Original Article

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Accuracy of bone height and thickness measurements in cone beam computed tomography using different voxel sizes in maxilla and mandible

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Abstract

Background: Cone Beam Computed Tomography (CBCT) is used to evaluate the hard tissue of the maxillofacial area, and the dose received by the patient depends on the resolution of the images. This study investigated the effect of CBCT resolution (voxel size) on its linear measurement accuracy.

Methods: This in vitro study was conducted on 19 human mandibles and 11 dry maxillae. On each jaw, four anterior and four posterior regions were examined. Markers were placed in the designated areas using gutta-percha. The jaws were scanned at three voxel sizes (100, 150, 200 µm). The bone height and thickness were measured in the prepared images and compared with the sizes obtained. Paired t-test, t-test, one-way ANOVA, and Tukey's post-hoc tests were used for statistical analysis.

Results: Buccal and lingual bone height measurements showed significant differences across voxel sizes ($p < 0.05$), with higher resolution (100 µm) yielding greater accuracy. No significant difference was found in bone thickness measurements between resolutions ($p = 0.20$). Height measurements were significantly less accurate in anterior than posterior regions ($p < 0.05$). No significant difference was observed between maxilla and mandible except for buccal height at medium and standard resolutions. All CBCT measurements underestimated actual dimensions. Thickness measurements were more accurate than height measurements.

Conclusion: Using high resolution in CBCT machines is recommended to reduce linear measurement error when there is a short distance to the critical anatomical structures.

Keywords: Cone beam computed tomography, Mandible, Maxilla.

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Dental radiography has been an important part of diagnosis in the oral and maxillofacial region. Two-dimensional imaging techniques have drawbacks in demonstrating the complexity of anatomical structures and related pathologies (1, 2). These shortcomings include magnification, distortion, and superimposition (3, 4) Cone-Beam Computed Tomography (CBCT) has become popular owing to its higher resolution, faster scan, lower cost, and lower radiation dose compared to traditional Computed Tomography (CT) (5, 6). CBCT machines differ in exposure parameters, such as voltage, tube current, exposure, and field of view (FOV), resulting in a difference in the quality of images (7). The accuracy of CBCT images is influenced by many factors, including device properties (e.g., nominal resolution), exposure (mA, kV, and the number of base images), image reconstruction software, motion artifact, and limitations of technicians in image interpretation (8). A study by Ibrahim et al. suggested that a smaller voxel size can lead to more detailed visualization of anatomical structures in CBCT (9). However, another study reported that morphological alterations in CBCT analysis are not associated with voxel sizes (10).

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These controversies require further investigations in this field. Since alveolar bone measurements are used for bone grafts, sinus lift, implant placement, examining periodontal health, and orthodontic treatment, the accuracy of these measurements is important, and the underestimation or overestimation of alveolar bone height may lead to diagnostic errors resulting in incorrect treatment (11). Therefore, this study aimed to examine the accuracy of CBCT images in measuring bone height and thickness in different jaw regions at different resolutions in comparison with direct measurements.

Methods

This study examined dry intact human jaws (19 mandibles and 11 maxilla). The jaws had unknown identities and no pathologic lesions or mechanical damage. The sample size was calculated considering Pauwels et al.'s study (12) as well as a significance level of 5%, a measurement error (d) of 8%, and using the following formula:

$$n = \frac{{z_{1-\alpha/2}}^2 * p * q}{d^2}$$

Eight regions of each jaw were marked: Four anterior regions (right and left lateral and canine) and four posterior regions (right and left first molar and second premolar). The anterior and posterior regions on the maxilla and mandible were marked using gutta-percha points. To this end, 0.5 mm pieces of Gutta-Percha points No. 40 were placed on the alveolar ridge in parallel at the buccal and lingual sides and a distance from the dental crest or teeth sockets, then fixed with glue. In this process, the upper part of the gutta-percha was placed in the coronal of the undercut, so that it could be measured with a caliper. The bone height and thickness were measured using a digital caliper (Guanglu/ Taizhou/ China) with 0.01 mm accuracy. The bone height was obtained by measuring the distance between the crest edge and gutta-percha points at the buccal and lingual sides. The bone thickness was obtained by measuring the distance between the buccal and lingual gutta-percha points. In total, 720 direct measurements were done. Then, the maxilla and mandible were scanned using ACTEON (Xmind trium Italy) at standard (8mA, 90kVp, 200µ, 11×8cm, 6S), medium (8mA, 90kVp, 150µ, 11×8cm, 7.2S), and high resolutions (8mA, 90kVp, 100µ, 11×8cm, 9S). All examinations were done by an observer in a semi-dark room using an LCD monitor 23.8-inch a color bit Depth of 24 (Dell, China) and OnDemand 3D Dental TM software. Reconstructed images were first reoriented for each scan to obtain a horizontal occlusal plane. In the cross-sectional view, bone height was obtained by measuring the distance between the buccal alveolar crest and gutta-percha at the buccal side and the distance between the lingual alveolar crest and gutta-percha at the lingual side (figure 1).

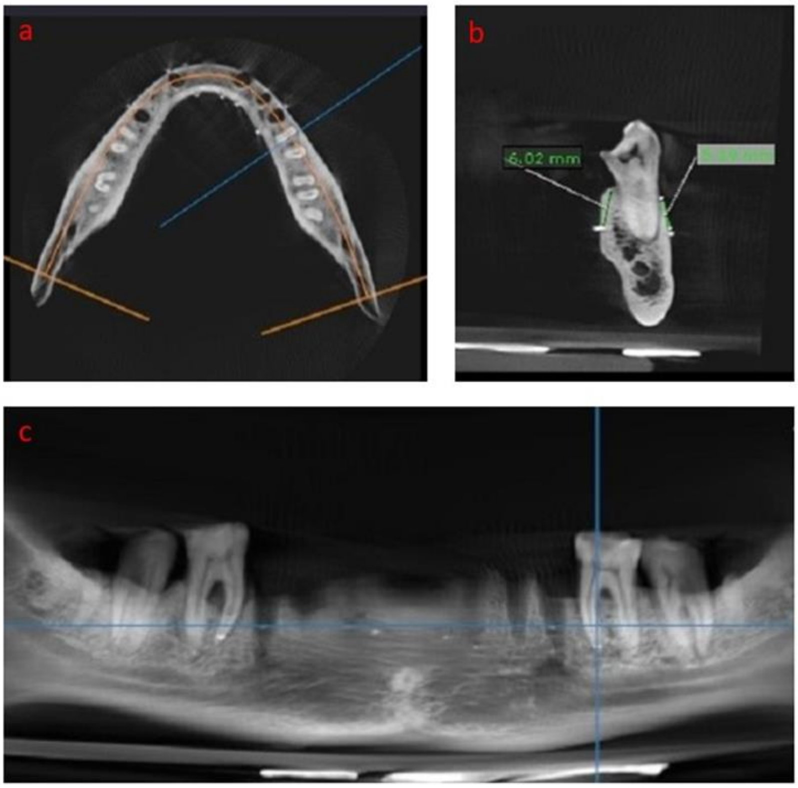

Figure 1. Measurement of bone height in CBCT image in (a) axial, (b) cross-sectional, and (c) panoramic views

To calculate the bone thickness, the distance between the buccal and lingual gutta-percha was measured (figure 2). The measurements were done on 44 anterior and 44 posterior regions of the maxilla and 76 anterior and 76 posterior regions of the mandible. In total, 2160 radiographic measurements were obtained. To examine intra-observer reproducibility, 400 radiographic measurements were randomly remeasured in a three-week interval. In addition, the interrater correlation coefficient was calculated.

In this study, one-way ANOVA, t-test, paired t-test, and Tukey's post-hoc test were used in SPSS 17 (SPSS Inc., Chicago, IL, USA) to compare the difference between the mean radiographic measurements and actual measurements. Moreover, a p-value < 0.05 was considered statistically significant.

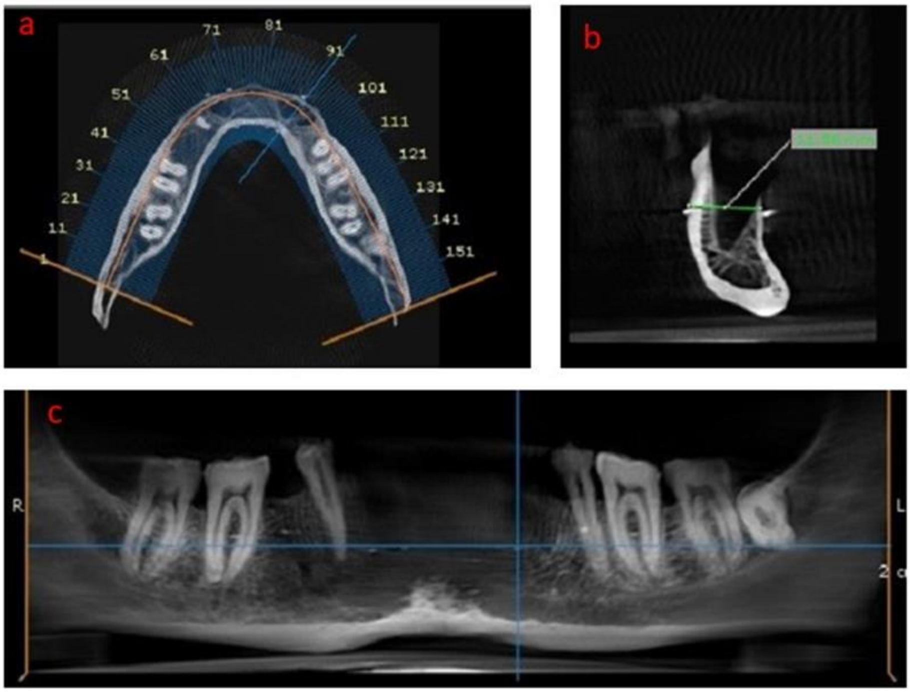

Figure 2. Measurement of bone thickness in CBCT image (a) axial, (b) cross-sectional, and (c) panoramic views

Results

In height measurements, the difference between various resolutions was significant ($p < 0.05$) while measuring the buccal and lingual heights; However, there was no significant difference in thickness measurements ($P= 0.2$). All height and thickness measurements in the CBCT images were less than the actual sizes (table 1). The thickness difference was not significant between the anterior and posterior regions with direct. However, the height difference (buccal and lingual) measured was significant in the anterior and posterior regions ($P < 0.05$). The difference was more in anterior regions compared with posterior ones (table 2). There was no significant difference between maxilla and mandible, except in buccal height measurement, at medium and standard resolutions (table 2). In these two resolutions, the difference in actual value was lower in the maxilla. The accuracy of the thickness measurement was greater than that of the height measurement (buccal and lingual). Since some samples had a very thin cortical wall, the use of radiographic measurement was impossible, which is presented as missing in the table. Missing was only observed in buccal height measurements. The amount of missing was higher at standard resolution (table 3). A difference of more than 1 mm between direct and radiographic measurements was considered as the clinical significance level. The intra-observer correlation based on ICC was 0.998 (CI 95% = 0/996-0/999, p < 0/001).

Table 1. Mean and standard deviation of direct measurement and various resolutions of CBCT

Variables	Direct	High Resolution	Medium Resolution	Standard Resolution	P-value
Buccal Height	5.54±2.18	5.38±2.24	5.19±2.11	5.05±2.15	0.001
Lingual Height	6.05±2.65	5.92±2.67	5.82±2.68	5.70±2.74	0.002
Thickness	9.73±2.26	9.72±2.3	9.71±0.14	9.71±2.29	0.2

Table 2. Mean absolute value of the difference (standard deviation) between direct and radiographic measurements by location, jaw, and resolution in millimeters

Variables		High Resolution	Medium Resolution	Standard Resolution
Buccal Height	Anterior	0.44 (0.33)	0.64 (0.58)	0.87 (0.68)
	Posterior	0.32 (0.23)	0.40 (0.28)	0.44 (0.34)
	P-value	0.003	0.001	0.001
	Maxilla	0.40 (0.29)	0.43 (0.37)	0.57 (0.39)
	Mandible	0.36 (0.29)	0.56 (0.50)	0.68 (0.64)
	P-value	0.23	0.008	0.002
Lingual Height	Anterior	0.38 (0.25)	0.44 (0.35)	0.60 (0.49)
	Posterior	0.33 (0.22)	0.40 (0.24)	0.45 (0.35)
	P-value	0.018	0.04	0.005
	Maxilla	0.35 (0.22)	0.36 (0.23)	0.51 (0.38)
	Mandible	0.34 (0.24)	0.46 (0.33)	0.59 (0.45)
	P-value	0.12	0.15	0.39
Thickness	Anterior	0.22 (0.19)	0.21 (0.17)	0.23 (0.18)
	Posterior	0.19 (0.14)	0.22 (0.18)	0.21 (0.15)
	P-value	0.6	0.7	0.7
	Maxilla	0.23 (0.15)	0.25 (0.17)	0.24 (0.18)
	Mandible	0.17 (19.0)	0.15 (0.2)	0.23 (0.21)
	P-value	0.89	0.5	0.94

Table 3. Difference between direct and radiographic measurements by lower and more than 1 mm difference

Variables		Lower than 1 mm difference	More than 1 mm difference	Missing
Buccal Height	High Resolution	94.6	3.3	2.1
	Medium Resolution	85.4	10	4.6
	Standard Resolution	76.3	17.9	5.8
Lingual Height	High Resolution	97.9	2.1	0
	Medium Resolution	95.8	4.2	0
	Standard Resolution	87.1	12.9	0
Thickness	High Resolution	100	0	0
	Medium Resolution	99.6	0.4	0
	Standard Resolution	99.2	0.8	0

Discussion

In measuring bone thickness and height (buccal and lingual), the results of this study indicated that lower voxel size (higher resolution) was more important for height measurement. The current findings also showed a higher accuracy of bone height measurement at 100 μ voxel size compared with 150 μ and 200 μ. On the other hand, Mukhia et al. examined the CBCT resolution accuracy at two resolutions (voxel sizes of 0.2 mm and 0.4 mm). The results of their study showed that the mean measurement error with a voxel size of 0.2 mm or 0.4 mm did not have any significant difference and having a larger voxel size can reduce radiation exposure (13). This finding contrasts with our study, where a significant improvement in measurement accuracy was observed with a decrease in voxel size to 0.1 mm. The discrepancy may be from differences in their methodology, which included fewer imaging parameters and did not account for variations in the density of the bone structures measured. Their focus on radiation dose reduction may have overshadowed the importance of achieving optimal measurement precision, especially in clinical scenarios requiring high accuracy, such as implant placement.

Furthermore, in line with the current findings, Van et al. reported that the accuracy of CBCT improved with smaller voxel size (14). Ding et al. also reported that device voxel size affected the accuracy of measurements (15). These findings were consistent with the findings of this study. On the other hand, Sang et al. suggested that changing the voxel size does not necessarily affect the accuracy of the CBCT technique (16). This controversy might have been due to the difference in the size of the voxel sizes as well as the methodologies of different studies.

In a study, Ganguly et al. used the voxel sizes of 0.16, 0.2, and 0.3 mm and observed that using smaller voxel sizes did not improve linear measurement accuracy. They also found that using a voxel size of 0.3 mm was sufficient for dental implant procedures. Their study was conducted on four intact embalmed cadaver heads (17). Differences in the results can be attributed to study conditions and different exposure parameters of the CBCT machine. FOV, mA, kVp, scanning duration, the distance between the source and receptor of the CBCT machine, and the used software were different in the two studies. Some properties of CBCT machines, including operator-independent variables (e.g. filtration, source-to-object distance, object-to-sensor distance, employed reconstruction algorithms, or different restrictive instruments) can affect the accuracy of measurements (18). The difference in exposure parameters, such as FOV and voxel size, can affect the quality of images and lead to measurement error. Voxel size has a great impact on the quality of CBCT images. For example, a small voxel size can improve CBCT's ability to differentiate between delicate structures, but it increases exposure time and radiation dose. A voxel size of 0.4 mm can accurately measure many structures in the maxillofacial area, except for the alveolar bone (19). The controversy surrounding the impact of voxel size on the accuracy of CBCT measurements stems from methodological differences, varying clinical contexts, and sample selection. It is crucial for future studies to adopt standardized imaging protocols, consider the biological variability of tissues, and examine the implications of both accuracy and radiation exposure to provide clearer guidance for clinical practice.

In this study, no significant difference was observed between measurement accuracy in the maxilla and mandible, except for the measurement of the buccal height at the medium and standard resolutions. The accuracy was higher in the maxilla at these resolutions. In a study by Luangchana et al., linear measurements in the maxilla were less accurate than those in the mandible. They attributed this to the lower density of the maxilla compared with the mandible because of a thin layer of cortical bone and a higher volume of spongy bone (20). Such disparities may arise from differences in the clinical scenarios each study addresses or the anatomical variations in the sample populations. In their study, they used partial or complete edentulous jaws, whereas the present study used edentulous jaws or jaws with teeth sockets. Moreover, in this study, there were more dentulous areas in the maxilla and a higher number of teeth sockets in the mandible, which could affect the results.

Many studies have reported that bone measurement is considered accurate if the error is less than 1 mm, which has been considered the clinical error threshold (18, 21). In this study, the clinical error was higher at standard resolution. In this study, the accuracy of bone height measurement (buccal and lingual) was lower in the anterior region compared with the posterior region. Moreover, the accuracy of lingual height measurement was higher than that of buccal height measurement in the anterior region. In a study, the measurement of labial bone showed that the thickness of the majority of labial bones in the anterior region (74.2%) was < 1 mm (22). The low thickness of cortical bone leads to partial volume averaging and blurring of a thin bony layer. Thin bones (near the voxel size) in CBCT images are not differentiable from their adjacent cement and thus, it is less visible for measurement (14, 23).

Since the buccal cortical plate was so thin in some cases in this study, the measurement of its height was not possible, even at the voxel size of 0.1 mm. et al. observed that a larger voxel size causes the risk of overestimation in detecting dehiscence (24). Furthermore, Behnia et al. observed that CBCT had good accuracy and reliability for bones with a thickness of more than 1 mm (25). This study showed that CBCT generated underestimated results, which is consistent with the findings of previous studies (19, 26). In general, underestimated results are clinically better than overestimated ones because they protect vital structures during implant procedures (20). The findings of this study suggested that in cases where the distance to nearby vital structures is small in 2D images, it is suggested to use higher resolutions of the CBCT for more accurate evaluation as well as to increase the accuracy of linear measurements.

The generalization of findings from *ex vivo* CBCT to *in vivo* conditions is difficult. The maxillofacial region has both soft and hard tissues. In the majority of experimental conditions, a dry skull or fixed cadaver in formalin is used, which does not represent clinical conditions. The accuracy of the linear measurement in *ex vivo* conditions may not be directly comparable to *in vivo* conditions. The soft tissue attenuates x-rays and reduces tissue contrast through increasing scattered beams and noise, possibly affecting the measurement accuracy (27). Higher radiography contrast can increase measurement accuracy in *ex vivo* conditions. Moreover, the accuracy and repeatability of measurements are affected by patients' motion under clinical conditions (18). It is suggested to conduct more *in vivo* studies that evaluate the effect of resolution on the accuracy of linear measurements in different CBCT devices. Moreover, using different exposure parameters can also be beneficial in assessing the accuracy of measurements via CBCT.

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Conflict of interests: There are no conflicts of interest.

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