Accuracy of Linear Measurements in Cone Beam Computed Tomography With Different Voxel Sizes

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Objective: *To evaluate the accuracy of linear measurements on dry mandible specimens using cone beam computed tomography (CBCT) images acquired with different voxel sizes.*

Methodology: *Eight human dry mandibles were submitted to CBCT examination, using the i-CAT (Imaging Sciences, Inc. Hatfield, PA) device and four protocols with different voxel sizes. Tomographic slices with a more central view of the markers, placed on six sites on each mandible, were selected to perform measurements. Values obtained from direct measurements on the dry mandible after sectioning them on the preestablished sites were compared with measurements from the tomographic images and the measurement error.*

Results: *There was no statistical difference between the measurement error of the protocols (*$P = 0.606$*). The mean value of the difference between the values obtained in the images and the dry mandible was smaller than 1 mm for all the protocols.*

Conclusion: *The accuracy of vertical and horizontal measurements, using CBCT (i-CAT) for the four protocols, was shown to be comparable with the measurements performed on the dry mandible. (Implant Dent 2012; 21:150–155)*

Key Words: cone beam computed tomography, tomography, voxel

The volumetric data from computed tomography (CT) and cone beam CT (CBCT) comprise a three-dimensional block of small cuboidal structures, known as voxels, which represent three-dimensional pixels. The voxel (the smallest detectable unit of volume) is isotropic in CBCT, that is, it has equal values for the three dimensions (height, width, and depth), whereas in conventional CT, the voxel is anisotropic (rectangular cubes in which at least one dimension is different) for helicoidal generation. The voxel size in CBCT is smaller than that of CT, and it may vary in the same CBCT device depending on the protocol chosen, which is based on the reason for the examination.[1–6]

Generally, the smaller the voxel size and the longer the scan time for the i-CAT (CBCT device), the better are the resolution and the details.[7] That may be a critical point once the diagnosis becomes more refined for the evaluation of bone trabecula local structure in fields such as periodontics and oral surgery.[7] However, according to the i-CAT device user guide, a smaller voxel size is associated with a longer scan time (total acquisition time for the entire area), which presents some disadvantages such as increased possibility of patient movement during the procedure, longer reconstruction time, and higher radiation doses.

The choice of the protocol, based on the voxel size, is a difficult exercise. A better understanding of the accuracy of the linear measurements for each of protocol can be important to establish the best protocol to be used in planning for dental implants, because the success of dental implant treatment is, in part, dependent on adequate diagnostic information about the bone structures of the oral region, including accurate linear measurements. This study aims to evaluate the accuracy of linear measurements done in the mandible in CBCT examinations acquired with different voxel sizes.

MATERIALS AND METHODS

Eight human dry mandibles fully edentulous, with alveolar processes resorbed, no damage or anomalies, but chosen randomly regarding other anatomical features, were used. Six sites in each mandible were selected for

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ISSN 1056-6163/12/02102-150
Implant Dentistry
Volume 21 • Number 2

DOI: 10.1097/ID.0b013e31824bf93c

evaluation, three for each side, in a symmetrical fashion (Fig. 1):

Incisor (I) located 1 cm from the medial sagittal line distal
Premolar (PM) by the mental foramen
Molar (M) located 1 cm from the mental foramen distal.

Lines (L1) perpendicular to the base of the mandible were drawn, by vestibular, from the selected sites, with a BIC Marcador Permanente CD.DVD (BIC, Brazil) pen with a 0.7-mm tip.

Hollow spherical markers were fixed on the mandible in the six preestablished sites, by placing a utility wax layer over the remaining bone ridge, to serve as a reference when choosing the measurement sites. Three-millimeter spherical markers were placed in the upper portion of the remaining bone ridge and 1-mm spherical markers, by vestibular, in the portion closest to the coronal level of the bone ridge (Fig. 1).

The previously calibrated i-CAT device (Imaging Sciences International, Hatfield, PA) was used to obtain the CBCT images, as recommended by the manufacturer. The mandibles were placed in a styrofoam box with water (16 cm × 14.5 cm × 10 cm) to simulate the attenuation of x-rays in the presence of the patient's soft tissue, so that the medial sagittal plane was perpendicular to the horizontal plane and the mandibular plane was parallel to the horizontal plane. The set was taken to the device and kept in position on the platform provided with the device.

Images of the mandible were obtained with a scan height (collimation) of 6 cm according to image acquisition protocols shown in Table 1. After the volumetric data acquisition, panoramic and parasagittal reformatting of the images was performed using Xoran (i-CAT software). The panoramic curve was generated manually according to the anatomy of each mandible specimen.

Images were examined by an expert in dental radiology with 8 years experience in CT. Each image was evaluated on the computer screen (Sync Master 2232 BW, Samsung Electronics Co, Suwon, South Korea, 21 inches and 1280 × 1024 resolution) at two distinct times. The measurements were made at real size within approximately 1 voxel, with a 2-week gap between the evaluations, using the same procedure under the same environmental conditions, without knowledge of the evaluation protocol.

The tomographic slice with the most central view of the markers was

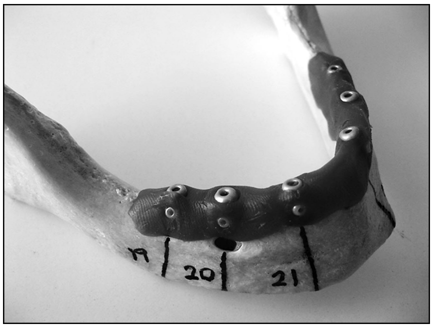

Fig. 1. Dry mandible with markers in position, on sites I, PM, and M.

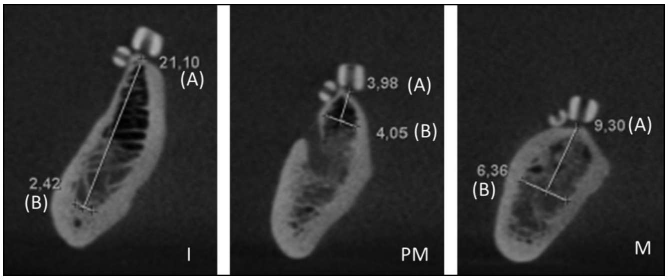

Fig. 2. Parasagittal tomographic images of the sites I, PM, and M, pointing out the vertical (*A*) and horizontal (*B*) measurements.

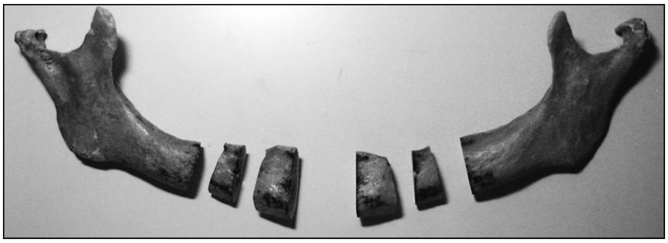

Fig. 3. Mandibular bone segments at the six preestablished sites.

Table 1. Image Acquisition Protocols

Protocol	Voxel Size (mm)	Scan Time (s)	kVp	mAs
1	0.2	40	120	46.72
2	0.25	40	120	46.72
3	0.3	20	120	23.87
4	0.4	20	120	23.87

Table 2. Vertical and Horizontal Measurements Evaluated According to the Established Sites

Sites	Vertical Measurements	Horizontal Measurements
I	Following the long axis of the bone profile, extending from the uppermost portion of the alveolar ridge to the inner contour of the mandible basilar cortical	By the height of the inner contour of the mandible basilar cortical, extending from the vestibular inner cortical to the lingual inner cortical
PM	Following the long axis of the bone profile, extending from the uppermost portion of the alveolar ridge to the upper contour of the mental foramen	By the height of the upper contour of the mental foramen, extending from the vestibular inner cortical to the lingual inner cortical
M	Following the long axis of the bone profile, extending from the uppermost portion of the alveolar ridge to the upper contour of the mandibular canal	By the height of the upper contour of the mandible canal, extending from the vestibular inner cortical to the lingual inner cortical

chosen for each region studied and, from the hollow portion of the markers and using the line measurement tool from the software, vertical and horizontal measurements were made: the implant bone height (*A*) and the bone width (*B*), following the precise protocol, which varied for each region evaluated, as outlined in Table 2 (Fig. 2). In a posterior position, using an electric saw, the mandibles were sectioned at the six preestablished sites immediately before the drawn lines L1, so that bone tissue in the site related to the tomographic slices was not lost. Bone segments were carefully abraded up to the lines L1 to reproduce the exact location to perform the measurements (Fig. 3).

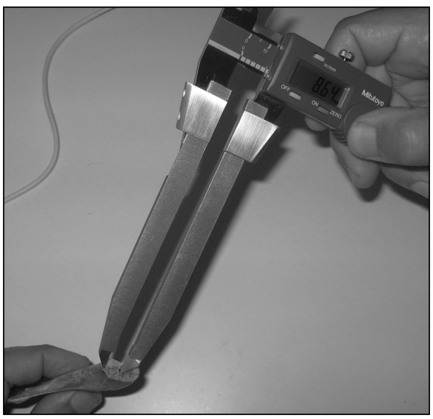

Fig. 4. Vertical (*A*) measurement obtained at the molar (M) site using a high precision digital caliper.

In the segments of the dry mandibles, the same vertical (*A*) and horizontal (*B*) measurements (Table 2 and Fig. 2) were obtained for each site using a high precision digital caliper (Fig. 4).

Values obtained from the direct measurements in the dry mandible and the measurements in the tomographic images were compared. The measurement error (ME) was calculated by subtracting the value obtained from the direct measurement on the dry mandible (*Y*) from the value obtained from the tomographic images (*X*), expressed as the absolute value as a percentage of the direct measurement on the dry mandible (the gold standard)[8]:

$$ME = \frac{|(X - Y)|}{Y} \times 100$$

The mean and median values of the ME for each protocol were established. The Friedman, Kruskal-Wallis, and Wilcoxon testes were used to compare the ME between the protocols, for general evaluation, by site and by measurement, respectively, followed by the Dunn test. Results with a P value <0.05 were considered to be statistically significant. To assess the reproducibility of the measurements between the evaluations and the gold standard, the Lin concordance coefficient (LCC) was used.

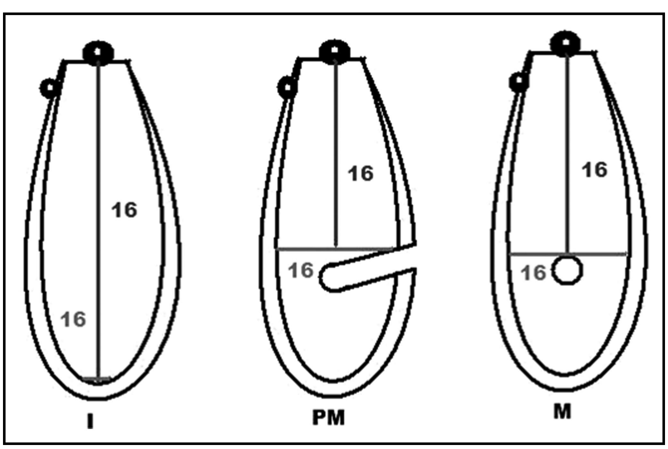

Fig. 5. Distribution of the number of measures performed by measurement (*A*, vertical; *B*, horizontal) and by site (I, PM, and M) for each protocol on the dry mandible.

RESULTS

Four hundred and eighty measurements were performed, 96 for each protocol (p1, p2, p3, and p4) and 96 measurements on the dry mandible (gold standard), according to the distribution shown in Figure 5. The mean (MD) and median (MN) of the ME for each protocol, for the overall assessment, by site and by measurement, are presented in Table 3. The representation of the median is more consistent because the distribution of the sample is not normal.

There was no statistically significant difference between the ME for protocols p1, p2, p3, and p4 in the overall assessment ($P = 0.606$), which shows that all behaved in the same way regarding the performance of linear measurements proposed here. Comparing the ME of the sites for each protocol, there was no statistically significant difference between the regions I, PM, and M for each protocol. For p1, p2, p3, and p4, $P = 0.3569$, $P = 0.6516$, $P = 0.1696$, and $P = 0.5141$, respectively. For the *A*

Table 3. MD and MN of the ME for Each Protocol (p1, p2, p3, and p4): Overall Evaluation, per Site, and per Measurement

	ME Overall (%)		ME Sites (%)						ME Measurements (%)			
			I		PM		M		Vertical		Horizontal	
	MD	MN	MD	MN	MD	MN	MD	MN	MD	MN	MD	MN
p1	12.65	8.54	14.62	5.96	13.56	9.71	9.59	8.04	8.20	6.09	17.11	9.37
p2	12.20	7.46	15.00	5.40	12.62	8.78	8.80	7.88	7.19	5.61	17.22	10.35
p3	12.18	7.46	13.52	6.05	13.16	9.41	9.85	7.60	8.13	6.42	16.22	9.35
p4	13.62	8.38	18.61	6.40	13.85	11.7	8.41	7.54	7.33	4.90	16.91	12.40

MD indicates mean; MN, median; ME, measurement error.

(vertical) and *B* (horizontal) measurements, we found significant differences between the ME for the four protocols: $P = 0.0276$, $P = 0.0066$, $P = 0.0194$, and $P = 0.0023$ for p1, p2, p3, and p4, respectively.

The majority of the values obtained from the images were lower than the real values (Fig. 6) and the ME was reduced in the four protocols; the mean value of the difference between the values obtained from the images and the dry mandible for p1, p2, p3, and p4 varied from 0.68 to 0.72 mm.

The LCC between the measurement on the tomographic images (Av) and the measurement on the dry mandibles (gold standard), in the overall assessment, by site and by measurement, shows high concordance for the four protocols (Table 4). The intraexaminer concordance, shown in Table 5, was very high for the overall assessment of the four protocols (varying from 0.960 to 0.986). The LCC of the intraexaminer concordance for the measurements performed on the dry mandible using the digital caliper was 0.987.

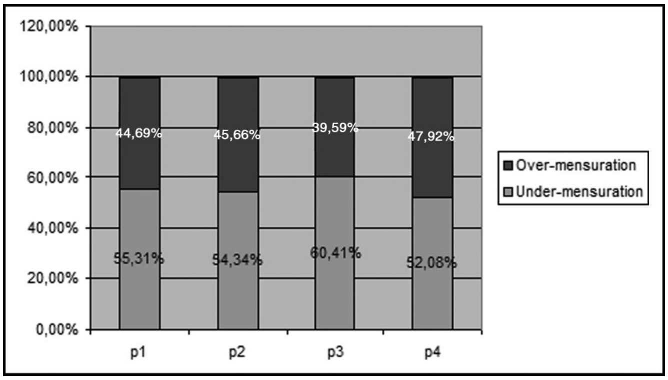

Fig. 6. Percentage of variation in the measurements for more and less per protocol.

Discussion

Successful dental treatment must be based on complete planning and that includes the use of images to help the diagnosis. In the preoperative evaluation of patients undergoing surgery for dental implant placement, for example, imaging examinations play an important role. Accurate evaluation of the quality and quantity of the remaining bone and the precise location of anatomical structures are necessary for successful treatment.[9–12]

The American Academy of Oral and Maxillofacial Radiology defends the position that the success of dental implant treatment is, in part, dependent on adequate diagnostic information about the bone structures of the oral region, including accurate linear measurements, such as the distances between anatomical structures or bone thickness.[13–16]

The accuracy of vertical and horizontal measurements using CBCT in the four protocols was comparable with the measurements performed on the dry mandible, which is in agreement with the findings of Lascala et al,[17] Lund et al,[16] Kamburoglu et al,[15] Damstra et al,[18] and Kamburoğlu et al[19] who used CBCT as the imaging examination and Nasel et al,[20] who used CT and magnetic resonance imaging.

The four CBCT protocols evaluated, with 0.2, 0.25, 0.3, and 0.4 mm voxels, are comparable with regard to the accuracy of the vertical and horizontal measurements, and there was no difference between them. Similar findings were found in a study per-

Table 4. LCC Between the Evaluation and Golden Pattern (Ev1_Golden), for Each Protocol (p1, p2, p3, and p4): Overall Evaluation, per Site and per Measurement

Protocols	LCC Ev1_Golden Overall	LCC Ev1_Golden Sites			LCC Ev1_Golden Measurements	
		I	PM	M	Vertical	Horizontal
p1	0.966	0.988	0.937	0.950	0.988	0.959
p2	0.968	0.954	0.949	0.898	0.991	0.817
p3	0.967	0.969	0.910	0.947	0.984	0.882
p4	0.958	0.952	0.916	0.921	0.992	0.794

LCC indicates Lin concordance coefficient.

Table 5. Lin Concordance Coefficient (LCC) Between the Evaluations (Ev1_Ev2), for Each Protocol (p1, p2, p3, and p4): Overall Evaluation, per Site and per Measurement

Protocols	LCC Ev1_Ev2 Overall	LCC Ev1_Ev2 Sites			LCC Ev1_Ev2 Measurements	
		I	PM	M	Vertical	Horizontal
p1	0.980	0.984	0.926	0.901	0.986	0.940
p2	0.986	0.991	0.943	0.899	0.995	0.947
p3	0.984	0.994	0.849	0.875	0.976	0.961
p4	0.960	0.972	0.862	0.831	0.972	0.840

LCC indicates Lin concordance coefficient.

formed by Liedke et al,[6] in which with 0.2, 0.3, and 0.4 mm voxels (i-CAT device) were used to evaluate cavities on the vestibular surface of roots, simulating external radicular resorption. They showed that the use of smaller voxels does not offer greater precision in the diagnosis or the distances measured using the i-CAT, despite the fact that the evaluations with smaller voxels are easier.[6]

There was variation in terms of noise, because it increases with an increase in resolution.[21] However, the noise does not affect the linear measurements made and the four CBCT protocols evaluated are comparable with regard to the accuracy of the vertical and horizontal measurements. There was no difference between them. This suggests that the benefit of increased image resolution outweighs the effect of noise on contrast resolution when measuring bone dimensions.[21] The noise might affect subjective evaluation, in research of fractures and root resorption.

The fact that measurement *A*, which represents bone height, was greater than measurement *B*, which represents bone thickness, may explain the significant difference between the ME of the vertical and horizontal measurements. It is possible that the ME is more evident when smaller distances are considered, because the absolute difference, although small, may represent a high relative value (ME). Thus, when planning for dental implants, the smaller the amount of bone available, the greater the probability of having a greater ME using CBCT.

Undermensuration, predominant in the evaluations, in agreement with the findings of Lascala et al[17] and Baumgaertel et al[22] and contradicting that of Sun et al,[23] has been shown to be safer clinically compared with overmensuration, because, under such condition, structures may be preserved when planning the placement of dental implants.[24]

The ME was reduced in the four protocols; the mean value of the difference between the values obtained from the images and the dry mandible, for p1, p2, p3, and p4, varied from 0.68 to 0.72 mm. Such measurements can be considered precise; for instance, in the preoperative evaluation for implants, measurements are considered to be acceptable within an ME of 1 mm[8,20] to 2 mm.[15]

Small differences between the gold standard and CBCT imaging measurements were also seen in a study performed by Stratemann et al[7] They found that values were even more reduced (0.07 ± 0.41 mm for the NewTom device and 0.00 ± 0.22 mm for the CB MercuRay device), because there was greater precision in the spots chosen as parameters, with markers at both edges. In our sample, the reference was clinical and the linear measurement was based on the identification of anatomical repairs (mandible inner cortical, mental foramen, mandibular canal), which more accurately reproduces the reality of dental planning in the clinic, where anatomical repairs are used as reference.

Therefore, in this study the accuracy of the vertical and horizontal measurements, using CBCT (i-CAT) for the four protocols, was shown to be comparable with the measurements performed on the dry mandible. Thus, because protocols p1 and p2 require a radiation dose almost double that required for protocols p3 and p4, and the scan time and mAs are almost doubled for p1 and 2 versus p3 and p4 (Table 1), the latter must be preferably indicated in the evaluation of the linear measurements.

However, subjectiveness in image evaluation was not the object of this study and images with smaller voxels have specific indications in evaluations that require greater visualization of detail, such as research on fractures and radicular resorption. There is also a need to investigate the influence of other variables in measuring distances besides the image quality, such as observer performance, selection of reference spots, mouse sensitivity, monitor resolution, efficiency of the software used and signal-to-noise ratio.

Conclusion

The accuracy of vertical and horizontal measurements for planning of dental implants, using CBCT (i-CAT) for the four protocols, was shown to be comparable with the measurements performed on the dry mandible. Thus, protocols with voxels of 0.3 and 0.4 mm must be preferably indicated in the evaluation of the linear measurements for planning of dental implants treatment, because the radiation dose is reduced.

Disclosure

The authors claim to have no financial interest in any company or any of the products mentioned in this article.

Acknowledgments

The authors thank CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico – Brazilian Research and Technology Council), Fapesb (Fundação de Amparo à Pesquisa do Estado da Bahia – Foundation for Research Support of the State of Bahia), and Clinica Odonto Bio Imagem for their contributions for this study.

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