A Histomorphometric Analysis of Heavily Loaded and Non-Loaded Implants

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Purpose: *To investigate the bone tissue response at the interface of loaded and non-loaded implants used in an orthopedic anchorage system after a continuous, non-axial force application of 5 N over 2 months.* ***Materials and Methods:*** *Twenty-nine Brånemark System implants were placed in the zygomatic arches of 5 dogs. After a healing period of 8 weeks, 20 implants (4 in each dog) were loaded during 8 weeks with a large non-axial orthopedic force application of 5 N. This force was directed between the implants and a maxillary splint to move the maxilla forward. Nine implants were not loaded during this period. At the termination of the experiment, all 29 implants were retrieved for radiographic as well as for histologic analysis. Computer-based histomorphometric quantifications were performed via light microscopy and computer software. Bone-metal contact (BMC), bone surface area (BSA) inside the threads, and the bone mirror area (BMA) of the implants were measured. Statistical comparisons between the loaded and non-loaded implants were carried out. In the group of loaded implants a 2-factor analysis of variance was used.* ***Results:*** *There were no statistically significant differences found in BMC, BSA, and BMA between the loaded and non-loaded implants, both for all the threads and for only the cervical region of the implants. Nor were there statistically significant differences between the non-pressure and pressure sides or for different lengths of the loaded implants.* ***Discussion:*** *The loaded implants maintained the osseointegration achieved during the 8-week healing period.* ***Conclusions:*** *The results of this study indicate that titanium implants can be used as anchorage for orthopedic force application systems.* (Int J Oral Maxillofac Implants 2002;17:405–412)

Key words: *animal study, dental implants, histologic analysis, orthodontics, orthopedic force application*

Osseointegrated implants, used as abutments for the fixation of dental prostheses, have been investigated frequently.[1–6] Specific criteria for placement of dental implants have been advocated, and adequate statistical methods used to analyze implant success have been reported.[7,8] However, the indications for using implants have been gradually extended even to regions of vital bone outside the oral cavity.[9,10]

In orthodontics, orthopedics, and oral surgery (distraction osteogenesis), the use of implants is commonly accepted for anchorage purposes.[11–25] Rigidity and stability of the implants can be helpful to resist reaction forces in displacing teeth and bones. The use of implants in the mandible for orthodontic anchorage purposes has been described by Roberts and associates.[11–16] Wehrbein and coworkers[17,18] recommended the clinical use of palatal implants as anchorage for orthodontic tooth movement in the maxilla. These studies have shown that osseointegrated implants, loaded by continuous orthodontic forces (1 to 3 N), have remained stable. To achieve skeletal orthopedic changes in the growing child, orthodontists use larger force magnitudes. To date, only a few studies have reported the use of

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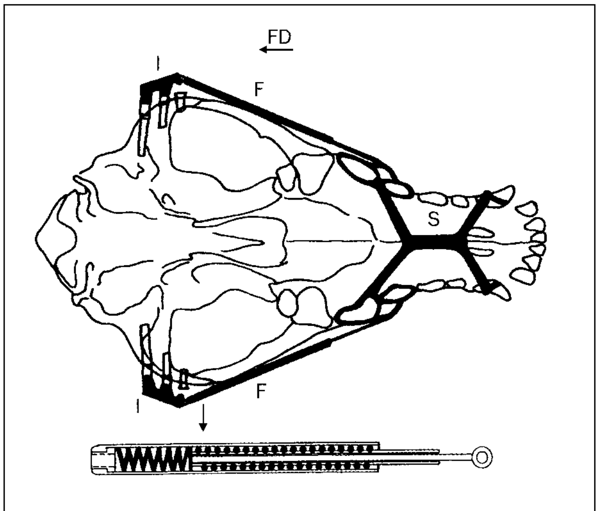

Fig 1 Occlusal view of a skull with the applied force system (F) between implants (I) and the maxillary splint (S). The force direction (FD) to the implants is indicated.

forces larger than 3 N on endosseous implants.[20–22] No knowledge exists about the maximum load that can be directly absorbed within the surrounding tissues without sacrificing the rigid bone-implant interface. Furthermore, according to the orthodontic literature, only a few studies have reported the resistance of implants to continuous horizontal (non-axial) forces.[21–24] In oral and maxillofacial surgery, osseointegrated implants can resist the expansion forces in distraction osteogenesis procedures.[25]

The aim of this experimental study was to investigate the bone tissue response at the interface of loaded and non-loaded implants used in an orthopedic anchorage system after a continuous, non-axial force application of 5 N over 2 months. The bone tissue response was quantified histomorphometrically on undecalcified cut and ground sections.

MATERIALS AND METHODS

Subjects and Implants

The study design involved 5 adult dogs with a complete set of permanent teeth. In each dog, 3 Brånemark System (Nobel Biocare, Göteborg, Sweden) titanium implants, 3.75 mm in diameter and 15, 10, and 7 mm in length, were placed in the posterior part of both the left and right zygomatic arch in the temporal bone under aseptic conditions, using the technique developed by Brånemark and coworkers.[26] In dog 4, only 1 control (7-mm) implant was placed because of a lack of space in the zygomatic arch. After a healing period of 8 weeks, the implants were re-exposed. Standard titanium abutments (3 or 5.5 mm in length) were connected to the implants. A gold splint connecting the 2 longest implants was screwed onto the abutments. A coil system was placed between each splint on the implants and a maxillary splint on the teeth (Fig 1). A bilateral, non-axial force of 5 N was exerted over 8 weeks by a coil system pushing between the connected implants in the zygomatic arch (anchorage system) and the maxillary splint. During the experimental period of 8 weeks, the third implant (control) was not loaded.

At the termination of the experiment 16 weeks postsurgery, the dogs were sacrificed. The loaded and non-loaded implants with the surrounding tissues were removed and radiographic and histologic analyses were carried out.

Histologic Preparation

Immediately after removal, the implants and surrounding tissues were immersed in 10% neutral buffered formalin. The laboratory handling of the specimens involved embedment in light-curing resin and cutting and grinding following the procedures described by Donath.[27] The undecalcified cut and ground specimens (thickness = 10 µm) were stained in a mixture of toluidine blue and pyronin G sol. Histomorphometric analyses were carried out on 20 loaded and 7 non-loaded implants. In 2 of the 9 control implants, it was impossible to evaluate bone measurements inside at least 6 threads, since the implants used as controls were shorter than the loaded implants and the section through the specimens was not always parallel to the axis of the implants. This resulted in fewer threads in 2 of the 9 control implants. Since a distinction was made between the cervical part of the implant and the entire length of the implant, at least 6 threads needed to be visible for further analysis. For uniformity reasons, these controls were not incorporated in the study. After the elimination of 2 controls, there was still at least 1 control implant in each dog (2 dogs with 2 control implants and 3 dogs with 1 control implant).

The quantifications were performed in a Leitz Aristoplan light microscope (Leitz, Wetzlar, Germany) using an objective of 10×; ie, a magnification of 100× and a zoom of up to 2.5× coupled with Leitz Microvid equipment connected to a personal computer. All measurements were carried out "directly in the eyepiece" of the microscope, using a mouse to outline the regions of interest.

The degree of bone-to-metal contact (BMC), as well as the bone surface areas (BSA) inside the threads, were measured (Fig 2). All available threads of the loaded and non-loaded implants were incorporated in the study. Analyses were performed for *(1)* all the threads of the implants, and *(2)* the cervical part of the implants, defined as the cervix of the implant with the first 3 upper threads. The amount of bone in the area immediately outside the same thread, the out-folded mirror image (BMA) area, was measured and compared with the bone volume inside the same threads. In the group of loaded implants, a 2-factor analysis of variance (ANOVA) for repeated measurements on both factors (length and side) was used for the measured bone percentages (BMC, BSA, and BMA). To compare the loaded with the non-loaded implants, a non-parametric test (Wilcoxon rank test) was used.

It should be emphasized that use of the terms "pressure" and "non-pressure side" only indicates the specific side of the implant regarding the force direction. In this study, the distal side was called the "pressure side," whereas the mesial side was called the "non-pressure side" of the implant. Although the terms "pressure" and "non-pressure" side are commonly used for tooth movement, these terms cannot be transferred to implants since they may behave differently in response to force application. Analogous terms for implants were chosen because they clarified the load direction of the implants.

RESULTS

Clinical Observations

An anterior force application of 5 N on the maxilla over 8 weeks resulted in an orthopedic displacement of the maxilla in the 5 dogs.[22] Clinically, the implants in the zygomatic arch appeared to resist the excessive non-axial forces well. No mobility, losses of loaded implants, adverse tissue reactions, or inflammation were observed during the experiment.

Radiographic Analysis

The radiographic analysis, carried out in a previous study,[28] showed bone tissue with a normal trabecular pattern. No obvious radiolucencies around or underneath the implants (loaded and non-loaded) were observed. Around the loaded implants, some marginal bone loss was seen at the cervical level. This bone loss seemed to be more pronounced on the non-pressure side of the loaded implants. Marginal bone loss measurements with a periodontal probe along the loaded implants demonstrated more bone loss at the non-pressure side compared with the pressure side.[28]

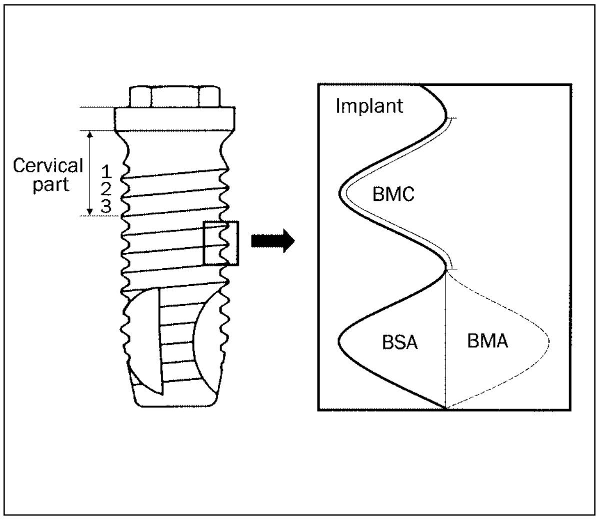

Fig 2 The degree of bone-to-metal contact (BMC), the bone surface area (BSA) inside the threads, and the bone mirror area (BMA) outside the threads were measured for all the threads and the cervical part of the implants.

Histologic Observations

Light microscopic assessments demonstrated that the abutment part of the loaded implants was surrounded mostly by fibrous tissue. The cervical part (upper part of the implant with the first threads) generally showed fibrous and/or granulation tissue. Infiltration of inflammatory cells and multinucleated giant cells was frequently observed. In this region, bone contact was minimal and bone density was low, with a high degree of vascularization. Some bone surface areas were undergoing resorption. The threaded part of the implants showed a higher degree of BMC and a higher percentage of bone inside the threads. The bone density was higher, with less heavily vascularized areas in this region. The apical part revealed mostly dense bone. There was no difference in bone quality between the pressure and non-pressure sides of the loaded implants in the different regions of the bone-implant interface.

For the control implants, connective tissue with a minor degree of infiltration of inflammatory cells was observed at the abutment and coronal part. Multinucleated giant cells were observed close to the implant surface. There was an equivalent bone density in the threaded and apical parts of the control implants compared with the loaded implants.

Histomorphometry

Bone-Metal Contact Percentage. When all threads were compared, there was no statistically significant difference obtained in the percent BMC between the loaded (36%) and the non-loaded (37%)

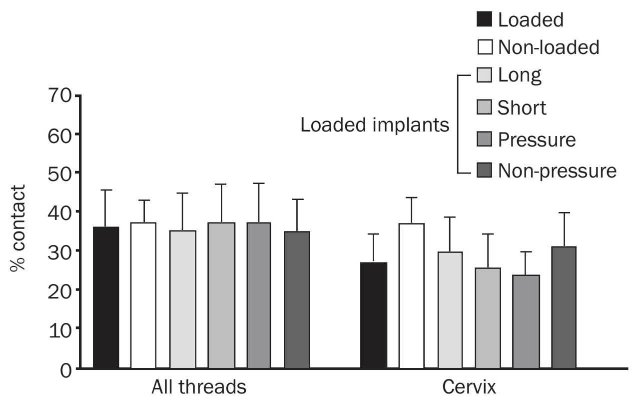

Fig 3 Mean bone-metal contact percentage (BMC) with standard deviation found at all the threads and at the cervix of the implants in the whole sample.

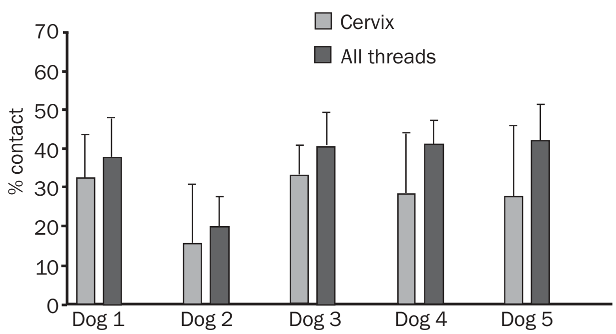

Fig 4 Mean BMC percentage with standard deviation of the loaded implants in the 5 different dogs for the 2 different regions.

implants (Wilcoxon rank test) (Fig 3). There was also no statistically significant difference obtained when the percentage of BMC was compared between the non-pressure (35%) and pressure sides (37%) of the loaded implants. Moreover, no statistically significant difference could be observed between the longest (35%) and the shortest (36%) loaded implant (ANOVA).

Considering the cervical part of the implants, there was a difference (not statistically significant) for the percentage of BMC between the loaded (27%) and the non-loaded (37%) implants (Fig 3). No statistically significant difference was observed between the non-pressure and the pressure sides and between different lengths of the loaded implants. In every dog, the percentage of BMC of the loaded implants was lower at the cervical part, compared with all the threads. Dog 2 always presented a lower degree of BMC percentage compared with the other dogs (Fig 4).

Bone Surface Area and Bone Mirror Area. Although the BSA percentage of loaded implants (60%) was higher than that of the non-loaded control group (52%), the difference was not statistically significant (Fig 5). A lower but not statistically significant percentage of BSA in the cervical part of the loaded implants (54%) was found compared to the amount of bone (60%) in the control implants.

In the loaded implants, there were no statistically significant differences in BSA between the pressure (58%) and non-pressure side (61%) or between the different implant lengths. Although some differences were observed between the investigated variables in the cervical part, compared to all the threads, none of these were significantly different (Fig 5).

The BMA measurements revealed no statistically significant difference between the loaded (67%) and non-loaded (69%) implants. Similarly, for the different lengths and for the sides (pressure versus non-pressure) of the loaded implants, no significant differences were found (Fig 6). Comparison of the bone area inside the threads (BSA) with the area immediately outside the threads (BMA) revealed a higher percentage in the latter case in all dogs.

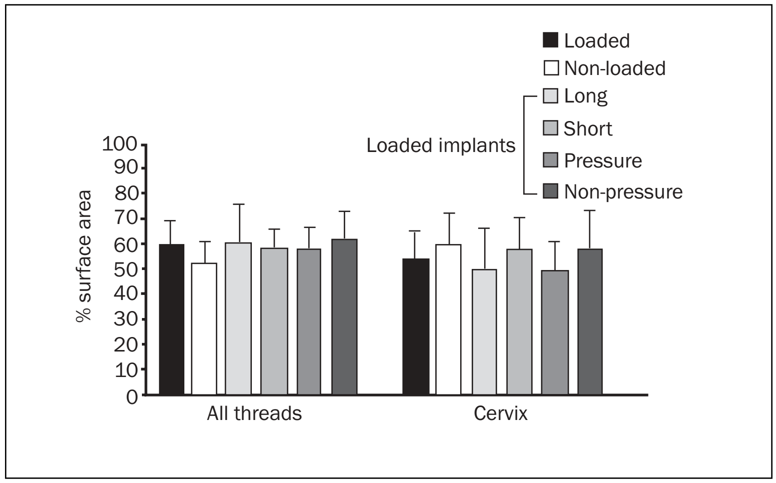

Fig 5 Mean bone surface area percentage with standard deviation for all the threads and the cervix of the implants in the whole sample.

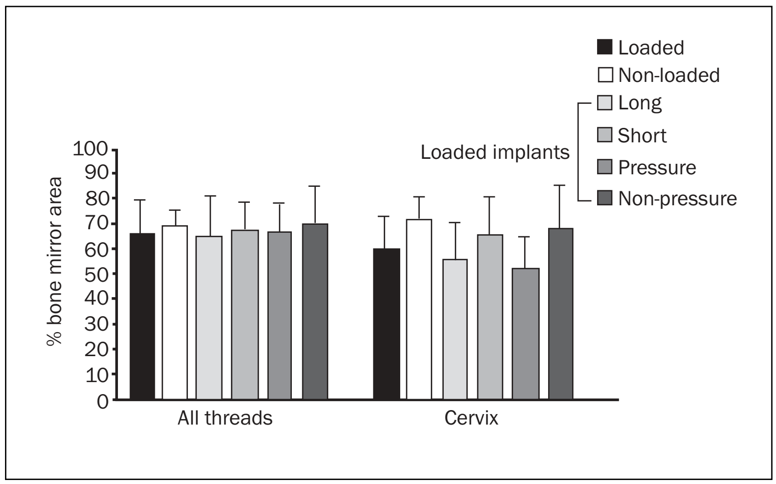

Fig 6 Mean bone mirror area percentage with standard deviation for all the threads and the cervix of the implants in the whole sample.

Generally, in the cervical region, the loaded implants demonstrated less bone area inside and immediately outside the threads compared to similar measurements performed in the control samples, where more bone inside and outside the threads was found. A statistically significant difference between the BSA (52%) and BMA (69%) was found in the control implants (Figs 5 and 6).

DISCUSSION

The indications for using dental implants in orthopedic applications are different from those in prosthetic dentistry. Initially, to obtain skeletal changes in orthopedics, larger force magnitudes are needed.[20–22] These forces must be absorbed directly through the implants by the underlying bone structures without sacrificing the rigid bone-implant interface. Moreover, the long-term conditions of dental implants (ie, marginal bone loss) that are used exclusively for anchorage and therefore are temporary are not as important as in prosthetic dentistry.

In this study, the material and technique developed by Brånemark and coworkers[26] were used. Commercially pure titanium implants were placed in the zygomatic arch of the temporal bone in 5 dogs. These implants served as anchorage units to create a forward orthopedic displacement of the maxilla with a coil system pushing between the implants and the maxilla.

A healing period of 2 months after implant placement was provided. According to Albrektsson and associates,[7,8] the absence of early loading during the healing phase is one of the important parameters for establishing osseointegration of prosthodontically loaded implants. Roberts and colleagues[12] stated that orthodontic loading (under 3 N) is relatively insignificant for the success of osseointegration compared to the stress of normal jaw function. Nevertheless, Roberts and colleagues[12–15] respected a "closed healing phase" of at least 4 months in earlier studies. In a recent publication, however,[16] they recommended initiation of orthodontic force at the time of implant placement in an attempt to strive for a 1-step surgical procedure.

In the present study, a large, non-axial force application of 5 N was used during an experimental period of 2 months. This force magnitude is higher than in orthodontic therapy. Therefore a healing period of 2 months was provided. Stability of the placed implants was tested after a healing period of 8 weeks by measuring the initial displacement of the implants immediately after loading.[28] This initial displacement was calibrated by means of a noninvasive laser-measuring technique (speckle interferometry). No initial mobility of the loaded implants was observed after the application of force, indicating adequate osseointegration. However, initially obtained osseointegration can be lost progressively, especially when a large orthopedic force is applied continuously over several months.[29] The orthopedic force application in this study resulted in displacement of the maxilla in a forward and upward direction by using the implants in the zygomatic arch as anchorage.[22] After the experimental period of 2 months, no implants were lost, and the clinical and radiographic analyses demonstrated that all implants appeared to be integrated. Radiographs of the anchor units revealed a normal bone pattern around the implants. There was no difference in the surrounding bone structure between the loaded and non-loaded implants.

The results of this study indicate that the loaded implants maintained the initially obtained direct bone contact during loading despite large, continuous, non-axial forces. Comparison with other studies is difficult to make, since most of them report the success of osseointegration after orthodontic loading, using smaller forces (less than 3 N). In the present study, a histologic evaluation was made of the amount of bone at the interface of non-loaded and loaded implants after non-axial force application. Histomorphometric analyses may indicate that the bone-to-implant contact is less favorable than the clinical and radiographic analyses suggest.[30,31]

Histomorphometry demonstrated osseointegration, ie, direct bone-to-implant contact. A BMC of 36% in the loaded implant group was not statistically significantly different from that of the non-loaded group (37%) considering all threads of the implant. Also, the BSA was not significantly different when all the threads of the loaded (60%) and non-loaded (52%) implants were compared. These results were in agreement with the findings of other studies. Helm and associates[32] reported that rigid endosseous implants had less than a quarter of their endosseous area in direct contact with bone. Moreover, Roberts and coworkers[12] stated that osseous contact on less than 10% of the surface is all that is necessary to resist orthodontic loads (under 3 N). Furthermore, Helm and associates[32] and Roberts and coworkers[12] concluded that the percentage of bone interface was independent of the force magnitude. Akin-Nergiz and colleagues[21] found that continuously loaded implants showed a significantly different range (40% to 56%) of osseous proximity within the 50-µm interface zone compared to implants that were loaded intermittently with masticatory forces (56% to 72%). The uncovered and unloaded implants (controls) demonstrated the lowest values of osseous proximity (29% to 39%). In the present study, the bone volume of the unloaded implants was on average smaller than the loaded ones, but this difference was not statistically significant.

Considering the cervical part of the implants, a statistically insignificant difference in BMC was found between the loaded (27%) and non-loaded groups (37%). In all dogs, a lower degree of BMC and BSA was found in the cervical part compared with the entire number of threads. Some bone surface areas were undergoing resorption in the cervical region of the implants. The magnitude and direction of the force probably created an adverse stress distribution around the cervical region of the implant. It is still unknown how the stress of functional loading is distributed around the threads. This stress distribution could be compared to bone histology at the bone-implant interface, and the change in stress environment may be related to the bone-remodeling mechanism. In a finite element analysis, Chen and coworkers found a strong stress pattern change immediately around the implant, which was reflected by a moderate change of stress between the threads and a significant increase in stress at the tips of the threads.[33] They did not find a specific larger stress distribution around the cervical region of the implants. Roberts and associates reported a high remodeling rate for cortical bone in the threads of a 2-stage endosseous implant placed in the retromolar region of the mandible for orthodontic anchorage.[13] No distinction in the remodeling rate was made for the different regions of the implants.

Since some clinicians use implants as abutments for prosthetic restorations after orthodontic treatment, this marginal bone loss may be important. Measurements of marginal bone loss with a periodontal probe along the loaded implants demonstrated a bone loss of 0.5 mm.[28] However, this amount of bone loss was similar to the results of clinical experiments.[1–6] After implant loading, a bone loss of 1 to 1.5 mm related to function during the first year is considered to be clinically acceptable. Neither Ödman and coworkers[34] nor Akin-Nergiz and associates[21] found any significant increase in probing depth after continuous orthodontic loading of implants.

In the loaded group of implants, histomorphometry revealed no statistically significant difference between the non-pressure and pressure side when considering the BMC and BSA percentages. These results are not in agreement with the clinical bone loss measurements and radiographic analyses of implants reported in a previous study.[28] In the radiographic and clinical analysis of the implants, more bone loss was observed at the non-pressure side. These changes were not observed in the histomorphometric measurements. Even in the cervical region of the implants, a significant difference could not be established. This lack of confirmation in the histomorphometric study could be the result of measurement differences between the clinical procedure, the radiographic imaging, and the histomorphometric analysis (which was carried out only at one specific section side). This finding may support the conclusion that clinical, radiographic, and histomorphometric analysis all have their merits and limitations in the evaluation of osseointegration.

Likewise, Akin-Nergiz and associates[21] failed to find a significant difference in probing depth between the continuously loaded pressure and tension side; nor did they find a significant progression of bone loss even after a period of 24 months. In a recent study, Wehrbein and coworkers[35] found increased remodeling activity around all loaded implants as well as at both the pressure and non-pressure side. They could not show any difference in remodeling activity between the different regions of the peri-implant bone.

In the group of loaded implants, the amount of bone in the mirror images (BMA) of all the threads was somewhat higher (66%) than the bone volume inside the threads (60%), but this was not statistically significant. In contrast, in the unloaded control group the BMA (69%) was significantly higher compared with the BSA (52%). As in other studies,[21,34] the uncovered and unloaded implants demonstrated the lowest values of osseous proximity, whereas the loading of implants resulted in an increase in remodeling of the peri-implant bone because of function.

A differential degree of bone response at the interface between the 5 dogs was observed (Fig 4). In 4 dogs, comparable bone values were found, whereas in dog 2 overall lower bone volume and BMC were observed for the loaded as well as for the unloaded implants. This difference could be the result of a difference in bone metabolism.

CONCLUSIONS

According to this study, histologic analysis of the implants revealed "osseointegration" despite a large, continuous orthopedic force application of 5 N over 8 weeks. Based on the results of this study, the use of titanium implants as anchorage for orthopedic force systems can be recommended. Moreover, implants initially used as anchorage for orthopedic or orthodontic tooth movement can be used later as support for prosthetic restorations.

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