

Histologic and Biomechanical Evaluation of the Effects of Implant Insertion Torque on Peri-Implant Bone Healing

Ugo Consolo, MD, DDS, Domenico Travaglini, DDS, Marzio Todisco, DDS,
Paolo Trisi, DDS, PhD, and Silvia Galli, DDS

Abstract: The aim of this study was to evaluate histologically and biomechanically the peri-implant bone healing around implants placed with high torque after a follow-up of 8 and 12 weeks. A total of 12 implants were placed in the lower edge of the mandible of 2 sheep. In each sheep, 3 implants were placed with a low torque ($<25 \text{ N} \cdot \text{cm}$, LT group) as a control, and 3 implants were placed with a high insertion torque (maximum torque, HT group). The sheep were killed after 8 and 12 weeks of healing, and the implants were examined for removal torque, resonance frequency analysis, and histologic analysis.

The mean insertion torque in the LT group was $24 \text{ N} \cdot \text{cm}$, whereas it was $105.6 \text{ N} \cdot \text{cm}$ in HT. All the implants osseointegrated and histologic analysis showed similar aspects of the peri-implant bone tissue for both groups and both healing times. Mean removal torque values for LT implants were 159.5 and $131.5 \text{ N} \cdot \text{cm}$ after 8 and 12 weeks, respectively, whereas those for the HT were 140 and $120 \text{ N} \cdot \text{cm}$ at 8 and 12 weeks, respectively. Implant stability quotient values were 26.6 and 76 for the LT group and 74 and 76 for the HT group at 8 and 12 weeks, respectively.

It could be concluded that high implant insertion torque does not induce adverse reaction in cortical bone and does not lead to implant failure.

Key Words: Dental implant, insertion torque, peri-implant bone
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Oral implant restorations are nowadays the most similar rehabilitations to natural dentation to be offered to patients.¹ Together with the continued innovation in oral implantology, it increases the

interest of the clinicians to offer their patient an immediate restoration on oral implants.²

The traditional implant-loading protocols provide that osseointegration (biologic stabilization) occurs before implants are exposed to occlusal loads.³ More recent protocols, on the other hand, propose shorter healing times and the immediate implant finalization, subjecting implants to mechanical stress during the early phases of healing.

Implant therapy was demonstrated, in various experimental clinical studies, to have high levels of predictability, even in case of immediate or early loading.^{4,5}

To perform an immediately loading protocol, one of the most important parameters to consider is the implant primary stability, which must be enough to support the functional and, eventually, the parafunctional loads.⁶ Researchers suggest that a high primary stability may avoid excessive micromovements of the implant in the bone, which are considered the most common cause of early implant failures.⁷

Obtaining an adequate mechanical stability of implants in the bone is influenced by many factors, among which especially are the procedures of surgical preparation of the implant bed, the implant macrogeometry, and the quality of the receiving bone site.⁸

The so-called underpreparation of the implant site, or the creation of an osteotomy with a diameter smaller than the fixture's diameter, determines the increase in the moment of force necessary to place the implant in its final position inside the bone site. It has been demonstrated that the higher this moment of force is, the higher is the implant primary stability.⁹ The moment of force is defined insertion torque of the implant, and it is considered one of the parameters to quantify implants' primary stability.

It has been proposed that an insertion torque excessively high may cause necrosis of the peri-implant bone in the receiving site and therefore the failure of the implant.^{10,11} However, no experimental study has yet demonstrated this assumption. Hence, it is necessary and actual to verify the influence of the insertion torque on the bone tissue.

A study recently published by Trisi et al¹² had the purpose of evaluating the role of the implant insertion torque on peri-implant bone tropisms during the first 6 weeks of healing of implants placed in the mandible of sheep. The present study aims to investigate the influence of a high implant insertion torque on the peri-implant bone at the later healing stages of 8 and 12 weeks. In particular, this study aimed to assess the relation between the implant insertion torque and the surrounding bone tissue, by means of the histologic and histomorphometric evaluation and the analysis of biomechanical data, as the removal torque and the implant stability quotient (ISQ).

MATERIALS AND METHOD

Study Protocol

Two hybrid female sheep, aged 4 to 5 years, were randomly selected. Exclusion criteria were general contraindications



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From the Facoltà di Odontoiatria e Protesi Dentaria, Università degli Studi di Modena e Reggio Emilia, and Department of Prosthodontics, Faculty of Odontology, Malmö Högskola, Malmö, Sweden.

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Address correspondence and reprint requests to Ugo Consolo, MD, DDS, Università degli Studi di Modena e Reggio Emilia, Facoltà di Odontoiatria e Protesi Dentaria, Via del Pozzo 71 41100 Modena; E-mail: librochirurgia@gmail.com

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to implant surgery and active infection or severe inflammation in the area intended for the implant placement.

Each sheep received 6 Screw Vent implants (Zimmer Dental, Carlsbad, CA), 3 in the left hemimandible with an insertion torque lower than 25 N · cm (control sites, low torque [LT]) and 3 in the right hemimandible with insertion torque maximum (test sites, high torque [HT]). All the implants were placed in the lower edge of the sheep mandibles, as so to avoid teeth extraction.

The animals were killed after 8 and 12 weeks of healing, one animal per healing time. At the time of reentries, resonance frequency analysis (RFA) was performed on all implants, removal torque was determined for 2 implants per hemimandible, and block sections of all implants were obtained to assess histologic and histomorphometric data.

Surgery

Before intervention, the animals were monitored at 1 week and fed with a standard diet. Before the surgery, all animals were fasted for 24 hours. All surgical procedures were performed under sterile conditions with general anesthesia.

The anesthesia of the animals was induced with intravenous injection of sodium thiopental (Pentothal; Hoechst AG, Frankfurt am Main, Germany). Physiologic saline was administered during the surgery.

The preparation of all the surgical sites and of all the implant beds was performed by the same surgeon, with the same surgical motor (W&H Elcomed GmbH, Bürmoos, Austria).

Twelve Screw Vent tapered implants (Zimmer Dental), 8 mm in length and 3.8 mm in diameter, were inserted. These implants are tapered, with a self-tapping threaded design, a 1-mm machined collar, and a hydroxyapatite-blasted and acid-etched surface (MTX; Zimmer Dental).

First, the surgical area was shaved, washed, and disinfected with povidone-iodine. After that, the inferior edges of the mandible were exposed through a 15-cm-long skin incision. The skin and facial layers were opened and closed separately. Once the cortical edge was dissected, implant sites were prepared in each side (left and right) of the mandible, positioned perpendicular to the edge of the crest and at a minimal distance of 4 mm between each other.

A 2.3-mm-diameter pilot drill was used to perforate the cortical layer, followed by an intermediate drill of 2.3 mm in the apical part and 2.8 mm in the coronal area. A drill with a diameter of 2.8 mm was then used to widen the implant site until the apex. External profuse irrigation with cold saline solution was used during the entire preparation. After this point, the preparation for the control and test sites differed.

On the left side, 3 implant sites were prepared with a final tapered drill (diameter from 3.4 to 3.8 mm), and these sites received implants with low insertion torque (LT, control). These implants (LT group) were inserted using a powered torque-control hand-piece adjusted to 10 N · cm. All the LT implants were positioned without any resistance after preparation of the implant sites with the final tapered drill; thus, limited primary stability was achieved.

On the right side, 3 implant sites were prepared only in the coronal 2 mm of bone with a final tapered drill. These sites (HT, test) received implants with high insertion torque using a manual torque wrench (Tonichi STC400CN) that registered each turn. Each implant was positioned with about 7 turns, for a mean insertion torque of 110 N · cm and a peak insertion torque around 150 N · cm (Fig. 1).

Cover screws were placed over the head of the implants, and periosteum and subdermal tissue were closed with resorbable sutures (Biosyn monofilament glycomer 631; Covidien, Dublin, Ireland). The skin was thereafter sutured with Nylon MONOSOF 2.0 (Monosoft monofilament polyamide; Covidien, Dublin, Ireland) external sutures.

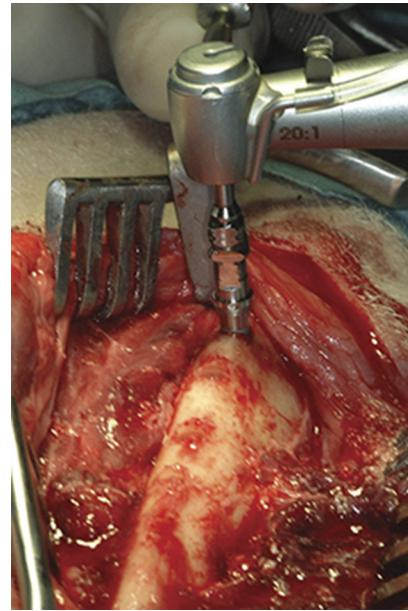


FIGURE 1. Placement of the implants in the lower edge of the sheep mandible.

After 8 and 12 weeks of healing, the first and the second sheep were killed, respectively, in both cases by an overdose of sodium thiopental (Hoechst). The surgical sites were reopened by the same full-thick flap of the first surgeries.

Resonance Frequency Measurement

The RFA value was measured for all implants at the time of the surgical reentries by means of Osstell device (Integration Diagnostics AB, Göteborg, Sweden). A transducer was directly connected to each implant, attached to the top of the implant, perpendicular to the mandibular crest, using a screw with 10 N · cm of torque. The ISQ, which ranged between 0 and 100, was registered twice for each implant, and an average value was taken.

Removal Torque Testing

Removal torque was measured at the time the animals were killed (8 and 12 weeks after implantation), to determine the implant stability in the bone bed. It was measured with a digital hand-operated torque wrench (Tonichi STC400CN, Northbrook, IL) by unscrewing the implants until interfacial failure occurred. The digital torque wrench automatically registered the peak removal torque value on the digital display. After the initial interface detachment, the implants were screwed back into their initial position as accurately as possible and retrieved for histologic analysis. This was done to provide an estimate of the bone-implant contact (BIC) at the time of histologic analysis. Although the interfacial detachment created an artifact at the interface, its analysis would still be reliable according to Sennerby et al,¹³ who used a similar procedure to study the morphology of the bone-metal rupture.

The removal torque was measured for 2 implants per side of the mandible, whereas 1 implant per side was left unscrewed to preserve an intact interface for histologic analysis and compared with the detached implants.

Histologic and Histomorphometric Analyses

Block sections of the inferior edge of the sheep mandibles were cut parallel to the longitudinal axis of the implants in a buccolingual direction. The specimens were immediately fixed in 10%

neutral-buffered formalin. After dehydration, the specimens were infiltrated with methyl methacrylate resin from a starting solution of 50% ethanol/resin and subsequently increasing up to 100% resin, with each step lasting 24 hours. After polymerization, the blocks were sectioned along the length of the implant buccolingually and then ground down to about 40 μm . Toluidine blue staining was used to analyze the different ages and remodeling patterns of the bone.

Histomorphometric analysis was performed on digitalized images obtained from the light microscope via a JVC TK-C1380 color video camera (JVC Victor, Yokohama, Japan) and a frame grabber. The images were acquired with a 10 \times objective and included the entire implant surface. Subsequently, the digitalized images were analyzed by the image analysis software IAS 2000 (Delta Sistemi, Rome, Italy).

For each section, the 2 most central sections (equidistant from the buccal and lingual) were analyzed and morphometrically measured. The histomorphometric parameters calculated using the IAS 2000 software were as follows:

- % cortical bone volume (% BV): the area occupied by bone matrix over the entire microscopic field, measured by outlining the bone surface area to determine the surface area of bone in the microscopic field and expressed as a percentage of the total biopsy area;
- % BIC: the linear surface of the implant in direct contact with bone matrix and expressed as a percentage of the total implant surface; and
- % cortical BIC: the linear surface of the implant in direct contact with bone matrix at the cortical passage and expressed as a percentage of the implant surface in the cortical passage.

RESULTS

The mean insertion torque of the implants in the LT group was 24.3 N \cdot cm, whereas in the HT group it was 105.8 N \cdot cm.

The animals recovered well from the surgery and healed without complication. Upon retrieval of the implants and surrounding tissue, all surgical sites showed good healing.

During the placement of HT implants, the fracture of the fixture mounts occurred in 2 cases. Small cracks were observed on the external surface of the cortical bone following HT implant placement.

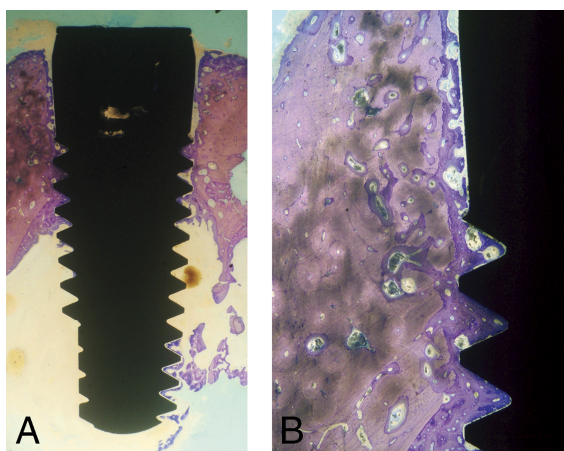


FIGURE 2. Control implant placed with a low insertion torque and retrieved after 8 weeks of healing. A, The implant is surrounded by bone tissue, although not yet completely mature. Note the bone extended within the thread spaces. A very thin gap is visible in some region, especially in the coronal area of the implant neck (original magnification $\times 10$). B, Note the bigger dimension and the irregular disposition of the osteocytes into the bone lacunae, attesting a bone not completely mature. Note the severe remodeling in the cortical bone at the interface with the implant (original magnification $\times 20$).

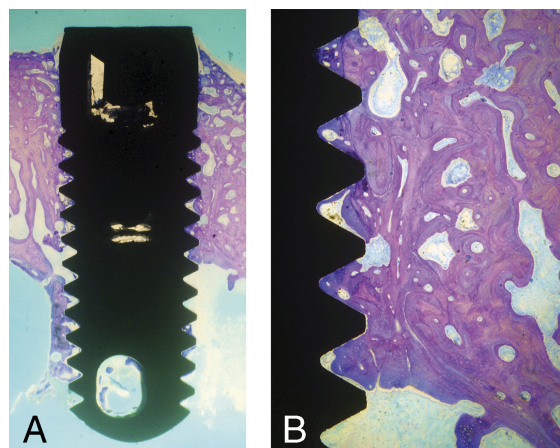


FIGURE 3. Control implant retrieved after 12 weeks of healing. A, The aspect of the bone is peculiar compared with all the other samples, appearing spongy and trabecular (original magnification $\times 10$). B, Note the bone in close contact with the implant, both in correspondence of the threaded part and the neck of the implant. The bone appears to be mature and mineralized (toluidine blue stain, original magnification $\times 20$).

Histologic Findings

The sheep mandibular bone was composed of a very dense, thick cortical layer (3–4 mm). The central part of the mandible did not show spongy bone, but only bone marrow, the neurovascular bundle, and very few thin trabeculae.

The samples that had been unscrewed to perform removal torque test were all precisely repositioned, and it was always possible to identify the detached surfaces, which had distinct edges that matched well with the implant profile, without interposition of soft tissues. Moreover, the morphometric values from the unscrewed implants were always very similar to the values from implants that had not been removed.

LT Implants

After 8 weeks of healing, the implants of the LT group appeared all osseointegrated, although they were surrounded by bone

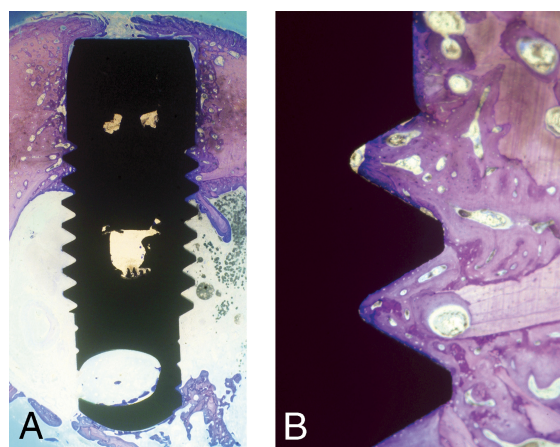


FIGURE 4. Test implant retrieved after 2 months of healing. A, New bone is visible in contact with the implant and within the threads. Signs of intense remodeling of the bone at the interface can be noted. Bone grew on top of the implant head as well (original magnification $\times 10$). B, Newly formed osteons can be noted. However, the maturation is not completed, as attested by the Haversian canals that are still wide and the disposition of the osteocytes. Note the so-called cement line between the old bone and new bone (original magnification $\times 25$).

not yet completely mature (Fig. 2A). This bone was anyway in close contact with the implant surfaces, being extended also between the threads of the implants. The not-completed maturation process was testified by the disposition, still irregular, of the osteocytes in the bone lacunae. In addition, those cells showed still bigger dimensions, attesting an early phase of maturation (Fig. 2B). It was possible to notice that the cortical layer at the interface between implant surface and the bone underwent severe remodeling that interested an area of a couple millimeters in the peri-implant bone tissue.

The aspect of the bone around the LT implants at the 12-week healing time appeared peculiar, compared with all the other specimens. This bone showed a more spongy aspect, with bigger spaces among the trabeculae (Fig. 3A). This aspect, however, seemed related more to the native structure of the bone in that zone of the mandible of the sheep killed after 12 weeks.

In fact, the bone tissue looked well adherent at the implant surfaces and in between the threads of the implants and appeared mature (Fig. 3B).

HT Implants

In the HT specimens left healed for 2 months, osseointegration of all implants was noted. New bone was formed in direct contact with the implant surfaces and between the threads (Fig. 4A). This bone presented newly formed osteons, some of which were still in the remodeling phase, attesting a good maturation, although not completed. Signs of intense remodeling of the peri-implant bone tissue were detectable. Those part of the implant surfaces with a more rough texture, due to the blasting and etching procedures, seemed to be in intimate contact with the bone, whereas in correspondence of the implant collar, where the surface was machined, a small gap at the interface was observed. However, a front-of-bone apposition was clearly detected in that zone, attesting that the osseointegration process was still going on. In the same zones, it was possible to recognize the so-called cement lines, those areas where the new bone had started to be apposed, which reflected the drilling cut edges. In other areas, a front of apposition and remodeling was not clearly demarked (Fig. 4B).

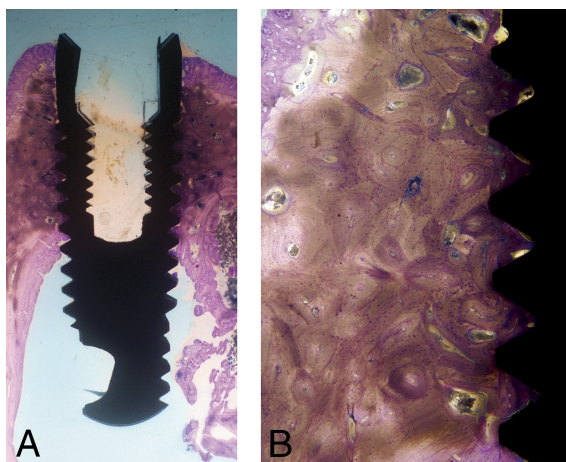


FIGURE 5. Test implant at 12 weeks. A, Note the well-matured and mineralized bone surrounding the implant, being in close connection with the implant surface in every area (toluidine blue stain, original magnification $\times 10$) B, Note the presence of mature osteons and the compact lamellar structure (original magnification $\times 20$).

TABLE 1.

	8-wk HT	8-wk LT	12-wk HT	12-wk LT
Insertion torque, Ncm	95	24	116.6	25
Removal torque, Ncm	140	159.5	120	131.5
ISQ	63.6	62.6	74	76
% BIC	46.06%	38.62%	45.94%	58.75%
% BV	56%	65.09%	80.67%	70.12%

HT, high-torque group; LT, low-torque group; ISQ, implant stability quotient; BIC, bone-to-implant contact; BV, bone volume.

At 3 months from insertion, the implants of the HT group showed osseointegration. Those implants were completely surrounded by bone (Fig. 5A), which presented a mature aspect and a compact lamellar structure, with secondary osteons (Fig. 5B). The bone was in direct contact with the implant surface, both between the threads and in correspondence of the implant collar.

Histomorphometric Findings

Findings at 8 Weeks

The mean cortical BIC of the samples of LT group was 38.62%, whereas in the HT group the mean value of cortical BIC was 46.06%.

As for the percentage of bone volume, the LT samples showed a mean result of 65.09%, and the HT samples showed an average value of BV of 56 (Table 1).

Findings at 12 Weeks

At this healing time, the cortical BIC of LT implants was 58.75%, and that of the HT samples was 45.94%. The BVs for the groups were 70.12% and 80.67%, respectively (Table 1).

Removal Torque Findings

At week 8 of healing, in the LT group the interfacial strength was very high, with a removal torque value of 159.5 N · cm, which represent a remarkable increase from the value of insertion torque of the implants of this group. The removal torque average value of the LT group at this time of healing was higher than that of the HT group, which was 140 N · cm.

After 3 months of healing, the mean values obtained from the reverse torque testing were 131.5 N · cm for the LT implants and 120 N · cm for the HT samples (Table 1).

RFA Values

The ISQ values were similar for both groups and at both healing times (Table 1).

DISCUSSION

Osseointegration of oral implants is a biologic phenomenon based on a series of biochemical events that lead to angiogenesis, to the differentiation of mesenchymal cells, to the deposition of extracellular osteoid matrix, to the mineralization of this matrix, and, successively, to its maturation, through a remodeling process.¹⁴

The stimulation of the peri-implant tissue, which occurs in case of immediate loading, on the one hand seems to some extent to activate the bone remodeling, but on the other hand, the immediate load can induce excessive micromovements of the implant in the bone, which may prevent the neoformation and apposition of bone tissue.¹⁵ The reduction of the risk of micromovements is

of fundamental importance when an immediate loading protocol is planned. Researchers suggested that an adequate primary stability prevents the occurrence of micromovements.¹⁶

One of the ways to evaluate the tridimensional implant primary stability is to measure the insertion torque of the implant, which is the moment of force needed to screw the implant into position and which reflects the intimate tridimensional contact between the walls of the implant osteotomy and the implant surface.

In an *in vitro* study, Trisi and colleagues¹⁶ inserted 120 implants in bovine bone samples of 3 different densities with 5 torque values: 20, 35, 45, 70, and 100 N · cm. Then they measured the micromovements of the implants under certain loading conditions and found a strong statistically significant correlation ($P < 0.001$) between the micromovements and the insertion torque of the implants, with a significant reduction of micromovements at the increasing of torque values. However, they observed that the difference of micromovements was not significant any more for torque values higher than 45 N · cm.¹⁷ In addition, they observed that the amount of micromovement, when applied force and torque did not vary, was dependent on the bone density, this amount being higher for lower densities.¹⁷

The implant companies themselves nowadays usually suggest the ideal insertion torque for each of their implant systems. Some studies recommend values of torque to which a minor risk of micromovements is associated.^{18,19} However, in literature, any experimental study with a proper follow-up to estimate the optimal value of insertion torque does not exist.

Higher values of insertion torque can be obtained with an underpreparation of the implant bed⁹; the entity of the underpreparation should be correlated to the bone density, being greater in bone of lower density.

However, it is true that high insertion torque creates strong compression and distortion in the peri-implant bone. High compression caused by elevated insertion torque has been claimed to disturb the local microcirculation, leading to necrosis of osteocytes, bone resorption, and finally to implant failure.¹¹ This phenomenon, the so-called bone pressure necrosis, seems to be widely accepted by the scientific community, although no study has been published proving this hypothesis. On the contrary, orthopedic experience in fracture stabilization has shown that compression of fracture sites by compression screws and osteosynthesis plates did not result in bone resorption, when the fracture ends were perfectly stable.²⁰ Compressing the fragments, instead, increased the fracture stability and led to uneventful healing without resorption. Small areas of plastic bone deformation observed in those cases, because of mechanical overload, were not removed by surface resorption, but by a remodeling process that took place into the surrounding bone up to few millimeters away from the surface and did not jeopardize the healing at the interface.²¹

On the other hand, common sense suggests that a decrease in surgical trauma during implant insertion can decrease the entity of the remodeling and the resorption of bone at the interface, diminishing as well the risk of implant failure.

A recent *in vivo* study, published by Trisi and coworkers,¹² attempted to verify the effect of high implant insertion torque on bone healing. The authors placed 40 implants in the mandibular lower edge of 5 sheep, 20 with a low insertion torque (control group) and 20 with high insertion torque (test group), and evaluated the early bone reaction at 1, 2, 3, 4, and 5 weeks after placement, by comparing histologic and histomorphometric findings to measurement of biomechanical strength and RFA. They found that the bone compression produced by high insertion torque did not induce deleterious bone resorption, but did produce bone microcracks, which accelerated bone remodeling as compared with the low-torque implants.¹²

In the control group, no remodeling processes were observed. A wide peri-implant gap, owing to the implant bed preparation, surrounded the implants in the first weeks of healing and was filled by new bone after 4 weeks. That histologic evidence was correlated to the sudden increase in the removal torque at the 4-week observation.¹² On the histology pictures from the implants of the test group, no peri-implant gap was observed, and the peri-implant bone was in intimate contact with the implant surface, as testified by the high value of % BIC, already at week 1.¹² At the third week of healing, an intense remodeling process was triggered in the peri-implant bone, which showed higher porosity and lower density. Nevertheless, the remodeling process did not affect the bone-implant interface, but more a deeper portion of the bone surrounding the implant. At 6 weeks of healing, a high degree of cortical porosity, induced by the remodeling process, was observed around the HT implants, and woven bone was present around the implant coronal area, giving the appearance of an infrabony pocket.¹²

In the present study, in which the healing periods were longer, at 8 weeks of healing in the HT group, new bone, with newly formed osteons, was found in direct contact with the implant surfaces and between the threads. In this bone, although with a mature aspect, signs of intense remodeling of the peri-implant bone tissue were still detectable. Those could be the effects of an intense bone remodeling during previous phases of healing, as shown by Trisi et al.¹²

After 3 months of healing, the peri-implant bone around implants inserted either at HT and LT was mature, dense, and compact, and it was in close contact with the implant surfaces. At this healing stage, microcracks were not detectable around any of the implants.

The removal torque test of implants has been proposed as a biomechanical indicator of the interfacial strength, between the implant surface and the peri-implant bone. This strength has been related to the amount of the implant surface in direct contact with the bone, also known as BIC. Removal torque had been found to be dependent on healing phase, implant surface, implant design, and bone density.²²

In the aforementioned study by Trisi et al,¹² the HT group had the reverse torque values higher than those of the LT group for all the durations of the study. The values of removal torque in the HT groups were higher than 60 N · cm at all healing times and reflected the high values of BIC. In the LT group, the values of reverse torque increased dramatically, while the healing of the implant sites proceeded, and from an average of 10.66 N · cm found at the first week, a mean value of 40 N · cm was reached at the sixth week. Again, the values were correlated with an increase in BIC.¹²

In the present study, the removal torque values were very high for both groups at both healing times, and there was no statistically significant difference.

The analysis of the resonance frequency had been proposed as a noninvasive evaluation of the implant stability. It has been suggested that immediately loaded and 1-stage implants with RFA values of 50 or more have a higher survival rate than implants with an RFA lower than 50.²³ In the present study, all the implants showed RFA values higher than 60 ISQ, without statistically significant differences between the 2 groups or between the different healing periods.

It must be pointed out that the results from the present study cannot be directly translated into clinical statements. First, this study was conducted in animals, in particular sheep, and therefore the results cannot be generalized to humans. In addition, the numbers of animals and implants were limited, because this study was meant to deepen the investigation of the previous *in vivo* experiment of Trisi et al.¹²

Another aspect to be taken into account is the bone density of the sheep mandible, as observed on histologic pictures, composed of a cortical layer extremely dense and a large medullary central

canal, which allows profuse vascularization. A similar aspect is unlikely to be found in patients. However, because the phenomenon of bone necrosis after compression was hypothesized only in cortical bone, the dense cortical bone layer of the sheep mandible was suitable to verify the validity of this hypothesis.

Moreover, it should be kept in mind that the implants in the present study were left to heal in a submerged fashion and without loading; therefore, conclusions cannot be drawn on whether the immediate loading would induce similar biomechanical or biologic conditions.

Furthermore, it should be noticed that, in the present experiment, a single-implant design was used. Because the implant macrogeometry is one of the features that influence either the initial implant adaptation to the bone site or the bone healing, further investigations should be performed to evaluate the effect of implant insertion torque on the biologic response of bone to implants with different shapes and surfaces.

Finally, the experience from the present in vivo study suggested that one of the major risks when placing an implant with an elevated torque was the damaging of the implant components.

In conclusion, within the limitation of the present study, it was shown that implants inserted with HT in a cortical and dense bone and let heal submerged, without loading, osseointegrated after 8 and 12 weeks of healing, without signs of compression necrosis. The peri-implant bone of both the control and test groups had a similar aspect in histologic sections, and histomorphometric and biomechanical values were very similar between the 2 groups.

REFERENCES

- Albrektsson T, Sennerby L, Wennerberg A. State of the art of oral implants. *Periodontol* 2000;47:15–26
- Misch CE, Wang HL, Misch CM, et al. Rationale for the application of immediate load in implant dentistry: part II. *Implant Dent* 2004;13:310–321
- Albrektsson T, Branemark PI, Hansson HA, et al. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. *Acta Orthop Scand* 1981;52:155–170
- Testori T, Meltzer A, Del Fabbro M, et al. Immediate occlusal loading of Osseotite implants in the lower edentulous jaw. A multicenter prospective study. *Clin Oral Implants Res* 2004;15:278–284
- Cannizzaro G, Leone M. Restoration of partially edentulous patients using dental implants with a microtextured surface: a prospective comparison of delayed and immediate full occlusal loading. *Int J Oral Maxillofac Implants* 2003;18:512–522
- Szmukler-Moncler S, Piattelli A, Favero GA, et al. Considerations preliminary to the application of early and immediate loading protocols in dental implantology. *Clin Oral Implants Res* 2000;11:12–25
- Szmukler-Moncler S, Salama H, Reingewirtz Y, et al. Timing of loading and effect of micromotion on bone-dental implant interface: review of experimental literature. *J Biomed Mater Res* 1998;43:192–203
- O'Sullivan D, Sennerby L, Meredith N. Measurements comparing the initial stability of five designs of dental implants: a human cadaver study. *Clin Implant Dent Relat Res* 2000;2:85–92
- Turkylmaz I, Aksoy U, McGlumphy EA. Two alternative surgical techniques for enhancing primary implant stability in the posterior maxilla: a clinical study including bone density, insertion torque, and resonance frequency analysis data. *Clin Implant Dent Relat Res* 2008;10:231–237
- Winwood K, Zioupos P, Currey JD, et al. The importance of the elastic and plastic components of strain in tensile and compressive fatigue of human cortical bone in relation to orthopaedic biomechanics. *J Musculoskelet Neuronal Interact* 2006;6:134–141
- Bashutski JD, D'Silva NJ, Wang HL. Implant compression necrosis: current understanding and case report. *J Periodontol* 2009;80:700–704
- Trisi P, Todisco M, Consolo U, et al. High versus low implant insertion torque: a histologic, histomorphometric, and biomechanical study in the sheep mandible. *Int J Oral Maxillofac Implants* 2011;26:837–849
- Sennerby L, Thomsen P, Ericson LE. A morphometric and biomechanical comparison of titanium implants inserted in rabbit cortical and cancellous bone. *Int J Oral Maxillofac Implants* 1992;7:62–71
- Davies JE. Understanding peri-implant endosseous healing. *J Dent Educ* 2003;67:932–949
- Meyer U, Joos U, Mythili J, et al. Ultrastructural characterization of the implant/bone interface of immediately loaded dental implants. *Biomaterials* 2004;25:1959–1967
- Trisi P, Perfetti G, Baldoni E, et al. Implant micromotion is related to peak insertion torque and bone density. *Clin Oral Implants Res* 2009;20:467–471
- Trisi P, De Benedittis S, Perfetti G, et al. Primary stability, insertion torque and bone density of cylindric implant ad modum Branemark: is there a relationship? An in vitro study. *Clin Oral Implants Res* 2011;22:567–570
- Otonari JM, Oliveira ZF, Mansini R, et al. Correlation between placement torque and survival of single-tooth implants. *Int J Oral Maxillofac Implants* 2005;20:769–776
- O'Sullivan D, Sennerby L, Jagger D, et al. A comparison of two methods of enhancing implant primary stability. *Clin Implant Dent Relat Res* 2004;6:48–57
- Marsell R, Einhorn TA. The biology of fracture healing. *Injury* 2011;42:551–555
- Schenk RK. Biology of fracture repair. In: Browner BD, Jupiter JB, Levine AM, et al. *Skeletal Trauma*. Philadelphia, PA: Saunders, 1992:31–76
- Johansson C, Albrektsson T. Integration of screw implants in the rabbit: a 1-year follow-up of removal torque of titanium implants. *Int J Oral Maxillofac Implants* 1987;2:69–75
- Shah KC, Lum MG. Treatment planning for the single-tooth implant restoration—general considerations and the pretreatment evaluation. *J Calif Dent Assoc* 2008;36:827–834