Alveolar Ridge Expansion: Comparison of Osseodensification and Conventional Osteotome Techniques

Jimmy H. Tian,† Rodrigo Neiva, DDS, MS,‡ Paulo G. Coelho, DDS, PhD,†§ Lukasz Witek, BME, PhD,† Nick M. Tovar, BME,† Ivan C. Lo,*† Luiz F. Gil, DDS, PhD,|| and Andrea Torroni, MD, PhD§*

Objective: The aim of this in vivo study is to compare the osseointegration of endosteal implants placed in atrophic mandibular alveolar ridges with alveolar ridge expansion surgical protocol via an experimental osseodensification drilling versus conventional osteotome technique.

Methods: Twelve endosteal implants, 4 mm × 13 mm, were placed in porcine models in horizontally atrophic mandibular ridges subsequent to prior extraction of premolars. Implants were placed with osseodensification drilling technique as the experimental group ($n = 6$) and osteotome site preparation as the control group ($n = 6$). After 4 weeks of healing, samples were retrieved and stained with Stevenel's Blue and Van Gieson's Picro Fuschin for histologic evaluation. Quantitative analysis via bone-to-implant contact (BIC%) and bone area fraction occupancy (BAFO%) were obtained as mean values with corresponding 95% confidence interval. A significant omnibus test, post-hoc comparison of the 2 drilling techniques' mean values was accomplished using a pooled estimate of the standard error with P-value set at 0.05.

Results: The mean BIC% value was approximately 62.5% in the osseodensification group, and 31.4% in the regular instrumentation group. Statistical analysis showed a significant effect of the drilling technique ($P = 0.018$). There was no statistical difference in BAFO as a function of drilling technique ($P = 0.198$).

Conclusion: The combined osseodensification drilling-alveolar ridge expansion technique showed increased evidence of osseointegration and implant primary stability from a histologic and biomechanical standpoint, respectively. Future studies will focus on expanding the sample size as well as the timeline of the study to allow investigation of long-term prognosis of this novel technique.

From the *New York University College of Dentistry; †Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, NY; ‡Department of Periodontology, College of Dentistry, University of Florida College of Dentistry, Gainesville, FL; §Hansjörg Wyss Department of Plastic Surgery, New York University Langone Medical Center, New York, NY; and ||Department of Dentistry, Federal University of Santa Catarina, Florianopolis, Brazil.

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Address correspondence and reprint requests to Andrea Torroni, MD, PhD, Hansjörg Wyss Department of Plastic Surgery, New York University, Bellevue Hospital Center, 462 1st Ave, Room 5S19A, New York City, NY 10016; E-mail: andrea.torroni@nyumc.org

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Endosseous titanium implants have proven to be a successful treatment option for the rehabilitation of partial or complete edentulism. The success of dental implant is attributed to the process of osseointegration that provides stability and long-term survival of these rehabilitations.[1–3]

In the area of implant research, investigations in surface engineering and implant macrogeometry designs have yielded a plethora of useful features that improve osseointegration and thus longevity of implant restorations for the patients.[4–7] In contrast, markedly smaller body of literature that explores the relation between instrumentation methods and osseointegration has been produced.[8–11]

Recently, a novel additive drilling design, osseodensification, has been introduced for placement of endosseous implant.[12,13] The mechanical engineering design of the drill is such that the bone particulate removed from the osteotomy wall is compacted against the osteotomy wall, creating a higher density environment that allows more intimate mechanical interlocking between bone and implant, thus achieving higher primary stability.[12,13]

An additional challenge that faces the endosseous dental implant therapies pertains to bone volume both in the vertical and horizontal directions at the edentulous site.[14–16] Volumetric bone deficit pertaining mainly to the transverse dimension, with adequate vertical dimension, results in the so-called "knife-edge" alveolar ridge atrophy, also defined as alveolar class IV by the Cawood and Howel classification of the edentulous jaws.[15] The alveolar ridge expansion technique (ARET) is a particularly useful surgical approach that allows transverse bone expansion and subsequently implant positioning in class IV alveolar atrophy.[17] The current iteration of ARET consists of creating a longitudinal osteotomy along the atrophic osseous crest, at which point a greenstick fracture is then introduced to the ridge. The fracture is subsequently expanded manually in the buccal-lingual direction via instrumentation with a sequence of osteotomes of increasing sizes.[17–19]

The current investigation evaluated the potential of combining ARET and osseodensification drilling as a predictable ridge expansion method, a combination not yet described in the literature, in a highly translational porcine model. Two hypotheses are tested: if the osseodensification expansion method achieves the same degree of ridge expansion relative to manual osteotomes, and whether implants placed via ARET with osseodensification ridge expansion would yield a statistically significant higher levels of primary stability and osseointegration indicators at bone-implant interface than those placed with manual osteotome expansion.

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METHODS

A total of 12 Ti-6Al-4V implants with internal connection (Intra-Lock International, Boca Raton, FL), 4 mm in diameter and 13 mm in length were utilized in this study between osseodensification and osteotome expansion groups: (n = 6 osseodensification implant placement and n = 6 conventional implant placement). The thread design was identical between the 2 groups, with the only difference being the ridge expansion method, whether it was with osteotome or osseodensification.

Animal Model and Surgical Procedures

This study included 6 minipig with an age of 24 months and an average weight of 30 kg. The study was conducted according to the ethical approval from the Institutional Animal Care and Use Committee of the Ecole Veterinaire d'Alfort under Animal Research: Reporting of In Vivo Experiments guidelines. Endosseous root-form implants were placed on horizontally deficient mandibular ridges secondary to prior extraction of maxillary premolars (12 weeks healing). Surgery was performed in a standardized fashion. Anesthesia was induced with sodium pentothal (15–20 mg/kg) in normasol solution into the jugular vein and maintained with isofluorane (1.5–3%) in O_2/N_2O (50/50). Animal monitoring included electrocardiography, end tidal CO_2, and SpO_2 and body temperature, which was regulated by a circulating hot water blanket. Prior to surgery, the surgical site was prepared and draped in sterile fashion. Using a #15 scalpel a crestal incision was performed along the atrophic crest in the premolar region bilaterally; a buccal and lingual full-thickness mucoperiosteal flap was elevated to expose the "knife edge" alveolar process, and a crestal corticotomy was performed using a fissure bur. Then, alveolar expansion techniques were randomly performed on either the right or left ridge by osseodensification (O) or conventional osteotomes (regular instrumentation, R) to achieve desirable ridge with for placement of 4.0 mm wide implants, in a split mouth design. The transverse dimension of the atrophic alveolar ridge before and after expansion was measured with a periodontal probe. Following preparation of implant osteotomies, 4 mm in diameter and 13 mm in length implants were placed and a primary stability was recorded. The final insertion torque of all implants was recorded by a digital torque meter (Tonichi STC2-G, Tonishi, Japan). Primary wound closure was achieved with 4-0 polytetrafluoroethylene interrupted sutures. After 4 weeks, the animals were euthanized with anesthetic overdose and the samples were retrieved for histologic quantitative analysis.

Each experimental group was processed for histologic and histomorphometric evaluation via progressive dehydration in ethanol and methyl salicylate prior to final embedding in methylmethacrylate. Standard nondecalcified histologic sections were prepared for each implant specimen according to standardized methodology. The samples were then sectioned along the implant's long axis with a slow-speed precision diamond saw (Isomet 2000; Buehler Ltd, Lake Bluff, IL) as thin slices of 300 μm thickness. Each tissue section was glued to an acrylic plate with a photolabile acrylate-based adhesive (Technovit 7210 VLC adhesive; Heraeus Kulzer GMBH, Wehrheim, Germany) before grinding and polishing under abundant water irrigation with progressively finer silicon carbide (SiC) abrasive papers (400, 600, 800, and 1200) (Metaserv 3000; Buehler Ltd) to a final thickness of 50 μm. The final sections were subsequently stained with Stevenel's Blue and Van Gieson's Picro Fuschin stains. Histologic observations and images were collected with an automated slide scanning system and specialized computer software (Aperio Technologies, Vista, CA). Histomorphometric evaluation was completed with specific image analysis software (ImageJ; NIH, Bethesda, MD). Bone-implant contact (BIC) and bone area fraction occupancy (BAFO) were quantified to evaluate the osteogenic parameters around the peri-implant surface. The BIC determines the degree of osseointegration by tabulating the bone percentage of bone contact over the entire relevant implant surface perimeter. The BAFO measures the quantity of bone (newly formed and nonvital autografted/native bone due to instrumentation) as a percentage of the space occupied within the implant threads.

TABLE 1. Ridge Expansion in Millimeters Before and After Expansion for the Different Instrumentation Methods

	Osseodensification		Osteotome	
Patient	Before	After	Before	After
1	3	7	4	7
2	4	7	4	7
3	4	6	5	7
4	3	7	3	6
5	5	7	4	6
6	4	6	5	7

Statistical Analysis

All biomechanical and histomorphometric testing data are presented as mean values with the corresponding 95% confidence interval values (mean ± CI). Ridge dimension, insertion torque, BIC%, and BAFO% data were analyzed using a linear mixed model. Given a significance omnibus test, post-hoc comparison of the 2 drilling techniques' mean values was accomplished using a pooled estimate of the standard error. Preliminary analyses showed homogeneous variances in the analysis of all 2 dependent variables (Levene test, all $P > 0.25$). All analysis was completed with IBM SPSS (v22; IBM Corp, Armonk, NY).

RESULTS

The mean ridge expansion dimension change is presented in Table 1 and was approximately 80% in the O group and 63% in the R group (Fig. 1A) with no statistical difference in the degree of ridge expansion between the 2 groups ($P = 0.156$). In contrast, the mean implant insertion torque of 56.7 Ncm in the O group was significantly higher than the 32.5 Ncm insertion torque in the regular osteotome group ($P < 0.001$) (Fig. 1B).

The mean BIC% value was approximately 62.5% in the O group, which decreased to approximately 31.4% in the R group (Fig. 1C).

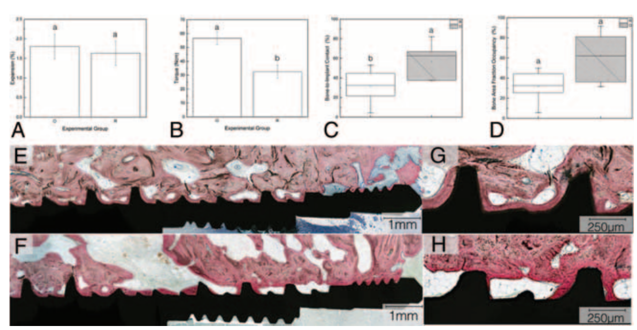

FIGURE 1. Quantitative comparison of (A) amount of ridge expansion in the bucco-palatal direction, and (B) implant insertion torque, between osseodensification (O) and regular (R) osteotome expansion techniques. (C) Bone-implant contact (BIC) and (D) bone-area fractional occupation (BAFO) as function of drilling technique between osseodensification (O) and regular (R) osteotome expansion techniques. The lower case letters indicate statistically homogenous groups. Survey view of bone-implant surface with (E) osseodensification and (F) regular osteotome. Magnified view of bone-implant interface in (G) osseodensification and (H) osteotome instrumentation.

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Statistical analysis showed a significant effect of the surgical preparation technique ($P = 0.018$). There was no statistical difference in BAFO as a function of surgical preparation technique ($P = 0.198$), albeit the substantial difference between the O group at 56.6% relative to 31.7% in the R group (Fig. 1D).

Survey histologic evaluations showed osseointegration of all implants. Both O and R groups showed integration with the newly formed bone in contact to the implant surface. For both drilling groups, the pattern of osseointegration showed similar features. Regardless of the surgical instrumentation method, the bone surrounding the implants in either groups showed extensive remodeling that included both sites of bone apposition and bone resorption in close proximity to the implant surface. Higher amount of bone was observed along the surface and within threads of the O group (Fig. 1E) relative to its R counterparts (Fig. 1F). Higher magnification optical micrographs further confirmed the survey observations, where extensive bone remodeling was occurring along the implant surface for all groups. New bone growth around clearly demarcated bone chip surfaces was observed for the O group (Fig. 1G); in contrast, the bone surrounding the R group (Fig. 1H) showed less bone chips with less discernable borders for such particulates.

DISCUSSION

Dental rehabilitation of horizontally deficient alveolar crests by osseointegrated implants can be challenging. Strategies such as host-derived block autografts to membrane-guided tissue regeneration have all been established as a predictable surgical therapy to augment bone volume prior to implant placement.[14,20,21] However, the augmentation of bone precedes dental implant surgery with an additional surgery for grafting and bone healing, adding additional time and costs to complete the treatment. In contrast, the ARET can simultaneously allow horizontal bone volume augmentation along with implant placement, all in one surgical visit to accomplish 2 goals: to expand the bone volume to adequately accept the implant body and to place the implant device. This, theoretically, shortens treatment period, reduce costs, and eliminate the need for a secondary surgical site when compared to augmentation of bone volume with autologous grafts.[18,22] The main drawback of the ARET is the unpredictable stability of the bone plates of the expanded alveolar ridge that may jeopardize the primary stability of the osseointegrated implants. A recent review has shown that ridge expansion is a technique-sensitive surgical protocol. In a systematic review on type of devices used in ARET, Jha et al report that manual instrumentation is the prevailing expansion method, at 65% of frequency in the examined series, while the frequency of usage of a motorized expansion tool is only 18%.[23] This operator dependence may be attributed to the high prevalence of using manual osteotomes, contributing to potential drawback that can impede the successful treatment outcome of ARET. Hypothesis of the present study is that simultaneously combining motorized osseodensification instrumentation with the ARET, an experimental surgical protocol has not been attempted to date, may decrease the technique sensitive aspect of the expansion technique.

The miniature swine model was utilized as it has been established as a highly translational model that closely mimics human anatomy and physiology, including in the bony architecture in the jaws.[24,25] Investigation of the surgical protocols with such biologic mimicry allows the results to be highly translatable for future clinical applications. Based on previous studies and our histologic observation of the bone healing process, the 4-week time frame marks the transition from the initial woven bone formation to the bone remodeling stage of the wound healing process,[26,27] thus an important milestone in the transition from primary to secondary implant stability.

Regarding the amount of expansion achieved with osseodensification drilling relative to conventional osteotome techniques, our results support the hypothesis that similar levels between rotary and manual instrumentation can be obtained. This evidence is in accordance with how reported in a study from Kao and Fiorellini[28] who compared mechanical ridge expansion and ridge splitting in a swine cadaver model; in the study the authors reported no statistically significant difference in crestal width gain between the 2 techniques, and primary stability achieved in all 36 implants positioned. Although the 2 techniques of mechanical ridge expansion and ridge splitting obtained the same degree of crestal width gain, the study showed a fewer incidence of ridge perforation in the motor-driven ridge expansion group compared with the ridge splitting group,[28] supporting our hypothesis that a mechanical-driven expansion may decrease the technique sensitive limitations of the manual expansion technique.

In our experience, the comparison of primary stability obtained at the time of surgery showed values ~75% higher for osseodensification drilling relative to conventional osteotome instrumentation. The present study also evaluated the osseointegration indicators BIC% and BAFO%, defined as histologic evidence of BIC and BAFO between implant threads; histologic examination at 4-week showed higher amounts of bone in close proximity to implants placed in O prepared sites. Quantitatively, the O technique demonstrated significant difference BIC% and substantially higher amounts of BAFO%, which is in agreement with the qualitative observation. Both qualitative observation and quantitative results are evidence that the osseodensification technique improves osseointegration indicators of ARET protocols as early as in 4 weeks of healing, suggesting a faster transition between primary and secondary stability, which is an important prognostic factor for successful long-term osseointegration of dental implant.

Despite the limitations of a small sample size, a relatively short time line, which did not allow for a complete secondary osteointegration of the implants, and the lack of mechanical pull-out test to compare the ultimate grade of osteointegration achieved at the end point, the histometric data for BIC% and BAFO% obtained, along with the insertion torque data, supports our hypothesis that implants placed via ARET with osseodensification ridge expansion would yield higher levels of primary stability and osseointegration indicators at bone-implant interface than those placed with manual osteotome expansion. Further investigation with increased sample size and longer time frame are required to corroborate this hypothesis and validate the clinical advantage of ARET via osseodensification technique.

CONCLUSION

The results of the present study show that osseodensification was compatible with ARET with observation of osseointegration without adverse effects on bone healing and provided histologic and biomechanical evidence of increases in osseointegration and implant primary stability, respectively. Limitations of the current investigation warrant further temporal investigation for longer long-term prognosis of implant osseointegration following ARET through osseodensification.

REFERENCES

1. Leventhal GS. Titanium, a metal for surgery. *J Bone Jt Surg Am* 1951;33:473–474
2. Albrektsson T, Brånemark PI, Hansson HA, et al. Osseointegrated titanium implants: requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. *Acta Orthop Scand* 2009;52:155–170

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3. Esposito M, Ardebili Y, Worthington HV. Interventions for replacing missing teeth: different types of dental implants. *Cochrane Database Syst Rev* 2014; (7):CD003815
4. Raghavendra S, Wood MC, Taylor TD. Early wound healing around endosseous implants: a review of the literature. *Int J Oral Maxillofac Implants* 2005;20:425–431
5. Coelho PG, Jimbo R, Tovar N, et al. Osseointegration: hierarchical designing encompassing the macrometer, micrometer, and nanometer length scales. *Dent Mater* 2015;31:37–52
6. Halldin A, Jimbo R, Johansson CB, et al. The effect of static bone strain on implant stability and bone remodeling. *Bone* 2011;49:783–789
7. Coelho PG, Jimbo R. Osseointegration of metallic devices: current trends based on implant hardware design. *Arch Biochem Biophys* 2014;561:99–108
8. Galli S, Jimbo R, Tovar N, et al. The effect of osteotomy dimension on osseointegration to resorbable media-treated implants: a study in the sheep. *J Biomater Appl* 2015;29:1068–1074
9. Giro G, Marin C, Granato R, et al. Effect of drilling technique on the early integration of plateau root form endosteal implants: an experimental study in dogs. *J Oral Maxillofac Surg* 2011;69:2158–2163
10. Sarendranath A, Khan R, Tovar N, et al. Effect of low speed drilling on osseointegration using simplified drilling procedures. *Br J Oral Maxillofac Surg* 2015;53:550–556
11. Yeniyol S, Jimbo R, Marin C, et al. The effect of drilling speed on early bone healing to oral implants. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013;116:550–555
12. Trisi P, Berardini M, Falco A, et al. New osseodensification implant site preparation method to increase bone density in low-density bone. in vivo evaluation in sheep. *Implant Dent* 2016;25:24–31
13. Huwais S, Meyer EG. A novel osseous densification approach in implant osteotomy preparation to increase biomechanical primary stability, bone mineral density, and bone-to-implant contact. *Int J Oral Maxillofac Implants* 2017;32:27–36
14. Elgali I, Omar O, Dahlin C, et al. Guided bone regeneration: materials and biological mechanisms revisited. *Eur J Oral Sci* 2017;125:315–337
15. Cawood JI, Howell RA. A classification of the edentulous jaws. *Int J Oral Maxillofac Surg* 1988;17:232–236
16. White GS. Treatment of the edentulous patient. *Oral Maxillofac Surg Clin North Am* 2015;27:265–272
17. Elnayef B, Monje A, Lin GH, et al. Alveolar ridge split on horizontal bone augmentation: a systematic review. *Int J Oral Maxillofac Implants* 2015;30:596–606
18. Bassetti MA, Bassetti RG, Bosshardt DD. The alveolar ridge splitting/expansion technique: a systematic review. *Clin Oral Implants Res* 2016;27:310–324
19. Agabiti I, Botticelli D. Two-stage ridge split at narrow alveolar mandibular bone ridges. *J Oral Maxillofac Surg* 2017;75:2115.e1–2115.e12
20. Sanz-Sanchez I, Ortiz-Vigon A, Sanz-Martin I, et al. Effectiveness of lateral bone augmentation on the alveolar crest dimension: a systematic review and meta-analysis. *J Dent Res* 2015;94:128S–142S
21. Niederauer GG, Lee DR, Sankaran S. Bone grafting in arthroscopy and sports medicine. *Sports Med Arthrosc* 2006;14:163–168
22. Altiparmak N, Akdeniz SS, Bayram B, et al. Alveolar ridge splitting versus autogenous onlay bone grafting: complications and implant survival rates. *Implant Dent* 2017;26:284–287
23. Jha N, Choi EH, Kaushik NK, et al. Types of devices used in ridge split procedure for alveolar bone expansion: a systematic review. *PLoS One* 2017;12:e0180342
24. Kobayashi E, Hishikawa S, Teratani T, et al. The pig as a model for translational research: overview of porcine animal models at Jichi Medical University. *Transplant Res* 2012;1:8
25. Mardas N, Dereka X, Donos N, et al. Experimental model for bone regeneration in oral and cranio-maxillo-facial surgery. *J Invest Surg* 2014;27:32–49
26. Gottlow J, Dard M, Kjellson F, et al. Evaluation of a new titanium-zirconium dental implant: a biomechanical and histological comparative study in the mini pig. *Clin Implant Dent Relat Res* 2012;14:538–545
27. Anchieta RB, Baldassarri M, Guastaldi F, et al. Mechanical property assessment of bone healing around a titanium-zirconium alloy dental implant. *Clin Implant Dent Relat Res* 2014;16:913–919
28. Kao DWK, Fiorellini JP. Comparison of ridge expansion and ridge splitting techniques for narrow alveolar ridge in a swine cadaver model. *Int J Period Rest Dent* 2015;35:e44–e49

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