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Gihan Omara
gihanomar35@gmail.com

Walaa Hamedb
drwalaadentist@gmail.com

Mostafa S. Ashmawy
mostafasaad@asfd.asu.edu.eg

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Accuracy of artificial bone defects measurements on two cone beam computed tomography scanners. A comparative study

Gihan Omar[a,*], Walaa Hamed[b], Mostafa S. Ashmawy[b]

[a] Faculty of Oral and Dental Medicine, Future University in Egypt, Egypt
[b] Faculty of Dentistry, Ain-Shams University, Egypt

A B S T R A C T

Introduction: Several CBCT systems are currently on the market variable in their image quality and ability to visualize anatomic structures. Those systems differ from each other in detector design, patient scanning settings, and data reconstruction parameters. Moreover, other scanning and reconstruction factors including scan field of view (FOV), voxel size and the number of basis projections used for reconstruction have significant influence on image quality in CBCT. The aim of this study is to compare two CBCT systems regarding their linear measurements accuracy.

Materials and methods: Eighteen bone defects were created in one dry skull by using a round diamond bur mounted on a high speed hand piece. The defects were fully injected with polyvinyl siloxane impression. The skull was scanned using Planmeca ProMax 3D (Planmeca, Helsinki, Finland) and i-CAT next generation (Imaging Sciences international, Hatfield, PA, USA). Images were uploaded to a third party software (On Demand, Cyber med Inc. South Korea) for applying the measurements. Several measurements of each rubber impression material were done using the measurement tool on the cross sectional images in order to determine the maximum diameter. Then the impression material was removed carefully from the mandible by a dental probe and all the rubber balls were measured with a digital caliber to determine the actual maximum diameter (gold standard). Numerical collected data were explored for normality by checking the data distribution.

Results: The results of the present study showed that the overall measurements by Planmeca showed statistically significantly higher mean measurement than the standard reference while i-CAT measurements showed non-statistically significant difference from the standard reference at all areas and also regarding the overall measurement. Regarding the overall error measurement and error percentage; Planmeca showed statistically significantly higher mean error and error percentage than I-CAT.

Conclusion: CBCT is highly accurate and reproducible in linear measurements in the axial and coronal image planes and in different areas of the maxillofacial region. According to the findings of the present study I-CAT is recommended when the purpose of the CBCT scan is to measure linear distances. This will result in lower patient radiation dose and faster scan time.

1. Introduction and review of literature

The advent of cone beam computed tomography (**CBCT**), with its three dimensional representation of maxillofacial structures, has led to major advances in diagnosis and treatment planning in various areas of dentistry [1,2].

The advantages of this technology are three dimensional (**3D**) images of dento-facial regions with lower cost, more convenient size, easier operation, quicker scans and lower radiation dose compared to medical computed tomography machines. CBCT technology is able to achieve radiation dose levels equivalent to a full-mouth series, and as low as two panoramic radiographs, depending on the setting in use [3–5].

The recent accuracy studies involving CBCT scans have shown not only that 3D measurements are much more accurate than 2D measurements, but also that they are close to reality [6,7]. Another study showed that CBCT has a higher sensitivity and diagnostic accuracy than intraoral digital or conventional radiographs when evaluating the presence of artificially created periapical bone defects [8].

Several CBCT systems are currently on the market variable in their image quality and ability to visualize anatomic structures [9,10].Those

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* Corresponding author.
E-mail addresses: gihanomar35@gmail.com (G. Omar), drwalaadentist@gmail.com (W. Hamed), mostafasaad@asfd.asu.edu.eg (M.S. Ashmawy).

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systems differ from each other in detector design, patient scanning settings, and data reconstruction parameters [11–13]. Moreover, other scanning and reconstruction factors including scan field of view (**FOV**), voxel size and the number of basis projections used for reconstruction have significant influence on image quality in CBCT.

So the aim of this study is to compare two CBCT systems regarding their linear measurements accuracy.

2. Materials and methods

Eighteen bone defects were created in one side of a dry skull by using a round diamond bur mounted on a high speed hand piece. The defects were created in the mandible in order to obtain three defects at the anterior area, three defects at the premolar area and three defects at the molar area. The same was repeated for the maxilla. The defects were injected with polyvinyl siloxane impression material (3 M ESPE Imprint™ II Garant™ Heavy Body, St Paul, USA). The impression material was injected inside the defects as to be flushed with the buccal surface of the bone. Each defect was assigned a number in order to be identified. The skull-mandible assembly was scanned using Planmeca ProMax 3D (Planmeca, Helsinki, Finland) and I-CAT next generation (Imaging Sciences international, Hatfield, PA, USA) Fig. 1(A&B).

During image acquisition, the smallest voxel size available was used (i.e. highest resolution) for this particular field of view (**FOV**) for each CBCT system. Exposure parameters were as follows: For Planmeca Promax 3D, (0.2 mm voxel size, 120kVp, 5 mA, 7sec exposure time, 8 × 8 cm FOV) and for i-CAT next generation, (0.125 mm voxel size, 90kVp, 12 mA, 12sec exposure time).

Images were saved as DICOM (digital imaging and communication in medicine) files and they were uploaded to On Demand software (Cyber med Inc. South Korea) for applying the measurements. Two radiologists with 15 and 17 years of experience performed the measurements twice separated by two weeks interval after agreement on the methodology of measuring the injected rubber material. Both observers viewed the images in a dimmed light room on the same computer monitor 17 inch HD LED (Dell Inc., Berkshire, UK). Sharpness filter was adjusted to (FILTER X1). Obtained images from both scanners were uploaded and several measurements of each rubber impression material was done using the measurement tool on the cross sectional images in order to determine the maximum diameter of the defect. This was accomplished by measuring the rubber balls from different planes and choosing the maximum measurement Fig. 2(A).

After completing measurements on the software, the impression material was removed carefully from the mandible by a dental probe and all the rubber balls were measured with a digital caliber (Mitutoya, Japan) to determine the actual maximum diameter (gold standard) as shown in Fig. 2(B). All data were tabulated and then numerical data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. All measurements showed normal (parametric) distribution while error measurements and error percentage data showed non-normal (non-parametric) distribution. Data were presented as mean, median, standard deviation (**SD**), minimum, maximum and 95% Confidence Interval (95% **CI**) for the mean values.

For parametric data; Paired *t*-test was used to compare between each modality and the standard reference. For non-parametric data; Wilcoxon signed-rank test was used to compare between measurement errors and errors percentage of the two CBCT systems. Intra and inter-observer agreements were assessed using Cronbach's alpha reliability coefficient and Intra-Class Correlation Coefficient (**ICC**). The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM[1] SPSS[2] Statistics Version 20 for Windows.

[1] IBM Corporation, NY, USA.

[2] SPSS, Inc., an IBM Company.

3. Results

Intra-observer agreement for all areas with Cronbach's alpha values ranged from (0.944–0.988) for Planmeca and (0.928–0.986) for i-CAT. Inter-observer agreement for all areas with Cronbach's alpha values ranged from (0.926–0.967) for Planmeca and (0.912–0.973) for i-CAT.

Measurements obtained from Planmeca CBCT system showed statistically significant higher mean measurement than the standard reference at the maxillary anterior and maxillary premolar areas. In all other areas; Planmeca measurements showed non-statistically significant difference from the standard reference. However, the overall measurement (regardless of area) showed statistically significantly higher mean measurement than the standard reference as shown in Table 1. Measurements obtained from i-CAT CBCT system showed non-statistically significant difference from the standard reference at all areas and also regarding the overall measurements as shown in Table 1.

Mean SD values and results of Wilcoxon signed-rank test for comparison between error measurements and error percentage of the two CBCT systems showed that there was no statistically significant difference between measurement errors of the two systems regarding each area. There was also no statistically significant difference between error percentages of the two CBCT systems regarding each area as shown in Table 2. However, regarding the overall error measurement and error percentage; Planmeca showed statistically significantly higher mean error and error percentage than i-CAT as shown in Fig. 3.

4. Discussion

In cases where bone destruction is expected, radiographs are valuable diagnostic tools as an adjunct to clinical examination. Two-dimensional (**2D**) periapical and panoramic radiographs are routinely used for assessment of the amount of bone destruction; which are limited by projection geometry and superimpositions of adjacent anatomical structures [14,15]. These limitations can be avoided by 3D imaging techniques such as cone beam computed tomography [16]. Therefore, the present study aimed to compare between measurement accuracy of artificial bone defects of images acquired by two CBCT systems. Several previous studies compared between different CBCT systems available in the market [17–20]. Authors compared the accuracy of CBCT systems regarding their ability to detect vertical root fractures [17–19], effect of metal artifact [20], reliability of cephalometric landmark identification [21], detection of external root resorption caused by impacted maxillary canines [22–24], visualization of root canals [25], radiation absorbed dose [26]. In the present study, measurements were performed at different areas in both arches; anterior, premolar and molar areas to test the error percentage in different areas of the jaws according to several researches regarding linear measurement accuracy [27–29].

To precisely test the accuracy of CBCT measurements, an accurate standard reference must be implemented as the lack of an accurate standard reference will generate bias in the results. Thus for the standard reference to be valid, it should be recorded using a tool which provides measurements with sub-millimeter accuracy as that recorded with a digital caliper [30,31]. On the other hand, other authors used different tools with sub-millimeter accuracy as the standard reference, Mengel et al. [32] used in their study a reflecting stereomicroscope with measuring ocular tool which had been examined for dental research purposes, and it was proved to be accurate with a high precession [33]. Ferrare et al. [34] used micro-CT in their study, but being another imaging modality, it has its own error and deviation from the real measurements, as when examined by Kim et al. [35], they found an error of 0.22 ± 0.635 mm.

In the present result, there was very good intra-observer agreement for all areas with Cronbach's alpha values ranged from 0.944 to 0.988 for Planmeca Promax 3D and 0.928 to 0.986 for i-CAT next generation and there was very good inter-observer agreement for all areas with

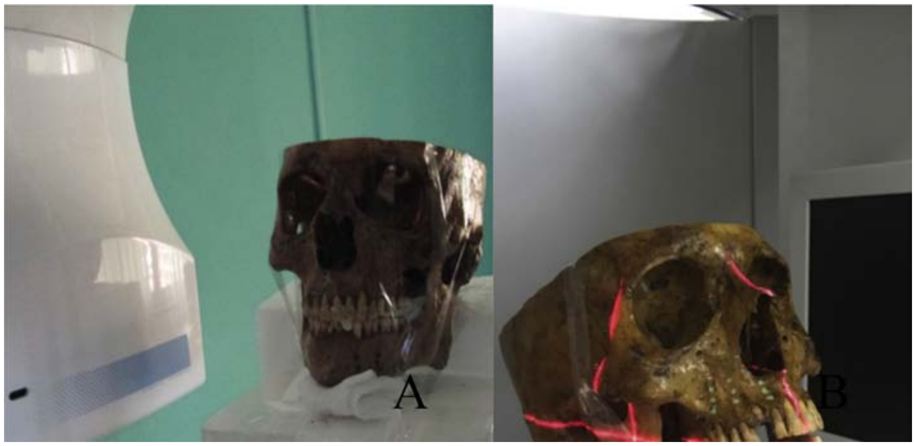

Fig. 1. Photo showing positioning of the skull-mandible assembly on the Planmeca CBCT machine **(A)** and i-CAT CBCT machine **(B)**.

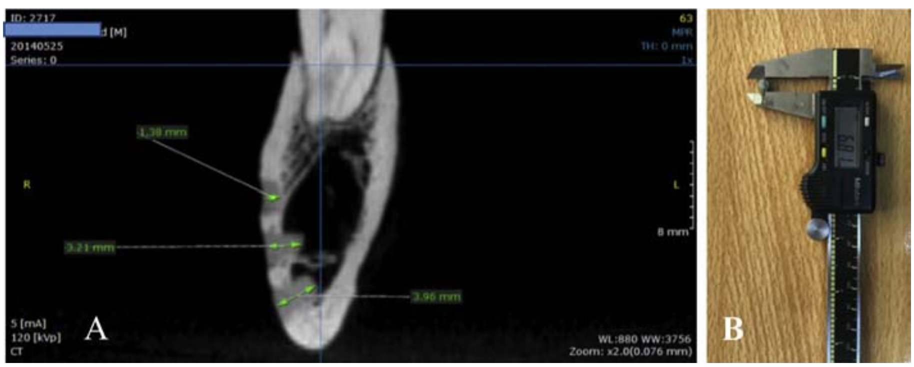

Fig. 2. A. Cross sectional image showing the measurements of the rubber's maximum diameter using On Demand software, **B**. Measurement of the rubber's maximum diameter using the digital caliber.

Table 1
Mean, standard deviation (SD) values and results of paired *t*-test for comparison between each CBCT system and the standard reference.

Area	Planmeca		Standard reference		Error		P-value
	Mean	SD	Mean	SD	Mean	SD	
Maxillary anterior	3.1	0.3	2.9	0.3	0.2	0.01	0.001*
Maxillary premolar	2.6	0.7	2.4	0.7	0.2	0.1	0.032*
Maxillary molar	3.1	0.5	2.8	0.7	0.3	0.2	0.142
Mandibular anterior	3.0	0.3	2.8	0.4	0.2	0.2	0.201
Mandibular premolar	2.2	0.2	2.3	0.2	−0.1	0.2	0.443
Mandibular molar	2.4	0.2	2.3	0.1	0.1	0.1	0.371
Overall	2.7	0.5	2.6	0.4	0.1	0.2	0.004*
	iCAT		Standard reference		Error		
Maxillary anterior	2.6	0.5	2.9	0.3	−0.3	0.2	0.138
Maxillary premolar	2.3	0.6	2.4	0.7	−0.1	0.3	0.678
Maxillary molar	2.8	0.7	2.8	0.7	0.01	0.1	0.784
Mandibular anterior	2.6	0.5	2.8	0.4	−0.2	0.2	0.413
Mandibular premolar	2.4	0.3	2.3	0.2	0.1	0.1	0.424
Mandibular molar	2.3	0.1	2.3	0.1	−0.08	0.1	0.420
Overall	2.5	0.5	2.6	0.4	−0.1	0.2	0.108

*: Significant at P ≤ 0.05.

Table 2
Mean standard deviation (SD) values and results of Wilcoxon signed-rank test for comparison between error measurements and error percentage of both CBCT systems.

	Area	Planmeca		iCAT		P-value
		Mean	SD	Mean	SD	
Error (mm)	Maxillary anterior	0.2	0.01	−0.3	0.2	0.109
	Maxillary premolar	0.2	0.1	−0.1	0.3	0.285
	Maxillary molar	0.3	0.2	0.01	0.1	0.109
	Mandibular anterior	0.2	0.2	−0.2	0.2	0.109
	Mandibular premolar	−0.1	0.2	0.1	0.1	0.285
	Mandibular molar	0.1	0.1	−0.08	0.1	0.285
	Overall	0.1	0.2	−0.1	0.2	0.011*
Error (%)	Maxillary anterior	7.6	1.0	−10.6	8.0	0.109
	Maxillary premolar	7.9	2.4	−2.4	15.2	0.285
	Maxillary molar	11.1	9.1	0.2	2.7	0.109
	Mandibular anterior	8.2	8.2	−5.6	9.7	0.109
	Mandibular premolar	−4.5	8.4	3.4	6.2	0.593
	Mandibular molar	4.1	6.3	−3.3	5.8	0.285
	Overall	5.7	7.6	−3.1	8.7	0.012*

*: Significant at P ≤ 0.05.

Cronbach's alpha values ranged from 0.926 to 0.967 for Planmeca Promax 3D and 0.912 to 0.973 for i-CAT next generation. These results proved that CBCT linear measurements are highly reproducible. This was in agreement with the results of Kamburoglu et al. [18], who found the inter-observer reliability to be 0.995 to 1 and intra-observer reliability to be 0.992 to 1. Also Oz et al. [36] found high inter-observer reliability of the CBCT measurements in the craniofacial area.

The results of the present study revealed that Planmeca Promax 3D showed statistically significantly higher mean error and error percentage than i-CAT next generation. The difference could be related to the kVp difference between the two systems as i-CAT next generation acquires the image using 120 kVp in contrast to 90 kVp used by Planmeca Promax 3D imaging sytem. Also the superiority of i-CAT next

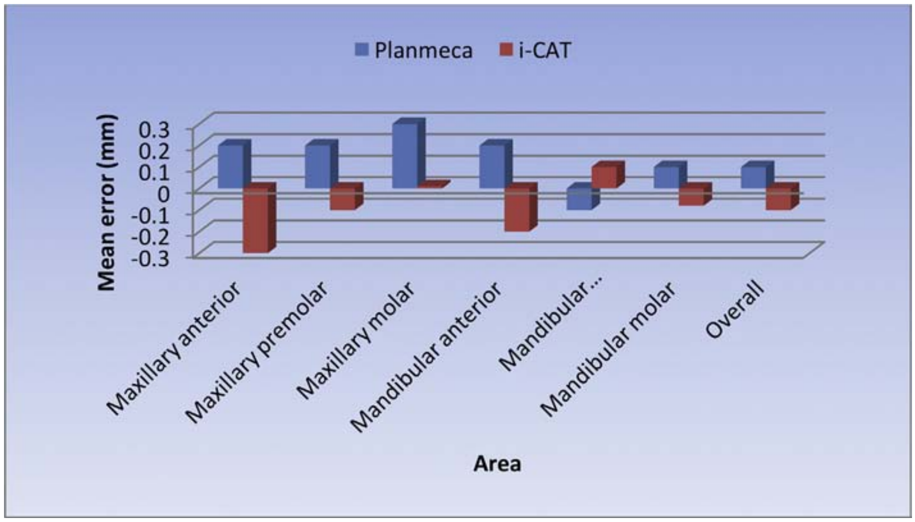

Fig. 3. Bar chart representing mean measurement errors of the two CBCT systems.

generation can be attributed to the inherent smaller voxel size 0.125 mm compared to 0.2 mm used by Planmeca Promax 3D [17]. This could result in better image viewing allowing the observer to accurately determine the object's borders.

Our results were consistent with other authors who investigated the reliability of linear measurements of CBCT imaging systems, as Pactas et al. [37] and Fatemitabar et al. [38] who compared KaVo 3D (KaVo Dental GmbH, Biberach, Germany) and Planmeca respectively with multidetector CT, Dalessandri et al. [39] who compared three CBCT systems; Newtom 3G (Quantitative Radiology, Verona, Italy), Kodak 9500 (Trophy Radiologie, Croissy-Beaubourg, France) and Planmeca Promax 3D. Also Pinsky et al. [40] who investigated I-CAT next generation system. Finally Stratemann et al. [41] who compared Hitachi MercuRay (Hitachi Medico Technology, Tokyo, Japan) with real measurements from digital caliper.

5. Conclusion and recommendations

CBCT is highly accurate and reproducible in linear measurements in the axial and coronal image planes and in different areas of the maxillofacial region. According to the findings of the present study i-CAT is recommended when the purpose of the CBCT scan is to measure linear distances. This will result in lower patient radiation dose and faster scan time.

When comparing 2 different machines, we have a lot of exposure parameters and it would be better in future studies if you choose 0.2 voxel size in both machines to eliminate the resolution parameter and test the machines properly.

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