CLRD in Clinical and Laboratorial Research in Dentistry | Oral Radiology

Influence of voxel size on the accuracy of linear measurements taken in CBCT images

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ABSTRACT | *Objectives:* Cone-beam computed tomography (CBCT) has brought innovation to imaging examination methods, and has shown great potential in the maxillofacial area. The aim of this study was to evaluate the influence of different resolution values on the accuracy of linear measurements performed using a CBCT system. *Methods:* Seven pig mandibles were used in this study. Measurements were taken of the mesiodistal distance of the right and left first molars. The mandibles were scanned using an iCAT CBCT apparatus and different voxel sizes, namely 0.125 and 0.25 mm. The images thus obtained were visualized using Xoran CT software, and the linear measurements were taken at different times by two examiners who used the software's electronic ruler. A digital caliper was used to perform the measurements on the anatomical specimens. The data were analyzed statistically. *Results:* The results indicated no statistically significant difference between the measurements obtained by both examiners. As for the methods used in this study, no statistically significant difference was observed between the measurements obtained with the digital caliper and those obtained using CBCT. Similarly, no significant difference was observed between the measurements obtained using the different CBCT protocols. *Conclusion:* There is no significant difference between linear measurements obtained from CBCT images with 0.125 or 0.25 mm voxel sizes.

DESCRIPTORS | Radiology; Cone-Beam Computed Tomography; Voxel.

RESUMO | **Influência do tamanho do voxel na acurácia de medidas lineares obtidas em imagens de TCFC** • *Objetivo:* A tomografia computadorizada de feixe cônico (TCFC) introduziu uma inovação nos métodos de exame por imagem e tem apresentado grande potencial na área maxilofacial. O objetivo deste estudo foi avaliar a influência de diferentes resoluções (voxels) sobre medidas lineares obtidas utilizando-se a TCFC. *Método*: Foram utilizadas 7 mandíbulas suínas neste estudo. Foram obtidas medidas da distância mésio-distal dos primeiros molares direito e esquerdo. As mandíbulas suínas foram escaneadas num aparelho iCAT com voxel de 0,125 e 0,25 mm. As imagens obtidas foram visualizadas no software Xoran CT, e as medidas lineares foram realizadas por dois examinadores em tempos distintos com o auxílio da régua eletrônica do software. Os mesmos utilizaram um paquímetro digital para a medição realizada nas peças anatômicas. Os dados foram submetidos à avaliação estatística. *Resultados:* Os resultados apontam não haver diferença estatisticamente significativa entre as medidas obtidas por ambos os avaliadores. Com relação aos métodos empregados, não se observou diferença estatisticamente significativa entre as medidas obtidas com o paquímetro digital e com a TCFC. Da mesma forma, não se observou diferença significativa entre as medidas obtidas utilizando-se os diferentes protocolos de TCFC. *Conclusão:* Não há diferença significativa entre medidas lineares de imagens de TCFC obtidas com tamanho de voxel de 0,125 e 0,25 mm.

DESCRITORES | Radiologia; Tomografia Computadorizada de Feixe Cônico; Voxel.

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• **Received:** Jun 18, 2014 •**Accepted:** Nov 05, 2014

INTRODUCTION

Cone-beam computed tomography (CBCT) has brought innovation to imaging examination methods. This technique has shown a great potential in the maxillofacial area, with faster acquisition of volumetric images and lower radiation doses compared to those used in helical computed tomography (CT).[1-3]

CBCT can be applied in several fields of dentistry, including implant dentistry, surgery, and oral diagnosis.[1] However, further evaluation of the accuracy of linear measurement data is necessary to expand its application.[1-3] Diagnosis and treatment of facial asymmetries require precise measurements of various anatomical sites. Therefore, conventional radiographs are not recommended due to the effects of geometric projection and horizontal and vertical magnification.[2,4]

Image accuracy has been confirmed for several different CBCT devices. In addition, it was observed that the accuracy of images may be influenced by factors such as voxel resolution.[3,5] In CBCT images, volume is represented by voxels, and each voxel is assigned a value in the gray scale, which, in turn, represents the radiographic density of the corresponding structure. A reduction in voxel resolution can result in a low-quality image, with more artifacts and less detailed anatomical information than that of the real structure.[3,5]

Therefore, the aim of this study was to evaluate the influence of different voxel resolutions on the accuracy of linear measurements taken in CBCT images.

MATERIALS AND METHODS

This study was approved by the Ethics Committee for Animal Use (CEUA, in Portuguese), Institute of Biomedical Sciences, University of São Paulo (protocol No. 052/2012).

Seven dry pig mandibles were used, and all animals came from the same slaughterhouse. Age, gender, and date of slaughter of the animals were not considered. Measurements were taken of the mesiodistal distance of the right and left first molars (two measurements per mandible), for a total of 14 measurements.

The mandibles were scanned in a CBCT unit (i-CAT Vision CB500; Gendex Dental Systems, Hatfield, PA, USA) using the following parameters for the X-ray source:

- 120 kV;
- variable current (mA; regulated by the equipment according to the exposure necessary to achieve the volume to be analyzed);
- 360° rotation;
- focal area of 0.5 mm;
- Flat Panel-type sensor (amorphous silicon; 13 × 13 cm);
- 14-bit grayscale;
- FOV of 8 × 8 cm;
- voxel sizes of 0.25 and 0.125 mm; and
- scanning time of 23 s.

The mandibles were positioned following the reference lines of the equipment: the reference line was centered on the mandibular symphysis (Figure 1) and positioned on the most eminent mental foramen (Figure 2).

The images thus obtained were visualized using Xoran CT software. Two examiners (AV1 and AV2) performed the linear measurements (sagittal sections; 200% magnification) at different times, using the software's electronic ruler (Figures 3 and 4).

The same examiners used a digital caliper (Coolant Proof Absolute; Mitutoyo Sul Americana Ltda, São Paulo, SP, Brazil) for measuring the same distances described above on the anatomical specimens.

The examiners' procedures were standardized for both software tool and digital caliper.

All values were transferred to an electronic spreadsheet (Microsoft Excel, Microsoft Office,

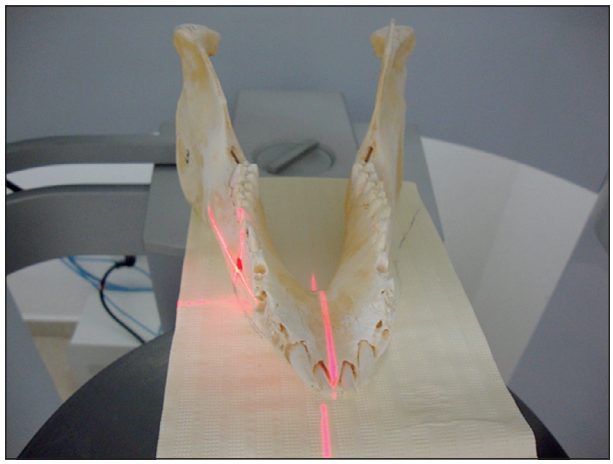

Figure 1 | Positioning of the pig mandible in the cone-beam computed tomography unit: the reference line was centered on the mandibular symphysis.

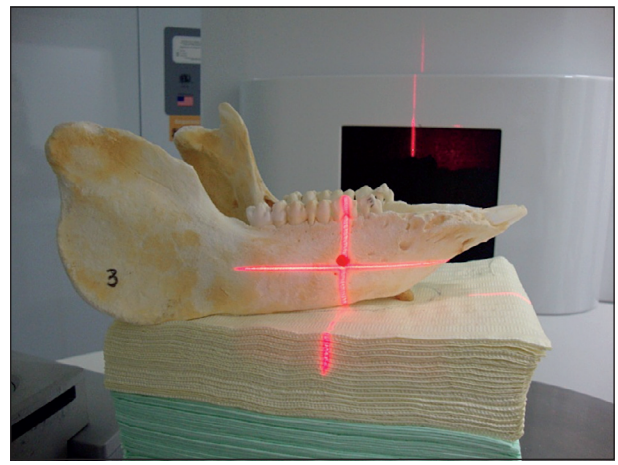

Figure 2 | Positioning of the pig mandible in the cone-beam computed tomography unit: the reference line was positioned on the most eminent mental foramen.

Figure 3 | Image visualized using Xoran computed tomography software.

Microsoft Corporation, Redmond, WA, USA) and statistically analyzed (ANOVA and Mann-Whitney) using Origin software (version 8,7.5; OriginLab Corporation, Northampton, MA, USA). The significance level was set for a p-value < 0.05. The Bonferroni and Tukey corrections were applied for significant differences.

RESULTS

Initially, we sought to identify differences in all measurements between the right and left sides (Table 1). The results showed no difference between the data for molars on both sides. Therefore, the total sample (14 measurements) was utilized.

According to the statistical evaluation, there

was no significant difference between the measurements performed by examiners AV1 and AV2 using the three methods (Table 2). This confirmed the standardization of the examiners' procedures and the appropriateness of the methodology.

Table 3 shows an analysis of the data obtained using the different methods. The results indicate no statistically significant difference between the measurements obtained with the caliper and those obtained using CBCT. Similarly, no significant difference was observed between the measurements obtained using the different CBCT voxel sizes.

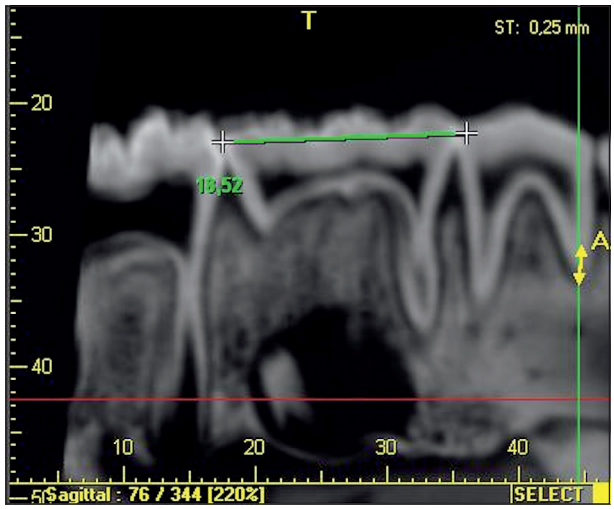

Figure 4 | Use of the software's electronic ruler.

DISCUSSION

Three-dimensional information has become an important input for surgical diagnosis and planning in the oral and maxillofacial regions. In recent years, CBCT has achieved a great acceptance among clinicians in the dental field, and has replaced helical CT in various tasks given its low scanning time and low dose of radiation.[1-3,5]

Investigators have worked with linear measurements in CBCT images and found CBCT measurements to be similar to those obtained *in vivo*, thus validating measurement and planning protocols for anatomical sites for implant placement and orthognathic surgery. Furthermore, CBCT eliminates the difficulty associated with positioning the patient's head and with possible uncertainties in measurements derived from asymmetry or malposition of the patient.[1,2] In the present study, we obtained images of pig mandibles using a CBCT device. Given that positioning of the skull does not interfere with

Table 1 | Linear measurements taken by the two examiners of the mesiodistal distance of the right (R) and left (L) mandibular first molars, using the direct and indirect methods.

Methods	Examiners	Sides	Mean values	Standard deviations	*P* values*
Caliper	AV1	R	18.49	0.978	0.369
		L	18.5	0.998	0.377
	AV2	R	18.42	0.943	0.356
		L	18.53	0.910	0.344
CBCT* (voxel: 0.125 mm)	AV1	R	18.37	0.936	0.354
		L	18.07	0.830	0.313
	AV2	R	18.11	0.806	0.304
		L	18.07	0.888	0.335
CBCT (voxel: 0.25 mm)	AV1	R	18.11	1.133	0.428
		L	17.78	1.103	0.416
	AV2	R	18.14	0.946	0.357
		L	18.10	0.944	0.357

CBCT: cone-beam computed tomography; *significant for $p < 0.05$.

Table 2 | Comparison of data obtained by the two examiners according to the methods used to obtain linear measurements of the mesiodistal distance in the total sample (N = 14) of pig mandibles.

Methods	Examiners	Mean values	Standard deviations	*P* values*
Caliper	AV1	18.49	0.949	0.253
	AV2	18.482	0.892	0.238
CBCT* (voxel: 0.125 mm)	AV1	18.225	0.865	0.231
	AV2	18.091	0.815	0.217
CBCT (voxel: 0.25 mm)	AV1	17.949	1.087	0.290
	AV2	18.125	0.908	0.242

CBCT: cone-beam computed tomography; * significant for p < 0.05.

Table 3 | Comparison of data obtained by each examiners according to the methods used to obtain linear measurements of the mesiodistal distance in the total sample (N = 14) of pig mandibles.

Examiners	Methods	Mean values	Standard deviations	*P* values*
AV1	Caliper	18.496	0.949	0.253
	CBCT* (voxel: 0.125 mm)	18.225	0.865	0.231
	CBCT (voxel: 0.25 mm)	17.949	1.087	0.290
AV2	Caliper	18.482	0.892	0.238
	CBCT (voxel: 0.125 mm)	18.091	0.815	0.217
	CBCT (voxel: 0.25 mm)	18.125	0.908	0.242

CBCT: cone-beam computed tomography; * significant for p < 0.05.

the measurement of interest, and that pigs have a pattern of growth and embryological development similar to that of humans[6] (being also similar in their anatomy and pathophysiology),[7] we considered the protocol valid.

In clinical practice, CBCT image quality can be influenced by many factors such as field of view, tube voltage and amperage of the apparatus, as well as spatial resolution as defined by voxel size. Images with an increased spatial resolution have less metal artifacts and an increased signal-to-noise ratio. However, there is an increase in the scanning time and a risk of patient movement, with a consequent increase in the radiation dose received by the patient.[3,5] Therefore, although CBCT has improved in terms of unnecessary exposure to radiation, the relationship between radiation dose and image quality should be part of the protocol choice process, since the radiation emitted has ionizing properties.[5]

Previous studies on the relevance of voxel size in linear measurements found no difference between the resolutions considered.[3,5,8,9] Damstra *et al.*[3] compared the data obtained using CBCT (voxels of 0.25 and 0.4 mm) with that obtained using a digital caliper (regarded as the gold standard). There was no statistically significant difference between the measurements obtained on CT images and the actual anatomical measurements. Torres *et al.*[8] compared four CBCT protocols (voxels of 0.2, 0.25, 0.3, and 0.4 mm) and all of them showed to be effective, without any significant difference between them for vertical and horizontal measurements. Patcas *et al.*[9] evaluated bone height and thickness and found that measurements obtained on images with a 0.4 mm voxel size were as accu-

rate as those obtained on images with a 0.125 mm voxel size. Similarly to that reported in the literature, this study found no significant difference between measurements obtained on images with voxels of 0.125 and 0.25 mm (Table 3). In addition, we highlight that the increase in voxel resolution did not result either in greater image accuracy or greater diagnostic accuracy. Nevertheless, the literature emphasizes that images with lower voxel values have specific indications for the evaluation of root fracture and resorption because these require more detail.[8] Thus, we emphasize that the influence of other aspects on the accuracy of linear measurements should be investigated.

In conclusion, there is no significant difference between linear measurements obtained from CBCT images with voxel sizes of 0.125 or 0.25 mm. Further studies on variables that may interfere with the accuracy of linear measurements are warranted.

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