Original Article

# Reliability of Grayscale Value for Bone Density Determination in Oral Rehabilitation using Dental Implants


## Abstract

**Introduction:** Quality and quantity of jaw bones have been previously classified in literature using different methods. Imaging modalities such as computed tomography (CT), successfully determine bone density of jaws. This study aims to establish the role of cone-beam CT (CBCT) in determining the density of cortical and cancellous bones at different jaw sites. **Materials and Methods:** Eighty-three possible implant sites in healthy patients were evaluated using NewTomGiano CBCT machine. Cross-sections were obtained and cortical and cancellous bone densities on different aspects of the virtual implant in terms of Hounsfield unit (HU) were determined using New Net Technologies software version 6.1 and were classified according to software from D1 to D4. Data were entered into SPSS software (version 19.0) and were statistically analyzed. **Results:** The mean HU showed the highest value for cortical and cancellous in the anterior mandible (mean HU 1874.01 and 1131.73, respectively) followed by the posterior mandible (mean HU 1789.20 and 872.95, respectively) and least in posterior maxilla (mean HU 1068.26 and 830.04, respectively). Maximum D1 bone type was found in cortical bone and D2 bone type was noted in cancellous bone area. Males showed very highly significant cortical bone thickness ($P < 0.001$) whereas females showed more cancellous bone thickness but the results were nonsignificant. **Conclusion:** A high degree of concordance between different regions of jaw bones with a strong correlation between the four bone types was obtained. Bone density plays a pivotal role in determining the prognosis of the implant. CBCT has proven to be beneficial in bone density analysis.


**Keywords:** *Bone density, cone-beam computed tomography, diagnostic imaging, implant stability*

**Shalu Rai, Deepankar Misra, Akansha Misra[1], Himanshi Tomar, Ayush Dhawan, Rohit Gupta**

*Departments of Oral Medicine and Radiology and [1]Oral Pathology, Institute of Dental Studies and Technologies, Ghaziabad, Uttar Pradesh, India*

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***Address for correspondence:***
*Dr. Deepankar Misra, Department of Oral Medicine and Radiology, Institute of Dental Studies and Technologies, Kadrabad, Modinagar, Ghaziabad - 201 201, Uttar Pradesh, India.
E-mail: deepankarmisra@rediffmail.com*

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## Introduction

The quantity and quality of available bone at a future implant site play a major role in its overall success and failure.[1] Misch suggested a classification of bone density according to computed tomography (CT) numbers expressed in Hounsfield units (HU) and has been used for the objective quantification of direct bone density measurements.[2,3]

HU in CT is considered a gold standard to assess bone density. However, due to high radiation exposure, the use of CT in the maxillofacial region is limited.[4-6] The present knowledge on HU in cone-beam CT (CBCT) images provides limited information and acknowledges lacunae between HU (pixel values) and grayscale (voxel values) obtained from the present (CBCT) systems, arising due to differentials in the degree of X-ray attenuation between the two systems.[7-9]

The objective of this study was to evaluate the bone density of future dental implant sites using CBCT and New Net Technologies (NNT) Software used in the NewTom Giano machine. Bone type according to the software (i.e., D1, D2, D3, and D4) was used for the determination of HU unit for cortical and cancellous bone at the virtual implant site.

## Materials and Methods

This observational retrospective study was conducted in the department of oral medicine and radiology from August 2020 to August 2021. It consisted of CBCT scans of patients who reported to a Diagnostic Centre in Western Uttar Pradesh and Delhi (National Capital Region), India. The sample size consisted of 83 prospective implant sites of partially edentulous patients. The sample size was derived using power calculation considering the previously published studies which yielded 80.0% power ([Type II error = 0.20] and 5% Type I error probability [$\alpha = 0.05$]) in detecting the



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true statistically significant difference between cortical and cancellous bone densities across the study sites.[10-12]

Bone density in cortical and cancellous bone sites was determined. Cortical bone density was analyzed on four aspects, i.e., buccal, palatal, crestal, and apical, making altogether 332 sites; whereas cancellous bone density was evaluated at 83 sites, respectively. The obtained bone densities were classified as anterior and posterior maxilla and anterior and posterior mandible in incisors, canines, premolars, and molars regions according to the respective implant site. The ethical clearance was obtained from the institutional ethical committee and was IDST/IERC/2015–18/14.

Inclusion criteria were high-resolution scans of partially edentulous patients undergoing assessment for implant treatment, who gave consent for the use of scans for research purpose. Exclusion criteria were patients with any systemic disease, infections, or craniofacial deformities or consuming any drugs that influence the bone quality or recent history of radiotherapy and bone graft in the region of interest were excluded from the study.

CBCT scans were obtained by NewTomGiano unit (QR SRL Company, Verona, Italy) with an 8 cm × 5 cm collimated field of view (FOV) and exposure parameters of kVp of 90, mAs of 14.64, and exposure time of 3.6s. The CBCT volumes obtained were displayed with a 0.250 mm thickness. Digital Imaging and Communications in Medicine file obtained as raw data were reconstructed using CBCT software NNT viewer software version 6.1, QR Sri, Company, Verona, Italy.

Four regions of interest (ROI) were determined in each maxillary and mandibular arches, respectively, for which multiple cross-sections were created perpendicular to each ROI. Insert "Implant Tool" was used to place a virtual implant at the selected site with appropriate height and width. The "Trace Profile" tool was selected to measure the maximum and minimum cortical bone density at all four sites and the "Trace Region" tool was selected to measure the minimum, maximum, and mean cancellous bone density in terms of HU.

The obtained densities were classified from D1 to D4 as different bone qualities [Figures 1 and 2]. These values ranged from D1: 1250 to 2000 HU, D2: 850–1250 HU, D3:350–850 HU, and D4: 250–350 HU.

All measurements were observed and evaluated by an independent and experienced Maxillofacial Radiologist. Data were fed into Statistical Package for Social Sciences (SPSS) software version 19.0, SPSS Incorporation's headquarters, Chicago (Ill., USA) and were statistically analyzed by Chi-square test with 5% level of significance. Independent "*t*"-test, Mann–Whitney *U*-test, and Analysis of Variance test were utilized.

## Results

The anterior maxilla consisted of 44 sites in cortical bone (24 in incisors and 20 in canine) and 11 sites in cancellous bone (6 in incisors and 5 in canines); the posterior maxilla consisted of 84 sites in cortical bone (40 in premolars and 44 in molars) and 21 sites in cancellous bone (10 in premolar and 11 in molars); anterior mandible consisted of 68 sites in cortical bone (36 in incisors and 32 in canines) and 17 sites in cancellous bone (9 in incisors and 8 in canines); posterior mandible consisted of 136 sites in cortical bone (68 in premolars and 68 in molars) and 34 sites in cancellous bone (17 in premolars and 17 in molars) [Table 1].

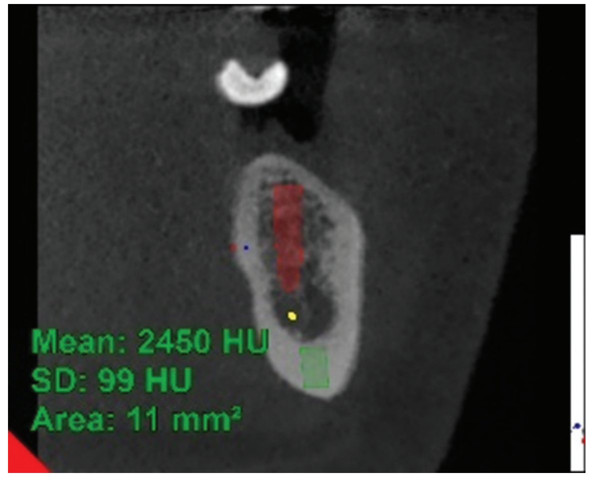


**Figure 1: Cone beam computed tomography New Tom Software image showing Cortical bone density at apical of implant**

The cortical bone density in the anterior maxilla ranged from 101 to 2424 HU with mean density of 1343.65 HU (±379.59); in posterior maxilla ranged from 132 to 2410 HU with mean density of 1068.26 HU (±396.81); in anterior mandible ranged from 372 to 2796 HU with mean density of 1874.01 HU (±416.81); in posterior mandible ranged from 144 to 2796 HU with mean density of 1789.20HU (±501.32) and the results were found to be statistically very highly significant ($P < 0.001$) [Table 1].

The cancellous bone density in anterior maxilla ranged from 194 HU to 1776 HU with mean density of 846.72HU (±224.69) HU; in posterior maxilla ranged from 32 HU to 1955 HU with mean density of 830.04HU (±347.87); in anterior mandible ranged from 189HU to 2232 HU with a mean density of 1131.73HU (±243.91); in posterior mandible ranged from 246 HU to 2295 HU with mean thickness of 872.95HU (±293.30) and the results were found to be statistically highly significant ($P < 0.001$) [Table 1].

The densities obtained were classified by the NNT software from D1 to D4 as different bone qualities. These values ranged from D1: 1250–2000 HU, D2: 850–1250 HU, D3:350–850 HU, and D4: 250–350 HU.

In this study, the range of cortical and cancellous bone densities of D1, D2, D3, and D4 bones, respectively, is shown in Tables 2 and 3. The values obtained for both cortical and cancellous bones were found to be statistically highly significant, respectively ($P < 0.001$).

**Table 1: Hounsfield unit in cortical and cancellous bone**

| Region | Number of sites | | Minimum HU | | Maximum HU | | Mean HU | | SD | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cortical | Cancellous | Cortical | Cancellous | Cortical | Cancellous | Cortical | Cancellous | Cortical | Cancellous |
| Anterior maxilla | 44 | 11 | 101 | 194 | 2424 | 1776 | 1343.6591 | 846.7273 | 379.5902 | 224.695 |
| Posterior maxilla | 84 | 21 | 132 | −32 | 2410 | 1955 | 1068.2619 | 830.0476 | 396.8133 | 347.878 |
| Anterior mandible | 68 | 17 | 372 | 189 | 2796 | 2232 | 1874.0147 | 1131.735 | 416.1873 | 243.913 |
| Posterior mandible | 136 | 34 | 144 | −246 | 2796 | 2295 | 1789.2096 | 872.955 | 501.3258 | 293.304 |
| Total | 332 | 83 | 101 | −246 | 2796 | 2295 | 1565.1220 | 911.626 | 552.42408 | 307.956 |

For cortical bone: ANOVA ($F$)=61.100, $P$<0.001 (VHS). For cancellous bone: ANOVA ($F$)=4.158, $P$<0.001 (VHS). ANOVA: Analysis of variance; HU: Hounsfield unit; VHS: Very highly significant

**Table 2: Bone type according to Hounsfield unit in cortical bone as per the software**

| Bone type | Number of sites | Minimum HU | Maximum HU | Mean±SD (HU) |
|---|---|---|---|---|
| D1 | 229 | 144 | 2796 | 1827.8952±421.82308 |
| D2 | 74 | 295 | 2033 | 1090.7365±240.71700 |
| D3 | 27 | 132 | 1933 | 736.0000±244.51121 |
| D4 | 2 | 101 | 554 | 223.0000±171.82695 |
| Total | 332 | 101 | 2796 | 1565.1220±552.42408 |

$P$<0.001 (VHS). HU: Hounsfield unit; SD: Standard deviation; VHS: Very highly significant

**Table 3: Bone type according to Hounsfield unit in cancellous bone as per the software**

| Bone type | Sites | Minimum | Maximum | Mean±SD |
|---|---|---|---|---|
| D1 | 21 | −33 | 2295 | 1109.3571±263.78164 |
| D2 | 29 | 101 | 2231 | 1020.2586±252.47283 |
| D3 | 21 | 85 | 1589 | 654.7143±225.10123 |
| D4 | 12 | −246 | 1788 | 752.6667±258.35963 |
| Total | 83 | −246 | 2295 | 911.6265±307.95622 |

$P$<0.001 (VHS). SD: Standard deviation; VHS: Very highly significant

For cortical bone, in maxilla, D1 bone type was found to be maximum (66.7%) in incisor region which was highest in buccal and palatal aspects (83.3%), respectively. In canines D1 bone type was found to be maximum (60%) which was highest on buccal and apical aspects (80%), respectively. D1 bone type was found to be maximum (47.5%) in the premolar region which was highest on the palatal aspect (60%). In molars D2 bone type was found to be maximum (63.6%) which was highest on buccal aspect (72.7%). In mandible, D1 bone type was found to be maximum (94.4%) in the incisor region which was highest on buccal and crestal aspect (100%), respectively. In Canines D1 bone type was found to be maximum (90.6%) which was highest on the buccal and apical aspects (100%), respectively. In premolars, D1 bone type was found to be maximum (76.5%) which was highest on the buccal and apical aspect (94.1%), respectively. In molars D1 bone type was found to be maximum (89.7%) which was highest on buccal and palatal aspects (94.1%), respectively [Table 4].

For cancellous bone, in maxilla, D2 bone type was found to be maximum (66.7%) in incisor region. In canines, D3 bone type was maximum (60%). D2 bone type was maximum (50%) in premolars. In molars, D3 bone type was maximum (45.5%). In mandible, D2 bone type was maximum in incisor region (55.6%). In canines, D2 bone type was maximum (75%). D3 and D4 bone types were maximum (41.2%) in premolars. In molars, D1 bone type was maximum (76.5%) [Table 5].

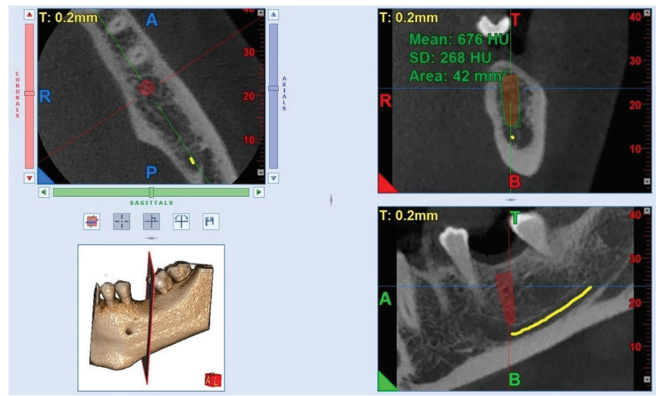


**Figure 2: Cone-beam computed tomography New Tom Software image showing cancellous bone density with mean area**

A higher cortical bone density was found in males which was statistically highly significant ($P$ < 0.001). Higher cancellous bone density was found in females which was statistically nonsignificant ($P$ = 0.719) [Table 6].

## Discussion

Quantitative and qualitative preoperative evaluation of bone density is essential for the success of implant placement.[13] It has been previously reported in numerous studies that a strong correlation exists between higher bone density and success of implants.[3,10,14-17] Therefore, a reliable, accurate, and flexible quantitative scale is required to help the clinician in categorizing bone quality.

Bone density values in terms of HU are determined by CT and have been used in the past.[7-9,13] HU is considered as relative density rather than the true density of a bone.[9,13,18,19] The reliability and accuracy of CBCT values (known as grayscale values) in determining bone densities are still not clearly understood and have been contradicted in many previous literatures.[13] Most of these studies found overestimated values of HU in CBCT systems. Dahiya

**Table 4: Teeth-wise comparison of Hounsfield unit in cortical bone**

| Region | Teeth | Aspects | D1, *n* (%) | D2, *n* (%) | D3, *n* (%) | D4, *n* (%) | Total, *n* (%) |
|---|---|---|---|---|---|---|---|
| Anterior maxilla | Incisor | Buccal | 5 (83.3) | 1 (16.7) | 0 | 0 | 6 |
| | | Palatal | 5 (83.3) | 1 (16.7) | 0 | 0 | 6 |
| | | Crestal | 2 (33.3) | 3 (50.0) | 0 | 1 (16.7) | 6 |
| | | Apical | 4 (66.7) | 1 (16.7) | 1 (16.7) | 0 | 6 |
| | | Total | 16 (66.7) | 6 (25.0) | 1 (4.2) | 1 (4.2) | 24 |
| Anterior maxilla | Canine | Buccal | 4 (80.0) | 1 (20.0) | 0 | 0 | 5 |
| | | Palatal | 3 (60.0) | 2 (40.0) | 0 | 0 | 5 |
| | | Crestal | 1 (20.0) | 4 (80.0) | 0 | 0 | 5 |
| | | Apical | 4 (80.0) | 1 (20.0) | 0 | 0 | 5 |
| | | Total | 12 (60.0) | 8 (40.0) | 0 | 0 | 20 |
| Posterior maxilla | Premolar | Buccal | 5 (50.0) | 5 (50.0) | 0 | 0 | 10 |
| | | Palatal | 6 (60.0) | 2 (20.0) | 2 (20.0) | 0 | 10 |
| | | Crestal | 3 (30.0) | 4 (40.0) | 3 (30.0) | 0 | 10 |
| | | Apical | 5 (50.0) | 4 (40.0) | 1 (10.0) | 0 | 10 |
| | | Total | 19 (47.5) | 15 (37.5) | 6 (15.0) | 0 | 40 |
| Posterior maxilla | Molar | Buccal | 3 (27.3) | 8 (72.7) | 0 | 0 | 11 |
| | | Palatal | 2 (18.2) | 6 (54.5) | 3 (27.3) | 0 | 11 |
| | | Crestal | 1 (9.1) | 3 (27.3) | 6 (54.5) | 1 (9.1) | 11 |
| | | Apical | 0 | 7 (63.6) | 4 (36.4) | 0 | 11 |
| | | Total | 6 (13.6) | 24 (54.5) | 13 (29.5) | 1 (2.3) | 44 |
| Anterior mandible | Incisor | Buccal | 9 (100) | 0 | 0 | 0 | 9 |
| | | Palatal | 8 (88.9) | 1 (11.1) | 0 | 0 | 9 |
| | | Crestal | 9 (100) | 0 | 0 | 0 | 9 |
| | | Apical | 8 (88.9) | 1 (11.1) | 0 | 0 | 9 |
| | | Total | 34 (94.4) | 2 (5.6) | 0 | 0 | 36 |
| Anterior mandible | Canine | Buccal | 8 (100) | 0 | 0 | 0 | 8 |
| | | Palatal | 6 (75) | 1 (12.5) | 1 (12.5) | 0 | 8 |
| | | Crestal | 7 (87.5) | 1 (12.5) | 0 | 0 | 8 |
| | | Apical | 8 (100) | 0 | 0 | 0 | 8 |
| | | Total | 29 (90.6) | 2 (6.3) | 1 (3.1) | 0 | 32 |
| Posterior mandible | Premolar | Buccal | 16 (94.1) | 0 | 1 (5.9) | 0 | 17 |
| | | Palatal | 16 (94.1) | 1 (5.9) | 0 | 0 | 17 |
| | | Crestal | 4 (23.5) | 9 (52.9) | 4 (23.5) | 0 | 17 |
| | | Apical | 16 (94.1) | 1 (5.9) | 0 | 0 | 17 |
| | | Total | 52 (76.5) | 11 (16.2) | 5 (7.4) | 0 | 68 |
| Posterior mandible | Molar | Buccal | 16 (94.1) | 1 (5.9) | 0 | 0 | 17 |
| | | Palatal | 16 (94.1) | 0 | 1 (5.9) | 0 | 17 |
| | | Crestal | 14 (82.4) | 3 (17.6) | 0 | 0 | 17 |
| | | Apical | 15 (88.2) | 2 (11.8) | 0 | 0 | 17 |
| | | Total | 61 (89.7) | 6 (8.8) | 1 (1.5) | 0 | 68 |

**Table 5: Teeth-wise comparison of Hounsfield unit in cancellous bone**

| Region | Teeth | D1, *n* (%) | D2, *n* (%) | D3, *n* (%) | D4, *n* (%) | Total |
|---|---|---|---|---|---|---|
| Anterior maxilla | Incisor | 0 | 4 (66.7) | 1 (16.7) | 1 (16.7) | 6 |
| | Canine | 0 | 2 (40) | 3 (60) | 0 | 5 |
| Posterior maxilla | Premolar | 0 | 5 (50) | 2 (20) | 3 (30) | 10 |
| | Molar | 1 (9.1) | 4 (36.4) | 5 (45.5) | 1 (9.1) | 11 |
| Anterior mandible | Incisor | 3 (33.3) | 5 (55.6) | 1 (11.1) | 0 | 9 |
| | Canine | 2 (25) | 6 (75) | 0 | 0 | 8 |
| Posterior mandible | Premolar | 2 (11.8) | 1 (5.9) | 7 (41.2) | 7 (41.2) | 17 |
| | Molar | 13 (76.5) | 2 (11.8) | 2 (11.8) | 0 | 17 |

*et al*., and Wang *et al*. in their studies concluded that CBCT could be considered in the determination of densities of different bones and bone values obtained from CBCT as grayscale values are comparable to CT numbers.[11,20,21]

**Table 6: Gender-wise bone density in cortical and cancellous bone**

| Type of bone | Gender | Minimum HU | Maximum HU | Mean±SD (HU) | 95% CI | *t*-test | *P* |
|---|---|---|---|---|---|---|---|
| Cortical | Male | 101 | 2796 | 1810.8026±511.98971 | 1693.81927.80 | 4.544 | <0.001 (VHS) |
| | Female | 132 | 2796 | 1492.1855±543.78093 | 1425.26–1559.12 | | |
| Cancellous | Male | 60 | 2295 | 904.9531±301.88280 | 829.55–980.36 | 0.360 | 0.719 (NS) |
| | Female | −246 | 2231 | 934.1053±335.22735 | 772.53–1095.68 | | |

NS: Nonsignificant; HU: Hounsfield unit; SD: Standard deviation; CI: Confidence interval; VHS: Very highly significant

Thus, the present study was conducted for the determination of bone quality in relation to HU by software.

The mean densities of cortical bone in the anterior maxilla, posterior maxilla, anterior mandible, and posterior mandible obtained in this study were comparable to those observed by Elkhidir *et al*. who found that there was no difference in density values obtained from CT and CBCT and anterior mandible showed the highest density values in comparison to different jaw sites.[10]

In a study conducted by Noaman and Bede, anterior mandibular mean bone density was 679.6 ± 141.67 HU, followed by anterior maxilla (460.25 ± 136.42 HU), posterior mandible (394.4 ± 128.37 HU), and posterior maxilla (229.62 ± 144.48 HU).[13] These findings were not consistence with values obtained in our study, where the mean density in terms of HU was maximum in anterior mandible followed by the posterior mandible, anterior maxilla, and posterior maxilla in cortical bone and cancellous bone which was statistically highly significant ($P$ < 0.001) [Table 1]. The findings were similar to those obtained by Ivanova *et al*., Elkhidir *et al*., Ko *et al*., Wang *et al*., and Cao *et al*.[8,10,12,19,22] Therefore, the success rate of implant placement in the posterior maxilla is lowest and the dentist must carefully place implant in this region.

The values obtained in our study are higher than those reported by Noaman and Bede which may be attributed to differences between CBCT scanners or variations in the age and the gender of the patients.[13] Ko *et al*. in their study found that CBCT density measurement can be affected by scanning parameters and the location of ROI within the scanner.[19]

Furthermore, differences in bone quality from D1 to D4 based on HU in our study were clearly reported in different regions of cortical bone of both the jaws with mean values of D1 as 1827.89 HU reported in maximum number of sites ($n$ = 229) which indicates denser bone which has a greater risk of overheating during implant installation, D2 as 1090.73 HU and D3 as 736.00 HU reported in 74 and 27 sites, respectively, which is most favorable bone for implant placement and osseointegration and D4 as 223.00 HU which was noted in only 2 sites and requires a careful surgical technique due to the risk of implant failure. The results of our study were highly significant ($P$ < 0.001) [Table 2]. Similar results have been previously reported in a study by Suttapreyasri *et al*. where a strong correlation was reported between bone, subjectively classified as D1 or D4 (based on drilling resistance), and the bone density as measured histomorphometrically.[21] However, Noaman and Bede could not distinguish the subtle differences between D2 and D3 using CBCT values of different bones and have combined them into one group, due to difficulty in differentiating between D2 and D3 based on a subjective visual evaluation or quantitative bone density measurements.[13]

Cancellous bone showed the mean values of D1 as 1109.35 HU, D2 as 1020.25 HU and D3 as 654.71 HU, and D4 as 752.66 HU, with the maximum of D2 bone type noted in 29 sites [Table 3]. Males had higher mean HU value as compared to females which was highly significant ($P$ < 0.001). Similar results were obtained by studies conducted by Ivanova *et al*. and Suttapreyasri *et al*.[8,21]

Many factors such as beam hardening effect, partial volume averaging and under-sampling in CBCT volumes, projection data discontinuity-related effect, differences between CBCT devices in terms of exposure parameters (kVp, mA, exposure time, and voxel size), changes in the volume of the FOV, and changes in the relationships of size and position between the FOV and the object result in changes in grayscale values of CBCT.[4,5,8,9,23] Therefore, these factors must be taken into consideration for the determination and validation of HU as bone density parameter. In another study, it was found that grayscale values might not represent actual density values as there is no consensus regarding the accuracy of CBCT to determine the mineral density of craniofacial bone structures.[24]

HU obtained from each of the CBCT scans is analogs to grayscale values. Since HU are calculated from CT images coinciding with the same points on CBCT scans and applying linear regression analysis the subjective grayscale values can be obtained from CBCT images. Chennoju *et al*. conducted similar studies and found no significant difference between the mean original HU units and the mean calculated HU units, thus making the equation reliable for calculating HU units from CBCT grayscale values.[3]

One limitation of the study was bone densities were classified according to Misch's Classification; however, in the recent literature, the use of Pareskevic classification of bone density is favored. This classification includes D5 and D6 bone where the posterior of the mandible is hollow and even the cortical lining is poorly mineralized.[24]

Another limitation was the variability of the gray values in CBCT due to differences in FOV (region of interest). This could be corrected by use of algorithms during or after image acquisition. However, differences in image acquisition due to different configuration of CBCT machines questions the validity of these correction methods of gray values obtained in CBCT to provide consistent values.

## Conclusion

A high degree of concordance was found between bone density of future dental implant sites using CBCT and NNT Software. A strong correlation between the four bone qualities was found between the different regions of the mouth in cortical and cancellous jaw bones and the differing HU.

However, future research with a more extensive sample size in a wider ethnic population by involving more sites and postoperative implant stability should be assessed, to achieve a greater correlation between HU and grayscale values in CBCT.

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### Conflicts of interest

There are no conflicts of interest.

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