The Effect of Osteotomy Dimension on Implant Insertion Torque, Healing Mode, and Osseointegration Indicators: A Study in Dogs

Charles Marin, PhD,* Estevam Bonfante, PhD,† Rodrigo Granato, PhD,* Rodrigo Neiva, MSc,‡ Luiz Fernando Gil, MSc,§ Heloisa Fonseca Marão, PhD,¶ Marcelo Suzuki, DDS,|| and Paulo G. Coelho, PhD#

Purpose: *This study investigated the effect of the osteotomy diameter for implant placement torque and its effect on the osseointegration.*

Materials and Methods: *Eight male beagle dogs received 48 implants (3.75 mm × 10 mm) in their right and left radius, 3 implants per side and allowed to heal for 3 weeks. Three experimental groups were evaluated. Group 1: implant with an undersized osteotomy of 3.0 mm; group 2: osteotomy of 3.25 mm, and group 3: osteotomy of 3.5 mm. The insertion torque was recorded for all implants. Histological sectioning and histometric analysis were performed evaluating bone-to-implant contact (BIC) and bone area fraction occupancy (BAFO).*

Results: *Implants of group 1 presented statistically higher insertion torque than those of groups 2 and 3 (P < 0.01). No differences in BIC or BAFO were observed between the groups. From a morphologic standpoint, substantial deviations in healing mode were observed between groups.*

Conclusion: *Based on the present methodology, the experimental alterations of surgical technic can be clinically used with no detrimental effect over the osseointegration process. (Implant Dent 2016;25:739–743)*

Key Words: surgical techniques, bone, histology, dental implants

Implants have proven to be a predictable treatment with a high success rate.[1,2] Most of the studies concerning implant success evaluated a classic protocol established by a Swedish scientific groups,[3,4] where implants were allowed to heal submerged until osseointegration to be subsequently restored to success levels seldom reported lower than 95% in controlled clinical evaluations.

Over the past decade, there has been improvements in dental implant as the design at the macro,[5–7] micro,[8] and nanometer[9,10] scales allowed the bone response to endosteal implants in order to improve the osseointegration of devices and then allowed the clinicians more aggressive rehabilitation. For instance, immediate loading of implants in selected cases has become routine for oral rehabilitation when initial stability was achieved, even in more challenging clinical scenarios as fresh extraction sockets.[11–13] For such protocols, it is imperative that implant primary stability is achieved, and therefore the interplay between implant hardware components such as implant macrogeometry and related surgical instrumentation and their effect on the bone healing environment must be carefully considered.

The interaction between drilling technique and implant macrogeometry plays a pivotal role on initial stability for immediate loading to reduce motion between implant and bone that could impair osseointegration and/or immediate provisionalitation.[12,14,15] In clinical scenarios, primary stability is provisionalization, most often achieved by undersizing osteotomy dimensions,[16] so higher insertion torque levels are obtained.

*Assistant Professor, Postgraduate Program in Dentistry UNIGRANRIO, University School of Health Sciences, Duque de Caxias, Rio de Janeiro, Brazil.
†Assistant Professor, Department of Prosthodontics, University of Sao Paulo, Bauru College of Dentistry, Bauru, Sao Paulo, Brazil.
‡Associate Professor, Department of Periodontology, University of Florida College of Dentistry, Gainesville, FL; Director of the Graduate Program in Periodontics of the University of Florida College of Dentistry, Gainesville, FL.
§PhD Candidate, Department of Dentistry, Division of Oral and Maxillofacial Surgery, Federal University of Santa Catarina, Florianopolis, Santa Catarina, Brazil.
¶Assistant Professor, Department of Oral and Maxillofacial Surgery, University of the West of Sao Paulo, Presidente Prudente, Sao Paulo, Brazil.
||Associate Professor, Department of Prosthodontics and Operative Dentistry, Tufts University School of Dental Medicine, Boston, MA.
#Associate Professor, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, NY.

Reprint requests and correspondence to: Heloisa Fonseca Marão, PhD, Rua José Bongiovani 700, Cidade Universitária, Presidente Prudente, São Paulo, Brasil CEP: 19050-920, Phone: +55 18 981496862, Fax: +55 18 3229 1000, E-mail: heloisafonsecamarao@yahoo.com.br

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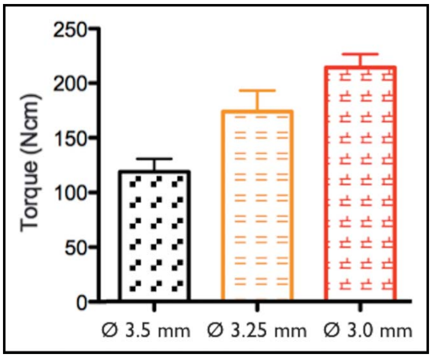

Fig. 1. Insertion torque (N·cm) of implants placed in 3 different undersized preparation sites (3.0, 3.25, and 3.5 mm). A significant decrease in insertion torque was observed from 3.0 to 3.5 mm final drilling. Different asterisks represent the statistically significant differences ($P < 0.01$).

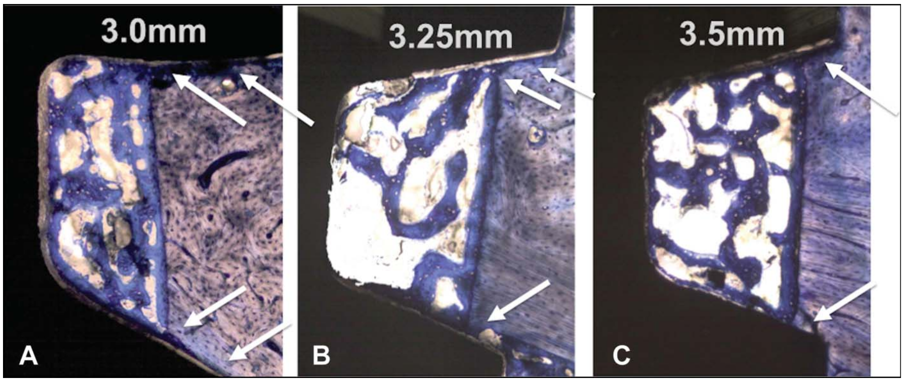

Fig. 2. Histological micrographs of the implants drilling (**A**) 3.0 mm, (**B**) 3.25 mm, and (**C**) 3.5 mm, respectively, after 3 weeks of healing. Arrows depict an absence of bone resorption in compressed bone areas after implant placement. Toluidine blue-stained.

Although it may seem intuitive that high insertion torque levels are required to achieve primary stability, a study demonstrating that insertion torque does not necessarily translate into decreased micromotion along with a plethora of preclinical studies that have demonstrated that excessive torque levels may substantially change osseointegration pathway healing modes has warranted further investigation of what trends are obtained by osteotomy size variation.[17,18]

For instance, prior experimental studies have shown that early interfacial remodeling is proportional to underdrilling techniques that result in progressive degrees of implant insertion torque during placement. This series of studies demonstrated that as early as 3 weeks after implantation changes in osseointegration pathways are notable where tighter fit implants present substantial interfacial remodeling, whereas looser fit implants present healing chambers (formed between implant inner diameter and osteotomy dimension outer diameter) presenting bone formation.[19,20] This series of studies demonstrated that although lower degrees of insertion torque are achieved if larger diameter osteotomies are drilled, initial implant stability was achieved and a lower stability dip after placement was observed as a result of intramembranous-like bone within the chambers, warranting investigation of such macrogeometry/surgical instrumentation relationship for other implant systems in an attempt to develop implant surgery procedures that will better balance insertion torque, stability dip, and bone healing modes around implants ultimately leading to atemporally stable implant systems.[19,21–23]

This study evaluated the influence of osteotomy dimension on the insertion torque, healing mode, and osseointegration indicators and an implant system, which presents a progressive thread design and a tapered macrogeometric configuration.

MATERIALS AND METHODS

Forty-eight threaded endosseous implants, 3.75 mm in diameter and 10 mm in length (Osteofix Implant Surface—Adin Tuareg Implants) were used. The surface characteristics, histological analysis, and mechanical testing were previously published.[24] For the laboratory *in vivo* model, 8 adult male beagle dogs approximately 1.5 years old were acquired after the approval of the Ethics Committee of Écólé Nationale de Vétérinaire Affort—Maison Affort—France. All surgical procedures were performed under general anesthesia. Medetomidine 8.5 μg/kg and morphine 0.2 mg/kg were used as premedication intravenous access. To induce general anesthesia, propofol 4 mg/kg was used. After tracheal intubation, anesthesia maintenance was performed with 2% isoflurane (adjusted for the percentage of exhaled 1.2%) with mechanical ventilation at 10 mL/kg (approximately).

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, a 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 interpolated distribution, the drilling technique was performed according to manufacture recommendation and the final diameter was 3.0-, 3.25-, and 3.5-mm per site, the distance between implants was 1 cm. During the implant placement, the final insertion torque of each implant was recorded with a portable digital torque meter (Tohnichi, Tokyo, Japan), with a 200-N·cm load cell. Cover screws were placed to avoid tissue ingrowth. 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, Johnson & Johnson, Miami, FL). The implants were remaining for 3 weeks.

Postoperative antibiotic and antiinflammatory medications included a single dose of benzyl penicillin benzathine (20,000 UI/kg) intramuscularly and ketoprofen 1% (1 mL/5 kg). The euthanasia was performed by means of anesthesia overdose, and the limbs were retrieved by sharp dissection. The soft tissue was removed using surgical blades, and an

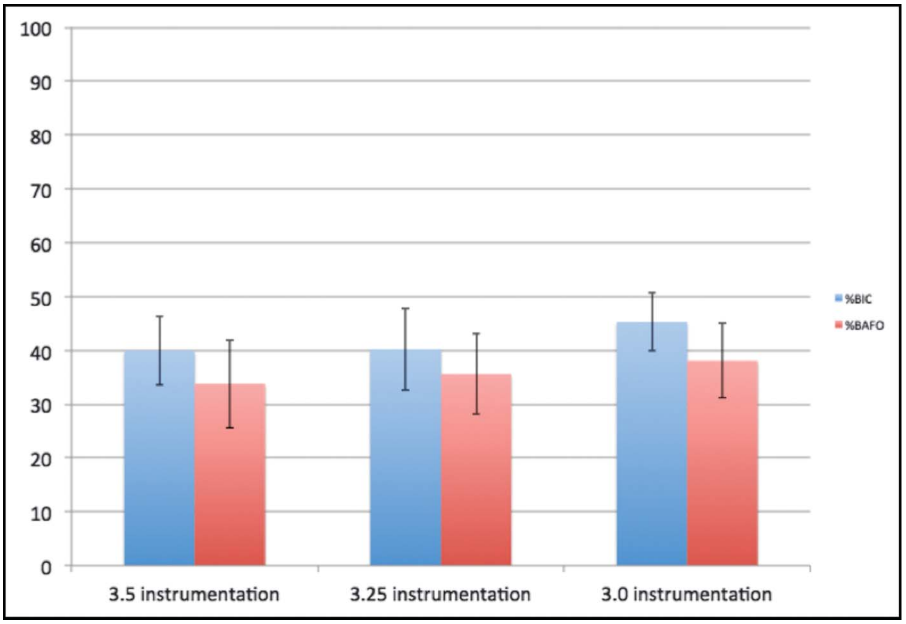

Fig. 3. Histometric analysis—statistical summary of drilling site dimension for BIC and BAFO. No differences in BIC and BAFO were observed between the sites drilling. However, an overall increase in both BIC and BAFO was observed in the 3-mm site drilling when compared with 3.25 mm and 3.5 mm. (mean ± 95% CI).

initial clinical evaluation was performed to determine implant stability. If an implant was clinically unstable, it was excluded from the study. The samples 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, 1200, and 2400; 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) and bone area fraction occupancy (BAFO) was determined using computer software (Image J; National Institutes of Health, Bethesda, MD), at ×50 to ×200 and ×100 magnification, respectively. The regions of BIC along the implant perimeter were subtracted from the total implant perimeter, and calculations were performed to determine the BIC. 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 by multiple paired *t* tests. Statistical significance was set at $\alpha = 0.05$, and post hoc testing for multiple comparisons used the Dunn test.

RESULTS

The surgical procedures and postop period were uneventful. No postoperative complications were detected, and all implants were clinically stable and included in the present evaluation. The results of initial insertion torque are presented in Figure 1. The torque decreased as a function of drilling diameter from 3.0 to 3.25 to 3.5 mm. A significant difference in torque levels was observed between the 3.0-mm and 3.5-mm groups ($P < 0.01$), and the 3.25-mm group presented with intermediate values without significance relative to the 3.0-mm and 3.5-mm groups.

Histological analysis showed intimate contact between implant and trabecular/cortical bone in all experimental groups, including in close proximity or substantially away from the osteotomy wall (Fig. 2, A–C). This evaluation also demonstrated different patterns of bone healing among groups, depicted by assorted amounts of intramembranous-like or appositional pathway. The amount of woven bone observed increase in direct proportion with the diameter of drilling diameter, as presented in the Figure 2, A–C.

Qualitatively, the 3.0-mm group presented the highest contact degree between the pristine bone and the implant surface resulting in a healing chamber space of approximately one third of the thread length that at 3 weeks was filled with woven bone (Fig. 2, A). For the 3.25-mm group, more than half of thread length comprised a healing chamber occupied by woven bone (Fig. 2, B). Conversely, implants placed in 3.5 drilling sites presented healing chambers effect comprising close to the whole thread extension (Fig. 2, C). Statistical assessment of BIC and BAFO showed no significant differences among groups, all at $P >$ 0.40 (Fig. 3).

DISCUSSION

Because the osseointegration process was described[3] and clinically accepted as an oral rehabilitation modality,[4] substantial changes of classic 2 stages protocol are proposed based on several modifications of implant surface,[25] macrogeometry,[6] and drilling technic.[26] Actually preoperatory tomographic analysis and improved implant designs are proposed to reach the primary stability, considered as a key-factor for osseointegration and allowing immediate loading.[27] In fact, absence of initial insertion torque can lead to the regular high osseointegration success rates in clinical studies,[28] but the scenario of immediate loading requires high degrees of primary stability,[29] something often times wrongly associated with high insertion torque values. Preclinical and clinical evaluation of implant initial stability has previously been performed by different methods that include resonance frequency analysis, implant stability quotient, insertion torque, and removal torque.[30–33] Although all of these methods are indicators of implant stability potential, none of them has the ability to determine the degree of implant resistance to micromotion known to influence the process of osseointegration.

A multitude of previous studies have demonstrated the relationship between drilling dimension and implant macrogeometry in a variety of early healing scenarios.[8,19,34–38] Such a scenario has been the subject of recent reviews on bone healing pathways as a function of the dimensional interplay between implant and surgical instrumentation dimensions, where regions of compressed bone (in intimate contact with the implant) undergo interfacial remodeling; at the same time, which regions where healing chambers are formed undergo rapid intramembranous-like healing without the need of a cell-mediated interfacial remodeling that results in varied degrees of stability loss as osseointegration is established.[21,39] This study evaluated how insertion torque, healing mode, and osseointegration indicators varied as a function of drilling dimension for an implant system presenting a progressive thread design macrogeometry that aims to maximize implant primary stability.

As previously described in our previous investigations concerning a different implant design, our results depicted an inverse linear relationship between insertion torque and drilling dimension.[19,35] However, different than our previous investigations that showed interfacial remodeling as the chief osseointegration pathway for implants more tightly fit into their respective osteotomies, this study revealed a scenario where healing chambers formed regardless of instrumentation diameter. The presence of these healing chambers to lower or higher degrees depending on surgical instrumentation diameter is related to the low implant inner thread diameter and allowed a healing pathway recently coined as hybrid healing, where rapid intramembranous-like bone formation occurs within chambers in tandem with interfacial remodeling at regions where bone was primarily engaged/compressed by the implant. Also, different from our previous studies, despite the high degree of engagement between implant bulk and bone for the 3.0 mm and 3.25 mm osteotomies, substantially lower degrees of bone resorption were observed at 3 weeks at regions where bone was primarily engaged by the implant immediately after placement, indicating that the presence of healing chambers of varied sizes was relatively effective in decreasing the excessive bone compression levels observed for other implant hardware at 3 weeks *in vivo* (Fig. 2). Such observation is of paramount importance if one is attempting to minimize interfacial remodeling in an attempt to substantially decrease or potentially eliminate implant stability dip after placement for an atemporally stable healing scenario.

CONCLUSION

Given the histomorphologic results observed for the different groups, the osseointegration indicators, BIC, and BAFO quantified in this study, tend to be statistically equivalent for all groups (which was not surprising), and further support the reduced amount of interfacial remodeling along with the intramembranous-like bone formation observed within healing chambers of varied size. The favorable healing observed for the 3 groups when one regards the development of atemporally stable implant systems warrants further investigation in an attempt to determine the optimal drilling dimension that will lead to the highest degrees of implant stability over time once biomechanical assessment was not performed in this study.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

APPROVAL

This study was approved by the Ethics Committee of Écólé Nationale de Vétérinaire Affort—Maison Affort—France, #10.10.12-03.

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