Influence of mandibular positioning on the accuracy and reliability of linear measurements on cone beam CT using different voxels and two software programs

Influência do posicionamento mandibular na acurácia e confiabilidade de medidas lineares em tomografia computadorizada de feixe cônico utilizando diferentes *voxels* e dois *softwares*

Vinícius Tadeu Batistussi França[*]
Elen de Souza Tolentino[**]
Lilian Cristina Vessoni Iwaki[***]
Leticia Ângelo Walewski[****]
Matheus Herreira-Ferreira[*****]
Wilton Mitsunari Takeshita[******]
Mariliani Chicarelli da Silva[*******]

Abstract

Objective: this study evaluated the accuracy and reliability of linear measurements on cone beam CT (CBCT) scans in two software programs, using different voxels and varying mandible positioning. Material and methods: CBCT images of 10 human mandibles with 25 markers were obtained using different acquisition protocols (0.250, 0.300, 0.400-mm voxels) and mandible orientations (centered, rotated 10° laterally to right and left, tilted 10 up and down); fourteen measurements were carried out on the multiplanar reconstructions in XoranCat and OsiriX Lite software programs. The findings were compared to physical measurements using a digital caliper. ANOVA and correlation coefficient tests were used, at $\alpha = 0.05$. Results: there was no statistically significant difference when the measurements were compared in acquisitions with different voxel sizes analysed in both software programs. Mandibular positioning changes did not influence the measurements. No differences were found when the values were compared between the software programs and the digital caliper. Conclusion: linear measurements in both programs were reliable and accurate compared with physical measurements when using all acquisition protocols. The accuracy and reliability of the measurements were not influenced by variations in the mandible positioning.

Keywords: dimensional measurement accuracy; cone beam computed tomography; diagnostic imaging; mandible; software.

http://dx.doi.org/10.5335/rfo.v25i3.11730

[*] DDS, Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil.
[**] PhD, Professor of Dental Radiology and Stomatology, Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil.
[***] PhD, Professor of Dental Radiology and Stomatology, Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil.
[****] DDS, MSc, Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil.
[*****] DDS, Oral and Maxillofacial Radiology Resident, State University of Maringá, Maringá, Paraná, Brazil.
[******] PhD, Professor of Dental Radiology, Department of Dentistry, Federal University of Sergipe, Lagarto, Sergipe, Brazil.
[*******] PhD, Professor of Dental Radiology and Stomatology, Department of Dentistry, State University of Maringá, Maringá, Paraná, Brazil.

Introduction

Interest in tridimensional imaging has grown in recent years. This exam modality overcomes the limitations of radiographs, allowing the analysis in different planes (coronal, sagittal and axial)[1], and enabling improved clinical and surgical diagnosis and planning[2]. Cone-beam CT (CBCT) is being more frequently applied for assessment in different clinical situations due to several advantages in relation to helical CT[3-6], such as lower radiation dose and less artifacts. Currently, CBCT is considered as a reliable technology for linear measurements, e.g., of anatomical sites, orthodontic assessment, and pre-operative evaluation for dental implants[7], as demonstrated by previous studies comparing this exam with high precision callipers[8,9]. Nevertheless, the literature has also shown that CBCT measurements are often lower than actual values[7,8], although they are very close.

After the image acquisition in the CBCT device, the data are stored in DICOM (Digital Imaging and Communication in Medicine) format and can then be exported to other image file formats, allowing the use of different software programs, including those in the public domain[10]. However, since these programs use different reconstruction algorithms, it is important to assess how they behaves when processing data, and whether there is any distortion in measurements when the data is converted.

There are some factors that may influence the quality of the CBCT scan, leading to differences in image resolution and measurement accuracy[11], such as the voxel size[11], the software program[11], and the patient's positioning[12,13]. These parameters vary among CBCT devices and imaging protocols[14]. The voxel is the smallest unit of the 3D image, and its size directly influences the image quality[11]. Similarly, the orientation of the patient's head is an issue of concern. The correct patient positioning is guided by the manufacturer. However, in a clinical situation, minimal technical errors and/or minor patient movement is always expected, even when using head-positioning devices.

In this context, it is speculated that the combination of factors (such as software program, voxel size and patient positioning) may interfere with the CBCT image, compromising the measurements clinically. Thus, the aim of this work is to evaluate the accuracy and reliability of mandibular linear measurements in two CBCT software programs, with acquisition protocols varying the voxel size and the mandible positioning.

Material and methods

After ethical approval (62133916.1.0000.0104) ten macerated human mandibles with preserved bone cortices were selected without distinction of sex and ethnicity. The null hypothesis of this study was that there is no difference in CBCT linear measurements when imaging the mandible in different orientations, voxels sizes and using different software programs.

Hyperdense 2x2 mm cylindrical silicon-based markers with a central orifice of 0.5 mm of diameter were glued directly onto the selected points of the mandibles with an ethylene-vinyl acetate polymer, to standardize both physical and virtual measurements[9,15]. Twenty-two mandibular points with easy visualization and demarcation[9,15] were selected: Coron - point localized on the superior limit of the coronoid process (bilateral); MF - the most lower and posterior point of the mental foramen (bilateral); LLco - point localized on the lateral limit of the condyle (bilateral); MLco - point localized on the medial limit of the condyle (bilateral); AC - the most upper point of the alveolar crest on the mental foramen region (bilateral); R1 - the most concave point on the anterior border of the mandibular ramus (bilateral); R2 - the point directly opposite to R1 on the posterior border of the mandibular ramus (bilateral); R3 -the deepest point on the sigmoid notch (bilateral); Go - the midpoint on the curvature of the angle of the mandible where the ramus and the body of the mandible meet (bilateral); MandF - the most lower and posterior point of the mandibular foramen (bilateral); Me - the most inferior midpoint of the chin on the outline of the mandibular symphysis; and AC.Me - point localized on the alveolar crest in the mental region (Figure 1).

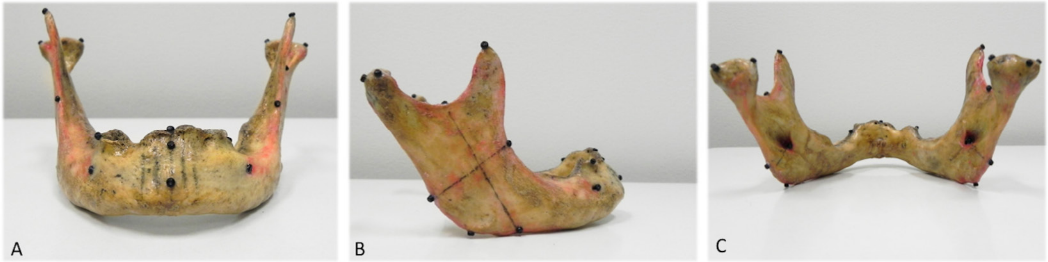

Figure 1 – Twenty-two mandibular points defined with hyperdense cylindrical silicon-based markers: (a) anterior, (b) lateral and (c) posterior view. The points were used to standardize both physical and virtual linear measurements.

Source: authors.

The physical measurements were performed by one observer twice, with interval of 30 days between them, using a digital caliper (Mitutoyo® Sul Americana Ltd., Suzano, SP, Brazil) with a 0.1-mm-thick edge as a reference for the central orifices of the markers[9]. Then, each mandible was positioned on the acrylic table of the i-Cat Next Generation device (Imaging Sciences International, Hatfield, PA, USA) without soft tissue coverage[9] and the acquisition protocols used were a field of view (FOV) of 13x16 cm (120kVp, 3-8mA) and voxels sizes of 0.250 mm, 0.300 mm and 0.400 mm.

The positioning of the mandibles varied in each acquisition protocol as follows: i) the median sagittal plane positioned perpendicular to the ground with the occlusal plane parallel to the ground (according to the manufacture's instruction); (ii): the mandible rotated 10° laterally to the right; (iii) the mandible rotated 10° laterally to the left; (iv) the mandible tilted 10° up; and (v) the mandible tilted 10° down. In order to stabilize of the mandibles and facilitate their positioning, a base with utility wax was made. For up and down positioning, a utility wax ramp was made to allow inclination.

The original data were stored in DICOM format and transferred to two software programs: XoranCat version 3.1.62 (Xoran Technologies, Ann Arbor, MI, USA) - proprietary software of the CBCT equipment; and OsiriX Lite (Pixmeo SARL, Switzerland) - available for free. The scans were independently assessed by two calibrated radiologists with at least eight years of experience with CBCT in a Dell screen 15.6″ with resolution of 1920×1080 pixels (Dell, Eldorado do Sul, RS, Brazil) running the Windows XP (Microsoft, Redmond, WA, USA). The measurements were performed twice, with interval of 30 days in between, to evaluate the intra- and inter-examiner agreement.

The linear measurements were carried out directly on the multiplanar reconstructions (axial, coronal and sagittal). The coordinates for the spatial orientation of each software were used to obtain the best visualization of the centre of each reformatted marker and to confirm the location of the points. The reference to standardize the axial and sagittal planes was the midline and a perpendicular line between the right and left mentual foramen, coinciding with the horizontal and vertical planes, respectively. For the coronal plane standardization, a line perpendicular to the other two lines was used, thus concluding the positioning of the images in the three spatial planes. In each software, the mandibular points should match the center of the markers. When they did not coincide during the correction of the mandibular position, new rotation was performed until their convergence, allowing the measurement, as seen in Figure 2.

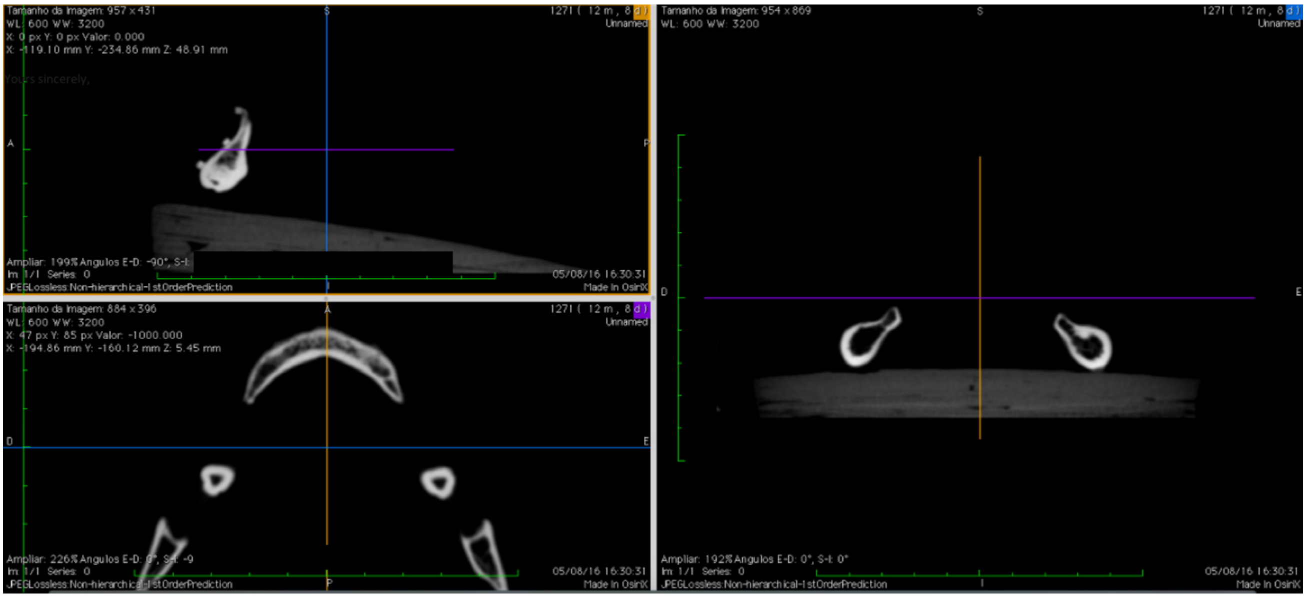

Figure 2 – Software OsiriX Lite (Pixmeo SARL, Switzerland). The multiplanar planes were rotated, allowing the points of interest to appear in the same plane.

Source: authors.

Fourteen linear measurements (in millimetres) were carried out directly on the mandibles (physical measurements) and on the two software programs using the three different voxels (virtual measurements) and varying the mandibular positioning: MF-MF (distance between left and right mental foramen); R2-R2 (distance between left and right R2); MLco-MLco (distance between left and right MLcon); Go-Coron (distance between Go to Coron bilaterally); R1-R1 (distance between left and right R1); R2-R3 (distance between R2 to R3 bilaterally); MF-AC (distance between mental foramen to alveolar crest bilaterally); AC.Me-Me (distance between AC.Me to Me); MLco.l-LLco.r (distance between left MLco to right LLco); MLco.r-LLco.l (distance between right MLco to left LLco); LLco-LLco (distance between right and left LLco).

Statistical analysis

Analysis of variance for repeated measures (ANOVA) test was used to compare voxels, software programs and mandible positioning. To evaluate the accuracy of the different software programs when mandibles were tilted/rotated, the correlation coefficient (CC) was applied. The level of intra and interobserver agreement was assessed by Kappa statistics. The data were analysed on Prism 5.0 software (GraphPad Software Inc, La Jolla, CA) and values of $p < 0.05$ were considered significant.

Results

Kappa value for intra- and interobserver agreement ranged from 0.89 –1.00. There were no statistically significant differences in the linear measurements when the mandibles were rotated or tilted in all acquisitions (voxel size 0.250, 0.300, 0.400 mm) and in both software programs. Physical and virtual measurements did not present significant differences (Tables 1-3).

Table 1 – Mean values (mm) of the physical and virtual linear measurements for the different mandibular positions in the XoranCat and OsiriX Lite software programs, using a 0.250 mm voxel size.

		XoranCat						OsiriX Lite					
Me	**Cp**	**OPPG**	**10°R**	**10°L**	**10°U**	**10°D**	**p**	**OPPG**	**10°R**	**10°L**	**10°U**	**10°D**	**p**
1	45.51	45.20	45.30	45.29	45.2	45.27	1.00	45.30	45.29	43.46	45.3	45.40	0.93
2	95.32	95.07	95.09	95.15	95.2	95.24	1.00	95.32	95.32	95.32	95.32	95.32	0.98
3	83.45	83.57	83.70	83.53	83.6	83.59	1.00	83.57	83.62	83.53	83.4	83.50	1.00
4	83.14	83.45	83.51	83.62	83.7	83.43	0.99	83.55	83.63	83.74	83.6	83.50	0.99
5	17.46	17.08	17.32	17.24	17.4	17.23	0.99	17.00	16.96	16.90	17.1	17.12	0.99
6	16.63	16.50	16.50	16.35	16.4	16.35	0.99	16.05	16.11	16.16	16.2	16.20	0.99
7	24.07	24.07	23.98	23.91	24.0	23.96	1.00	23.76	23.60	23.63	23.9	23.84	1.00
8	13.21	13.31	13.41	13.44	13.4	13.45	1.00	13.11	13.20	13.14	13.1	13.18	1.00
9	12.08	10.58	10.76	10.55	10.89	10.43	1.00	11.93	11.77	11.90	11.8	11.85	1.00
10	26.22	26.10	26.20	26.07	26.2	26.05	1.00	25.84	25.97	25.83	26.1	26.10	1.00
11	26.66	26.57	26.53	26.46	26.6	26.58	1.00	26.27	26.47	26.46	26.6	26.44	1.00
12	82.07	82.27	81.86	81.96	81.8	81.83	0.99	82.06	82.01	81.97	81.9	81.95	0.99
13	55.70	55.38	55.54	55.54	55.7	55.13	1.00	55.16	55.18	55.16	55.4	55.27	1.00
14	54.63	54.64	54.17	54.25	54.4	54.26	1.00	54.23	54.07	54.02	54.2	54.14	1.00

ANOVA test. Me= measurements; Cp= caliper; OPPG: oclusal plane parallel to the ground; 10°R: mandible rotated 10° laterally to the right; 10°L: mandible rotated 10° laterally to the left; 10° U: mandible tilted 10° up; 10° D: mandible tilted 10° down.

Source: authors.

Table 2 – Mean values (mm) of the physical and virtual linear measurements for the different mandibular positions in the XoranCat and OsiriX Lite software programs, using a 0.300 mm voxel size.

		XoranCat						OsiriX Lite					
Me	**Cp**	**OPPG**	**10°R**	**10°L**	**10°U**	**10°D**	**p**	**OPPG**	**10°R**	**10°L**	10°U	10°D	p
1	45.51	45.09	45.34	45.14	45.3	45.11	0.99	45.26	45.29	45.16	45.4	45.36	1.00
2	95.32	95.23	95.11	95.32	95.3	95.10	1.00	95.24	95.20	95.14	95.3	95.24	1.00
3	83.45	83.64	83.65	83.64	83.6	83.73	1.00	83.61	83.47	83.42	83.4	83.43	1.00
4	83.14	83.62	83.47	83.63	83.7	83.58	0.99	83.52	83.74	83.74	83.7	83.58	0.99
5	17.46	17.09	17.91	17.38	17.3	17.21	0.98	16.90	16.93	16.93	17.2	17.09	0.99
6	16.63	16.43	16.49	16.26	16.3	16.34	0.99	16.12	16.04	16.08	16.2	16.05	0.98
7	24.07	23.98	24.01	23.92	24.0	23.94	1.00	23.63	23.72	23.73	23.8	23.80	1.00
8	13.21	13.24	13.41	13.30	13.5	13.52	1.00	13.27	13.18	13.09	13.1	13.18	1.00
9	12.08	10.81	11.04	10.87	10.28	10.74	1.00	11.92	11.94	11.86	11.9	11.89	1.00
10	26.22	26.23	26.14	26.10	26.0	26.12	1.00	25.80	25.84	25.99	26.0	26.11	1.00
11	26.66	26.46	26.57	26.48	26.4	26.56	1.00	26.33	26.43	26.40	26.5	26.48	1.00
12	82.07	81.91	81.87	81.99	81.8	81.77	1.00	81.89	81.99	82.02	81.7	81.90	0.99
13	55.70	45.09	45.34	45.14	45.3	45.11	0.99	55.07	55.18	54.97	55.2	55.25	0.99
14	54.63	95.23	95.11	95.32	95.3	95.10	1.00	54.02	54.02	53.98	54.1	54.15	1.00

ANOVA test. Me= measurements; Cp= caliper; OPPG: oclusal plane parallel to the ground; 10°R: mandible rotated 10° laterally to the right; 10°L: mandible rotated 10° laterally to the left; 10° U: mandible tilted 10° up; 10° D: mandible tilted 10° down.

Source: authors.

Table 3 – Mean values (mm) of the physical and virtual linear measurements for the different mandibular positions in the XoranCat and OsiriX Lite software programs, using a 0.400 mm voxel size

		XoranCat						OsiriX Lite					
Me	**Cp**	**OPPG**	**10°R**	**10°L**	**10°U**	**10°D**	**p**	**OPPG**	**10°R**	**10°L**	**10°U**	**10°D**	**p**
1	45.51	45.46	45.20	45.18	45.3	45.42	0.99	45.24	45.27	45.25	45.3	45.28	1.00
2	95.32	95.12	95.13	95.21	95.3	95.01	1.00	95.33	95.17	95.08	95.3	95.24	1.00
3	83.45	83.36	83.67	83.83	83.7	83.65	0.99	83.75	83.77	83.52	83.5	83.47	1.00
4	83.14	83.49	83.50	83.62	83.7	83.45	0.99	83.57	83.70	83.73	83.7	83.70	0.99
5	17.46	17.13	17.24	17.26	17.4	17.16	0.99	16.91	16.97	16.78	17.1	17.08	0.99
6	16.63	16.46	16.35	16.49	16.3	16.29	0.99	16.07	16.00	16.18	16.1	16.17	0.98
7	24.07	23.94	23.87	23.92	24.0	23.99	1.00	23.57	23.56	23.57	23.7	23.71	1.00
8	13.21	13.34	13.37	13.41	13.4	13.47	1.00	13.35	13.19	13.15	13.1	13.22	1.00
9	12.08	12.28	12.37	12.34	12.3	12.32	1.00	11.91	11.86	11.71	11.8	11.83	1.00
10	26.22	26.08	26.11	26.03	26.0	26.06	1.00	25.89	25.89	25.92	26.0	25.94	1.00
11	26.66	26.32	26.42	26.37	26.4	26.44	1.00	26.29	26.45	26.27	26.3	26.40	0.99
12	82.07	82.14	82.09	81.98	81.9	81.81	0.99	81.89	81.94	82.02	81.9	81.97	0.99
13	55.70	55.75	55.50	55.22	55.6	55.19	0.99	55.17	55.13	55.08	55.3	55.25	0.99
14	54.63	54.24	54.17	54.11	54.2	54.24	1.00	54.12	54.06	53.99	54.1	54.09	1.00

ANOVA test. Me= measurements; Cp= caliper; OPPG: oclusal plane parallel to the ground; 10°R: mandible rotated 10° laterally to the right; 10°L: mandible rotated 10° laterally to the left; 10° U: mandible tilted 10° up; 10° D: mandible tilted 10° down.

Source: authors.

A very strong correlation was observed between both software programs (CC>0.99), even when the mandible was tilted/rotated, as showed in Table 4.

Table 4 – Coefficient of correlation (CC) between physical and virtual linear measurements in the different mandibular positions in both software programs

Mandible positioning	XoranCat	OsiriX Lite
Oclusal plane parallel to the ground	0.99	0.99
Mandible rotated 10° laterally to the right	0.99	0.99
Mandible rotated 10° laterally to the left	0.99	0.9
Mandible tilted 10° up	0.99	0.98
Mandible tilted 10° down	0.99	0.99

Source: authors.

Discussion

Currently, CBCT software programs are assisting dental practitioners in the diagnosis and planning within the dental specialities[16], e.g. linear and angular measurements for the purpose of orthodontic treatment[8], orthognathic surgery or dental implants planning[7]. Successful orthodontic and surgical treatments require accurate and reliable imaging of the craniofacial complex[13]. Because of the advances in CBCT scanners and software, it is possible to take advantage of CBCT information in a clinical setting[16]. It is known that there are some parameters that may influence the quality of the CBCT exam, such as the detector type, image resolution, FOV, voxel size, software, artefacts, and patient movement. Some of these factors vary among CBCT equipment and with different imaging protocols[14], which may lead to differences in the images' measurements[11]. Some authors[7,8] agree that CBCT measurements may underestimate the anatomic truth. However, corroborating the present data, some investigations found that virtual linear measurements are reliable when compared with the physical measurements[8,9,10,15-19]. The direct evaluation of patients or objects with high precision callipers remains the standard from which to judge other measurement techniques[13,19], and, for this reason, was used as the reference standard.

As well as the CBCT instruments, the number of software programs increased rapidly. The original images can be exported in the third-party proprietary and also non-proprietary DICOM (digital imaging and communications in medicine) file format, allowing the use of public domain image processing software[10]. In this process, CBCT-basis images - which are similar to lateral and posterior–anterior "cephalometric" radiographical images - are compressed in a volume, which is re-segmented as primary axial reconstructions, to be compressed as a DICOM file[10]. Because these programs use different reconstruction algorithms, it is important to assess how they behave when processing data and whether the conversion process is secure.

The available investigations regarding the reliability of CBCT software programs include free (InVesalius[9], RadiAnt[9], KDIS3D[10], OnDemand3D[20]), proprietary manufacturer acquisition (XoranCat[9,10,21]) and purchased (InVivo[10,20], Dolphin Imaging[10,15,19,20]) programs. All these studies suggest that the DICOM conversion process is safe and that all programs are reliable. We investigated a proprietary manufacturer acquisition software (XoranCat) and a third-party program available for free (OsiriX Lite). The XoranCat is provided by the i-Cat equipment and acts as both acquisition and viewing software. The OsiriX supports Microsoft Windows and Apple MacOS and, for this reason, is a widely used DICOM viewer. The OsiriX Lite version can be downloaded from the Internet. Both software packages showed high accuracy rates (CC>0.99) without statistically significant differences were found between physical and virtual linear measurements, with excellent intra- and inter-observer reliability. A previous study[9] also demonstrated that the choice of the software does not influence on CBCT accuracy for linear measurements in multiplanar reconstructions. It contributes to show that, among the extensive amount of software programs available, the clinician may also opt for packages available for free.

The i-Cat Next Generation was used in the present investigation, because of its ability to offer such different acquisition settings, supplying the demands of various specialties. Also, this system is among the more commonly used units in the world. The protocol used was a 13x16cm FOV, which covered the entire mandible, and 0.250, 0.300 and 0.400-mm voxels available in the i-Cat instrument[9]. According to some authors[17] the variation in the voxel size may influence the precision of measurements. Because different voxel sizes have a direct influence on the image quality[11], we also compared the possible interference of this parameter in the linear measurements and, corroborating previous data[9,18,21], no statistical difference in the measurements were found when different voxel sizes were used. For this reason, we agree with the Ballrick *et al.*[18] (2008), Tolentino *et al.*[9] (2018) and also Gungor & Dogan[21] (2017) that a 0.400-mm voxel may be adequate for taking measurements in craniofacial structures, providing a shorter scanning time and lower exposure to radiation, enabling good resolution for diagnosis or planning in most cases. Reduced voxel sizes are a better option in cases that demand extremely accurate images[9], since the diagnosis is easier when small voxels are used[22].

Unlike some studies[15,17], which evaluated the precision of measurements in three-dimensional models, in this investigation the measurements were performed in multiplanar reconstructions, as previously reported[9]. We used fourteen linear measurements, while the other authors used twenty-five[9], seventeen[15] and twenty[13] measures. The use of cylindrical hyperdense silicon-based markers was previously reported as a good alternative for landmark representation[9,15], due to their characteristics, such as low cost, absence of metallic artefacts, easy identification and precise identification of the points[15]. Poleti *et al.*[15] (2016) associated the excellent reliability found with the characteristics of the marker. A methodological limitation in this study was the alignment of the images. Typically, the two anatomical landmarks between which a line is drawn are not identifiable on the same slice when thin slices are utilized (0.5–1.0 mm)[12]. This is due to variations in the location of the landmarks and also because of the mandibular positioning changes. Therefore, it was necessary to scroll through the slices back and forth or right and left to identify the anatomical landmarks on both sides bilaterally or antero-posteriorly, as previously described[12]. However, this repositioning did not statistically influence the linear measurements. We speculate that if silica markers were not used, the results could have diverged, influencing the final effect of this evaluation.

In addition to comparing the software programs and the voxel size interference on the reliability of linear measurements, we also evaluated the combination of these factors with changes in patients positioning. CBCT equipment have integrated head-positioning devices (e.g. upper lip and chin rest) to ensure stabilization. Nevertheless, they may cause obliteration and distortion of the patient's facial soft tissues[13] for orthodontic and/or orthognathic purposes, for example. The accuracy with respect to the orientation of the patient's head without head-positioning devices is still inconclusive. In general, manufacturers recommend that the patient's medial sagittal plane be positioned perpendicular to the ground with the occlusal plane parallel to the ground, in a 'centralized' position. However, in clinical conditions, variations in imaging parameters, subjects, and structures of interest make it difficult to confidently apply these instructions. A minor patient movement in the focal trough of the CBCT is unplanned and may not be noticeable and may influence the accuracy of linear measurements.

Hassan *et al.*[12] (2008) scanned dry skulls in ideal and rotated positions (tilted 15° laterally) and found that measurements based on 3D CBCT surface images were accurate, and that slight variations in the position of the patient's head did not influence the accuracy of the measurements. Berco *et al.*[23] (2009) found no statistically significant differences when they compared the accuracy and reliability of CBCT measurements with physical measurements of a dry skull when the Frankfort horizontal was plane parallel to the floor, and with the Frankfort horizontal plane aligned 45° to the floor. El-Beialy *et al.*[13] (2011) changed the orientation of the skull to six positions and showed that the accuracy and reliability of CBCT linear measurements were not affected by changing the skull orientation. All of these studies used only one voxel size.

Perfect concordance was found between the coordinates of the different positions compared with the centered position in the present study.

These results agree with those of Hassan *et al.*[12] (2008), Berco *et al.*[23] (2009) and El-Beialy *et al.*[13] (2011) even though the tilt we used was not only in the lateral direction as described by Hassan *et al.*[12] (2008) and Berco *et al.*[23] (2009), but also in different directions. We chose to change the mandible orientation by only 10°, as an attempt to simulate common positioning errors in the clinical practice. Actually, no information could be found in the literature with regard to the incidence and extent of patient positioning errors in a scanner[12]. In this context, we could infer that if the patient's head is stable during scanning, the spatial position of the mandible in the focal trough of the CBCT will not affect the outcome. This is an expected situation, e.g. when scanning a child.

Conclusion

In conclusion, linear measurements on XoranCat and OsiriX Lite were reliable and accurate compared with physical measurements when using all acquisition protocols, with excellent intra and inter-observer agreement. Variations up to 10° in mandibular position did not affect the accuracy and reliability of linear measurements based on CBCT multiplanar reconstructions. The measurements performed when mandibular positioning was altered were not influenced by software and voxel size. However, we emphasize the limitations of this *in vitro* study, since accuracy may vary in clinical situations, when other parameters are involved, such as attenuation of soft tissues and metallic artefacts.

Resumo

Objetivo: este estudo avaliou a acurácia e confiabilidade das medidas lineares em exames de tomografia computadorizada de feixe cônico (TCFC), em dois *softwares*, utilizando diferentes *voxels* e variando o posicionamento da mandíbula. Material e Métodos: 10 imagens de TCFC de mandíbulas humanas com 25 pontos foram obtidas, usando diferentes protocolos de aquisição (0.250, 0.300, 0.400-mm *voxels*) e orientações da mandíbula (centralizada, rotacionada 10° lateralmente para direita e esquerda, inclinada 10° para cima e para baixo); 14 medidas foram realizadas nas reconstruções multiplanares nos *softwares* XoranCat e OsiriX. Os achados foram comparados com as medidas físicas através de um paquímetro digital. O teste ANOVA e o coeficiente de correlação foram utilizados com $p < 0,05$. Resultados: não houve diferença estatisticamente significante quando as medidas foram comparadas em aquisições com diferentes tamanhos de *voxels* em ambos os *softwares*. A posição da mandíbula não influenciou nas medidas. Nenhuma diferença foi encontrada quando os valores foram comparados entre os *softwares* e o paquímetro digital. Conclusão: as medidas lineares em ambos os *softwares* foram confiáveis e acurados comparados a mensuração física em todos os protocolos. A acurácia e a confiabilidade das mensurações não influenciaram de acordo com as variações de posicionamento da mandíbula.

Palavras-chave: precisão da medição dimensional; tomografia computadorizada de feixe cônico; diagnóstico por imagem; mandíbula; *software*.

References

1. Nasseh I, Al-Rawi W. Cone Beam Computed Tomography. Dental Clinics of North America 2018; 62(3):361-91.
2. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. Int J Oral Maxillofac Surg 2009; 38:609-25.
3. Schulze RKW, Drage NA. Cone-beam computed tomography and its applications in dental and maxillofacial radiology. Clinical Radiology 2020; 75(9):647-57.
4. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 2008; 106(1):106-14.
5. Caetano APF, Sousa TO, Oliveira MR, Evanglista K, Bueno JM, Silva MA. Accuracy of three cone-beam CT devices and two software systems in the detection of vertical root fractures. Dentomaxillofac Radiol 2021; 50(3):20200334.
6. Vaz SLA, Vasconcelos TV, Neves FS, Freitas DQ, Haiter-Neto F. Influence of cone beam computed tomography enhancement filters on diagnosis of simulated external root resorption. J Endod 2012; 38:305-8.
7. Lascala C, Panelaa J, Marques M. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol 2004; 33:291-4.
8. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009; 136:19-25.
9. Tolentino ES, Yamashita FC, De Albuquerque S, Walewski LA, Iwaki LC, Takeshita WM, *et al*. Reliability and accuracy of linear measurements in cone-beam computed tomography using different software programs and voxel sizes. J Conserv Dent 2018; 21:607-12.

10. Melo SLS, Haiter-Neto F, Correa LR, Scarfe WC, Farman AG. Comparative diagnostic yield of cone beam CT reconstruction using various software programs on the detection of vertical root fractures. Dentomaxillofac Radiol 2013; 42:20120459.

11. Costa FF, Gaiz BF, Umersubo OS, Pinheiro LR, Tortamo IP, Cavalcanti MGP. Use of large-volume cone-beam computed tomography in identification and localization of horizontal root fracture in the presence and absence of intracanal metallic post. J Endod 2012; 38:856-9.

12. Hassan B, Setelt P, Sanderink G. Accuracy of three-dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. Eur J Orthod 2008; 23:1-6.

13. El-Beialy AR, Fayed MS, El-Bialy AM, Mostafad YA. Accuracy and reliability of cone-beam computed tomography measurements: Influence of head orientation. Am J Orthod Dentofacial Orthop 2011; 140:140-57.

14. Librizzi ZT, Tadinada AS, Valiyaparambil JV, Lurie AG, Mallya SM. Cone-beam computed tomography to detect erosions of the temporomandibular joint: effect of field of view and voxel size on diagnostic efficacy and effective dose. Am J Orthod Dentofacial Orthop 2011;140:e25-30.

15. Poleti ML, Fernandes TM, Pagin O, Moretti MR, Rubira--Bullen IR. Analysis of linear measurements on 3D surface models using CBCT data segmentation obtained by automatic standard pre-set thresholds in two segmentation software programs: an in vitro study. Clin Oral Investig 2016; 20:179-85.

16. Grauer D, Cevidanes LSH, Proffit WR. Working with DICOM craniofacial images. Am J Orthod Dentofacial Orthop 2009; 136:460-70.

17. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 2008; 78:387-95.

18. Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Am J Orthod Dentofacial Orthop 2008; 134:573-82.

19. Timock AM, Cook V, McDonald T, Leo MC, Crowe J, Benninger BL, *et al*. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. Am J Orthod Dentofacial Orthop 2011; 140:734-44.

20. El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010; 137: S50.e1–S50.e9.

21. Gungor E, Dogan MS. Reliability and accuracy of cone-beam computed tomography voxel density and linear distance measurement at different voxel sizes: A study on sheep head cadaver. J Dent Sci 2017; 12(2):145-50.

22. Liedke GS, Silveira HED, Silveira HLD, Dutra V, Figueiredo JAP. Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. J Endod 2009; 35:233-5.

23. Berco M, Rigali PHJR, Miner MR, Deluca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop 2009; 136:17.e1-9.

Corresponding address:

Matheus Herreira-Ferreira
Avenida Mandacaru, 1.550
Zip Code: 87080-000 – Maringá, PR, Brazil
Telephone/fax number: +55 44 3011-9055
E-mail: matwzferreira@gmail.com

Recebido: 09/10/2020. Aceito: 14/06/2021.