Effect of Drilling Dimension on Implant Placement Torque and Early Osseointegration Stages: An Experimental Study in Dogs

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Purpose: Primary stability has been regarded as a key factor to ensure uneventful osseointegration of dental implants. Such stability is often achieved by placing implants in undersized drilled bone. The present study evaluated the effect of drilling dimensions in insertion torque and early implant osseointegration stages in a beagle dog model.

Materials and Methods: Six beagle dogs were acquired and subjected to bilateral surgeries in the radii 1 and 3 weeks before death. During surgery, 3 implants, 4 mm in diameter by 10 mm in length, were placed in bone sites drilled to 3.2 mm, 3.5 mm, and 3.8 mm in diameter. The insertion torque was recorded for all samples. After death, the implants in bone were nondecalcified processed and morphologically and morphometrically (bone-to-implant contact and bone area fraction occupancy) evaluated. Statistical analyses were performed using the Kruskal-Wallis test followed by Dunn’s post hoc test for multiple comparisons at the 95% level of significance.

Results: The insertion torque levels obtained were inversely proportional to the drilling dimension, with a significant difference detected between the 3.2-mm and 3.8-mm groups ($P = .003$). Despite a significant increase in the bone-to-implant contact over time in vivo for all groups ($P = .007$), no effect for the drilling dimension was observed. Additionally, no effect of the drilling dimension and time was observed for the bone area fraction occupancy parameter ($P = .31$). The initial healing pathways differed between implants placed in bone drilled to different dimensions.

Conclusions: Although different degrees of torque were observed with different drilling dimensions and these resulted in different healing patterns, no differences in the histometrically evaluated parameters were observed.

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The use of dental implants to replace missing teeth has become one of the most successful treatment modalities in dental practice. Despite the predictability of the conventional protocol involving 2 surgical stages established by Brånemark et al.,1,2 the quest for decreased treatment periods between device placement and its subsequent functional loading has fostered implant engineering design modifications at different length scales.3 Of special interest is the challenge of immediate/early functional loading of single implant crowns that, unlike multiple units, lack mutual or cross-arch stabilization,4,5 resulting in decreased primary stability that is strongly influenced by the combination of implant design, loading conditions, surgical technique, and bone density and quality.6

From a clinical perspective, the consensus is that implant stability immediately and early after placement is desirable, because the relative motion between implant and bone could risk osseointegration.2,7,9 Thus, implant and surgical drilling technique interplay that provides high degrees of implant primary stability, low levels of compressive stress immediately after placement, and low degrees of micromotion have been regarded as potential benefits in the quest for atemporal implant stability during the early stages of osseointegration. Considering that implant stability is influenced by the interplay between implant design and the surrounding bone, it has been suggested that a high peak insertion torque is desirable for improved implant stability during osseointegration,9–11 especially because these studies have shown that high insertion torque values prevent adverse micromovement under loading greater than 100 μm. In contrast, several studies have suggested that high insertion torque values do not necessarily translate into high degrees of primary stability.12–14

Although changing the design parameters are insightful from a purely engineering standpoint, it must be considered that bone is a dynamic tissue that will respond to surgical procedure stimulation and/or the interaction between the implant macrogeometry and its associated drilling dimensions.15

The ideal condition of implant atemporal stability during the early healing periods has been questioned, because several biomechanical and histologic studies have shown that even if implant primary stability is rendered during placement, owing to the initial remodeling and subsequent bone apposition, a decrease in implant stability is likely to be observed before the bridging of the old bone and implant surface renders the system with secondary stability.16–18 Such a rationale has led to the presumption that if osteoclastic activity undermines primary stability before new bone formation prevents implant micro-motion, a stability decrease will take place early after implantation.19

It is common practice to use “underdimensioned” drilling dimensions in an attempt to increase the primary stability.9 However, although greater degrees of insertion torque levels can be achieved by placing implants in sites of undersized dimensions, the host-to-implant early response can be affected, because high degrees of bone mechanical strain can evolve immediately after placement. Although the ever-increasing number of published studies on this topic has shed light on different aspects of implant design and primary stability, the complexity of the possible multivariable interaction, including different implant designs, drilling dimension and implant geometry interplay, and timetables for the initiation of implant function has not yet provided an informed platform for implant/prosthetic system design rationale. Thus, the present study evaluated the effect of drilling dimensions on insertion torque and early implant osseointegration stages in a beagle dog model.

Materials and Methods

Thirty-six, commercially pure grade 2, threaded endosseous implants, 4 mm in diameter and 10 mm in length (Colosso, Emfils, Itu, Brazil), with a grit-blasted and acid-etched surface, were used. For the laboratory in vivo model, 6 adult male beagle dogs approximately 1.5 years old were acquired after the approval of the Ethics Committee for Animal Research at Universidade Federal de Uberlandia, Brazil.

Before general anesthesia, intramuscular atropine sulfate (0.044 mg/kg) and xylazine chlorate (8 mg/kg) were administered. A 15 mg/kg ketamine chlorate dose was then used to achieve general anesthesia.

The surgical site was the central region of the radius diaphysis. After hair shaving, skin exposure, and antiseptic cleaning with iodine solution at the surgical and surrounding area, an ~5-cm length incision to access the periosteum was performed and a flap reflected for bone exposure.

Three implants were placed along the radius from proximal to distal in an alternated distribution, with starting drilling dimension (3.2-, 3.5-, and 3.8-mm final drill diameter) interchanged in every radius to minimize bias from the different implantation sites (sites 1 to 3 from proximal to distal). Therefore, the 36 implants of the drilling technique, remaining in vivo for either 1 or 3 weeks (right and left radii provided samples that remained in vivo for 1 and 3 weeks, respectively), were allocated to sites 1 to 3 in an equal distribution. This approach resulted in balanced surgical procedures that allowed the comparison of the same number of implant surfaces per time in vivo, limb, surgical site (1 through 3), and animal. The
Implants were placed at distances of 1 cm from each other along the central region of the bone. The implants were inserted in the drilled sites, and the maximum insertion torque was recorded with a portable digital torque meter (Tohnichi, Tokyo, Japan), with a 200-Ncm load cell for each implant placed.

After placement, each implant received its proprietary cover screw to avoid tissue overgrowth. The soft tissue was sutured in layers according to standard procedures, with the periosteum sutured with Vicryl 4-0 (Ethicon, Johnson & Johnson, Miami, FL) and the skin with 4-0 nylon (Ethicon).

Postoperative antibiotic and anti-inflammatory medications included a single dose of benzyl penicillin benzatine (20,000 UI/kg) intramuscularly and ketoprofen 1% (1 mL/5 kg). The dogs were killed by an anesthesia overdose, and the limbs were retrieved by sharp dissection. The soft tissue was removed by surgical blades, and an initial clinical evaluation was performed to determine implant stability. If an implant was clinically unstable, it was excluded from the study.

The bones containing the implants were reduced to blocks and immersed in 10% buffered formalin solution for 24 hours. The blocks were then washed in running water for 24 hours and steadily dehydrated in a series of alcohol solutions ranging from 70% to 100% ethanol. After dehydration, the samples were embedded in a methacrylate-based resin (Technovit 9100, Heraeus Kulzer GmbH, Wehrheim, Germany) according to the manufacturer’s instructions. The blocks were then cut into slices (~300-μm thickness), aiming the center of the implant along its long axis, with a precision diamond saw (Isomet 2000, Buehler, Lake Bluff, IL), and glued to acrylic plates with an acrylate-based cement. A 24-hour setting time was allowed before grinding and polishing. The sections were then reduced to a final thickness of ~30 μm using a series of SiC abrasive papers (400, 600, 800, 1,200 and 2,400; Buehler) in a grinding/polishing machine (Metaserv 3000, Buehler) under water irrigation. The sections were then toluidine blue-stained and referred to optical microscopy at 50× to 200× magnification (Leica DM2500M, Leica Microsystems GmbH, Wetzlar, Germany) for histomorphologic evaluation.

The bone-to-implant contact (BIC) was determined at 50× to 200× magnification (Leica DM2500M, Leica Microsystems GmbH) using computer software (Leica Application Suite, Leica Microsystems GmbH). The areas occupied by bone were subtracted from the total area between the threads, and calculations were performed to determine the BAFO (reported in percentages). Statistical evaluation of torque, BIC, and BAFO was performed using the Kruskal-Wallis test. Statistical significance was set at 95%, and post hoc testing for multiple comparisons used the Dunn test.

Results

The surgical procedures and follow-up showed no complications regarding the procedural conditions or other immediate clinical concerns. No postoperative complications were detected, and no implant was excluded from the study because of clinical instability after death.

The insertion torque recorded for each drilling group is presented in Figure 1. The torque decreased as a function of drilling diameter from 3.2 to 3.5 mm to 3.8 mm. A significant difference in torque levels was observed between the 3.2-mm and 3.8-mm groups ($P = .003$), and the 3.5-mm group presented with intermediate values without significance relative to the 3.2-mm and 3.8-mm groups.

Qualitative evaluation of the biologic response showed intimate contact between the cortical and trabecular bone for all groups at both implantation times, including regions that were in close proximity or substantially away from the osteotomy walls (Fig 2).

The toluidine blue-stained thin sections presented an appositional bone healing mode at regions where intimate contact existed between the implant surfaces and bone immediately after placement (Figs 3, 4). These regions comprised the vast majority of the...
perimeter of implants placed into the 3.2-mm and 3.5-mm drilling sites, and the outer aspects of the threads of implants placed into 3.8-mm drilling sites. In contrast to implants placed into the 3.2-mm and 3.5-mm drilling sites, the initial healing pattern observed in proximity of the implant inner thread diameter and drilled walls (forming healing chambers) when implants were placed into 3.8-mm drilling sites followed an intramembranous-type healing mode (Figs 3, 4).

Temporal morphologic changes were observed for the different experimental groups. At 1 week, implants placed into 3.2-mm and 3.5-mm drilling sites presented extensive necrotic bone areas in the region between the first 3 implant threads (Figs 3A, 3B). These necrotic regions evolved to remodeling sites that were present along with newly formed bone at 3 weeks implantation time (Figs 4A, 4B).

At 1 week, the implants placed into the 3.8-mm drilling sites presented a chamber filled with osteogenic tissue between the implant inner diameter and the drilled wall (Fig 3C). Initial osteoid nucleation was observed in minor amounts within the healing chamber (Fig 3C). Primary engagement by the threads’ outer region without extensive necrotic bone areas was observed (Fig 3C). At 3 weeks, extensive woven bone formation was observed at the drilled bone walls and implant surface and within the healing chamber volume (Fig 4C).

Statistical assessment of BIC showed significantly greater values for all groups at 3 weeks relative to 1 week ($P = .07$; Fig 5A) for all groups. Within the different implantation times, no significant differences were observed between experimental groups. The BAFO results showed a temporal increase from 1 to 3 weeks for all groups (Fig 5B); however, no significant differences were detected within the experimental groups at the different times in vivo and between experimental groups within the times in vivo ($P = .31$).

**Discussion**

During the past 40 years, dental implant therapy protocols substantially deviating from the classic 2-stage protocol have been suggested, typically under the rationale of implant design modifications that would improve the odds of implant temporal stability during the initial stages of healing. From a literature review of early implant stability in which the clinical, histologic, and biomechanical components were considered, Raghavendra et al. established an empirical implant stability chart. This stability chart has been widely accepted, not only because high degrees of primary stability are often achieved, but also because of the support that numerous histology-based studies have provided concerning the potential mechanical stability loss given interfacial remodeling followed by bone apposition that finally results in secondary stability.

Primary stability assessment of implants and its related clinical implication has been a challenge, because it is not only dependent on insertion torque and host bone density, but also on implant geometry, surgical drilling dimensions, and surface characteristics. During the past 5 years, the biomechanical aspects of implant primary stability have been studied using different methods such as resonance frequency analysis, implant stability quotient, histologic measurements, contact endoscopy, insertion torque,
and removal torque. However, little has been published concerning the effect of the drilling dimension and related torque level variation or its implication for the early stages of osseointegration. The present study evaluated how insertion torque and osseointegration measurable parameters (BIC and BAFO) at early implantation times behaved when implants 4 mm in diameter and 10 mm in length were placed in bone sites drilled to 3.2, 3.5, and 3.8 mm.

The results obtained for maximum torque during placement showed that the smaller the dimension of the drilled site, the greater the increase in torque detected, such that the 3.2-mm group presented with significantly greater values than the 3.8-mm group, and the 3.5-mm group presented with intermediate values. Such differences resulted from the greater degree of compression and friction between the implant and bone during placement as the drilled site dimension decreased.

Although different insertion torque values were observed among the groups, a different healing mode pattern was observed for the drilled sites of 3.5 mm or less and the 3.8-mm group. For the 3.2-mm and 3.5-mm groups, examination of the histologic sections showed that significant degrees of contact between bone and the implant perimeter occurred immediately after placement, and after 1 week, a necrotic region was observed at the region between the threads. At 1 to 3 weeks, this necrotic bone region underwent remodeling, along with new bone formation, resulting in osseointegration. The early biologic sequence observed in these histologic sections was similar and consistent with those previously described for screw-root form implants.

In contrast, the interplay between the 3.8-mm surgical drilling dimension and implant geometry resulted in void spaces between the implant and the osteotomy that were filled with a blood clot immediately after implant placement. Our histomorphologic results for the 3.8-mm group are in direct agreement with previous work that showed that after a few days, large blood clots filling large healing chambers or the regions between bone and implant healing chamber walls will evolve toward a provisional matrix of connective tissue presenting with a high

**FIGURE 3.** Optical micrographs of implant–bone interface at 1 week showing that implants placed into A, 3.2-mm and B, 3.5-mm drilling sites presented with necrotic bone areas in region between first 3 implant threads (white arrows). C, Implants placed into 3.8-mm drilling sites presented with chamber (red arrows) filled with osteogenic tissue between implant inner diameter and drilled wall. Initial osteoid nucleation was observed in minor amounts within healing chamber (blue arrow).

content of mesenchymal cells. This stroma will then serve as a scaffold for an intramembranous-like ossification, which, according to our experimental model species and bone site in this animal model, started to take place at 1 week and was well developed at 3 weeks. The absence of extensive necrotic bone spots at regions where the implant was in intimate contact with the bone indicates that compression was relieved compared with the bone around the implants placed into 3.2-mm and 3.5-mm drilled sites.

FIGURE 4. Optical micrographs of implant–bone interface at 3 weeks showing that implants placed into A, 3.2-mm and B, 3.5-mm drilling sites presented with extensive remodeling, along with newly formed bone. C, At 3 weeks, implants placed into 3.8-mm drilling sites presented with extensive woven bone formation at drilled bone walls and implant surface and within healing chamber volume.


FIGURE 5. BIC (P = .007) and BAFO (P = .31) results (mean ± SD) for different experimental groups at 1 and 3 weeks in vivo. Number of asterisks depicts statistically homogeneous groups.

No differences were observed in BIC and BAFO among the experimental groups at 1 and 3 weeks in vivo, and overall increases were observed for all groups over time (significant for BIC and not significant for BAFO). Although different physical relationships were achieved between the implant and bone for the different groups, where intimate contact was achieved for implants placed into the 3.2-mm and 3.5-mm drilled sites and healing chambers formed around implants placed into 3.8-mm drilled sites, the necrotic bone regions decreased both BIC and BAFO to levels comparable to the void spaces comprised by the healing chambers present at 1 week. Through different ossintegration pathways, where remodeling and new bone formation was the chief pathway for implants placed into the 3.2-mm and 3.5-mm drilled sites, and intramembranous-like ossification occurred around implants placed into 3.8-mm drilled sites, these numbers increased for all experimental groups over time in a comparable fashion.

From a theoretical standpoint, one might consider that the temporal stability of these implant systems will follow different pathways. Although smaller drilling dimensions might increase primary stability, a greater amount of a necrotic “dieback” and interfacial remodeling will take place, potentially decreasing implant stability over time until secondary stability has been achieved through new bone formation between the implant surface and pristine bone. In contrast, although lower degrees of primary stability can be achieved through larger drilling dimensions, the compressive strain release could minimize the amount of necrotic “dieback” and remodeling at the regions, rendering primary stability to the implant, along with rapid woven bone filling in the healing chambers might increase the speed of secondary stability achievement. From an implant design perspective, it is apparent that multifactorial studies addressing morphometric and surgical drilling dimension variation should be addressed to determine what combination/circumstance would result in the greatest degrees of stability over time. Finally, it should be stressed that extrapolating healing data from animal models to human healing is, at present, a challenge owing to the lack of controlled experiments in both models for cross-reference in the literature and should be carefully performed.

References