RESEARCH

Accuracy assessment of the axial images obtained from cone beam computed tomography

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Objective: The aim of this study was to evaluate accuracy of linear measurements assessed from axial tomograms and the influence of the use of different protocols in two cone beam CT (CBCT) units.

Methods: A cylinder object consisting of Nylon® (Day Brazil, Sao Paulo, Brazil) with radio-paque markers was radiographically examined applying different protocols from NewTom 3G™ (Quantitative Radiology s.r.l, Verona, Veneto, Italy) and i-CAT™ (Imaging Sciences International, Hatfield, PA) units. Horizontal (A–B) and vertical (C–D) distances were assessed from axial tomograms and measured using a digital calliper that provided the gold standard for actual values.

Results: There were differences when considering acquisition protocols to each CBCT unit. Concerning all analysed protocols from i-CAT™ and Newtom 3G™, both A–B and C–D distances presented underestimated values. Measurements of the axial images obtained from NewTom 3G™ (6 inch 0.16 mm and 9 inch 0.25 mm) were similar to the ones obtained from i-CAT™ (13 cm 20 s 0.3 mm, 13 cm 20 s 0.4 mm and 13 cm 40 s 0.25 mm).

Conclusion: The use of different protocols from CBCT machines influences linear measurements assessed from axial images. Linear distances were underestimated in both equipments. Our findings suggest that the best protocol for the i-CAT™ is 13 cm 20 s 0.3 mm and for the NewTom 3G™, the use of 6 inch or 9 inch is recommended.

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Introduction

CT has been previously used as the chosen technique to diagnose the maxillofacial complex and to plan implant and bone graft placement. The cone-beam CT (CBCT) protocols had been developed to enhance image quality with lower doses of radiation in relation to the conventional CT.

Mozzo et al¹ and Arai et al² were the first to present CBCT machines for use in dentistry. Since then, many publications have described its applications and defined its characteristics, which include high radiographic quality in images of dentomaxillofacial areas, lower doses of radiation, less time spent during image-acquisition and reduced costs.^{3–8} However, publications evaluating CBCT image accuracy have only appeared from 2003 onwards.^{9–19}

The CBCT machines differ in types of sensors, field of view (FOV) sizes, spatial resolutions and software. The small FOV is recommended in cases in which high resolution is required (accessory canals, radicular fractures, bone fenestration and bone height). The medium FOV works better for oral surgery, temporomandibular joint (TMJ) assessment, studies of bone lesions and implantology. In cases in which a full facial analysis is required, as in a three-dimensional (3D) cephalometric analysis, the large FOV is the best choice. Therefore, the experiment was conducted with image acquisition protocols applying 2 different FOVs for the i-CAT™ (Imaging Sciences International, Hatfield, PA) machine (20 cm and 13 cm) and 3 different FOVs for the NewTom 3G™ (Quantitative Radiology s.r.l, Verona, Veneto, Italy) (12 inch, 9 inch and 6 inch).

With the evolution of CBCT, the flat panel sensor became most used for its high resolution since it produces less noise, it is not sensitive to magnetic fields

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and it does not require frequent calibration. The i-CAT™ presents 3 types of image-acquisition protocols with the 13 cm FOV, where the acquisition time varies (10 s, 20 s or 40 s) and the voxel size also ranges from 0.4 mm to 0.25 mm.^{20–22}

The voxel size is determined by the size of each pixel in the image receptor, generating isotropic voxels (height = width = depth) that result in high clarity images, increasing the capacity to reproduce the hard-tissue details, mainly of delicate structures such as the lamina dura.²³ Theoretically, smaller voxel sizes produce better images,^{24,25} but other factors such as daily calibration, sensor quality, device projection, patient stability and software influence the final clarity achieved.

The objective of this experiment was to assess and compare the accuracy of the measurements from the axial images obtained from two CBCT machines in relation to the real measurement size of the images. The authors used images of axial tomograms assessed from the i-CAT™ and the NewTom 3G™ at the São Leopoldo Mandic Oral Research Center, Brazil.

Materials and methods

This experiment used a geometric phantom that was manufactured with synthetic polyamide Nylon® 6.0 through a lathe in a cylindrical shape measuring 5 cm in diameter and 10 cm in length. It had 4 fine channels of 1 mm in depth each, displayed at 90° among themselves in the longitudinal axis of the cylinder, and 10 fine channels with 1 mm in depth each, displayed transversally with an interval of 10 mm among them. It was fixed onto an acrylic support which allowed it to have its longitudinal axis in a horizontal position and it was at 90° to an acrylic stand.

The phantom was sent to the Mitutoyo South American Metrology Laboratory Ltd. for dimensional calibration, where the PML measurement procedure (0024 1/1 version) was used with a room temperature of 20.0°C ± 0.5°C. In this procedure, the phantom diameter was verified four times in ten in each of the ten sections using two co-ordinates A–B and C–D, whereby an average of the results was obtained. The uncertainty in measurement was $U = 0.001$ mm based on the combined standard uncertainty multiplied by a coverage factor $k = 2.3$ for a confidence level of approximately 95%.

After the dimensional calibration of the phantom was executed, a small amount of zinc oxide and eugenol Type III was inserted into each intersection of the fine channels of the phantom to identify the “sections” selected for the experiment (Figure 1). To identify the “points” with zinc oxide and eugenol Type III, an adhesive paper with letters A, B, C and D was used with the corresponding numbers from one to ten.

After obtaining the real measurements, the phantom was scanned in the i-CAT™ and NewTom 3G™ machines, following image acquisition protocols with different spatial resolutions (Table 1).

Figure 1 Phantom’s image presenting co-ordinates A1, B1, C1 and D1

In the acquisition of tomographic images by the i-CAT™ device, the phantom was positioned so that its longitudinal axis remained at the vertical position in relation to the ground in the infero-superior axis, using an individual undergoing examination as a reference. The equipment has its own support for scanning objects, with a prosthesis type or surgical-radiographic guide (Figure 2). In the acquisition of tomographic images by the NewTom 3G™, a support was created and the phantom was placed in a centred position in the examination area, with its longitudinal axis parallel to the ground (Figure 3)

The phantom scan followed the daily calibration protocol of each equipment in the room temperature of 20.0°C ± 0.5°C. After the scan, the primary reconstruction with maximum resolution was executed, followed by the secondary reconstruction with 1.5 mm thickness, thus obtaining the axial images. Taking into consideration the position of the phantom on the CBCT units, the axial image measuring began from the first section. However, the first section was not used in the research

Table 1 Image-acquisition protocols with different spatial resolutions

Protocols
I. i-CAT™ FOV of 20 cm, in the acquisition of 40 s (voxel size = 0.4 mm)
II. i-CAT™ FOV of 13 cm, in the acquisition of 10 s (voxel size = 0.4 mm)
III. i-CAT™ FOV of 13 cm, in the acquisition of 20 s (voxel size = 0.3 mm)
IV. i-CAT™ FOV of 13 cm, in the acquisition of 20 s (voxel size = 0.4 mm)
V. i-CAT™ FOV of 13 cm, in the acquisition of 40 s (voxel size = 0.25 mm)
VI. NewTom 3G™ FOV of 12 inch (30.48 cm) (voxel size = 0.36 mm)
VII. NewTom 3G™ FOV of 9 inch (22.86 cm) (voxel size = 0.25 mm)
VIII. NewTom 3G™ FOV of 6 inch (15.24 cm) (voxel size = 0.16 mm)

FOV, field of view

Figure 2 Phantom placed at the i-CAT™

since the zinc oxide and eugenol material was not limited to one identification point owing to its flow in the continuous solution of the fine channels in the surface. Therefore, the measuring was conducted from the second section onwards.

The proprietary software from each tomography system was used to assess these images. These images were viewed on a LCD flat-screen 17 inch monitor (LG model 5000:1 LG, Seoul, Korea) with a 1280×1024 pixel resolution and a maximum colour quality (12-bits), without the use of brightness and contrast tools or smoothing

filters. As indicated by the standard, the phantom diameter was measured in nine sections, using two co-ordinates (An/Bn and Cn/Dn) with numbers from two to ten, in the depth of each fine channel or between “points” with zinc oxide and eugenol Type III. This measurement was taken with the use of the program tool from each tomograph. For each axial image, measurements were taken horizontally (A–B distance) and vertically (C–D distance) four times, randomly, with an interval of 1 week.

The values of the four repetitions for each co-ordinate were referred to on a data spreadsheet (Excel,

Figure 3 Phantom placed at the NewTom 3G™

Microsoft, Seattle, WA) and ordered as follows: by tomograph, acquisition protocol, section and by distance (A–B and C–D). Based on the information collected, two statisticians conducted the experiments using the R software version 2.7.1 (GNU Project, Lucent Technologies, San Antonio, TX). The data collected were compared with the real measurements, calculating the minimum and maximum, the average and the standard deviation by tomograph and by the acquisition protocol. Moreover, an analysis of variance (ANOVA) was conducted, with two factors for the repeated measurements. The Tukey's test was applied to compare protocols, as well as the Wilcoxon test with Bonferroni correction to compare the average standard deviations among protocols. The level of significance was 95% ($\alpha = 5\%$) for all tests.

Results

i-CATTM tomograph

The *i-CATTM* tomography assessment showed that, in both A–B and C–D distances, all protocols presented values less than the real measurements (Figure 4a,b). Analysing the distances for each protocol, without axial image distinction, showed that the 13 cm, 20 s, 0.3 mm protocol presented the smallest standard deviations (0.157 mm for the A–B distance and 0.182 mm for the C–D distance).

Subsequently, to evaluate if there was a difference in the average distance measured between the protocols and the axial images, a variance assessment model was adjusted with two factors for repeated measurements. Both the

axial image factor as well as the interaction between the axial image and protocol did not present significant differences. There was no significant difference in the average distance observed among the axial images by protocol. Based on this result, a new model was adjusted with the protocol factor by itself and that showed a significant factor. There is at least one protocol that presents a different A–B average distance compared with the rest. Analogue analysis was conducted for the C–D distance, where the only significant factor was the protocol. A Tukey comparative test was applied to identify in which protocols a difference had occurred (Table 2).

There were statistical differences among all protocols and real measurements (averages presented shorter distances). The comparison between protocols showed that the 20 cm, 40 s, 0.4 mm protocol differs from the rest (*i.e.* it presented the least average distance). There was also a statistical difference between the 13 cm, 40 s, 0.25 mm protocol and the 13 cm, 20 s, 0.3 mm protocol. Between the 13 cm, 20 s, 0.4 mm protocol and the 13 cm, 40 s, 0.25 mm protocol, the former presented a higher average in the A–B distance. The 20 cm, 40 s, 0.4 mm protocol was statistically different from the rest, presenting a lower average. There was no statistical difference between the remaining protocols.

An observation based on this assessment showed that all protocols on average have underestimated the measurements. The most critical case occurred in the 20 cm, 40 s, 0.4 mm protocol. Since no statistical difference was identified within the 13 cm protocols, an assessment to discover which protocol was most precise was conducted, so that the one that presented the least measurement variability could be chosen. In order to do this, the standard deviations were compared with the axial image of the protocols (Figure 5a,b). For the C–D distance, the

Figure 4 (a) Box-plot (mean) graphic for A–B distances (in mm) using different protocols for *i-CATTM*. (b) Box-plot (mean) graphic for C–D distances (in mm) using different protocols for *i-CATTM*

Table 2 *P*-values for A–B and C–D distances applying different protocols to i-CAT™

Protocols	Distance A–B		Distance C–D	
	Difference (mm)	<i>P</i> -value	Difference (mm)	<i>P</i> -value
2 × 1 (20 cm, 20 s, 0.4 mm × real)	−1.213	<0.0001*	−1.055	<0.0001
3 × 1 (13 cm, 10 s, 0.4 mm × real)	−0.813	<0.0001*	−0.613	<0.0001
4 × 1 (13 cm, 20 s, 0.3 mm × real)	−0.675	<0.0001*	−0.559	<0.0001
5 × 1 (13 cm, 20 s, 0.4 mm × real)	−0.733	<0.0001*	−0.593	<0.0001
6 × 1 (13 cm, 40 s, 0.25 mm × real)	−0.583	<0.0001*	−0.484	<0.0001
3 × 2	0.400	<0.0001*	0.442	<0.0001
4 × 2	0.538	<0.0001*	0.496	<0.0001
5 × 2	0.480	<0.0001*	0.462	<0.0001
6 × 2	0.630	<0.0001*	0.571	<0.0001
4 × 3	0.138	0.0527	0.054	0.8718
5 × 3	0.080	0.5582	0.020	0.9983
6 × 3	0.230	<0.0001*	0.129	0.0829
5 × 4	−0.058	0.8390	−0.034	0.9818
6 × 4	0.093	0.3916	0.075	0.6247
6 × 5	0.150	0.0251*	0.109	0.2148

Protocols: 1 = real measure; 2 = 20 cm, 20 s, 0.4 mm; 3 = 13 cm, 10 s, 0.4 mm; 4 = 13 cm, 20 s, 0.3 mm; 5 = 13 cm, 20 s, 0.4 mm; 6 = 13 cm, 40 s, 0.25 mm

*Significance level of 5%

13 cm, 20 s, 0.3 mm protocol presented the least standard deviation variability among axial images.

A Wilcoxon test with Bonferroni correction was applied to compare the average standard deviation between protocols. Since there were five protocols, the total number of comparisons was ten. Each individual comparison was statistically significant if the *P*-value was $\leq 0.05/10 = 0.005$. The Wilcoxon test showed that there was no difference between the protocols in relation to the average standard deviation for both measurements. Therefore, statistically the protocols were equally precise.

NewTom 3G™ tomograph

Following the same line of reasoning, a similar assessment was conducted for the measurements obtained

from the NewTom 3G™ tomography. Notably, based on this assessment, the 12 inch, 0.36 mm protocol presented the greatest difference from the real measurements (Figure 6a,b).

Similar to the i-CAT™ tomography analysis, variance analysis models were applied, verifying that only the protocol factor was significant.

According to the Tukey's test result (Table 3), all protocols presented A–B and C–D distance averages that were inferior to the real measurements. The 12 inch, 0.36 m protocol was statistically different from the rest, presenting the lowest average. There was no significant difference between the 9 inch, 0.25 mm and the 6 inch, 0.16 mm protocols in relation to the average A–B distance. Therefore, as it occurred in the i-CAT™

Figure 5 (a) Box-plot standard deviation (SD) graphic for A–B distances using different protocols with the i-CAT™. (b) Box-plot (SD) graphic for C–D distances using different protocols with the i-CAT™

Figure 6 (a) Box-plot (mean) graphic for A–B distances (in mm) using different protocols with the NewTom 3G™. (b) Box-plot (mean) graphic for C–D distances (in mm) using different protocols with the NewTom 3G™

tomograph, all NewTom 3G™ protocols have underestimated the distances on average. Figure 7a,b presents the standard deviations of the axial images by protocol for the A–B and C–D distances, respectively.

To compare the protocols in relation to the average standard deviations between the axial images, the Wilcoxon test with Bonferroni correction was applied for multiple comparisons. Since there are three tests in total, the difference was significant when the value of P was $\leq 0.05/3 = 0.0167$. No significant difference was observed among protocols in relation to the average standard deviation of the axial images for both distances (Table 4).

Comparison between tomographs

To assess which of the two tomography systems is more accurate and precise, the measurements of the axial images obtained from the 6 inch, 0.16 mm and the 9 inch, 0.25 mm protocols from the NewTom 3G™ were compared with the ones obtained from the 13 cm, 20 s, 0.3 mm, the 13 cm, 20 s, 0.4 mm and the 13 cm, 40 s,

0.25 mm protocols from the i-CAT™. These protocols presented the best results for each tomograph.

The Tukey multiple comparisons data showed that there was a significant difference between the 13 cm, 20 s, 0.3 mm and the 9 inch, 0.25 mm, the 13 cm, 40 s, 0.25 mm and the 9 inch, 0.25 mm, the 13 cm, 40 s, 0.25 mm $\times$ 6 inch, 0.16 mm and the 13 cm, 40 s, 0.25 mm $\times$ 13 cm, 20 s, 0.4 mm protocols. The A–B distance measurements obtained from the i-CAT™ were on average greater than the ones obtained by the NewTom 3G™. Regarding the C–D measurement, there was no difference between the two tomography protocols. In relation to precision, the standard deviations were compared using an axial image of each protocol.

Table 5 presents the results from the Mann–Whitney tests comparing protocols. There was no significant difference among the protocols for both measurements, except for the 13 cm 20 s 0.3 mm $\times$ 9 inch 0.25 mm and the 13 cm 40 s 0.25 mm $\times$ 9 inch 0.25 mm cases. Therefore, one can say that there was no significant statistical difference in relation to the precision of the tomographs.

Table 3 P -values for A–B and C–D distances applying different protocols to Newtom 3G™

Protocols	Distance A–B		Distance C–D	
	Difference (mm)	P value	Difference (mm)	P value
12 inch 0.36 mm $\times$ real	–1.406	<0.0001*	–1.145	0.0000*
9 inch 0.25 mm $\times$ real	–0.814	<0.0001*	–0.498	0.0000*
6 inch 0.16 mm $\times$ real	–0.725	<0.0001*	–0.487	0.0000*
9 inch 0.25 mm $\times$ 12 inch 0.36 mm	0.592	<0.0001*	0.647	0.0000*
6 inch 0.16 mm $\times$ 12 inch 0.36 mm	0.681	<0.0001*	0.658	0.0000*
9 inch 0.25 mm $\times$ 6 inch 0.16 mm	0.089	0.1367	0.011	0.9958

*Significance level of 5%

Figure 7 (a) Box-plot standard deviation (SD) graphic for A–B distances using different protocols with the NewTom 3G™. (b) Box-plot (SD) graphic for C–D distances using different protocols with the NewTom 3G™

Discussion

The present study used a geometric phantom with previously known and calibrated measurements. This makes the dimensional comparison quite adequate and, while it presents the establishment of pure comparisons as advantageous, it also allows great reproducible parameters and it does not involve the exposure of living tissues. Overall, this type of method does not reproduce some physical phenomenon such as attenuation of the radiation beam, dispersed radiation and noise that occur in anthropometric studies.^{10,11,15,16,18,19} In relation to the measuring methodology, the image of each phantom section was denominated as axial image and the measurements were conducted by using a software linear measurement tool from each tomograph. These measurements were made amongst the images of the zinc oxide points of the fine channels according to the co-ordinates by a single observer randomly in four sessions, with a 1 week interval between each session. This methodological limitation had the purpose of lowering or eliminating the sample bias.

Table 4 Comparison of the A–B and C–D standard deviation distances for NewTom 3G™

Protocols	Distance A–B <i>P-value</i>	Distance C–D <i>P-value</i>
9 inch, 0.25 mm × 12 inch, 0.36 mm	0.7174	0.5344
6 inch, 0.16 mm × 12 inch, 0.36 mm	1.0000	0.3531
9 inch, 0.25 mm × 6 inch, 0.16 mm	0.7872	0.1205

In relation to the i-CAT™ tomograph, and in all the protocols, the A–B distance as well as the C–D distance presented shorter measurements than the real measures and there was divergence in relation to the variability among the axial images. These data corroborate the ones described in the literature.^{11,13,14,16}

The data assessment must be conducted following some criteria as all the protocols presented significant statistical differences from the real measurements. It is important to note that, in this experiment, the statistical data are accurate up to hundredths of a millimetre in relation to the phantom and this can influence the statistical significance. In the comparison of the average difference of the A–B distance and the C–D distance, observed in the protocols in relation to the real measurement, only the 20 cm, 40 s, 0.4 mm protocol had a difference greater than 1 mm (1.21 mm for the A–B distance and 1.05 mm for the C–D distance). This difference is significant from a clinical point of view because dimensions of this grandeur influence the viability of implant installation or even the selection of implant sizes. However, it is important to note that this protocol is not recommended for assessment of small structures for example, as is used in cephalometric analysis. The remaining protocols, which can be used for implant planning, have demonstrated an average difference of 0.6 mm and 0.7 mm from the real measurement. These values, if not ideal, can still provide sufficient accuracy for the selection of implants by the surgeon, as long as this small limitation is known.

The i-CAT™ tomograph's 13 cm, 20 s, 0.3 mm and 13 cm, 20 s, 0.4 mm protocols presented lower standard deviations and less variability among the axial images. For the C–D distance, the 13 cm, 20 s, 0.3 mm protocol presented the least variability of the standard

Table 5 Comparison between NewTom 3G™ and i-CAT™ protocols

Protocols	Distance A–B	Distance C–D
	P-value	P-value
6 inch, 0.16 mm × 9 inch, 0.25 mm	0.7872	0.1205
13 cm, 20 s, 0.3 mm × 9 inch, 0.25 mm	0.3696	0.0188
13 cm, 20 s, 0.4 mm × 9 inch, 0.25 mm	0.4739	0.7883
13 cm, 40 s, 0.25 mm × 9 inch, 0.25 mm	0.9288	0.0164
13 cm, 20 s, 0.3 mm × 6 inch, 0.16 mm	0.5316	0.8932
13 cm, 20 s, 0.4 mm × 6 inch, 0.16 mm	0.3757	0.1684
13 cm, 40 s, 0.25 mm × 6 inch, 0.16 mm	10.000	0.3752
13 cm, 20 s, 0.4 mm × 13 cm, 20 s, 0.3 mm	0.9287	0.1409
13 cm, 40 s, 0.25 mm × 13 cm, 20 s, 0.3 mm	0.3732	0.2456
13 cm, 40 s, 0.25 mm × 13 cm, 20 s, 0.4 mm	0.2145	0.0618

deviation among the axial images. Regarding accuracy, there was no difference among the protocols in relation to the average standard deviation of the axial images for both measurements. Therefore, statistically the protocols were equally accurate.

The NewTom 3G™ tomograph generated standard values which were very similar to the images of the i-CAT™ tomograph. All the protocols for the NewTom 3G™ tomograph also presented results that underestimated the real values of the phantom, coinciding with results from the studies of Yamamoto *et al*,¹³ Araki *et al*,¹⁴ Lascala *et al*,¹⁶ Loubele *et al*,^{10,11} and Stratemann *et al*.¹⁹

When comparing the average difference of the A–B and C–D distances observed in the protocols in relation to the real measurement, only the 12 inch, 0.36 mm protocol presented a difference greater than 1 mm (1.4 mm for the A–B distance and 1.14 mm for the C–D distance). These findings are similar to the ones found for the i-CAT™ tomograph and therefore can be interpreted in the same way. This protocol is recommended for cephalometric analysis, while the remaining protocols are recommended for more accurate analysis, such as implantodontics, periodontics and endodontics.

The 40 s, 0.25 mm (i-CAT™) and the 6 inch, 0.16 mm (NewTom 3G™) protocols were the most accurate, that is the results achieved were very close to real ones. These results were expected since both presented the smallest voxel size of each tomograph, and therefore they are the ones that generate clearer images according to Hatcher and Aboudara²⁴ and Stratemann *et al*.¹⁹ In conclusion, these are the most accurate protocols for the i-CAT™ tomograph and the most recommended for use in implant dentistry.

Previous studies with different voxel sizes showed that differences between CBCT measurements from all voxel sizes were small and not statistically and clinically significant.^{26,27} Similar studies^{28,29} confirmed the accuracy and emphasized that the mean difference for the 0.3 mm voxel size was the smallest.

The comparison between tomographs was one of the primary objectives of this present work and it has become interesting since both devices used distinct

methods of image acquisition: the flat panel for the i-CAT™ and the image intensifier for the NewTom 3G™. The first hypothesis, based on clinical experience and some literary works,^{21,20} was that the flat panel would present better results. Lund *et al*⁹ assessed the accuracy and precision of linear measurements, the influence of different object positions in CBCT images and the effect of different systems for reformatting and viewing the tomograms on measurement values. They concluded that the use of a flat panel detector unit showed a high level of agreement with actual distances. Our results confirm these previous findings regarding the accuracy of flat panel detectors.

The measurements obtained by the i-CAT™ tomograph were on average larger than the ones obtained by the NewTom 3G™. This difference could be related to the voxel size and the type of sensor. Since the i-CAT™ presents protocols with smaller voxel size and the flat panel type sensor, it produces images with greater resolution than the NewTom 3G™.^{20–22}

Our results showed that there was no significant difference among the protocols for the A–B and C–D measurements for all protocols, except for the 13 cm, 20 s, 0.3 mm × 9 inch, 0.25 mm and the 13 cm, 40 s, 0.25 mm × 9 inch, 0.25 mm cases. Therefore, one could state that there was no statistical difference in relation to the accuracy of the tomographs. This result corroborated with the data described by various authors.^{13–17,27} According to Baba *et al*,²⁰ the refined isotropic resolution of both systems is the factor that led to satisfactory results regarding accuracy.

There is a great variation in the methodology used in the published studies described and the clinical significance of the accuracy of the measurements depends on the required level of accuracy. If the CT data are used in the pre-surgical planning, sufficiently accurate and predictable information allows the physician to plan the treatment and assess the surgical results. The more complex the surgery, the more critical it will be to have access to safe CT data to minimize the intraoperative risk and the inadequate result. The acceptable degree of error depends on the type and the complexity of the surgical procedures that are being planned and the objectives of the study.

Kumar *et al*³⁰ and Swennen *et al*³¹ reported that the method of 3D cephalometric assessment is efficient, exact and capable of evaluating hard- and soft-tissue analysis. Although both CBCT systems assessed in this work produced accurate images for linear measurement, with the less accurate protocols being of large FOVs (20 cm, 40 s, 0.4 mm for the i-CAT™ and the 12 inch, 0.36 mm for the NewTom 3G™), these results coincided with recent studies^{32,33} that reported the spatial resolution was lower at larger voxels.

A correction factor should be provided for the cases where a large FOV is required, for example during cephalometric analysis and in the construction of rapid prototyping models. Since the CBCT is a modality of image acquisition that is quite promising for the future,

further research should be done in order to establish the accuracy of the images in the craniofacial region.

Conclusions

According to the methodology applied, the following was observed:

- Among the i-CATTM protocols tested, the 13 cm, 20 s, 0.3 mm and the 13 cm, 20 s, 0.4 mm presented the

smallest standard deviations compared with the rest, with the 13 cm, 20 s, 0.3 mm protocol being the most accurate; among the NewTom 3GTM protocols tested, the 9 inch, 0.25 mm and the 6 inch, 0.16 mm were the most accurate; and statistically both tomographs were equally accurate.

- For both horizontal and vertical linear measurements, all protocols presented smaller values compared with the phantom measurements. However, only in the large FOV protocols was this difference greater than 1.0 mm.

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