

# Reproducibility of bone plate thickness measurements with Cone-Beam Computed Tomography using different image acquisition protocols

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## Abstract

**Introduction:** A smaller voxel dimension leads to greater resolution of Cone-Beam Computed Tomography (CBCT), but a greater dosage of radiation is emitted. **Objective:** Assess and compare the reproducibility of buccal and lingual bone plate thickness measurements in CBCT images using different image acquisition protocols, with variations in the voxel dimension. **Methods:** CBCT exams were taken of 12 dried human mandibles with voxel dimensions of 0.2, 0.3 and 0.4 mm using the i-CAT Cone-Beam 3-D Dental Imaging System. The thickness of the buccal and lingual bone plates was measured, with the i-CAT Vision software, on an axial section passing 12 mm above the right mental foramen. Intra-examiner and inter-examiner reproducibility was assessed using the paired t-test and independent t-test, respectively, with the level of significance set at 5%. **Results:** Excellent inter-examiner reproducibility was observed for the three protocols analyzed. Intra-examiner reproducibility was very good, with the exception of some regions of the anterior teeth, which exhibited statistically significant differences regardless of the voxel dimensions. **Conclusion:** The measurement of buccal and lingual bone plate thickness on CBCT images demonstrated good precision for voxel dimensions of 0.2, 0.3 and 0.4 mm. The reproducibility of the measurements of the anterior region of the mandible was more critical than that of the posterior region.

**Keywords:** Cone-Beam Computed Tomography. Alveolar bone. Reproducibility.

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## INTRODUCTION

A correct and precise diagnosis and treatment plan are fundamental for the success of orthodontic treatment. With the advent of Cone-Beam Computed Tomography (CBCT), orthodontists are able to obtain all the two-dimensional images (2D) that compose the orthodontic documentation during a single exam with the same precision of conventional radiographs, along with a detailed view of dentofacial structures.<sup>1,8,9</sup>

CBCT offers images of the labial/buccal and lingual bone plates, which are not apparent in conventional two-dimensional x-rays due to image superimposition.<sup>4</sup> Tooth movements in the buccolingual direction may cause bone dehiscence, as documented in studies involving animals and humans.<sup>17,18</sup> That constitutes a concern regarding the long-term periodontal integrity. Moreover, many patients, especially adults, may exhibit bone dehiscence prior to orthodontic treatment, which requires the orthodontist to plan more parsimonious dental movements.<sup>6,19</sup> Facial type has an effect on the thickness of the alveolar bone. Patients with a horizontal growth pattern have a greater buccolingual dimension of the alveolar ridge in comparison to hyperdivergent patients.<sup>6</sup> Thus, the morphology of the alveolar bone is one of the limiting factors of orthodontic movements.<sup>6</sup>

Previous studies have validated CBCT for quantitative analyses, demonstrating its highly precise measurements.<sup>2</sup> Measurement precision is related to the resolution of the image.<sup>11</sup> The spatial resolution of CBCT, in turn, depends upon the voxel dimension, which is the lowest image unit. A smaller voxel dimension leads to greater image resolution,<sup>14</sup> but also a higher dose of radiation.<sup>3</sup>

A number of studies have demonstrated the precision of linear measurements performed on CBCT images.<sup>7,10,11,12,15</sup> However, the influence of the voxel dimension on measurement precision of delicate structures, such as the buccal

and lingual bone plates, has yet to be demonstrated. Thus, the aim of the present study was to assess and compare the reproducibility of buccal and lingual bone plate thickness measurements in CBCT images using different image acquisition protocols with variations in the voxel dimension.

## MATERIALS AND METHODS

Twelve dried human mandibles with permanent dentition were selected from the Anatomy Department of the Bauru Dental School, Universidade de São Paulo, Brazil. CBCT scans were performed on each specimen using the i-CAT Cone-Beam 3-D Dental Imaging System (USA). Each mandible was embedded in a cube of no. 7 dental wax with water and detergent in order to simulate the density of the soft tissue. The base of the mandible was directly supported on the floor of the box and parallel to the ground. The following image acquisition protocols were used for each specimen:

1. Protocol 1: Field of view (FOV) of 8 cm, 120 kVp, 36.12 mAs, 0.2-mm voxel, 40-second scan time
2. Protocol 2: FOV of 8 cm, 120 kVp, 18.45 ma, 0.3-mm voxel, 20-second scan time
3. Protocol 3: FOV of 8 cm, 120 kVp, 18.45 ma, 0.4-mm voxel, 20-second scan time

The difference between protocols was essentially the voxel dimension, which is the smallest unit of the tomographic image. Thirty-six CBCT scans were performed, composing the overall sample.

Measurements were made using the i-CAT Viewer software. On the multiplanar reconstruction screen, the coronal section showing the right mental foramen was selected (Fig 1). On this section, the cursor representing the axial section was positioned on the superior border of the foramen. This cursor was then moved an average of 12 mm toward the occlusal direction, remaining in the level of the dentoalveolar region (Fig 1).

Due to the variation in the morphology of the mandibles analyzed, the cursor was moved more or less than 12 mm on some specimens in order to reach the region between the middle and apical thirds of the tooth roots.

On the axial section, the thickness of the labial/buccal and lingual bone plates was measured on all permanent teeth (Fig 2). The measurement extended from the external limit of the root to the external limit of the cortical bone, perpendicular to the contour of the dental arch on both sides (Fig 3).

The measurements were performed by two previously calibrated examiners. The first examiner repeated the measurements after an interval of at least 15 days. Statistical analysis involved the calculation of mean and standard deviation values of the labial/buccal and lingual bone plate thickness measurements for each tooth group (incisors, canines, premolars and molars). Paired t-tests were used for the intra-examiner comparison and the independent t-tests were used for the inter-examiner comparison, with the significance level of 5%.

## RESULTS

Table 1 displays the mean and standard deviation values for the measurements of labial/buccal and lingual bone plate thickness, along with the results of the intra-examiner comparison. There were statistically significant differences between the first and the second measurements for a single area using the 0.2-mm voxel protocol (buccal canine surface), for two areas using the 0.3-mm voxel protocol (lingual surface of incisors and canines) and for a single area using the 0.4-mm voxel protocol (lingual surface of incisors).

Table 2 shows the mean and standard deviation values for the measurements of buccal and lingual bone plate thickness, along with the results of the inter-examiner comparison. No statistically significant differences were found between the measurements of the two examiners.

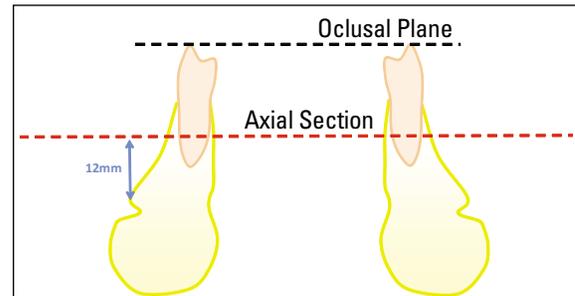


FIGURE 1 - Frontal reconstruction showing the right mental foramen used as reference to define the axial section for taking the measurements. The axial section passing an average of 12 mm above the superior border of the right mental foramen was used.

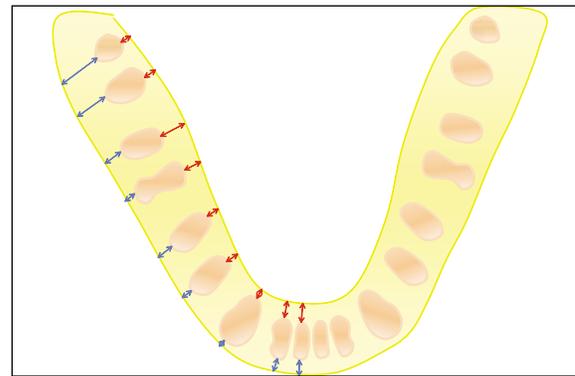


FIGURE 2 - Schematic representation of buccal and lingual bone plate thickness measurements in the selected axial section.



FIGURE 3 - Buccal and lingual bone plate thickness measurements in the axial section of one specimen (0.2-mm voxel).

TABLE 1 - Intra-examiner comparison for buccal and lingual bone plate thickness measurements (in millimeters) on CBCT images with voxel dimensions of 0.2, 0.3 and 0.4 mm.

		0.2-MM VOXEL							
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P	
		Mean	SD	Mean	SD				
<b>I</b>	B	0.72	0.38	0.73	0.37	0.01	0.50	0.61	
	L	1.13	0.48	1.00	0.42	-0.13	-1.54	0.13	
<b>C</b>	B	0.44	0.31	0.51	0.27	0.07	2.46	0.02*	
	L	1.12	0.56	1.17	0.53	0.05	1.03	0.31	
<b>PM</b>	B	0.43	0.36	0.42	0.31	-0.01	-0.24	0.81	
	L	1.36	0.92	1.33	0.98	-0.03	-0.70	0.48	
<b>M</b>	B	0.17	0.31	0.21	0.38	0.04	0.85	0.40	
	L	0.13	0.30	0.06	0.18	-0.07	-1.74	0.10	
		0.3-MM VOXEL							
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P	
		Mean	SD	Mean	SD				
<b>I</b>	B	0.82	0.44	0.79	0.41	-0.03	-0.58	0.56	
	L	1.17	0.49	0.97	0.48	-0.20	-4.52	0.00*	
<b>C</b>	B	0.56	0.31	0.55	0.20	-0.01	-0.05	0.95	
	L	1.30	0.66	1.07	0.64	-0.23	-3.68	0.00*	
<b>PM</b>	B	0.55	0.41	0.56	0.43	0.01	0.17	0.86	
	L	1.37	1.04	1.38	1.00	0.01	0.26	0.79	
<b>M</b>	B	0.05	0.14	0.07	0.23	0.02	1.00	0.33	
	L	0.05	0.23	0.04	0.16	-0.01	-1.00	0.33	
		0.4-MM VOXEL							
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P	
		Mean	SD	Mean	SD				
<b>I</b>	B	0.84	0.38	0.76	0.33	-0.08	-1.21	0.23	
	L	1.04	0.42	0.75	0.38	-0.29	-4.60	0.00*	
<b>C</b>	B	0.64	0.35	0.62	0.23	-0.02	-0.21	0.82	
	L	1.07	0.50	1.15	0.61	0.08	0.99	0.33	
<b>PM</b>	B	0.49	0.40	0.46	0.42	-0.03	0.43	0.66	
	L	1.14	1.14	1.16	1.11	0.02	0.34	0.73	
<b>M</b>	B	0.06	0.16	0.07	0.19	0.01	1.00	0.33	
	L	0.13	0.42	0.14	0.34	0.01	0.22	0.82	

I: incisors; C: canines; PM: premolars; M: molars; B: buccal bone plate; L: lingual bone plate; \* p < 0.05.

## DISCUSSION

Considering the increasing applicability of CBCT in Dentistry, it is very important to determine an image acquisition protocol capable of providing a three-dimensional view with the appropriate resolution to measure small structures,

such as buccal and lingual bone plates. A smaller voxel dimension leads to greater spatial resolution of the image, but also emits a greater amount of radiation.<sup>3</sup> In other words, the voxel dimension set during the exam is directly related to the radiation dose to which the patient is

TABLE 2 - Inter-examiner comparison for buccal and lingual bone plate thickness measurements (in millimeters) on CBCT images with voxel dimensions of 0.2, 0.3 and 0.4 mm.

		0.2-MM VOXEL						
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P
		Mean	SD	Mean	SD			
<b>I</b>	B	0.72	0.40	0.77	0.40	0.05	-0.53	0.59
	L	1.13	0.48	1.13	0.45	0.00	-0.01	0.98
<b>C</b>	B	0.44	0.31	0.57	0.29	0.13	-1.38	0.17
	L	1.12	0.56	1.33	0.59	0.21	-1.17	0.24
<b>PM</b>	B	0.43	0.36	0.54	0.32	0.11	-1.44	0.15
	L	1.36	0.92	1.46	1.04	0.10	-0.42	0.67
<b>M</b>	B	0.17	0.31	0.24	0.44	0.07	-0.48	0.62
	L	0.13	0.30	0.10	0.29	-0.03	0.26	0.79
		0.3-MM VOXEL						
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P
		Mean	SD	Mean	SD			
<b>I</b>	B	0.82	0.44	0.86	0.46	0.04	-0.39	0.69
	L	1.17	0.49	1.19	0.54	0.02	-0.17	0.85
<b>C</b>	B	0.56	0.31	0.62	0.33	0.06	-0.59	0.55
	L	1.30	0.66	1.33	0.60	0.03	-0.13	0.89
<b>PM</b>	B	0.55	0.41	0.56	0.39	0.01	-0.09	0.92
	L	1.37	1.04	1.55	1.11	0.18	-0.70	0.48
<b>M</b>	B	0.05	0.14	0.14	0.41	0.09	-0.85	0.40
	L	0.05	0.23	0.05	0.23	0.00	0.00	1.00
		0.4-MM VOXEL						
		1 <sup>st</sup> measurement		2 <sup>st</sup> measurement		Difference	T	P
		Mean	SD	Mean	SD			
<b>I</b>	B	0.84	0.38	0.94	0.37	0.10	-1.10	0.27
	L	1.04	0.42	0.96	0.43	-0.08	0.81	0.41
<b>C</b>	B	0.64	0.35	0.68	0.33	0.04	-0.43	0.66
	L	1.07	0.50	1.17	0.61	0.10	-0.56	0.57
<b>PM</b>	B	0.46	0.40	0.43	0.41	-0.03	0.33	0.73
	L	1.14	1.14	1.23	1.65	0.09	-0.33	0.73
<b>M</b>	B	0.06	0.16	0.03	0.14	-0.03	0.45	0.65
	L	0.13	0.42	0.15	0.44	0.02	-0.14	0.88

I: incisors; C: canines; PM: premolars; M: molars; B: buccal bone plate; L: lingual bone plate; \* p < 0.05.

submitted during the procedure. Thus, before selecting the image acquisition protocol, it is necessary to determine its cost-benefit ratio based on the ALARA principle (as low as reasonably achievable dose of radiation), in which the professional chooses the scanning protocol with the

lowest possible radiation dose, but with sufficient resolution for the identification of the structures to be assessed.

CBCT technology is very recent and the literature offers few investigations for the study of its reproducibility related to the image

acquisition protocol. Thus, the aim of the present study was to compare the reproducibility of thickness measurements of the buccal and lingual bone plates of permanent teeth in CBCT images with different voxel dimensions (0.2, 0.3 and 0.4 mm). The results revealed statistically significant differences in the intra-examiner comparison in some regions of the anterior teeth (Table 1). This corroborates the findings of previous studies. Tsunori et al<sup>16</sup> have measured the buccal, lingual and basal cortical bone thickness as well as the buccolingual width and height of the alveolar ridge using CBCT of 39 dry skulls and found few significant differences between the first and second measurements by a single examiner.<sup>16</sup>

Mol and Balasundaram<sup>13</sup> analyzed the precision of measurements of bone dehiscence using CBCT on five dry skulls. The authors compared measurements performed by six examiners using CBCT, conventional radiographs and the anatomic specimens and concluded that CBCT achieved the greatest diagnostic precision of the three methods. However, the authors found that the region of the mandibular anterior teeth showed less precision in comparison to other areas and concluded that the measurement of bone dehiscence in the anterior region is more limited with the NewTom 9000 scanner.<sup>13</sup>

In the present study, significant intra-examiner differences were found in the region of the anterior teeth (incisors and canines) although the differences between the first and second measurements did not surpass 0.30 mm (Table 1). The measurements of the bone plates in the posterior region were highly precise. It is likely that the difference in the reproducibility of the measurements between anterior and posterior teeth is due to the fact that the thickness of the bone plates is thinner in the anterior region compared with the posterior region. A thinner bone plate has less image resolution, decreasing the precision of linear measurements.<sup>14</sup>

This limitation of computed tomography may be due to the property denominated “partial volume averaging”; when the limit between two tissues is in the middle of a voxel, its density corresponds to the average density of the two structures it encompasses.<sup>14</sup> These results are in agreement with those described by Mol and Balasundaram<sup>13</sup>, who found less accuracy in the measurement of buccal bone dehiscence in the anterior region of the mandible in comparison with the posterior region on images generated with the NewTom 9000 scanner. Using helical computed tomography, Fuhrman found that only bone plates with a thickness of less than 0.2 mm were not apparent on the exam.<sup>5</sup> To date, no studies have indicated the least bone plate thickness that can be identified on CBCT images.

In 2008, Loubele et al<sup>10</sup> performed linear measurements of the buccolingual diameter of the alveolar ridge at previously marked points on an human maxilla comparing CBCT with helical CT and found no significant inter-examiner differences. The present study corroborates this finding, as inter-examiner reproducibility was excellent (Table 2).

Based on the results of the present study, the measurement of bone plate thickness proved to have similar reproducibility in the different image acquisition protocols, although the 0.2 mm voxel protocol has produced sharper images than the 0.3 and 0.4 mm voxel protocols. Further studies should be carried out to determine the accuracy of bone plate thickness measurements using CBCT images.

## CONCLUSION

The measurement of buccal and lingual bone plate thickness on CBCT images demonstrated good precision for exams obtained with voxels of 0.2, 0.3 and 0.4 mm. The reproducibility of the measurements in the anterior region of the mandible was more critical than that of the posterior region.

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