was 1 mm/s. The three most central slices through each screw (Fig. 1B) were analyzed with the built-in XCT 5.4 software of the pQCT. Eight square regions of interest (ROI) of 0.55 mm^2 were defined: four ROI tangential (T) to the screw section and located superior, inferior, mesial and distal, and four ROI immediately exterior (E) to the previous ones (Fig. 1E). The mean BMD, proportional to the attenuation of the X-ray beam within the corresponding voxels, was calculated for each ROI and expressed as mg hydroxy-apatite/cm^3. The values of the three slices were averaged for each ROI.

The cumulative survival of the miniplates was analyzed with the Kaplan–Meier method. Log-rank test was used to compare survival curves. Repeated measures of BMD values around the miniplates still present at the end of the experiment were averaged on a per-subject level. The authors then computed differences between means of ST and LT groups with *t*-test for independent samples (degree of freedom proportional to no of dogs/group). Differences between screws of the same dogs and differences between different zones around the same screws were tested with the paired *t*-test (degree of freedom proportional to number of dogs). All tests were 2-tailed and statistical significance was set at $p \leq 0.05$.

Results

The 10 dogs remained healthy during the experiment. All miniplates were clinically stable after insertion. The anchorage success rate, determined by the survival functions and defined as the percentage of stable miniplates at the end of the experiment, was 53% (Fig. 2). It was significantly higher ($p < 0.05$) for maxillary (70%) than for mandibular (38%) anchors, in the whole cohort as well as in the ST and LT subgroups. No significant difference between loaded and non-loaded miniplates was observed (57% vs. 50% respectively). The pairs of stable miniplates showed an unaltered distance throughout the experiment. Mobility occurred 4.9 ± 2.8 (mean ± SD) weeks after surgery and was systematically associated with gingival inflammation. The 37 mobile miniplates were distributed as follows: 24 ST and 13 LT, 17 loaded and 20 controls. Among them, 13 fell out.

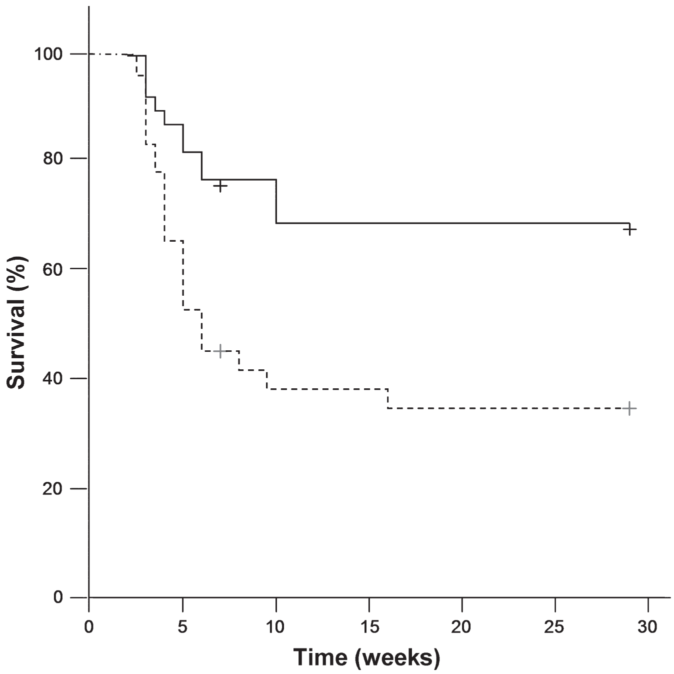

Fig. 2. Kaplan–Meier survival curves of maxillary (plain line) and mandibular (dotted line) miniplates.

Peripheral Quantitative Computed Tomography revealed bone in contact of both screws of the miniplates considered stable at sacrifice (Fig. 3A, B). The mobile miniplates showed a broad radiotransparent space around one (Fig. 3C) or two screws (Fig. 3D). BMD was measured around both screws of the 67 miniplates still present at the end of the experiment. No significant differences in BMD were found between the loaded and the control screws in any of the groups (ST and LT) for both maxilla and mandible, and for both T and E regions (Fig. 4A). No significant difference was observed between T and E zones around both loaded and control screws, although the mandibular T zone was systematically less dense than the E zone in the ST group.

Around the loaded screws (Fig. 4B), mesial and distal ROI were classified as compression or tension zones regarding the direction of load, whereas superior and inferior ROI were considered shear stress zones. BMD did not vary significantly according to the compression, tension or shear stress.

Bone mineral density was higher in LT than in ST dogs, particularly in the mandible ($p < 0.05$) (Fig. 4A).

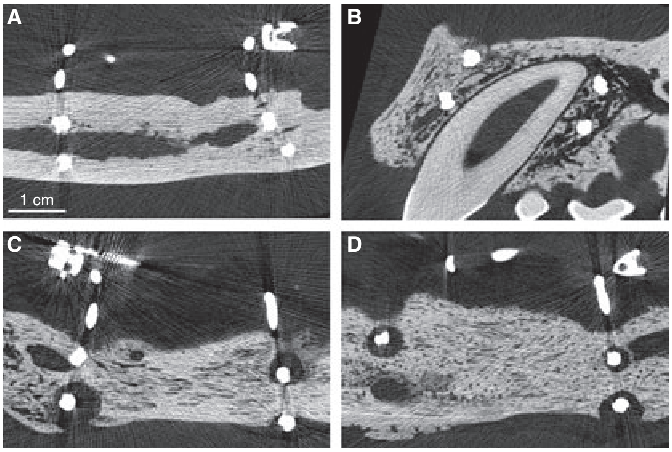

Fig. 3. pQCT slices through stable non-loaded miniplates of right mandible, LT dog (A), stable loaded miniplates of left maxilla, ST dog (B), mobile loaded miniplates of left mandible, ST dog (C), mobile non-loaded miniplates of right mandible, ST dog (D).

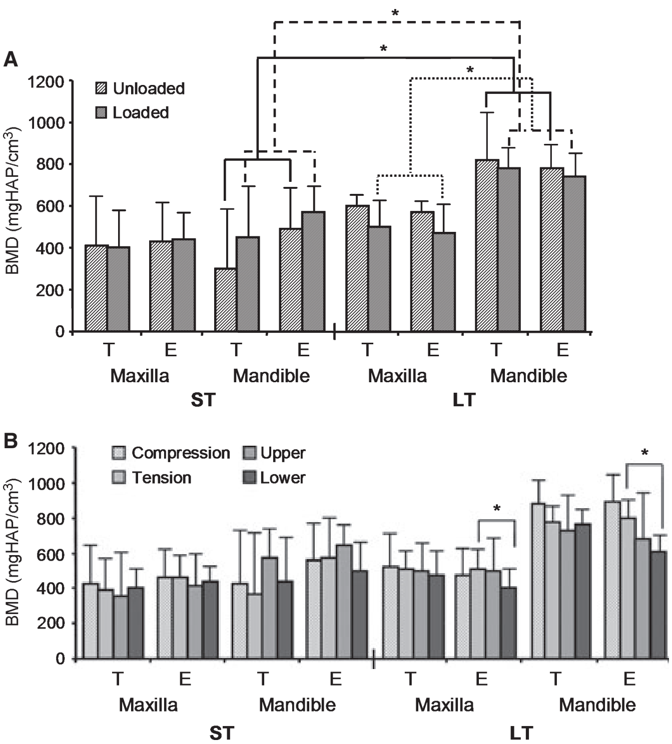

Fig. 4. Histograms of BMD (mean: plain bar/standard deviation: line), per subgroup. As one ST and one LT dog lost their four lower miniplates, mandibular measurements were assessed for four dogs per group. Five other plates fell out in different quadrants: the average BMD values for those quadrants were based on the remaining plates. Comparison of loaded and non-loaded screws (A). Comparison of the different regions of interest (ROI) around loaded screws: zones loaded in compression (compression), in tension (tension) and in shear stress either above (upper) or under (lower) the screws (B). BMD, bone mineral density, expressed in mg hydroxyapatite/cm^3 (mgHAP/cm^3); ST, short-term group; LT, long-term group; T, ROI tangential to the screws; E, ROI immediately exterior to the T zones; *statistically significant ($p < 0.05$).

In LT group, BMD values were higher in the mandibles than in the maxillas, but this difference was significant only for the loaded screws. In the maxillary loaded screws, BMD was significantly higher around the upper screws than around the lower ones only in the LT group. This difference was not observed in the mandible.

Discussion

This study, which tested a high number of orthodontic miniplates in animals, is the first one to yield quantitative data about peri-screw bone mineral density, particularly under loading conditions. This information is essential for TSAD use in orthodontics, as load might constitute a mobility risk factor or induce excessive bone response impeding miniplate removal.

Despite its efficiency, clinical use of orthodontic miniplates has been supported by few experimental data (16). In the present study, the total success rate of 53% is lower than in clinical observations –89 (17), 96.4 (18) and 92.5% (19) – but oral hygiene and patient compliance might be responsible for this difference, another study with miniscrews in dogs showing a similar success rate (20). Moreover, in the maxilla of patients, the Bollard system is used with three screws instead of two, which insures a better success rate but is not compatible with the dog anatomy (19). In spite of this high failure rate, the number of stable miniplates in our study was still relevant enough to obtain statistically valid quantitative data.

The healing period was chosen to last 2 weeks which, regarding the relative bone turnover rate, corresponds to the usual clinical healing time of 3 weeks (6), in order to reproduce the loading conditions that are used in patients and to analyze experimentally the osseous reaction in a comparable situation. Mobility occurred on average 5 weeks after miniplate placement (Fig. 2), which is comparable to what has been reported for miniscrews (21). This period could represent the most critical stage in the transition process between primary and secondary stability (22, 23), when anchorage stability critically depends on the completion of bone remodeling. In our experiment, the radiotransparent space surrounding the mobile screws clearly attested to imbalance between bone resorption and formation (Fig. 3).

The mandibular success rate, lower than the maxillary one, could be attributed to the smaller amount of attached gingiva in the dog, supporting the idea that miniplate connection bar exiting in the oral cavity through non-keratinized tissue constitutes a risk factor (24). Other clinical (17, 25, 26) and experimental (27) studies with miniplates and miniscrews observed a higher success rate in the maxilla compared to the mandible as well. Inflammation, associated with mobility in the present study, could play a role in the clinical evolution as oral hygiene was difficult to obtain (10). By contrast, loading had no definite effect on stability since the success rate was not significantly higher in loaded vs. non-loaded miniplates.

Bone mineral density evaluated with pQCT has been shown to be a reliable predictor of the true apparent density and morphological properties of bone (12, 14, 15). pQCT, which produces tomographies where the mineral density is quantitatively measured for each pixel, was preferred to microCT which assigns the pixel as being bone or non-bone (13). Loading of miniplates was reported to enhance bone-screw contact in dogs (28), but no quantitative assessment of the bone-screw interface with miniplates could be found in the literature. As observed in quantitative studies evaluating orthodontically loaded palatal or conventional implants (21, 29–37) or miniscrews (20, 38–41) our experiment did not lead to significant difference between loaded and non-loaded screws. Histomorphometric evaluation of bone volume/total volume in the same experimental material (11) strengthens the present densitometric evaluation as a valuable non-invasive alternative to quantitative histology, as already suggested by a fair correlation between histomorphometry and microtomography (42). Our initial hypothesis was thus confirmed: orthodontic loading of miniplates did not influence the local bone response in terms of BMD. Furthermore, absence of difference in density between zones loaded in compression and those loaded in tension (Fig. 4B) is consistent with the results obtained with orthodontically loaded dental implants (31, 35, 36, 43–47) and miniscrews (32, 48).

The slight increase in BMD around the maxillary screws from ST to LT (Fig. 4A, B) could be interpreted as the result of a balanced remodeling sequence achieving stability. The significantly lower values observed around the mandibular ST screws, notably in the T zone, might be due to the high number of mobile screws in this group. However, even when considering only the stable mandibular screws, BMD significantly increased with time, confirming the previously described progression of osseointegration with time (48).

Despite a higher bone density in the mandible than in the maxilla, confirmed by other studies (49), the better success rates in the maxilla [observed not only in this experiment, but also in clinical conditions (10, 19)] suggest once more that successful anchorage does not only depend on bone density, but also on specific features of the receptor site. In this perspective, trabecular maxillary bone could be more propitious than compact mandibular bone to ensure transition between primary and secondary stability.

Conclusion

To conclude, as miniplate stability and BMD of the surrounding bone were not significantly influenced by loading, orthodontic loading does not appear to increase risk for mobility nor to enhance bone density complicating miniplate removal. The first weeks of loading, concomitant with the transition between primary and secondary stability, could constitute the most critical period for miniplate success.

Clinical relevance

Orthodontic miniplates are increasingly used for skeletal anchorage. However, few experimental data are available to validate them. Particularly, osseointegration must be sufficient to achieve miniplate stability, but not excessive to allow their removal at the treatment's end. The present study aimed to investigate the bone density around screws supporting miniplates, and to assess how loading affects the bone reaction. Loading was shown not to influence the bone density in the range of orthodontic forces: loading can thus be excluded as a mobility risk factor. Loading does also not increase bone density, which warrants the easiness of the removal procedure.

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