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Influence of dental implantation on bone mineral density distribution: a pilot study

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PURPOSE. Masticatory loading triggers active bone remodeling, altering alveolar bone mineral density (BMD). While dental implants are placed to bear masticatory loading, their influence on changing bone properties has not been fully investigated. Objective of this pilot study was to examine whether the dental implantation has an effect on BMD distribution of bone by comparing dentate, edentulous, and edentulous patients with implants. **MATERIALS AND METHODS.** Cone beam computed tomography (CBCT) images of 19 partially edentulous patients (Dent), 19 edentulous patients (Edent), and 16 edentulous patients who received implants in the mandible (Edent+Im), were obtained. CBCT images were also obtained from 5 patients within Edent+Im group, before implant placement and after implant loading. Basal cortical bone region of the mandible was digitally isolated. A histogram of gray levels proportional to BMD was obtained to assess mean, histogram standard deviation (HSD), fifth percentile of low and high values (Low_5 and $High_5$) of the BMD distribution. Multivariate analysis of variance and paired t-test were used to compare the BMD parameters among the 3 dental status groups and between pre- and post-implantation, respectively. **RESULTS.** Edentulous patients with implants had significantly greater HSD and $High_5$ values compared to edentulous patients ($P < .013$). All other comparisons were not significant ($P > .097$). Mean, HSD, and $High_5$ values significantly increased after receiving implants ($P < .022$). **CONCLUSION.** The current findings suggested that receiving dental implants promoted oral bone mineralization for edentulous patients. The longitudinal investigation could provide valuable information on understanding the effects of implantation on the behavior of oral bone quality. [J Adv Prosthodont 2022;14:143-9]

KEYWORDS
Dental implant; Edentulous patients; Cone beam computed tomography; Bone mineral density

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INTRODUCTION

Masticatory force on teeth is transmitted to alveolar bone through periodontal ligament (PDL). As a result, active remodeling is triggered altering degree of mineralization in the alveolar bone next to teeth.[1] Average bite force for dentate individual has been reported to be around 300 N, whereas individual that are completely edentulous can produce around 165 N of force.[2] Because of the notable decrease in the functional load on the surrounding bone, the properties of bone may become different for the edentulous dental arch, compared to a fully dentate arch, over time. However, there is a lack of information on how edentulism can potentially influence the bone adaptation and eventually change the overall bone quality.

Replacement of teeth continues to exist for the edentulous patients in the United States. Despite the decrease in the percentage of edentulism over time, it is estimated that adults older than 65 needing complete dentures will increase from 33.6 million adults in 1991 to 37.9 million adults in 2020.[3] In order to maintain function, appearance or quality of life, need to replace teeth challenges oral health care providers in different ways, using removable or implant-supported prostheses, or in combination. It has been well-documented that prolonged use of complete denture can lead to the resorption in the remaining alveolar ridge.[4] For dental implant therapy, assessment of the surgical site, especially bone quality, is vital. Bone mineral density (BMD) has been associated with describing quality of bone needed for dental implant therapy.[1]

Examining the BMD of patients in various dental states or those that received dental implant therapy can provide a better understanding of how loss of dentition or placement of dental implants can influence the overall quality of jaw bone. Cone beam computed tomography (CBCT) is widely used for dental implants and several studies have shown that CBCT can reliably assess BMD (Fig. 1).[5-7] Thus, the objective of the current study was to examine whether placing dental implants has an effect on BMD distribution of oral bone by comparing dentate, edentulous, and edentulous with implant therapy patients.

MATERIALS AND METHODS

This pilot study was approved by the Institutional review board of The Ohio State University (Protocol #2011H0128). Under this IRB, there were total of 300 CBCT scans available in the database at the College

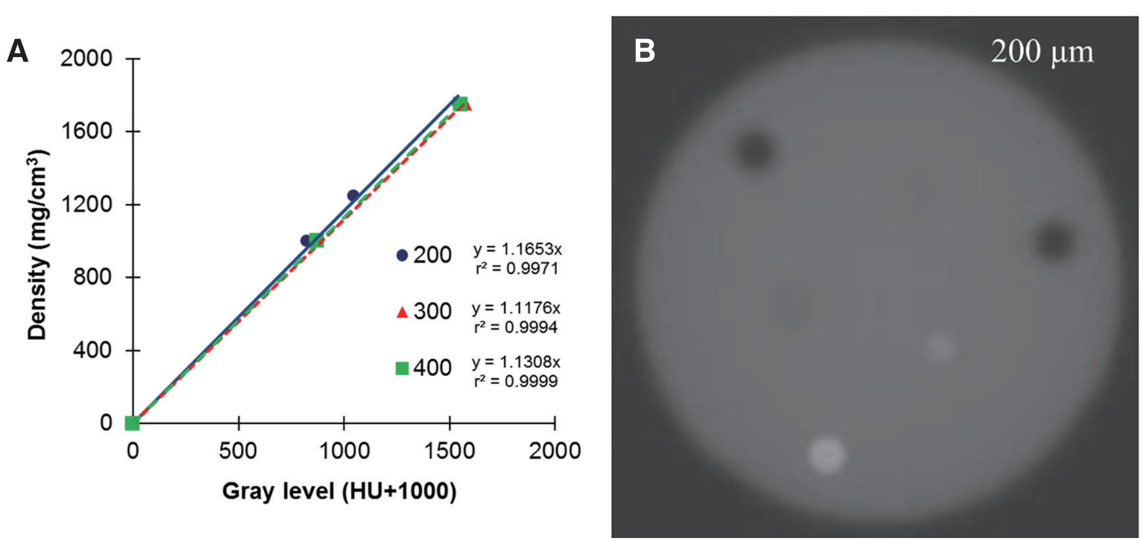

Fig. 1. (A) Strong positive correlations in the calibration curves of gray values for (B) phantoms of bone material with 3 different densities (1000, 1250, and 1750 mg/cm^3) scanned using 3 different resolutions (200, 300, 400 μm) of CBCT. HU, Hounsfeld units.[7]

of Dentistry and the following inclusion and exclusion criteria for three groups were formed: 1) Dentate group (DENT) - all teeth had to be present, no missing teeth 2) Edentulous group (Edent) - all teeth had to be missing and no implants present 3) Edentulous group with implants (Edent+Im) - must be edentulous and must have received endosseous implants on mandible. After searching through the 300 CBCT scans, 54 patients (25 males: 50 to 73 years old, and 29 females: 31 to 78 years old) met the criteria for the study. There were 19 dentate patients (Dent), 19 edentulous patients (Edent) without implant, and 16 patients who received 4 to 5 dental implants with fixed complete denture in the mandible, opposing a complete maxillary denture (Edent+Im). The Edent+Im group included the CBCT images of 5 patients (2 males: 63 to 64 years old, and 3 females: 51 to 68 years old) who had scans prior to dental implant surgery (Edent+Im_T1) and then another scan after receiving dental implants (Edent+Im_T2). The post-implantation periods for Edent+Im_T2 group were at the range of 7.9 and 58.8 months when CBCT was taken.

All of the patients' images were taken from the same CBCT scanner (iCAT; Imaging Science International, Hatfield, PA, USA) at 300 mm voxel size with a scanning energy (120 kV and 5 mA) and 8.9 seconds scanning time. Following methodology developed in the previous studies,[1,5,6] bone voxels in the 3D images were segmented from non-bone voxels using a heuristic algorithm. A basal cortical bone (CB) of the mandible, which was determined below apex of tooth root level, was digitally isolated from the CBCT image using an image analysis software (ImageJ; NIH, Bethesda, MD, USA) (Fig. 2). The gray level of each voxel was added by 1000 to the Hounsfield Unit (HU) in order to make the lowest HU value (-1000) of an air voxel to be zero. As such, all of the gray levels in the image turned to be positive to compare absolute values between images. A histogram of gray levels that are proportional to BMDs was obtained from each CBCT image. A mean value (Mean) was calculated by dividing the sum of gray levels by the total bone voxel counts.

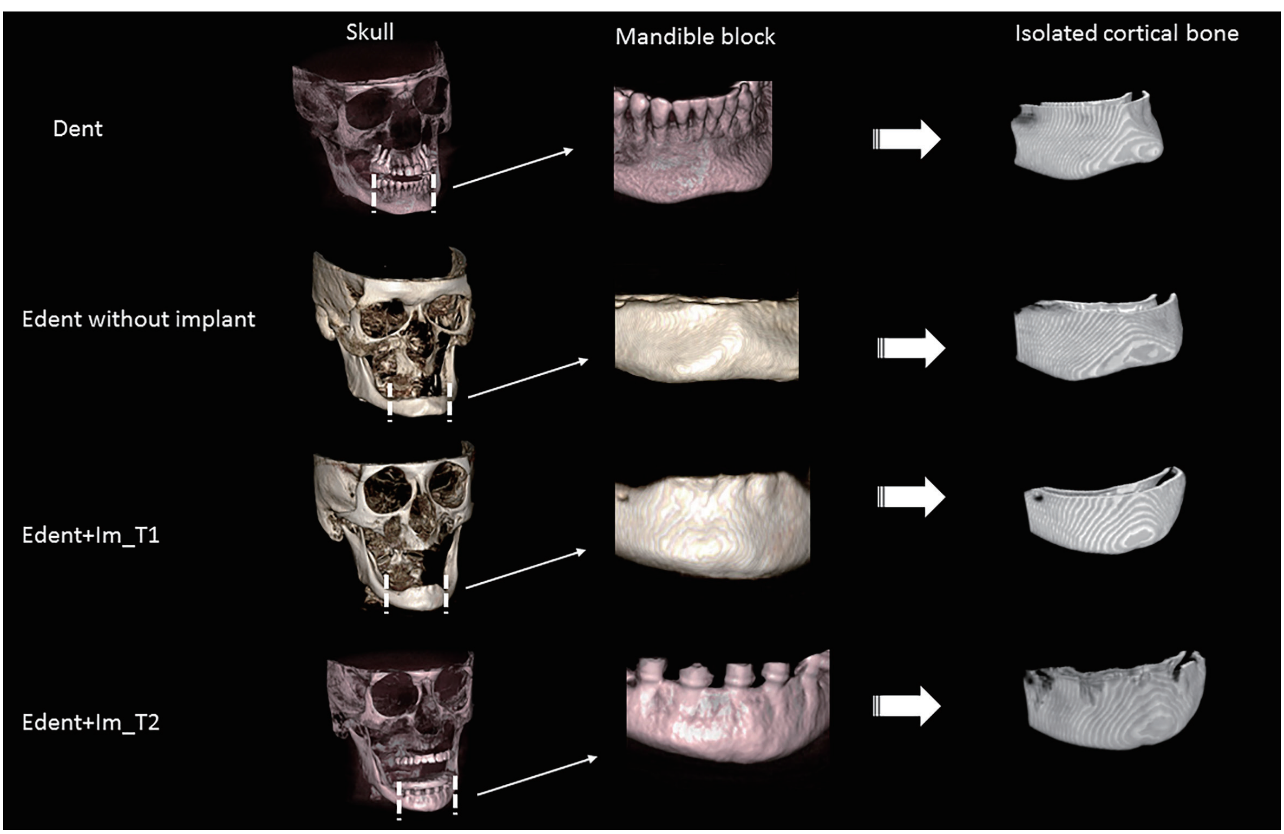

Fig. 2. Digital isolation of basal cortical bone using the CBCG images for dentate (Dent), edentulous without implants (Edent), and edentulous with implants (Edent+Im) groups before (T1) and after (T2) implantation.

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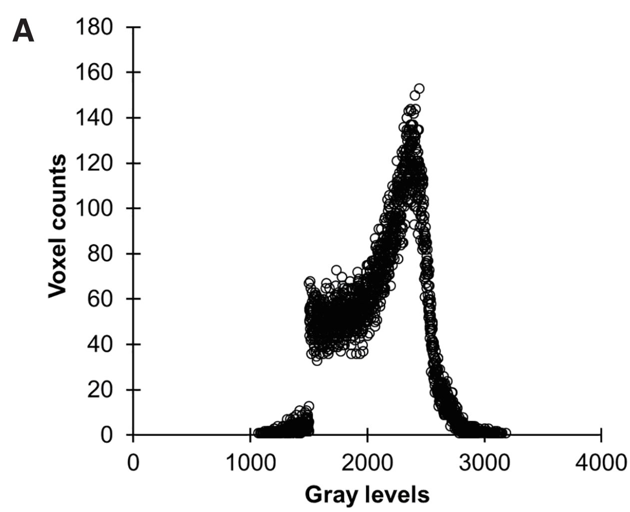
The histogram standard deviation (HSD), which represents heterogeneity of the gray levels, was also obtained. The 5th and 95th percentiles of the voxel counts in the gray level histogram were determined to be low and high gray levels (Low_5 and $High_5$) (Fig. 3A).

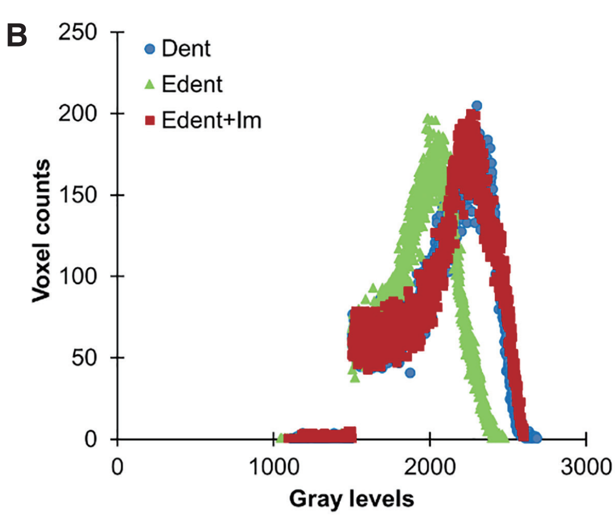
Analysis of variance (ANOVA) followed by Tukey-Kramer HSD post-hoc tests were performed to compare the gray level parameters among the three groups (Dent, Edent, and Edent+Im). A paired t-test was used to compare the gray level parameters of 5 images scanned between before and after implantation (Edent+Im_T1 and Eden+Im_T2). Significance was set at $P < .05$.

RESULTS

The gray level histograms of each group have been successfully obtained (Fig. 3B, C). The SD and $High_5$ values of Edent+Im group had significantly higher values than those of Edent group ($P < .013$) (Table 1 and Fig. 4). All other parameters were not significantly different among the three groups (Dent, Edent, and Edent+Im) ($P > .097$).

The Mean, SD, and $High_5$ values of edentulous with implants group scanned after (Edent+Im_T2) implantation was significantly higher than those before implantation (Edent+Im_T1) ($P < .022$) (Table 2).





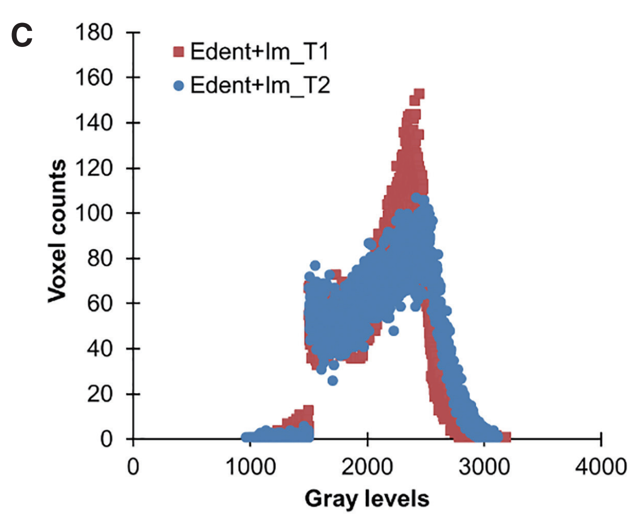


Fig. 3. (A) Gray level parameters obtained from a typical histogram, (B) comparison of basal cortical bone (CB) gray levels histograms of edentulous with implants group between before (Edent+Im_T1) and after (Edent+Im_T2) implantation, and (C) comparison of CB gray levels histograms of Dent, Edent, and Edent+Im groups.

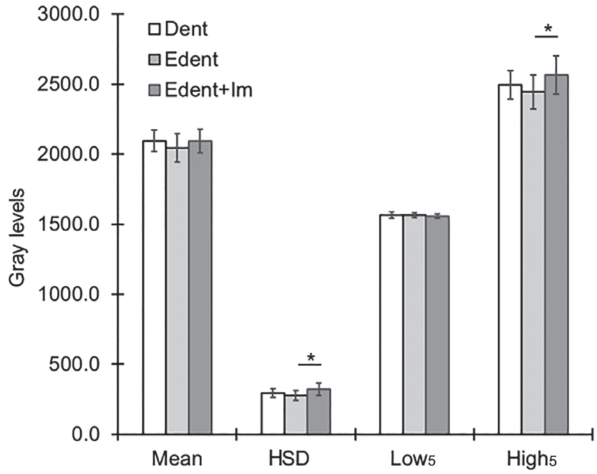


Fig. 4. Comparison of gray level parameters between dentate (Dent) (n = 19), edentulous (Edent) (n = 19), and edentulous with implants (Edent+Im) (n = 16) groups. *; $P < .013$

Table 1. Values of gray level parameters (Mean, HSD, Low_5, and $High_5$) for dentate (Dent) (n = 19), edentulous (Edent) (n = 19), and edentulous with implants (Edent+Im) (n = 16) groups (mean ± standard deviation)

	Mean	HSD	Low_5	$High_5$
Dent	2094.63 ± 76.31	295.74 ± 30.82	1564.42 ± 22.54	2493.58 ± 100.69
Edent	2046.65 ± 101.29	276.38 ± 36.18	1565 ± 18.42	2444.21 ± 123.03
Edent+Im	2091.89 ± 83.34	321.99 ± 43.01	1557.13 ± 15.73	2564.81 ± 136.14

Table 2. Comparisons of gray level parameters (Mean, HSD, Low_5, and $High_5$) of edentulous with implants group between before (Edent+Im_T1) and after (Edent+Im_T2) implantation (n = 5 for each group) (mean ± standard deviation)

	Mean	HSD	Low_5	$High_5$
Edent+Im_T1	2011.18 ± 74.32	280.23 ± 39.53	1541.8 ± 22.38	2408.8 ± 110.31
Edent+Im_T2	2096.57 ± 67.65	341.87 ± 33.65	1553.2 ± 13.81	2618.6 ± 104.47
P value	.017	.022	.133	.005

DISCUSSION

Reliability of CBCT based BMD measurement has been controversial mainly because of artefacts in the CBCT images.[7] However, previous studies have demonstrated that the gray levels of CBCT image are proportional to the BMD values by showing their strong positive correlations with known density of hydroxyapatite phantoms.[6,7] The CBCT based BMD values were also comparable with those measured by a higher resolution micro-CT as a gold standard.[5] A clinical study showed that the CBCT based BMD is significantly changed dependent on patients' gender with aging and suggested a potential diagnostic tool for postmenopausal osteoporosis.[1] Having these validations, the current study quantified BMD distribution of human jaw bone using the same clinical CBCT as used in the previous studies.

The Low_5 value can be used to estimate the BMD in a newly formed bone region, which is not fully mineralized. In contrast, the $High_5$ value can represent the BMD of a pre-existing bone region that is mature containing high mineral contents. The HSD values account for heterogeneity of BMD distribution that is determined by differences between Low_5 and $High_5$ values. As such, the higher $High_5$ value after implant

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placement suggests that receiving dental implants for edentulous patients (Edent+Im group) could improve oral cortical basal bone mineralization compared to edentulous patients (Edent group).

The BMD distributions of the dentate patients (Dent group) and edentulous patients (Edent group) were not significantly different for the basal cortical bone. This finding indicated that masticatory force applied on teeth is not responsible for determining mineralization of the mandibular basal bone. Teeth are surrounded by periodontal ligament (PDL) that can absorb a substantial amount of the masticatory force and transmit it to the alveolar bone. Bone cells in the PDL and alveolar bone are stimulated by mastication triggered active bone remodeling.[8-11] It was observed that the active bone remodeling increases newly formed bone tissues and resorbs the pre-existing bone tissues at the alveolar bone region producing less Low_5 and $High_5$ values with increasing HSD values than the cortical basal bone.[5,12] Further, a histological study showed that this masticatory force induced active bone turnover is a local effect limited up to 51 mm from PDL.[11] These previous observations support the current finding that dentition did not have effects on the BMD parameters of the cortical basal bone.

The dental implant directly contacts on the alveolar bone without the PDL. As such, most of masticatory force on the implant is transmitted to the alveolar bone and stimulates active remodeling of bone up to 300 mm from the implant surface.[12] In addition to these local changes of alveolar bone next to the implant, the current longitudinal study showed that masticatory loading on the implants also increases the basal cortical bone mineralization by implantation for the edentulous patients. With the use of complete dentures in longitudinal studies, the loss of mandibular bone height was demonstrated and this phenomenon of residual ridge resorption was theorized as being multi-factorial.[4] With the use of fixed implant-supported prosthesis, studies have shown a significant increase in masticatory forces and efficiency for patients.[13-15] As bone responds to the change in the load placed on the mandible, it has been shown that the make-up of the Haversian system undergoes changes in the mineral composition as a response to the load.[12] The current findings indicated that direct load transmission from implant to adjacent bone increases BMD at the basal cortical bone, which could help maintain the mechanical stability of the dental implant and oral bone under daily masticatory loading.

A limitation of the current study may be that the BMD distribution of alveolar bone was not investigated. The BMD next to the metal implant could not be accurately assessed due to streak artifacts under CT scanning. As previous studies provided sufficient information for the characteristics of the alveolar bone with and without dental implantation[1,11,16] but relatively less information for the basal cortical bone, the current study refers those previous studies to compare the current results from the basal cortical bone. Another limitation might be the limited number of patients' CBCT images obtained from the database. These were unidentified CBCT scans, and therefore any pertinent medical history, systemic conditions, or medications that can potentially influence bone mineralization were not included. Because it is not routine practice to obtain CBCT after dental implant treatment, finding patients with pre- and post-operative CBCT may be difficult. Also, the powers of the significant result for the HSD and $High_5$ were acceptable with 90% and 74%, respectively. Thus, the results of current study support to develop future studies collecting more CBCT images by collaborative efforts with other institutions.

CONCLUSION

We found that receiving dental implant therapy for edentulous patients promoted remineralization in the cortical bone area of the mandible. Lack of dentition and PDL may be responsible for this phenomenon to occur as response to the change in masticatory forces through implant prostheses. CBCT for diagnoses and treatment planning for implant surgery is widely used among clinicians yet using this technology to follow up and monitor the changes of bone quantity and quality is not a common practice. The current study showed that longitudinal information on how bone changes over time can be obtained through periodic CBCT scans. This can provide valuable information on understanding the behavior of oral bone quality.

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