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Original article

Evaluation of cancellous bone density in the alveolar bone by cone-beam computed tomography in Taiwanese adults

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Background: The preoperative evaluation of bone quality and stability at the site of a dental implant is important for the long-term prognosis of the implant.

Objective: We evaluated the density and its distribution of cancellous bone in the alveolar bone between a Taiwanese cohort and a U.S. cohort.

Methods: A retrospective analysis using cone-beam computed tomography (CBCT) images was conducted on 1211 Taiwanese and 154 U.S. adults who were evaluated for dental implants. Reconstructed representations of the anterior, premolar, and molar maxillary regions, and of the anterior, premolar, and molar mandibular regions were evaluated in consideration of age, gender and ethnicity.

Results: The mean cancellous bone density was significantly higher at mandibular as compared to maxillary sites (all $p \leq 0.001$). In Taiwanese more than 55 years old, men had higher cancellous bone densities than that in women at all sites (except mandible anterior site) (all $p < 0.001$). Taiwanese women more than 55 years old had significantly lower bone densities than women less than 55 years old at maxilla anterior and premolar sites and mandible premolar and molar sites (all $p < 0.05$). This did not occur in Taiwanese men or the U.S. cohort. Taiwanese had higher cancellous bone densities at mandibular sites than the U.S. cohort. Mandibular sites had significantly higher densities than maxillary sites. Taiwanese had higher cancellous bone densities at mandible sites than the U.S. cohort. Male Taiwanese had higher cancellous bone densities than females. For female, but not male, Taiwanese, the cancellous bone density decreased when the age increased.

Conclusion: CBCT can be used to evaluate alveolar cancellous bone density to predict primary stability prior to implantation.

Keywords: Alveolar, bone, CBCT, density

Initial stability upon the placement and development of osseointegration are major issues that are instrumental for the outcome of dental implants. The available bone volume, and bone quality and architecture, are all factors that determine the type of implant and influence the surgical procedure, and represent factors associated with the outcome of dental implant surgery [1-4]. Consequently, preoperative evaluation of the implant site is important for the long-term prognosis of dental implants.

Numerous radiologic techniques are available to measure bone volume [5, 6]. Historically, measuring the degree of film blackness or the panoramic mandibular index from conventional radiographic images has been a common method to determine the distribution density of bony tissue. However, such techniques are inherently limited by exposure time, projection angulation, and development conditions. Furthermore, methods that quantify bone density with rudimentary grading methods rarely are able to reflect accurately the condition of the bone at the implantation site.

Determining the local bone architecture and the bone mineral density (BMD) may offer a more comprehensive characterization of the bone at the implantation site. Quantitative computed tomography (QCT) (i.e., the quantitative interpretation of values derived from Hounsfield units [HU] with a suitable

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calibration procedure) is a useful preoperative tool to determine BMD at recipient implantation sites [7-9]. QCT can provide diagnostic and prognostic information. However, while QCT can be used to evaluate and quantify alveolar bone density, published alveolar bone density values derived from QCT represent the average density of cancellous (spongy) bone and much higher density cortical bone [10]. Measurements of average BMD values for both segments do not provide the necessary information for assessing implant positions, since BMD values vary locally [9-12]. In addition, different bone densities may be found at various anatomical regions (e.g., the anterior and posterior sites of the maxilla and the mandible) [10]. Variations in adult bone density can also reflect age, sex, and ethnic group differences, yet most studies have been conducted on non-Asian populations [6]. These intrapatient, interethnic, and sex-based variations underscore the importance of a site-specific bone tissue evaluation in each patient prior to implant installation [10].

Evaluating the BMD locally or by averaging values obtained over small regions of interest, comparable in size to the implant, more accurately reflects local bone properties. Cone-beam computed tomography (CBCT), which is appropriate for use in the dental setting, offers the possibility to measure separately the BMD of cortical and cancellous bone over small regions [12]. This modality is able to provide sub-millimeter resolution, with short scanning times and much lower radiation dosages than conventional CT scans. In addition, CBCT can provide highly detailed 3-dimensional (3D) images of dentomaxillofacial structures [13-15], which is an important complement to examine BMD, as the combination of both measurements can explain 94% of the strength of trabecular bone.

Given the relative scarcity of Asian BMD data for potential implant sites, and the need to differentiate between cortical and cancellous bone densities, this retrospective study was conducted to measure the cancellous bone density distribution in a Taiwanese adult cohort and a smaller US adult cohort, to provide practical information for the selection and placement of the sites for dental implants.

Material and methods

Subjects

This was a retrospective analysis conducted on CBCT images acquired from 1211 Taiwanese and 154 U.S. adults (≥20 years) evaluated for dental implants at the Oral Pathology Department of the School of Dentistry of Kaohsiung Medical University in southern Taiwan (Republic of China). The study was reviewed and approved by the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital (KMUH). Informed consent was waived by the ethical committee because this was a retrospective analysis. The study did not use specific inclusion and exclusion criteria based on medical conditions; all subjects who were eligible to undergo dental implantation were included in the analysis. Both the Taiwanese and U.S. subjects who were consecutively scheduled to undergo the procedure were included in the analysis.

Cone-beam computed tomography system

CBCT scans were acquired with an I-CAT Cone Beam 3-D Dental Imaging System (Imaging Sciences International, Hatfield, PA, USA) using default parameters (120 kVp, 90 mAs, 6 cm field of view, 0.4 mm voxel size, medium sharpness filter). The acquired images were reconstructed into multiple-plane views (axial, sagittal, coronal, and panoramic) and three-dimensional representations (**Figure 1**). The cross-sectional views perpendicular to the axial plane were chosen to calculate the bone density after selecting the regions of interest (ROI) in the dental arch (**Figure 2**). The CBCT unit was calibrated daily.

Cone-beam computed tomography image analysis

Image reconstruction from CBCT scans yielded 0.4-mm thick cross-sectional images. Maxillary and mandibular sites were selected from the reconstructed cross-sectional images for measuring the bone density. The following sites were evaluated: maxillary anterior (Site 1), premolar (Site 2), and molar (Site 3) regions; mandibular anterior (Site 4), premolar (Site 5), and molar (Site 6) regions. Sites were classified as nest-design: sites 1–3 were within the maxillary and sites 4–6 nested within the mandible. Only the dentate right side image of the maxilla or mandible was analyzed. If the right side was edentulous, the left side image of the maxilla or mandible could be substituted.

To ensure homogeneity, an approximately 1-mm square ROI at each site was selected for evaluation. The ROI used mostly trabecular bone, and by software measurement, it was possible to ensure that the ROI was the same for all participants. The ROI did not include cortical bone or teeth and was chosen to avoid

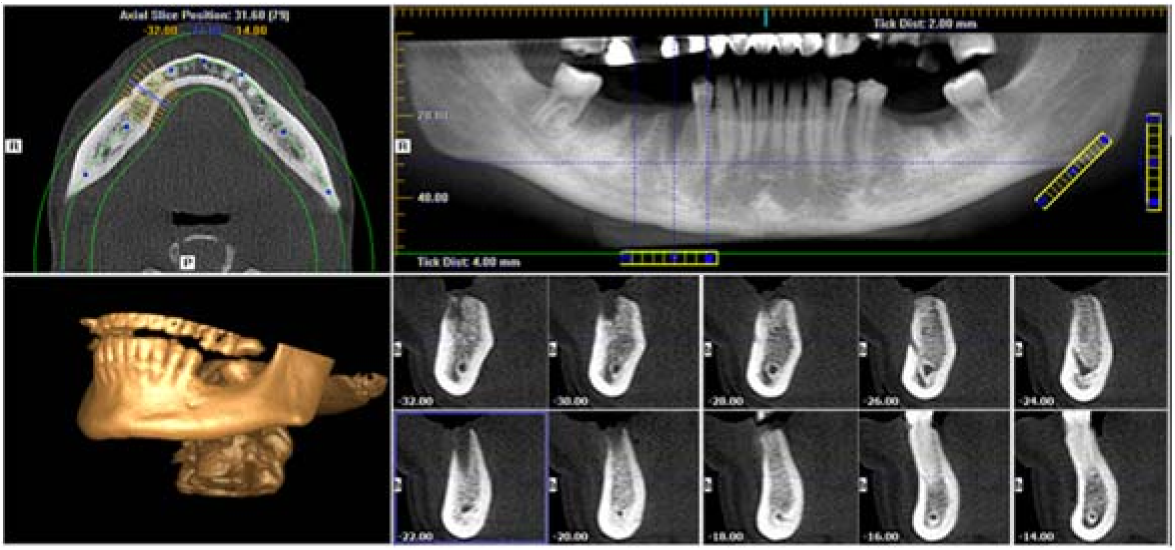

Figure 1. CBCT images reconstructed into multiple-plane views (axial, sagittal, coronal, and panoramic) and three-dimensional representations

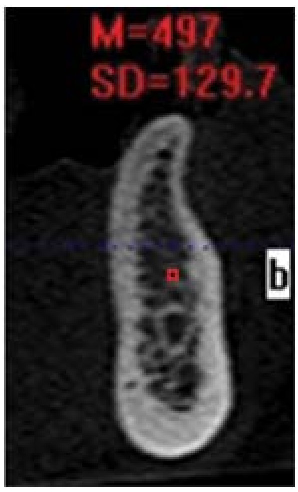

Figure 2. CBCT cross-sectional views perpendicular to the axial plane

nerves and blood vessels. The ROI was selected from alveolar bone below the teeth sockets, and as much as possible, we attempted to use the same locations in each statistical group. Trabecular bone was measured at a depth of 7 to 10 mm from the center of the ridge, bucco-lingually, using the "HU Statistics" tool in the proprietary software, and we did our best to use the same depth for each participating subject. This range was chosen because it represents the depth of a common tooth implant. Bone density at each site was measured blindly by two dental X-ray technicians who each had at least 5 years of experience with CT imaging measurements, and the mean density, expressed in HU, was calculated by cohort, site, gender, and dental status (dentate vs. edentate). To test for interobserver consistency, 10 randomly selected subjects were remeasured by each technician after a period of 1 week and measurements were compared in the same patient.

Statistical analysis

Comparison of baseline characteristics between the Taiwanese and the US cohorts was performed using the independent two-sample *t* test for age, and the Chi-square test for gender and jaw distributions. Age was represented as mean ± standard deviation (SD) and gender and jaw distributions were described by number (n) and percentage (%). A linear mixed model with adjusted Bonferroni multiple comparison was performed to evaluate the difference in cancellous bone density between the Taiwanese and US cohorts or between men and women. The dental bone density was represented as estimated marginal means ± standard errors.

Intraclass coefficient of correlation (ICC) values > 0.8 were considered to be in excellent agreement in interobserver bone density measurements performed by independent technicians. All statistical assessments were two-sided and considered significant if $p < 0.05$. Statistical analyses were performed using SPSS 15.0 statistical software (SPSS, Chicago, IL).

Results

Of the 1211 patients from Taiwan, 543 were male (44.8%) and 668 were female (55.2%) with a mean age of 51.49 (range 20–84 years) (**Table 1**). Of the 154 US patients, 74 were male (48.1%) and 80 were female (51.9%), with a mean age of 49.83 years (range 20–85 years). There was a significant difference between the Taiwanese and the US groups in the percentage of mandibular versus maxillary jaw setting (p <0.001). Intraobserver reliability of CBCT measurements of sites in the maxilla and mandible in the Taiwanese cohort was excellent (all ICC >0.8) (**Table 2**).

In either the Taiwanese or the U.S. cohorts, mean cancellous bone density in the mandibular sites (anterior, premolar and molar) was significantly higher than at the corresponding maxillary sites except mandible anterior site in subjects less than 55 years old in the U.S. cohort (**Table 3**). For subjects less than 55 years old, cancellous bone density at all the mandibular sites in the Taiwanese cohort was significantly higher than that in the U.S. cohort (p <0.05). Furthermore, Taiwanese subjects more than 55 years old had significantly lower cancellous bone density at maxilla anterior and premolar sites than those less than 55 years old while the U.S. subjects more than 55 years old had significantly higher cancellous bone density at mandible anterior and premolar sites ($p < 0.05$).

Table 1. Baseline characteristics of the Taiwanese and U.S. cohorts

	Taiwan (n = 1211)	**U.S. (n = 154)**	***p***
Age, y (mean ± SD)	51.49 ± 11.78	49.83 ± 15.92	0.121
Sex, n (%)			0.450
Male, n (%)	543 (44.8)	74 (48.1)	
Female, n (%)	668 (55.2)	80 (51.9)	
Jaw, n (%)			<0.001*
Maxillary	496 (41.0)	49 (31.8)	
Mandible	492 (40.6)	49 (31.8)	
Full	223 (18.4)	56 (36.4)	

* Significant difference between Taiwan and U.S., p <0.05

Table 2. Intraclass correlation coefficients of CBCT measurements in the Taiwanese cohort

	Maxilla	**Mandible**
Anterior	0.997	0.993
Premolar	0.995	0.999
Molar	0.999	0.998

Table 3. Mean cancellous bone density, by site, in the Taiwanese and U.S. cohorts

	Taiwan (n = 1,211)	**U.S. (n = 154)**	***p***
Maxilla			
Anterior (site 1)			
Age <55 years	302.74±12.07	365.65±31.18	0.061
Age >55 years	256.39±11.91†	317.13±31.72	0.074
Premolar (site 2)			
Age <55 years	236.48±11.84	259.00±30.56	0.492
Age >55 years	200.41±12.29 □	244.56±32.71	0.207
Molar (site 3)			
Age <55 years	206.51±12.33	215.18±31.84	0.800
Age >55 years	188.88±13.75	214.40±13.75	0.514
Mandible			
Anterior (site 4)			
Age <55 years	417.36±12.34	320.80±33.62	0.007*
Age >55 years	422.24±12.88	393.06±31.97 †	0.398
Premolar (site 5)			
Age <55 years	434.00±12.38	300.33±33.74	<0.001*
Age >55 years	441.13±13.85	388.88±34.35 †	0.159
Molar (site 6)			
Age <55 years	420.88±13.15	260.85±35.84	<0.001*
Age >55 years	428.70±16.09	324.28±39.91	0.016*

* Significant difference between Taiwan and U.S. using linear mixed model, $p < 0.05$
† Significant difference between age <55 years old and age >55 years old, $p < 0.05$

Next, the subjects were further stratified by sex. In the Taiwanese more than 55 years old, men had higher cancellous bone densities than that in women at all sites (except mandible anterior site) (all $p < 0.001$l, **Table 4**). In the Taiwanese less than 55 years old, men had higher cancellous bone densities than women only at maxillary molar site (240.98±19.48 vs. 180.50±16.92, $p = 0.020$). Taiwanese women more than 55 years old had significantly lower bone densities than women less than 55 years old at the maxilla anterior and premolar sites and mandible premolar and molar sites (all $p < 0.05$). However, Taiwanese men more than 55 years old had significantly higher bone densities than men less than 55 years old at mandible premolar and molar sites (all $p < 0.05$). However, for the U.S. cohort, there were no significant differences between men and women in either the less than 55 years old group or the more than 55 years old group. Only U.S men more than 55 years old had significantly higher cancellous bone density at mandible premolar site than subjects with less 55 years old ($p < 0.05$). Taiwanese men and women less than 55 years old had higher cancellous bone densities at mandible premolar and molar sites than the U.S. subjects (all $p < 0.05$) while only Taiwanese men less than 55 years old had higher cancellous bone density than U.S. men at mandible anterior sites ($p < 0.05$). At the mandible molar site, Taiwanese men more than 55 years old also had significantly higher bone density than the U.S. ($p < 0.05$).

Discussion

In this retrospective study, we analyzed the alveolar cancellous bone density at selected mandibular and maxillary sites by CBCT in the Taiwanese and U.S. cohorts with the consideration of sex and age. Generally, mandibular sites had significantly higher densities than maxillary sites. Taiwanese had higher cancellous bone densities at mandibular sites than the US cohort. Taiwanese men had higher cancellous bone densities than women. For Taiwanese women, but not Taiwanese men, the cancellous bone density decreased when the age increased. However, this did not occur in the U.S. cohort. In recruiting this specific population of patients who were planned to undergo dental implantation,

Table 4. Mean cancellous bone density, by site, in males and females

	Taiwan (n=1211)			U.S. (n=154)		
	Male (n = 543)	**Female (n = 668)**	***p***	**Male (n = 74)**	**Female (n = 80)**	***p***
Maxilla						
Anterior (site 1)						
Age <55 years	291.45±19.19	311.26±16.67	0.436	351.24±31.76	375.94±26.85	0.555
Age >55 years	312.10±17.19	206.94±16.19†	<0.001*	333.93±35.26	294.94±43.19	0.456
Premolar (site 2)						
Age <55 years	255.53±18.95	222.10±16.46	0.184	267.04±25.87	253.26±21.87	0.686
Age >55 years	246.73±18.05	159.29±17.01†	<0.001*	266.00±33.36	212.39±40.85	0.315
Molar (site 3)						
Age <55 years	240.98±19.48	180.50±16.92	0.020*	167.12±31.35	249.51±26.49	0.049*
Age >55 years	242.75±20.24	141.06±19.07	<0.001*	224.26±36.14	199.61±44.26	0.668
Mandible						
Anterior (site 4)						
Age <55 years	418.97±19.80	416.50±16.81	0.915	297.12±32.18‡	341.21±29.87	0.320
Age >55 years	442.21±18.67	400.95±19.27	0.125	369.63±31.15	413.89±29.37	0.306
Premolar (site 5)						
Age <55 years	419.85±19.90	444.20±16.90	0.351	263.00±30.13 ‡	332.52±27.98‡	0.097
Age >55 years	491.04±19.65†	387.93±20.28 †	<0.001*	374.38±35.69†‡	401.78±33.65	0.579
Molar (site 6)						
Age <55 years	434.89±21.09	410.78±17.91	0.384	243.24±34.41 ‡	276.03±31.95 ‡	0.488
Age >55 years	506.48±22.40 †	345.79±23.13 †	<0.001*	340.29±42.17 ‡	310.04±39.71	0.604

*Significant difference between males and females using linear mixed model, $p < 0.05$

† Significant difference between age <55 years old and age >55 years old, $p < 0.05$

‡ Significant difference between Taiwan and U.S., $p < 0.05$

findings from this study that utilized CBCT as the 3D diagnostic tool would provide a more accurate evaluation of the alveolar bone status prior to the procedure. This would subsequently reduce the procedural risk and increase the successful implantation rate in this particular patient population in general.

Previous studies have demonstrated a positive association between the primary stability of an implant and bone mineral density at the recipient site [4], and there is evidence that bone quality evaluated by specific CBCT is highly correlated with the primary stability of implants [15]. Hence, preoperative density value estimations by CBCT may allow clinicians to predict implant stability. Knowledge of the Hounsfield value as a quantitative measurement of bone density can be helpful as a diagnostic tool [8]. In addition, Hounsfield density measurements can help estimate bone quality and the prognosis of implants [9]. However, differences in bone densities according to depth should be considered when selecting and placing miniscrew implants [16]. Some studies have reported a higher failure rate for shorter implants [17, 18]; whereas overall survival rates exceeding 78% have been documented with 7-mm-long implants [19]. The current study measured cancellous bone density at a depth of 7 to 10 mm representing the simulated placement of an implant to a depth suitable for a better outcome. Moreover, our study was especially designed to measure separately the density of cancellous alveolar bone, because combining cortical bone density, which is over 1000 HU, with cancellous bone density, which is much lower, is inherently limiting.

Naitoh et al. [20] noted that, while the voxel values of CBCT are not absolute values to reflect the bone density, there is a high-level correlation (r = 0.965) between voxels of CBCT and bone mineral density of multislice CT that was reported in the literature [21]. The authors concluded that voxel values of the mandibular cancellous bone on cone-beam CT could be used to estimate bone density. Similar conclusions were reported by other authors [22].

Our data indicate that 150–350 HU is the most common range of densities observed in the maxillary alveolar bone and 350–850 HU is the most common range found in the mandible. These data are somewhat discrepant with HU values previously reported by Misch [23]. Although speculative, such discrepancies may, in part, reflect ethnic and racial differences in alveolar bone densities. While alveolar bone density data from Asian populations have been reported [24], our analysis is exceptional in that it retrospectively compares HU values between an Asian and predominately non-Asian populations.

There is lack of report about alveolar bone densities for Taiwanese. It is noteworthy that our data showed Taiwanese had highly significant higher mean cancellous bone density in the mandible sites than the U.S. Because of the difference of life style or genetic variation, bone mineral density can be different among different races or ethnicities [25]. In our study, we also found that Taiwanese men had higher alveolar cancellous bone density than Taiwanese women only when they became older than 55 years. This might be the result of increasing loss of bone mineral density in Taiwanese women, since Taiwanese women more than 55 years old had less cancellous bone density than Taiwan women less than 55 years old. This did not occur in Taiwan men or in the US cohort. This suggests Taiwan women or Asian women might be inclined to loss alveolar cancellous bone mineral density. For Asians, the alveolar cancellous bone density would be more inclined to show gender or age specificity. We did not observe this kind of specificity in the U.S. cohort. However, the size of the U.S. cohort was relatively smaller. We also do not know whether this phenomena occurs in alveolar cortical bone density. However, our findings indicated that the alveolar cancellous bone density had unique character compared with alveolar cortical bone. To evaluate bone quality for dental implantation, alveolar cancellous bone density should be specifically investigated with a consideration of sex and age.

These finding have clinical implications, given the association between bone quality evaluated by CBCT and the stability of the implants. In particular, clinicians treating Asian patients should be alert to these differences and the implications, particularly for maxillary implants. Our findings may lead to an increase in the utilization of 3D diagnostic tools to provide improved accuracy for evaluating alveolar bone densities before dental implantation. Therefore, clinical policy and practices may experience a gradual shift towards acquiring cancellous bone density using such tools as part of the preimplantation assessment in future. More specifically, dentists should assess the bone type and cancellous bone densities before performing dental implantation. This will allow the dentists to adjust the dental implantation plan and the selection of implant body accordingly, all towards the goal of ensuring the postprocedure stability of the implant body and degree of bony integration. Past diagnostic instruments have typically averaged the densities of cortical bone and cancellous bone, resulting in misinterpretation of higher bone density that has led to overly optimistic treatment plans. Therefore, both providers and patients can receive a more realistic evaluation of the bone densities and improved treatment outcomes using our approach.

One of the limitations of the current study is the small sample size of the participating U.S. group, which is because we did not find more participants that could be included in the study. A more definitive conclusion should be obtained from future study with a larger sample. An additional aspect that was reported by Mah et al. [26] is the variability in the HU values that are obtained by CBCT, as compared with values obtained by medical CT (MDCT) scanners. Nevertheless, despite this limitation, HU is routinely being used by dentists to evaluate bone density and, therefore, we believe that our findings have practical values.

In summary, the present study shows that CBCT unveils a distinct pattern of the cancellous alveolar bone density in younger and older male and female Taiwanese and U.S. patients. The use of CBCT can help predict the primary stability of an implant, before its insertion, and the information it provides may also have additional prognostic value.

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