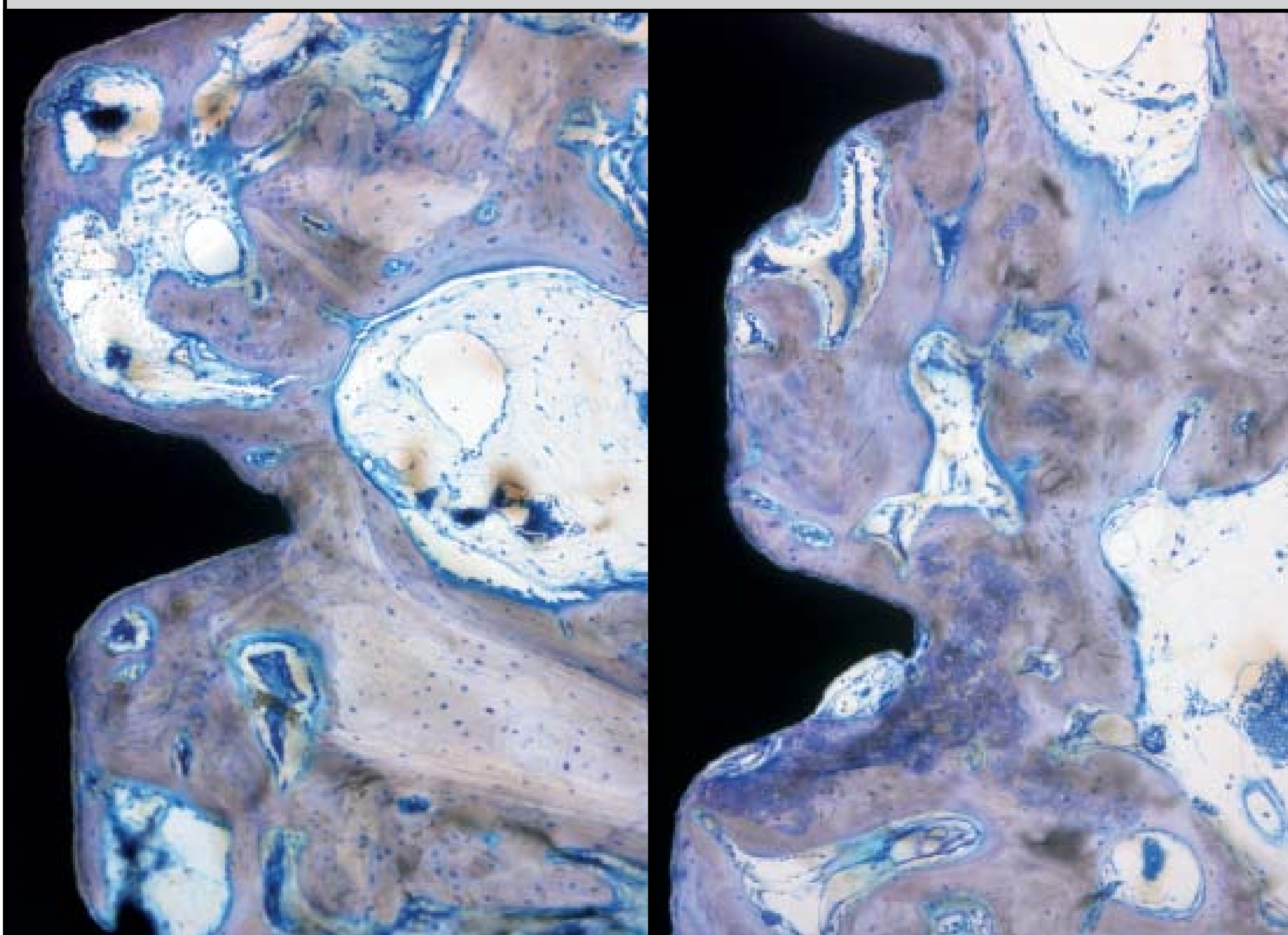
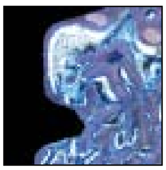


# The Impact of Bone Compression on Bone-to-Implant Contact of an Osseointegrated Implant: A Canine Study



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*The dental community's interest in early loading of endosseous implants provides the stimulation to test the ability of modified implant designs as well as surgical techniques to enhance the establishment and maintenance of implant stability. This preclinical canine study examined this potential by implementing several implant design and surgical technique modifications to an existing tapered implant system. The design and site preparation changes were intended to induce different compression states on the native bone, hypothetically affecting the primary stability and the rate and extent of osseointegration. The outcomes of the modifications were evaluated using resonance frequency analysis, radiographic analysis, light microscopy, and histomorphometric measurements. Three compression scenarios were tested, with each demonstrating excellent clinical, radiographic, and histologic results throughout the evaluation period. However, the scenario intended to induce a moderate degree of compression provided the best overall results, supporting its use in early loading protocols.* (Int J Periodontics Restorative Dent 2012;32:637–645.)

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The purpose of this study was to determine the impact of bone compression on bone-to-implant contact (BIC) with different implant designs. Contemporary implant designs are focused on optimizing the early mechanical or primary stability of the implant and the secondary or final stability achieved upon successful osseointegration. The implant's mechanical stability is impacted directly by bone quality and quantity, implant macrodesign, and the implant's relationship with the prepared osteotomy.[1] The implant's secondary stability is affected by many of these same factors but also has been demonstrated to be influenced by other host factors, including wound site blood supply and the implant's surface design.[2]

In clinical application, various methods, including insertion torque and resonance frequency analysis (RFA), are typically used to quantify primary stability. Secondary stability, or osseointegration, is usually gauged by the overall outcome measure of implant survival. However, in research, measures such as RFA, mechanical disruption testing, and histomorphometric analysis are often used to gain additional insight into the rate and extent of osseointegration.

The major tenants of the implant macrodesign used in this study were directly borrowed from an existing tapered implant system (Biomet 3i), but significant modifications were introduced to the implant surface, implant collar design, and implant-abutment connection interface. In addition, since this study focused on evaluating different degrees of bone compression, one of the scenarios tested had the implant's self-cutting features removed to induce a higher state of compression.

## Method and materials

This prospective, randomized, controlled preclinical trial enrolled 10 mixed foxhounds to analyze the impact of bone compression on dental implant primary stability and osseointegration. The study protocol was approved by the Institutional Animal Care and Use Committee at PARF. The animals were obtained and allowed to assimilate to laboratory conditions for 14 days prior to the first surgical procedure.

### *Surgical extraction phase*

Ten foxhounds, each weighing at least 25 kg, were selected for this study. The bilateral mandibular second, third, and fourth premolars and the first molar were subsequently extracted with full mucoperiosteal flaps under general and local anesthesia to create edentulous spaces for future implant placement. The flaps were coapted and sutured without tension using multiple interrupted sutures and were allowed to heal for 45 days.

### *Surgical implant placement*

A crestal incision was made to maximize preservation of the keratinized tissue, and full-thickness mucoperiosteal flaps were reflected 45 days postextraction. Two implants per side were inserted into each animal according to a predetermined randomized distribution pattern.

Three hypothetical initial bone compression states were simulated for this study (low, moderate, and high compression).

- Group A (low compression): The implant site was tapped to the dimension of the implant thread (major and minor). Upon placement, the self-cutting implant was not required to directly cut or compress bone.
- Group B (moderate compression): The implant site was prepared to the minor diameter of the implant. Upon placement, the self-cutting implant design was required to cut and displace the bone volume of the threads. As the implant was inserted, the bone chips were deposited into the cutting feature recesses and moved apically, creating the potential for indirect compression in the apex.
- Group C (high compression): The implants were modified to remove the cutting features. The implant site was then prepared to the minor diameter of the implant. Upon placement, there was direct compression of the bone by the threads. Cutting and displacing of bone fragments did not occur.

All implant sites were randomly assigned to receive a prototype tapered commercially pure titanium implant (3.4-mm diameter, 8.5 mm long) with a new surface (Biomet 3i). The surface included a new hybrid design. The implant's coronal aspects included the decreased surface roughness of a dual acid etching topography, while the apical surface roughness was increased. More specifically, the apical surface consisted of three distinct levels of topography, which were intended by the manufacturer to enhance secondary stability through the healing phase. The three levels of topography included submicron topography (deposition of 10 to 100 nm of hydroxyapatite covering approximately 50% of the surface), micron topography (dual acid etching, 1 to 3 μm of pitting), and hybrid coarse micron topography (mean absolute height deviation [Sa] of $< 0.6$ μm coronally and approximately 1.5 μm apically).

In addition, the implant prototype included a shortened collar (0.5 mm versus 1.25 mm) compared to the currently available tapered implant, which resulted in a greater thread run-out.

Implant osteotomies were performed with torque-reduction rotary instruments at 1,200 to 1,500 rpm using sterile saline solution. The implants were delivered with an insertion device and a torque-indicating hand ratchet according to the manufacturer's guidelines, and the peak torque was recorded. The implants were placed so that the top of the collar was level with the osseous crest (epicrestal). Immediately after implant placement, RFA assessments of all implants were performed using a resonance frequency analyzer (Osstell) before healing abutments were placed. The RFA device transformed the resonance frequency value for each assessment to implant stability quotient (ISQ) units. The surgical flaps were adapted around the healing abutments using tension-free wound closure with interrupted horizontal mattress sutures. Postsurgical radiographs were then taken. The animals were monitored on a daily basis for healing abnormalities. All animals received a soft diet for the duration of the healing period.

*Sacrifice*

Two animals were immediately sacrificed, while two animals each were sacrificed on days 7, 14, 28, and 56. Additional radiographs were taken after each sacrifice, and ISQ values were obtained. Each mandible was resected en bloc and immediately placed in fixative for histologic preparation and evaluation.

*Specimen preparation and analysis*

Fixed samples were dehydrated in a graded series of ethanols using a dehydration system with agitation and vacuum. The blocks were infiltrated with Kulzer Technovit 7200 VLC resin. Infiltrated specimens were placed into embedding molds, and polymerization was performed under ultraviolet light. Polymerized blocks were sectioned in a mesiodistal direction and parallel to the long axis of each implant. The slices were reduced by microgrinding and polishing using an Exakt grinding unit to an even thickness of 30 to 40 μm. Sections were stained with toluidine blue/Azur II and examined using both a Leica MZ16 stereomicroscope and a Leica 6000DRB light microscope.

## Results

Implants were evaluated as to their survival, ISQ value, radiographic interpretation of mesial and distal bone levels, light microscopy, and histomorphometric analysis to determine BIC.

*Survival*

All animals remained healthy until their predetermined date of sacrifice. All implants were successful, with no clinical compromise observed.

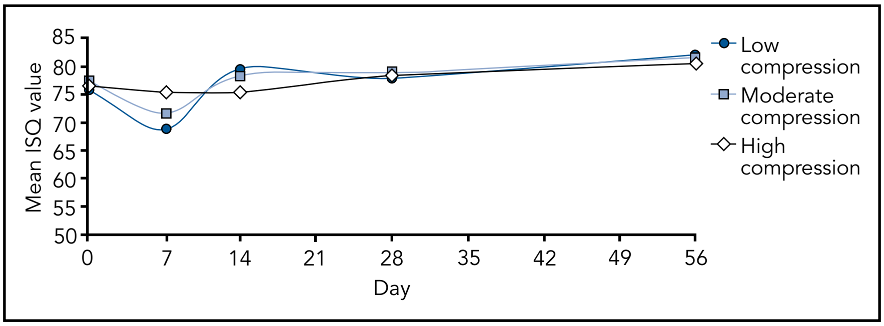



**Fig 1** *RFA results.*

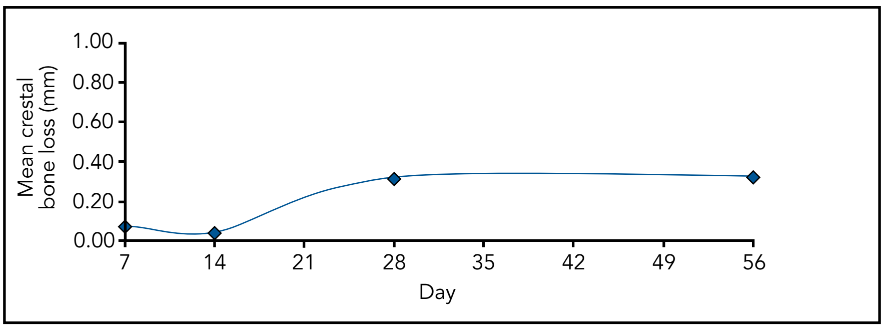



**Fig 2** *Combined crestal bone loss for all three groups.*

### *ISQ measurement*

Figure 1 provides the RFA results. The implants from groups A (low compression), B (moderate compression), and C (high compression) all demonstrated high ISQ values at baseline, with a modest but nonstatistical decrease in stability at day 7. The mean ISQ values for groups A and B trended higher by day 14, providing an indicator of osseointegration. All three groups achieved mean ISQ values greater than 78 by day 28, which is generally considered to be a high degree of stability capable of supporting loading.[3] It is interesting to note that implants in group C (high compression) did not achieve higher ISQ values.

### *Radiographic analysis*

Radiographic analysis provided direct evidence of epicrestal implant placement. The mean position of the top of the implant collar was measured at 0.07 mm supercrestal.

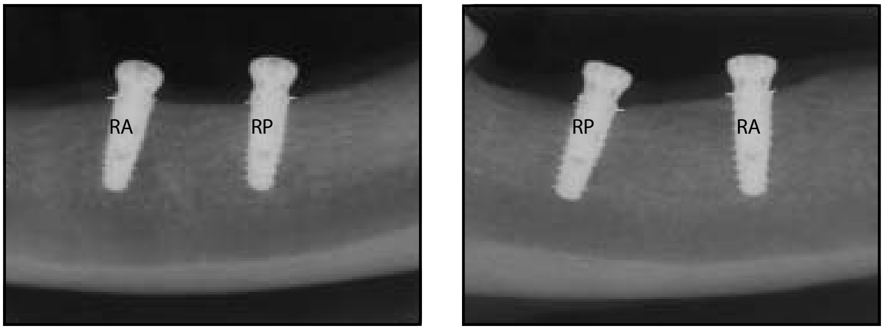
Minimal differences were noted in crestal bone loss between the three scenarios tested. This result was not unexpected considering that the implant surface, collar design, implant-abutment connection, and induced compression state on the implant collar were equivalent for all scenarios. The three groups each used a line-to-line countersink built into the shaping drill to create the collar portion of the osteotomy. Figure 2 provides the combined crestal bone results for the three scenarios, while Figs 3a and 3b demonstrate representative radiographic results.

### *Histology*

The results of the light microscopy analysis were highly informative, following the expected pattern of increased BIC according to the timeframe.

**Baseline (day 0)**

Day 0 images were used to assess baseline bone quality and to detect differences in the bone adjacent to the implant immediately after placement. By examining the histologic images from day 0, a baseline of existing bone structure could be




**Figs 3a and 3b** *Radiographs of implants in group B (moderate compression scenario) at* (left) *baseline and* (right) *day 56. RA = right anterior; RP = right posterior.*

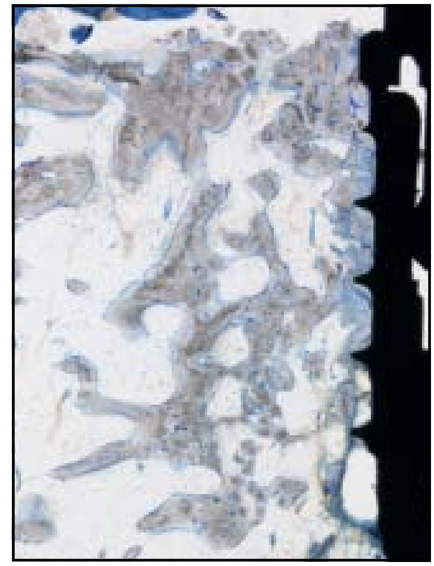


**Fig 4** *Histologic image of a group B (moderate compression scenario) specimen at day 0.*

established (Fig 4). In this canine model, the existing bone consisted of 1 to 3 mm of cortical bone surrounding an underlying region of relatively low-density trabecularized bone.

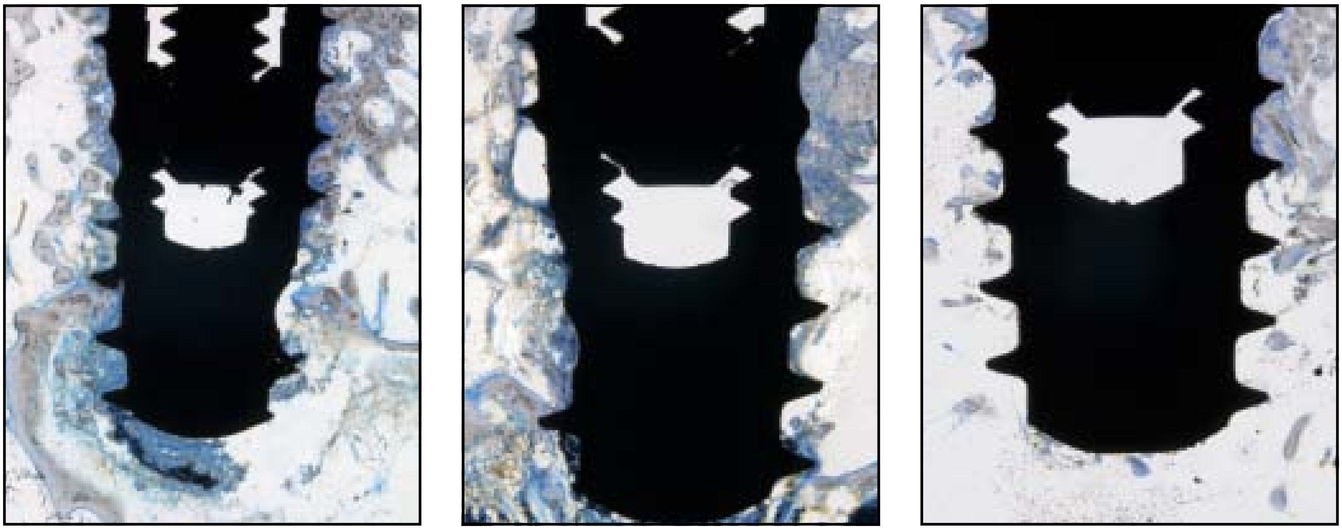
In addition to establishing a baseline, a histologic difference was observed between groups A and B versus group C (Figs 5a to 5c). The apexes of group A and B implants, created using a self-cutting implant or tap, were surrounded with bone chips. The group C implant apexes were relatively void of these fragments. This difference could have resulted from self-cutting implant designs displacing the bone apically into the trabecular region, versus the direct bone compression pattern of the noncutting design.

### Day 7

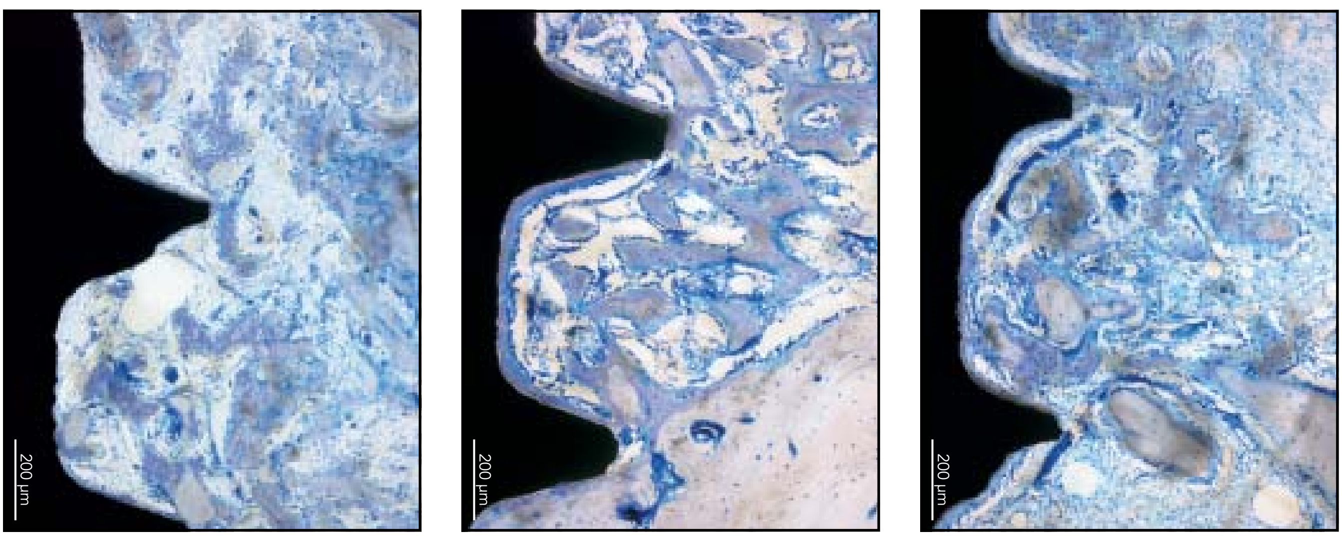
At day 7, de novo bone formation was observed to be more pronounced in group B (Figs 6a to 6c). This qualitative finding was also confirmed with histomorphometric analysis. At this time point, cellular activity surrounding the implant was observed to be at its highest. The overall cellular response appeared to be greatest for the group C compression scenario.

### Day 14

The differences among the three compression groups were less detectable at 14 days (Figs 7a to 7c). Qualitatively, bone fill generally appeared greater in groups B and C. However, the BIC in group A was well established.



**Figs 5a to 5c** *Histologic specimens for the three bone compression scenarios at day 0.* (left) *Group A (low);* (center) *group B (moderate); and* (right) *group C (high).*

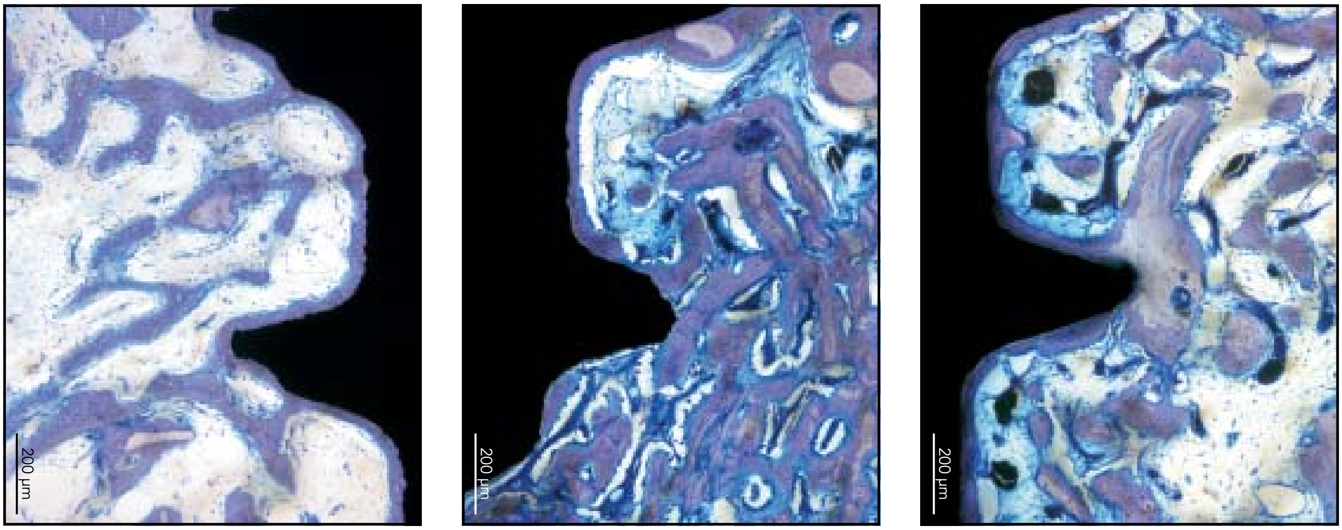



**Figs 6a to 6c** *Histologic specimens for the three bone compression scenarios at day 7.* (left) *Group A (low);* (center) *group B (moderate); and* (right) *group C (high).*

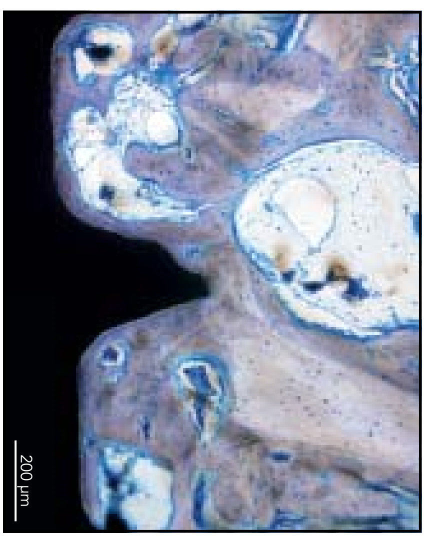
### Days 28 and 56

Similar to day 14, no observable differences were detected between compression scenarios at days 28 and 56 (Figs 8a and 8b). Bone formation continued to occur in all groups, primarily observed by increased bone volume fill inside and around the implant threads.

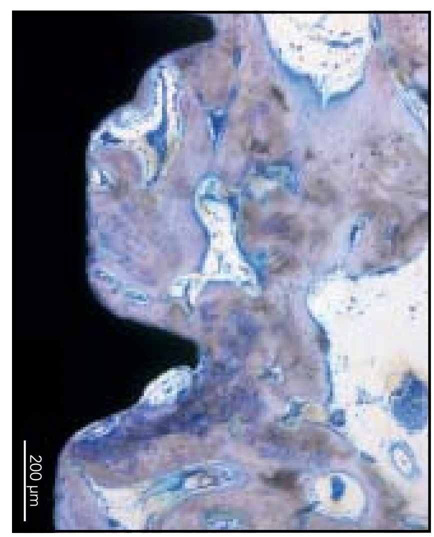
The histologic results at days 0 and 56 demonstrate the ability of titanium implants to transform the native bone environment, thus allowing support of the prosthesis. Figures 9a and 9b demonstrate the native bone environment at days 0 and 56. Within 2 months of implantation, the low-density bone and




**Figs 7a to 7c** *Histologic specimens for the three bone compression scenarios at day 14.* (left) *Group A (low);* (center) *group B (moderate); and* (right) *group C (high).*




**Figs 8a and 8b** *Histologic specimen of a group B (moderate compression) sample at* (left) *day 28 and* (right) *day 56.*




tissue around the implant at day 0 was completely replaced with high-density de novo bone.

*Histomorphometric analysis*

Figure 10 summarizes the histomorphometric analysis. The analysis demonstrated substantial improvement in BIC from day 0 to day 56 for all groups. Group A showed a significant positive change from day 7 to day 14 and then settled at approximately 70% by day 56. Group C, with no cutting features, caught up by day 28, reaching 76% by day 56. Group B implants exhibited the highest BIC at day 7 and then remained in the mid-70s until the conclusion of the study. One might interpret the results as reasonable evidence that implants in group B (moderate compression scenario) would be the best choice for early loading since the initial BIC profile was superior.

**Figs 9a and 9b** *Native bone environment of a group A (low compression) specimen at* (left) *day 0 and* (right) *day 56.*

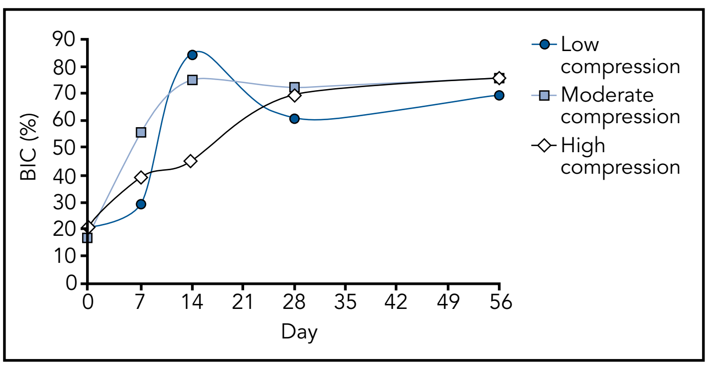



**Fig 10** *Results of the histomorphometric analysis.*

## Discussion

This research analyzed the potential for early implant stability as expressed by BIC, ISQ values, and periapical radiographs. In this study, modifications of existing tapered implants were made to test different compression scenarios (low, moderate, and high). A single-stage technique with transgingival healing abutments was used to include a degree of loading in the model. However, because the masticatory apparatus of canines is so far removed from humans, the clinical correlation of this loading profile is unknown.

The study showed that the clinical impact of compression most likely exists in the initial healing period (< 28 days) of a canine model. The group C compression scenario (high compression) did not seem to influence primary stability and only demonstrated a minor impact on osseointegration at the earliest time points. Subsequently, this study did not find any correlation between the high compression scenario and increased incidence of compression necrosis.

It has been postulated that when inadvertent or excessive torque has been placed on an implant during insertion, a phenomenon described as compression necrosis might occur and lead to implant failure.[4,5] It has also been postulated that the compression of bone beyond its physiologic tolerance might result in ischemia with subsequent necrosis or sequestrum formation.[4] It is critical to understand that multiple variables are typically required to create an excessively high compressive scenario. These include high initial bone density, an underprepared osteotomy, and the use of implants designed to be compressive (eg, non-self-cutting, increased thread size/volume).

In this research, a high compression scenario (group C) was simulated but limited by the canine biology and site preparation used. Subsequently, the level of compression generated by the noncutting implant design variant was higher than that in the other groups but may not have been excessive. This finding could explain why no evidence of compression necrosis was detected.

A number of preclinical investigations on canines have been published to examine the dynamic process of osseointegration, including de novo bone formation phases around dental implants.[6–9] The pattern of bone formation observed in this study was consistent with previous descriptions of bone modeling and remodeling around dental implants.

While the osseointegration results in this study were impacted by the compression state, it is also understood that the material, implant geometry, and surface additionally play critical roles. The choice of these variables potentially impacted the authors' abilities to detect differences between the scenarios tested, since the baseline design was theoretically preoptimized to provide osseointegration robustness.

Several preclinical studies evaluated RFA values in relation to osseointegration and noted no correlation between the histologic parameters of osseointegration and ISQ values.[8,9] A similar finding was noted in this study. Although there was no significant difference in ISQ values for all three groups tested during the observation period, there was substantial improvement in BIC during this period, and the ISQ was not able to differentiate this change. It is important for researchers to validate RFA values of new implant designs with supportive histomorphometric analyses.

The RFA results and histomorphometric outcomes of this study can be compared to similar published canine research. For example, in 2009, investigators reported an 8-week mean BIC of 58% for implants with a sandblased, large-grit, acid-etched surface and BIC of 37% for a turned control. In this same study, the ISQ results for the implants tested reached maximum values in the 60s.[9] In comparison, the implants in this study consistently achieved ISQ values exceeding 80 and 70% or greater BIC at an equivalent 8-week time point.

## Conclusions

An existing tapered implant system design was modified to determine the impact of bone compression on implant stability and the histologic parameters of osseointegration. The implant system evaluated demonstrated substantial BIC percentages as well as high ISQ values for each of the three compression scenarios tested. The moderate compression scenario, created by the self-cutting implant design, demonstrated the most promise for enhanced establishment and maintenance of implant stability.

## Acknowledgment

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