Effects on Ridge Dimensions, Bone Density, and Implant Primary Stability with Osseodensification Approach in Implant Osteotomy Preparation

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Purpose: To compare the amount of bone expansion, bone density change, and implant primary stability with an osseodensification technique to a conventional drilling protocol. Materials and Methods: Twenty-four bovine rib segments (20 × 25 × 4 mm) with a 1-mm outer layer of cortical bone were randomly divided into two groups: an osseodensification group and a conventional drilling group. Each bone sample received one 4.1 × 10–mm implant. The density of the peri-implant bone before and after osteotomy was measured. After implant placement, primary stability was assessed. A laser surface scanner was used before and after implant placement to compare the dimension of crestal bone width and volumetric expansion. Histomorphometric analysis was performed to compare the bone-to-implant contact percentage (BIC%) of the two groups. Results: The peripheral and apical bone mineral density around the implants was significantly increased, and a statistically significantly higher peripheral BIC% was found in the osseodensification group. A significant increase in volume and bone width after implant placement was found in both groups. However, there were no significant differences in volume and bone width change at all three locations and in implant stability between the osseodensification and conventional drilling protocols. Conclusion: Within the limitations of this study, the osseodensification protocol increased the bone mineral density and primary bone-to-implant contact. Also, this study suggests that implant placement by osseodensification or conventional drilling can increase ridge dimensions in narrow alveolar ridges. Int J Oral Maxillofac Implants 2021;36:474–484. doi: 10.11607/jomi.8540

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Dental implants are used for replacement of missing teeth and serve as anchors for dental prostheses in partially and completely edentulous arches. One important factor for successful osseointegration is primary implant stability. The lack of primary stability can be associated with a higher implant failure rate because the implant may not achieve successful osseointegration. Several techniques have been introduced to enhance primary implant stability, including implant design (macrogeometry) and surface modifications (microgeometry), enhanced insertion torque, placement of a larger implant into an undersized osteotomy, osseotome techniques, lateral ridge expansion by screw-type expanders, the bone spreader technique, and, more recently, the osseodensification technique.

Osseodensification was first introduced by Huwais as a technique designed to compress the bone in an osteotomy site using specially designed burs (Densah burs, Versah). When using these burs under counterclockwise rotation with irrigation by bouncing motion, it could induce hydrodynamic compression to densify the bone. After expanding the bone, the viscoelastic properties of bone will provide some “spring back” effect around the osteotomy site, which is believed to result in greater immediate bone contact with endosteal implants and to enhance the primary stability. Use of the osseodensification protocol not only increases bone density, but because of the elastic properties of the bone, bone expansion was observed in a sheep iliac crest study and a retrospective human study.

Resorption of the alveolar ridge after tooth extraction often results in inadequate buccolingual dimension for proper implant placement to restore the natural tooth position with a normal emergence profile. Implants should be placed in a position with at least 1.8 to 2.0 mm of bone thickness on the facial and lingual aspects to prevent further bone loss and soft
tissue recession after placement. In order to place an implant in an atrophic alveolar ridge, bone augmentation techniques have been utilized since the early 1990s to rebuild deficient alveolar ridges to allow placement of implants in an ideal position. However, bone augmentation techniques are not without complications, including graft infection, graft failure, postsurgical healing times before implant placement, and added patient expense.

To avoid the limitations of bone augmentation surgery, the osseodensification protocol might be an alternative way to achieve alveolar ridge expansion. To the best of the authors’ knowledge, the amount of bone expansion achievable by osseodensification vs conventional drilling techniques has not been previously reported. Accordingly, the primary aim of the present study was to compare the amount of bone expansion after using osseodensification burs vs the conventional drilling technique. The secondary goal was to compare the mechanical effect of using osseodensification burs on primary implant stability, bone density, and bone-to-implant contact vs the conventional drilling technique using a bovine rib bone model.

**MATERIALS AND METHODS**

**Sample Preparation**

Bovine rib bones obtained from a local slaughterhouse were used for this study. All the bone was from one 75% Angus steer, less than 36 months of age. Each rib was 15 cm in length and 3 cm in height and width in a cross-sectional view. Before starting experimentation, the samples were prepared by removing the attached muscular tissue and periosteum and sectioning them into pieces measuring 30 mm long. On each rib section, the surfaces were trimmed by a dental plaster trimmer (Model trimmer, Whip Mix) to provide smooth and flat surfaces. These rib sections mimicked the atrophic human alveolar ridge, where the width was narrow superiority but gradually became wider toward the bottom, close to a trapezoid shape, with the side for osteotomy preparation on the top measuring 4.0 mm in width. Only the rib sections with trabecular core sizes of approximately 3 mm in width on the top and 5 to 6 mm in width at the middle were selected. The thickness of cortical bone on each rib section was trimmed to 0.5 to 1.0 mm, measured at 0.5 to 1.0 mm from the top, to mimic the average natural human alveolar ridge cortical bone thickness in the anterior maxilla area.

After the preparations, these rib sections were converted from what has been classified as D2 to D3 bone according to the Bone Quality Index from Lekholm and Zarb, commonly found in human posterior edentulous ridges. The bottom third of each rib piece was fixed in a base made from die stone, measuring 7 mm in height (Fig 1). These bases were the reference to facilitate surface analysis. In each base, three reference points were made using a carbide round bur to facilitate analysis. A total of 24 models were created according to the sample size justification based on the pilot study. Only one implant was placed in each rib section. All the rib sections and the created bone models were stored in sterile saline (0.9% NaCl) at 4°C during the entire experimental period until the specimens were sent for histomorphometric analysis.

**Implant Osteotomy Protocol**

After sample preparation and being randomly divided into the test or control groups using SPSS Statistics software (IBM, released in 2017), a total of 24 implant osteotomy sites were created in these samples by a single surgeon (Y.-T.Y.). With respect to the test group, osteotomy preparation was started with a 1.4-mm round bur, followed by a 1.7-mm pilot drill and then by the osseodensification burs (Densah bur, Versah) with diameters of 2.3, 3.0, 3.3, and 3.5 mm. Following the manufacturer’s instruction, the burs attached to the implant motor (Surgic Pro+, NSK) were used in a pumping motion and a counterclockwise rotation under sterile saline solution irrigation at 1,100 rpm. For the control group, a conventional implant drill (Straumann)
sequence was used for osteotomy preparation. The process began with a 1.4-mm round bur, and subsequent drills with 2.2-, 2.8-, and 3.5-mm widths were followed and irrigated with saline as recommended by the manufacturer. All sites were prepared to an 11-mm depth. After osteotomy, $4.1 \times 10^{-6}$-mm implants (Straumann Bone Level SLA titanium implants) were placed 1 mm apical to the top surface of each bone model. The orifice of the implant osteotomy was covered by dental plaster to avoid interference from the metal during surface scanning.

**Surface Analysis: Volume Change and Width Expansion**

All the specimens were scanned before osteotomy preparation and after implant placement to determine the amount of bone expansion. The specimens were coated with opacification powder (Denu Easy Scan) and scanned with a laser scanner (Dental Wings 7 Series; Dental Wings). After all the scanned data were converted into stereolithography (STL) files, the surface analysis was performed using Netfabb software (Autodesk Netfabb). Volumetric differences were measured at three locations (upper, middle, and lower) by comparing the model before osteotomy and after implant placement. Upper, middle, and lower sections of the bone were first defined from the model before osteotomy as 1 to 4, 4 to 7, and 7 to 10 mm apically from the top of bone model. The volumes of the upper, middle, and lower sections before osteotomy and after implant placement were computed by Netfabb software, and the volume change in each section was calculated (Fig 2). To measure the width expansion, the STL files of the upper, middle, and lower sections before and after implant placement were superimposed based on the calculation of Netfabb software to get the best match of these two models. A slight adjustment was made by checking the three reference points. The specimens were divided into three planes based on the distance to the top of the bone models before osteotomy: 1, 4, and 7 mm (H1, H4, and H7). Afterward, the width expansion was measured on these three planes (Fig 3). To calibrate...
the measurement error, each numerical value was repeated three times. The mean value of these three measurements was used for statistical analysis.

**Bone Mineral Density**

To measure the sample peri-implant bone mineral density (BMD), a peripheral quantitative computed tomography unit (pQCT Research SA+, Stratec, Medizintechnik) was used. The total BMD (mg/cm³) was measured by the embedded pQCT software before and after osteotomy preparation to compare the differences. Contour-mode 1 with threshold 0, peel-mode 2 with inner threshold 100, and F01 filter were chosen to include all total bone mass and to reduce the noise. The scans were made in the mesiodistal cross-sectional direction to the middle of the specimens. The sites to measure the peripheral density were based on the bone peripheral to the osteotomy, where four region of interest (ROI) areas (0.3 × 2 mm, in the depth of 4 to 6 mm, 8 to 10 mm, two on the left and two on the right side, Figs 4a and 4b) were selected to calculate the average density around the osteotomy site. To measure the peripheral density before implant osteotomy at the same site on the same bone model, the previously used four ROI area positions were saved as templates to measure the density. The peripheral density difference was calculated by comparing the average density before and after implant osteotomy. The density apical to the osteotomy site was measured by one ROI area (0.3 × 2 mm, in the depth of 10 mm, Figs 4c and 4d). The apical density difference was calculated by comparing the density before and after implant osteotomy.

Because the total BMD by pQCT only calculated the total mineralized materials without including soft tissue, fluid, or air, to calculate the real BMD on the selected ROI areas, the density and the mineralized area were multiplied to get the mass, and then the mass was divided by the area of the ROI to calculate the real BMD (BMD = [BMD of mineralized materials × mineralized area]/ROI area).
Implant Placement and Primary Stability Evaluation
After completion of the osteotomies in both the control and test groups, implants (Straumann BL SLA titanium implants; 4.1 × 10 mm) were inserted into preparation sites using a hand wrench to a depth 1.0 mm apical to the bone crest by the same single operator (Y.-T.Y.). Primary stability was assessed three times after implant placement using an Osstell ISQ probe (Osstell AB) to determine the implant stability quotient (ISQ) value.

Histologic Preparation and Bone-to-Implant Contact Analysis
After implant stability measurements, both the control and test group specimens were processed for histologic and histomorphometric analysis. For each specimen, the most central section was analyzed and morphometrically measured. All the specimens were fixed in 10% neutral-buffered formalin and dehydrated using ethanol, then embedded in polymethylmethacrylate blocks. The blocks were sectioned and polished to approximately 50 μm, parallel to the long axis of the implant. Toluidine blue stain was used for analyzing the sectioned specimens. The histomorphometric analysis was performed by digitizing the images through a fluorescence microscope (BZ-X800, Keyence) with objective lens (4×) and imaging software (Image-Pro, Media Cybernetics). The peripheral and apical bone-to-implant contact percentages (BIC%) were calculated by a single user (Y.-T.Y.). If there was a gap between the implant surface and bone surface analyzed by imaging software, it was defined as noncontact. The BIC% of each specimen was calculated by dividing the surface length of the implant surface in bone by the length where direct bone-to-implant contact was observed. The flowchart of the research protocol is shown in Fig 5.

Statistical Analysis
Two-way repeated-measures analysis of variance (ANOVA) was used to evaluate differences in bone density, cortical bone thickness, bone expansion volume, and width of expansion between the experimental and control groups before osteotomy, after implant placement, and for changes from pre- to post-osteotomy. The repeated-measures ANOVA was used for comparing testing of the changes from pre- to post-osteotomy within each group. Repeated factors due to multiple measurement locations within a sample were also included as appropriate for each type of measurement. Implant primary stability (ISQ) and BIC% were compared between the two groups using two-sample t tests. A 5% significance level was used for all tests.
RESULTS

Surface Analysis: Volume Change and Width Expansion

The initial bone width of the surface prior to the osteotomy was 4.09 (± 0.14) mm in the control group and 4.03 (± 0.18) mm in the test group (P > .05).

A significant increase in bone volume after implant placement was found in both groups except for the lower portion of the control group. The bone expansion in the test group was 8.20 (± 0.96) mm³ for upper, 3.24 (± 0.59) mm³ for middle, and 1.80 (± 0.38) mm³ for lower (all P < .05), while it was 9.26 (± 1.14) mm³ for upper (P < .05), 2.25 (± 0.60) mm³ for middle (P < .05), and 0.91 (± 0.45) mm³ for lower (P > .05) in the control group. Bone expansion volume differences between the test group and the control group were as follows: 1.07 (± 1.50) mm³ for upper, −0.99 (± 0.84) mm³ for middle, and −0.90 (± 0.59) mm³ for lower (all P > .05; Fig 6).

Primary Stability

After implant placement, the mean ISQ values for test and control groups were calculated to be 78.39 (± 5.13) and 77.61 (± 7.12), respectively. Both groups showed no significant differences in ISQ after implant placement (P > .05).

Bone Mineral Density

The pQCT images showed a thin layer of compacted bone with < 0.5 mm thickness around the implant osteotomy site after using osseodensification burs. There was more disruption of the osteotomy outer layer in
the conventional drilling group, while the preserved bone chips and the original trabecular pattern together formed a compacted bone layer around the osteotomy site in the osseodensification group, in which some portions of these compacted bone layers were continuous under the pQCT image (Figs 8a and 8b).

Comparisons of pQCT data demonstrated that there were no significant differences in peripheral and apical BMD before experimentation. It was 102.60 (± 20.72) and 101.51 (± 44.90) mg/cm³ in the test group, while it was 99.06 (± 36.77) and 108.12 (± 62.73) mg/cm³ in the control group (\( P > .05 \)). After using osseodensification burs and conventional drills, the pQCT result showed that both peripheral and apical BMD around the implants was significantly increased in both groups. The peripheral BMD increased to 197.32 (± 36.91) and 120.29 (± 45.82) mg/cm³ individually. However, the test group showed an approximately 4.5 times greater peripheral BMD increase compared with the control group (94.72 ± 38.38 vs 21.24 ± 19.74 mg/cm³, \( P < .05 \); Fig 9a). The apical BMD increased 57.34 (± 27.97) mg/cm³ in the test group and 23.60 (± 25.79) mg/cm³ in the control group (\( P < .05 \)). The apical BMD increased two times more in the test group using osseodensification burs. \( *P < .05 \).

**DISCUSSION**

In the present study, increases in bone volume and bone width were seen in both groups. However, the differences in terms of bone volume change and width expansion were not significant between these two groups. One explanation may be that a 4.1-mm-diameter implant was placed in an undersized osteotomy created by the average 3.5-mm-diameter final drill in both groups. The volume change and width expansion were more evident on the upper portion than the lower portion of the model in both groups (Figs 6 and 7). It was because the models in this study mimicked the atrophic human alveolar ridge, where the

**BIC Analysis**

After histomorphometric analysis, the mean peripheral BIC% for test and control groups was calculated to be 47.52 (± 13.15) and 32.19 (± 9.27), respectively. The test group indicated a significantly higher level of peripheral BIC% than the control group (\( P < .05 \); Fig 11a), while there was no significant difference in the mean apical BIC% (60.51 ± 22.68 vs 43.10 ± 22.05; \( P > .05 \); Fig 11b).

**Histology Observation**

The histologic sections of the control group demonstrated bone trabeculae that were fractured and lodged between the remaining intact trabecular bone (Fig 10a). However, in the test group, certain bone trabeculae were deformed and bent around the implant (Fig 10b).
The width was slightly tapered from the top to the bottom. Therefore, the effect of bone expansion was not evident on the lower portion.

The bone width expansion after the osseodensification technique was 0.75 ± 0.22 mm, 0.21 ± 0.09 mm, and 0.07 ± 0.05 mm in the upper, middle, and lower regions, respectively. It was reported that the horizontal bone gain after a guided bone regeneration technique was 4.6 mm (range: 2 to 7 mm) with autogenous bone block graft, anorganic bovine bone mineral (ABBM), and resorbable collagen membranes after an average healing time of 5.8 months. Another study using autogenous bone graft, ABBM, and synthetic resorbable membranes (glycolide and trimethylene carbonate) reported a mean increase of 5.56 ± 1.45 mm horizontal bone width after an average of 8.12 months. Based on the aforementioned studies, it could be concluded that the amount of horizontal bone gain using the osseodensification technique was significantly less than that following a guided bone regeneration technique.

From the present study, a similar mean ISQ value of approximately 77 was observed in both groups. These results indicate that both techniques could obtain high primary stability in these bone models after implant placement. In a similar study comparing the primary stability with the osseodensification technique and the conventional drilling technique with porcine tibia models, both groups showed comparable ISQ values. The reason why both groups showed high primary stability might be because these implants were placed in an undersized osteotomy with 1 mm of dense cortical bone. Using the resonance frequency analysis (RFA) technique by measuring ISQ values to assess implant stability without damaging the bone-implant interface allows monitoring of implant stability at various stages of treatment and at different observation periods. However, measuring ISQ values as a method to predict implant failure risk is still controversial. One randomized controlled trial study compared immediately placed implants vs delayed implants and found no significant correlations between the baseline ISQ values and early implant stability.
implant failure. Another retrospective study reported that when ISQ values were below 70 and 75 at implant placement, a significantly higher implant failure rate could be found afterward. Even though tracking ISQ values for primary implant stability could be clinically useful, the achievement of high primary stability might be detrimental to the implant survival and marginal bone loss due to the high interfacial strain between the implant surface and the bone.

Some studies using insertion torque or removal torque measurements to determine primary implant stability found that the osseodensification technique obtained both higher insertion and removal torques, which suggests that a higher implant stability could be attained following the osseodensification technique. Nonetheless, one should be careful in making definitive conclusions from these studies due to differences in study and implant design, varying bone densities, analysis methods, and follow-up periods. Additionally, there are multiple factors that influence the long-term success of dental implants besides primary implant stability. Above all, whether the osseodensification technique could improve implant primary stability and subsequent implant survival rates needs to be evaluated with more scientific studies.

Data from the present study showed that both groups demonstrated increased BMD around the peripheral implant osteotomy wall and apical portion. However, the osseodensification technique resulted in significantly higher bone density compared with the conventional drilling technique on both peripheral and apical areas. In the previous study using a porcine tibia model, microcomputed tomography (micro-CT) images showed a crust of compacted bone with increased BMD around the periphery of osseodensification osteotomies but not around the conventional drilling osteotomies. However, that study did not quantify the increase in bone density. The present study was able to quantify the numeric value of the density changes, and pQCT images in this research showed not only the compacted bone layer around the osseodensification group, but also the discontinuous bone mass around the conventional drilling group.

The present histologic results showed that there was a difference between the edge of the implant osteotomy wall and the trabecular bone, even though the layer of the compacted bone was very thin. Due to the extremely heterogeneous nature of the cancellous bone, there was a large standard deviation in the bone density. To overcome this problem, this study selected five small ROI areas around the implant osteotomy site after implant drilling. The positions of these five ROI areas were registered for the measurement of the density before implant drilling. The advantage of this method is that the exact density change of these five particular areas could be measured. Those density changes could be considered as the densification effect during osteotomy preparation.

There are several ways to measure BMD: the bone volume fraction (BV/TV) using histomorphometry, Hounsfield unit values using computed tomography (CT), dual-energy x-ray absorptiometry (DXA), pQCT, and micro-CT. There were several reasons that the present study selected pQCT over other methods. First, the goal of this study was to measure the density change on the same bone model. Using histomorphometric methods only allows researchers to measure the density before histology preparation. Second, conventional CT and DXA could not detect small BMD changes, while pQCT and micro-CT could, due to the difference in their voxel sizes (140 to 400 and 500 μm vs 30 to 41 μm). Third, both pQCT and micro-CT have demonstrated satisfactory precision and accuracy in BMD measurement in a mouse model. However, using micro-CT is more time-consuming than using pQCT, and the cost is higher. If the exact position of the plane to measure density is known, with the aid of the red laser line on the pQCT machine to locate the scanning plane, the same cross-sectional plane could be scanned on the middle portion of one bone model at different time points. Also, notice that the BMD measured in this study included the contribution of minerals from the existing bone next to the implant as well as from the bone debris from the drilling process.

The significance increase of the BMD after the osseodensification technique on the apical portion was not reported in the previous studies. A retrospective study reported enhanced apical bone density by compacting the bone chips into the apex with a nonexcavating drilling process after the osseodensification technique. Even though this study did not report how much apical bone density could be improved, the bone chips from the osteotomy together with irrigation solution might help to detach the sinus membrane from the sinus floor. The sinus bone height could increase 5.4 ± 1.9 mm on average compared to the baseline without sinus membrane perforations.

The histology sections in this study showed that the trabecular bone was fractured immediately adjacent to the osteotomy preparation after using conventional drills. Some bone chips were spread in between the trabecular bone. However, the trabecular bone in the osseodensification group was not fractured but tended to “bend” around the implant. The “bending” of the trabecular bone in the test group appears to form a denser bone layer that can better resist the forces from implant placement compared with the control group. The histologic outcomes also reflected the pQCT outcomes. Because the osseodensification group preserved more bone by bending the trabecular bone instead of bone
removal with conventional drills, the pQCT images demonstrated a continuous compact bone layer adjacent to the implant.

In the present study, the BIC% was higher in the osseodensification group in both peripheral and apical areas. A previous study using a sheep iliac crest model assessed the BIC% 6 weeks after implant placement following osseodensification burs vs conventional drills and found a significantly higher BIC% after use of osseodensification burs. However, another study using the same model measured the BIC% 2 months after implant placement. The results showed no significant differences between osseodensification burs or conventional drills for implant osteotomy preparation. While higher BIC% results from the condensation of peri-implant bone density after using the osseodensification technique, it does not always enhance the peri-implant bone healing and secondary implant stability, which might be due to the excessive strain and the disruption of the trabecular bone connectivity causing more osteoclastic activity. One of the limitations of the present study using the nonliving bovine bone models is that the peri-implant bone healing after the osseodensification technique could not be observed.

There are two unique features of the present study. First, this is the first study evaluating the effects of osseodensification on BMD changes and also the first study using surface analysis to measure the bone volumetric changes and bone width expansion with the osseodensification technique. Second, the bovine bone model used in this study mimics the shape of the natural human alveolar ridge, is a reproducible model to study the alveolar expansion condition after osseodensification preparation, and demonstrates similar elastic properties to human alveolar ridges. The elastic modulus is the parameter to determine the elasticity. Since the bovine bone had a similar trabecular elastic modulus but higher cortical elastic modulus to the human edentulous ridge, the cortical bone layer was trimmed to 0.5 to 1.0 mm in the present study, which was slightly less than the average human cortical bone thickness on the edentulous ridge, to justify the higher bovine cortical elastic modulus.

There were several limitations of this study. First, using opacification powder for surface scanning could affect the accuracy of the volumetric measurements. The reason for the use of opacification powder is that the 7 Series surface scanner was designed to scan plaster models. Dental impressions and reflective objects such as metal or a shiny surface with water adherence would cause light to scatter and bounce in uncontrollable directions, resulting in measurement errors. Considering the bone models with a wet, smooth bone surface would reflect light, the opacification powder was used to facilitate the scanning. However, the water-soluble scan spray might be washed off during the implant osteotomy procedure. In the present study, a limited portion of the opacification powder was lost while most of the opacification powder was still adherent to the bone surface. Even though the loss of opacification powder was limited in the present study, using the surface scan without the need of the opacification powder would be a better option to eliminate this confounding factor. Another limitation is the accuracy of the surface scanner. The precision of the 7 Series surface scanner varies. In a review paper about current surface scanners, the precision of the 7 Series scanner is 15 μm according to the manufacturer, while another study comparing the accuracy of five intraoral scanners found that the precision of the 7 Series scanner was 35.3 ± 42.4 μm. These deviations might also affect the bone expansion width at the different osteotomy depths, especially at 7 mm. Therefore, the use of a more precise scanner should be considered in future studies. Furthermore, implant osteotomy preparation by freehand might also cause the dehiscence if the path of the insertion was deviated. To avoid the manipulation error, using a system containing a handpiece in a straight up-and-down motion and mounting rims to stabilize the model to determine the drilling position precisely would be more optimal in this type of study.

CONCLUSIONS

Within the limitations of this study, the osseodensification protocol increased BMD. While this study demonstrated that implant placement by osseodensification resulted in some increase in ridge dimension, similar amounts of ridge expansion were seen using conventional drilling.

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