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Original Research

Evaluating the Accuracy of Linear Measurements in CBCT: The Role of Slice Thickness

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Abstract

Background: Since Cone-Beam Computed Tomography (CBCT) software programs allow the determination of slice thickness, this study was designed to evaluate the effect of different slice thicknesses on the accuracy of linear measurements in CBCT.

Method: In this cross-sectional study, 7 human skulls of unknown age and sex were selected. Vertical and buccolingual dimensions were measured in the anterior, middle and posterior regions of the right and left sides of the maxilla and mandible. Measurements were repeated at different slice thicknesses (1-, 2-, 3-, 4-, and 5-mm) in each area and compared. repeated measures ANOVA and Friedman tests were used as statistical methods.

Results: In all areas except the anterior maxilla, smaller slice thicknesses (1- and 2- mm) were associated with the lowest buccolingual dimensions, while larger slice thicknesses (5-mm) were associated with the highest buccolingual dimensions. For most areas, larger slice thicknesses (4- and 5-mm) resulted in the lowest vertical dimension, whereas smaller slice thicknesses (1- and 2- mm) provided the highest vertical dimension. The most accurate dimensions were obtained using the 1- and 2- mm slice thickness. The observed differences between slice thicknesses in horizontal measurements (buccolingual dimension) were mostly significant, but not in vertical measurements.

Conclusion: The difference in vertical and buccolingual dimensions when changing slice thickness from 1 to 5 mm using the Planmeca CBCT device is estimated to be less than 0.5 mm. This difference is clinically insignificant, meaning that the change in slice thickness does not affect the clinical accuracy of linear measurements in the maxillary or mandibular region.

Keywords: Cone-Beam Computed Tomography, slice thickness, accuracy, linear measurement.

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Introduction

CBCT is a new imaging technique used in dentistry to improve treatment planning with 3D images. Its advantage is the ability to measure anatomical structures, such as determining the width and height of the alveolar ridge for implant placement. This technique is commonly used in treatment planning for implant placement and jaw and facial reconstruction. CBCT characteristics are influenced by parameters such as field of view (FOV), slice thickness, and tube current (1). Slice thickness is particularly important for visualizing structures like the inferior alveolar nerve canal (1). Larger voxel size and slice thickness enhance image contrast, aid in identifying anatomical structures, and influence the accuracy of distance measurements. Some studies have investigated the effect of slice thickness on different aspects, including intact cortices, caries and implant site dimensions (2-4). Cross-sectional images with less thickness may offer more accurate information. A study found that the optimal results were achieved with a slice thickness of 3-mm and a filtration of 2-mm (5). However, another study found no difference between different slice thicknesses (1). In one study, the most accurate slice thickness for bone width was 4-mm and for bone height was 5-mm (6). This shows inconsistency in study results. The aim of this study was to evaluate how different slice thicknesses affect the accuracy of linear measurements in CBCT, as CBCT software allows determination of slice thickness.

Methods

This research was approved by the ethics committee of Mashhad University of Medical Sciences (IR.MUMS.DENTISTRY.REC.1401.133).

Skull selection and preparation

For this study, 7 human skulls were borrowed from the Anatomy Department of Mashhad Medical School.

Skull Selection Parameters:

1. Integrity of dental sockets (presence of teeth in the socket or ability to place them).
2. Coordination of lower and upper jaws for stability during position changes and imaging.
3. Integrity of bone margins and sinus areas.
4. Absence of fractures, anomalies, or severe deformities.
5. Continuous and intact buccal, lingual, and palatal cortical plates.

Premolar teeth (for their conical shape and ease of placement in the socket, as well as their radiopaque nature and absence of metal artefacts) were collected and trimmed before being embedded as markers in the toothless sockets of the desired areas. The upper and lower jaws were joined using rose wax.

A digital caliper gauge (Mitutoyo, Cd-6C, Japan) with an accuracy of 0.01 mm served as the gold standard for measurements. The true buccolingual diameter was defined as the maximum buccolingual diameter measurable with the caliper without interference from bone undercuts. The length of the tooth from the center of the coronal part to the apex was considered as the length reference.

Base construction

The base used in the experiment to hold the skull consisted of a wooden platform and a metal rod. The platform could rotate around the rod axis. A protractor was placed at the rotation point to measure the platform angle (Figure 1).

Skulls were assigned numbers from 1 to 7 and CBCT images were acquired for each skull in a standard position (central position and zero-degree platform angle).

Scanning steps

A Planmeca (ProMax 3D Classic, Helsinki, Finland) CBCT machine with FOV=8×8 and output conditions of 54 to 84 kVp, 8 mA, 12 s, and voxel size of 0.320 mm3 was used to prepare the CBCT images (Figure 2).

Measurement protocol

The scans were in DICOM format and analyzed with Romexis viewer 3.8.0 software.

Measurements were made in two dimensions: vertical and buccolingual, in the following areas of the maxilla and mandible:

1) Anterior region (central incisor tooth)
2) Middle region (first premolar)
3) Posterior region (mesial root of first molar)

First, the dental arch was drawn for the highest resolution panoramic image. The measurements were made using cross-sectional images. The most central section with the highest image resolution was selected for each region, and line A was drawn along the tooth from center of the crown to the apex of the tooth to measure the vertical dimension. In addition, the largest buccolingual dimension was measured in the central section as line B. All measurements were made at scale 1 (Figure 2).

The above measurements in each area, at 1-, 2-, 3-, 4- and 5-mm slice thickness, were compared with each other and with the measurements taken on the skull (as standard).

Results

In this study, the vertical and buccolingual dimensions in three regions of each jaw (anterior, middle, and posterior) were measured and analyzed at slice thicknesses of 1-, 2-, 3-, 4-, and 5-mm in 7 human skulls. The data were analyzed separately for each dimension.

Buccolingual dimension:

The buccolingual dimension data was checked for normality using the Shapiro-Wilk test. The distribution of the data was found to be normal for all variables (P-value>0.05).

There was no significant difference between the true buccolingual dimensions, and the measured dimensions at different slice thicknesses in the anterior right and left maxilla and the anterior left mandible using the repeated measures ANOVA. For a more detailed analysis, the LSD post hoc test was used, and the results are shown in Table 1.

The measured buccolingual dimensions in the 1- and 2-mm slice thicknesses had the least difference with the true dimensions.

Significant differences in mean buccolingual dimensions were observed using the repeated measures ANOVA for the anterior, middle, and posterior regions of the left and right mandible for different slice thicknesses ($P < 0.05$). In the maxilla, there were no significant differences in mean buccolingual dimensions between slice thicknesses in the left and right anterior regions ($P > 0.05$), but significant differences were found in the middle and posterior regions of both the left and right maxilla ($P < 0.05$).

For a more detailed analysis, the LSD post hoc test was used, and the results are shown in Table 2.

Vertical dimension:

The normality of the quantitative data in the vertical dimension was examined using the Shapiro-Wilk test. It was found that the data distribution of most variables was normal.

No significant difference was found between the true and measured vertical dimensions at different slice thicknesses in both jaws using the Friedman test. ($P > 0.05$).

There was a significant difference in the measured vertical dimensions for different slice thicknesses only in the left anterior region of the mandible ($P=0.012$) and the right middle region of the maxilla ($P=0.042$) using the Friedman test. For a more detailed analysis, Dunn's post hoc test was used, and the results are shown in Table 3.

Discussion

Slice thickness is particularly important for visualizing structures like the inferior alveolar nerve canal (1). Thinner slices are believed to provide more accurate information (5).

This study evaluated the effect of different slice thicknesses on the accuracy of linear measurements in CBCT. The results showed that buccolingual dimensions generally increase with thicker slices, while vertical dimensions decrease. The observed differences in horizontal measurements are mostly significant, but not in vertical measurements. However, the differences between measurements with different slice thicknesses were less than 0.5 mm, which is clinically insignificant.

Accurate knowledge of alveolar ridge width is crucial for implant treatment planning. It helps with selecting the appropriate implant diameter and determining the need for alveolar ridge augmentation.

In our study, in all 3 regions of the left and right mandible, the buccolingual measurements were lowest with 1- and 2-mm slice thickness. The difference in measurements was less than 0.4 mm for all slice thicknesses. In Sezgin et al.'s study (7), different slice thicknesses were used to measure bone lesions using CBCT. The thinnest slice thickness provided the most accurate measurements. Similar findings were observed in the present study. Abdinian and Baninajarian (8) investigated the effect of slice thicknesses on the panoramic view of CBCT. As the thickness increased, the accuracy decreased. However, Shokri et al. (6) found that increasing slice thickness increased the accuracy of the measurements to some extent. For instance, a slice thickness of 5-mm was reported as the most accurate for width measurement.

The 3mm slice thickness in the anterior maxilla differed the most from the standard condition in buccolingual dimensions. However, the 1- and 2-mm slice thicknesses yielded the most accurate buccolingual measurement. Buccolingual measurements in the anterior part of the maxilla showed no significant differences between five slice thicknesses. In the mid and posterior regions, accuracy decreased with increasing thickness. The 5-mm slice thickness was the furthest from the standard condition, and the 1- and 2-mm slice thickness provided the most accurate buccolingual measurements. There was a significant difference in buccolingual measurements between the different slice thicknesses in the middle and posterior regions of the maxilla. Other studies in this area have only examined the mandible and have not made measurements in each jaw separately. Moshfeghi et al. (9), in a study of the sheep mandible, reported that a 2-mm slice thickness had less measurement error than other slice thicknesses. Shokri et al. (6) found that a slice thickness of 5-mm provided the most accurate measurement for the human mandible. Sheikhi et al. (10) discussed various factors, such as artefacts, that contribute to differences in accuracy when using CBCT scans for linear measurements. The reported difference in the anterior region of the maxilla was not significant, meaning that the variation in slice thickness does not impact the measurement. The difference in buccolingual dimension measurement due to slice thickness in the middle and posterior regions was less than 0.3 mm, which is considered small and clinically acceptable.

Bone height is a crucial factor in implant treatment planning. It is necessary to have adequate bone height alongside bone thickness for successful implant treatment (11).

The measurements of the vertical dimension in the mandible were not significantly different between different slice thicknesses, except in the anterior part of the left half. A study by Goodarzi Pour et al. (1) found that different slice thicknesses in cross-sectional images did not significantly affect the visibility of the inferior alveolar canal. Root canal length measured at the 1.2 mm CBCT slice thickness was comparable to that measured with the Apex Locator in the Pham and Pham study, but measurements taken at other slice thicknesses differed significantly from those taken with the Apex Locator (12). However, Jasa et al. (13) reported that increasing the slice thickness and exposure parameters may improve the visibility of the unclear inferior alveolar canal. In a study by Shokri et al. (6), it was found that a slice thickness of 4-mm is the most accurate for evaluating vertical dimensions. However, in our study, we found that slice thicknesses of 1- and 2-mm provided more accurate measurements in most areas. The difference in results could be due to the separate examination of each part of each half jaw in the present study, as well as the use of different CBCT machines.

Accurate knowledge of maxilla dimensions is crucial in dentistry, especially for implant placement. Understanding its anatomy and proximity is vital to avoid sinus membrane damage during procedures like implant treatment or sinus lifts.

In this study, there was no significant difference in vertical measurements in the maxilla with different slice thicknesses. Previous studies have also noted CBCT image accuracy despite changes in slice thickness (1). However, no specific study has investigated the effect of changing slice thickness on maxilla measurements' accuracy.

In a study by Nikneshan et al. (14), it was found that a difference of less than 0.5 mm from the actual size was clinically acceptable. In the current study, the largest observed difference in buccolingual and vertical bone thickness compared to the standard condition was less than 0.35 mm, which is within the clinically acceptable range. Therefore, different slice thicknesses may affect the accuracy of horizontal and vertical measurements, but the amount of difference is clinically acceptable.

Several factors can impact image quality and linear measurement accuracy in CBCT scans. These include milliampere (mA) settings, voxel size, scan volume (field of view), type of scanner and detector, and the presence or absence of soft tissue and density of hard tissue (9). The type of CBCT device used and possible measurement errors may also contribute to variations in results across different studies. In addition, it is important to remember that the optimal CBCT image slice thickness varies depending on the intended use.

Conclusion

Measurements in both the vertical and buccolingual dimensions were found to have a difference of less than 0.5 mm from true dimensions for different slice thicknesses, which is considered clinically insignificant. The study results indicate that changes in slice thickness, whether in the maxilla or mandible, do not affect the accuracy of linear measurements made with the Planmeca CBCT unit.

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Authors Contributions:

SM, MS, AT conceptualized the study objectives and design. AT, SA are infectious disease specialists who contributed to data collection from patients along with SM. AT and MS drafted the study design protocols to be submitted to research centers. Data were was analyzed by AT and SM. Manuscript was drafted by SA, MS, and AT. All authors contributed in revisions.

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Tables:

Table 1: Comparing true buccolingual dimensions with measured buccolingual dimensions in different areas of the maxilla and mandible using different thicknesses

Location	Side		Second slice thickness (mm)	Anterior		Middle		Posterior	
				Difference In distance	P-value†	Difference In distance	P-value	Difference In distance	P-value†
mandible	Left	True	1	-	-	0.11	0.094	0.08	0.051
			2	-	-	0.03	0.148	0.08	0.051
			3	-	-	-0.19*	0.050	-0.03	0.176
			4	-	-	-0.20*	0.050	-0.06*	0.081
			5	-	-	-0.22*	0.033	-0.12*	0.008
	Right	True	1	0.03	0.051	0.02	0.064	0.02	0.184
			2	0.01	0.054	0.02	0.064	-0.02	0.184
			3	0.10*	0.016	-0.06*	0.048	-0.04	0.173
			4	0.10*	0.016	-0.10*	0.039	-0.15*	0.001
			5	-0.19*	0.003	-0.11*	0.039	-0.15*	0.001
maxilla	Left	True	1	-	-	0.02	0.060	0.04	0.093
			2	-	-	-.003	0.057	000	0.416
			3	-	-	-0.16	0.004	-0.15	0.000
			4	-	-	-0.22	0.003	-0.17*	0.001
			5	-	-	-0.23	0.003	-0.17*	0.001
	Right	True	1	-	-	0.09	0.051	0.08	0.082
			2	-	-	-0.02	0.210	0.08	0.082
			3	-	-	-0.07	0.182	-0.10*	0.053
			4	-	-	-0.17*	0.008	-0.17*	0.001
			5	-	-	-0.18*	0.008	-0.19*	0.001

†LSD post hoc test

Table 2: Pairwise comparison of different slice thicknesses in different areas of the maxilla and mandible regarding mean buccolingual dimension

Location		First slice thickness (mm)	Second slice thickness (mm)	Anterior		Middle		Posterior	
				Difference In distance	P-value†	Difference In distance	P-value†	Difference In distance	P-value†
mandible	Right Side	1	2	-0.01	0.052	0.00	-	-0.04	0.173
			3	-0.14*	0.010	-0.08*	0.034	-0.06	0.078
			4	-0.14*	0.010	-0.12*	0.026	-0.18*	0.003
			5	-0.22*	0.004	-0.13*	0.017	-0.18*	0.003
		2	3	-0.12*	0.009	-0.08*	0.034	-0.02	0.325
			4	-0.12*	0.009	-0.12*	0.026	-0.13*	.000
			5	-0.21*	0.004	-0.13*	0.017	-0.13*	0.000
		3	4	0.00	-	-0.04	0.140	-0.11*	0.005
			5	-0.08*	0.029	-0.05	0.067	-0.11*	0.005
		4	5	-0.08*	0.029	-0.01	0.111	0.00	-
	Left Side	1	2	0.00	-	-0.08	.105	0.00	-
			3	0.00	0.789	-0.31*	0.011	-0.11*	0.008
			4	0.00	0.789	-0.31*	0.011	-0.15*	0.008
			5	-0.11	0.052	-0.34*	0.009	-0.20*	0.010
		2	3	-0.009	0.789	-0.22*	0.004	-0.11*	0.008
			4	0.00	0.789	-0.23*	0.004	-0.15*	0.008
			5	-0.11	0.052	-0.25*	0.002	-0.20*	0.010
		3	4	0.00	-	0.00	0.356	-0.03	0.153
			5	-0.11*	0.002	-0.02	0.274	-0.09*	0.043
		4	5	-0.11*	0.002	-0.02	0.356	-0.05	0.081
maxilla	Right Side	1	2	--	--	-0.11*	0.001	0.00	-
			3	--	--	-0.16*	0.008	-0.19*	0.000
			4	--	--	-0.26*	0.001	-0.25*	0.001
			5	--	--	-0.27*	0.001	-0.27*	0.001
		2	3	--	--	-0.04	0.173	-0.19*	0.000
			4	--	--	-0.15*	0.004	-0.25*	0.001
			5	--	--	-0.15*	0.004	-0.27*	0.001
		3	4	--	--	-0.10	0.053	-0.06	0.137
			5	--	--	-0.10*	0.038	-0.08	0.082
		4	5	--	--	0.00	0.356	-0.02	0.134
	Left Side	1	2	--	--	-0.06*	0.038	-0.05	0.092
			3	--	--	-0.19*	0.002	-0.19*	0.000
			4	--	--	-0.25*	0.003	-0.21*	0.004
			5	--	--	-0.26*	0.003	-0.22*	0.004
		2	3	--	--	-0.12*	0.000	-0.14*	0.000
			4	--	--	-0.18*	0.002	-0.16*	0.001
			5	--	--	-0.19*	0.001	-0.16*	0.001
		3	4	--	--	-0.05	0.056	-0.02	0.356
			5	--	--	-0.06*	0.033	-0.02	0.298
		4	5	--	--	0.00	0.078	0.00	0.356

†LSD post hoc test

Table 3: Pairwise comparison of different slice thicknesses in different areas of the maxilla and mandible regarding mean vertical dimension

Location		First slice thickness (mm)	Second slice thickness (mm)	Anterior		Middle	
				Difference In distance	P-value†	Difference In distance	P-value†
mandible	Left Side	1	2	0.12	1.00	-	-
			3	0.16	0.225	-	-
			4	0.10	1.00	-	-
			5	0.23*	0.010	-	-
		2	3	0.04	1.00	-	-
			4	-0.02	1.00	-	-
			5	0.11	0.519	-	-
		3	4	-0.06	1.00	-	-
			5	0.07	1.00	-	-
		4	5	0.13	0.759	-	-
maxilla	Right Side	1	2	-	-	0.04	0.800
			3	-	-	0.07	0.310
			4	-	-	0.08	0.063
			5	-	-	0.10*	0.018
		2	3	-	-	0.02	0.447
			4	-	-	0.03	0.108
			5	-	-	0.06*	0.035
		3	4	-	-	0.00	0.398
			5	-	-	0.03	0.176
		4	5	-	-	0.02	0.612

†Dunn's post hoc test

Figure 1. The base used to hold the skull

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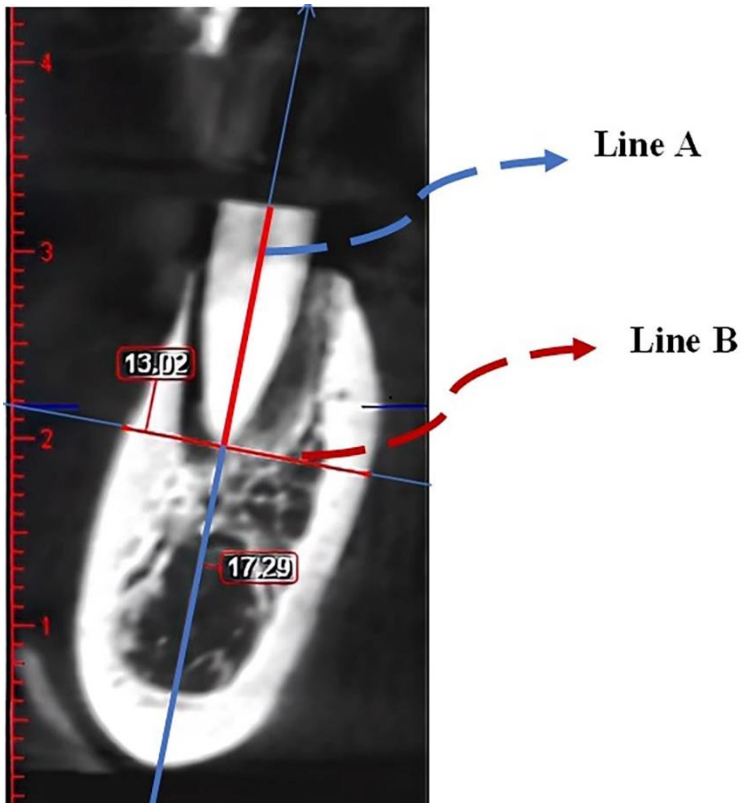

Figure 2: Measurement of vertical and buccolingual dimensions