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Accuracy and Reliability of Landmarks Identification Using Ultra Low Dose CBCT: An In-Vitro Study

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ABSTRACT

Purpose: The aim of this study was to assess the accuracy of ultra-low dose (ULD) CBCT in orthodontic landmark identification compared with standard dose CBCT on reconstructed lateral and posteroanterior views. **Materials and Methods:** 10 dry human skulls were scanned twice; once with standard CBCT standard radiation dose, and with ULD CBCT protocol operated at 90 kVp, 7.1 mA, 4.5 sec and 400μm voxel size. From each scan, a lateral and a posteroanterior cephalogram were reconstructed, and 33 landmarks were identified on them by 2 experts. All measurements were then repeated after 2 weeks for intra-observer reliability. **Results:** There was no statistically significant difference in landmarks identification between ULD and standard dose CBCT. The mean difference between both groups ranged between -0.12 to 0.51 in lateral view and -0.67 to 0.46 in posteroanterior view with excellent inter and intra observer agreement with an ICC value >0.7. **Conclusion:** Ultra-low dose CBCT with reconstructed lateral and posteroanterior views may be recommended for regular orthodontic diagnostic measurements and can replace the standard dose CBCT.

KEYWORDS

Cone Beam CT, Standard dose, Landmark Identification, Reliability, Ultra-low Dose

INTRODUCTION

Orthodontic diagnosis is pivotal for a successful treatment planning process. Various essential skeletal and dental diagnostic data are collected from radiographs in the transverse, sagittal and anteroposterior planes. Cone beam computed tomography (CBCT), since its development in the late 1990's as an accurate 3-dimensional (3D) imaging modality, has significantly evolved and contributed immensely to a deeper and more accurate diagnosis in the orthodontic field. It is advantageous over 2-dimensional (2D) and CT imaging, as it provides a 3D imaging modality with a lower dose of radiation, better spatial resolution, lower cost and lesser scan time when compared to CT [(1)].

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CBCT produces accurate images by providing isotropic voxels that are equal in all sides. In addition, it provides different resolutions that may reach 0.09 mm. The sub-millimetric resolution of CBCT is sufficient for detailed diagnostic measurements[2]. Despite the well-known advantages of CBCT images, their main limitation remains in their higher radiation dose compared to the conventional 2-Dimaging modalities. CBCT effective dose was measured to be 7 times higher than the dose of a panorama together with a lateral cephalometric image [3,4,5]. Hence, risk / benefit analysis together with the ALARA principle "as low as reasonably achievable" must be constantly considered before any CBCT investigation is requested [1,6,7]. Trials have been made to reduce the patient radiation dose while trying to maintain the advanced image quality. The quality of these images is affected by different parameters such as milliamperage mA, exposure time, kilovoltage kVp and field of view (FOVs) [8]. Radiation dose can be decreased either directly by decreasing one or more of the exposure parameters (kVp, mA and time) or indirectly by decreasing FOVs or voxels size[9,10].

The aim of this study was to assess the effect of lowering exposure time and mA- referred to as ultra-low dose CBCT protocol (ULD)- on landmarks identification used in orthodontic diagnosis in the lateral and posteroanterior reconstructed views.

MATERIALS AND METHODS

Ten dry human skulls were obtained from the Human Anatomy Department, Faculty of Medicine, Cairo University, with no demographic data regarding age or sex.

I- Skull preparation

For soft tissue simulation, each skull was covered with a block of pink wax (Cavex, Holland BV, modeling wax) of 10-12 mm in thickness. The wax was adapted carefully on the facial surface of the skull from the inferior border of the mandible till above the frontonasal suture [11].

II- CBCT Scan and Analysis:

The skulls were scanned using Planmeca ProMax 3D Mid CBCT machine (Planmeca Oy, Helsinki, Finland), available at the Oral and Maxillofacial Radiology Department, Faculty of Dentistry, Cairo University. Each skull was mounted on the machine in an upright position, having the laser beams centralizing the skull within the center of the CBCT scanner (fig. 1).

Figure(1) Photograph showing a dry human skull with soft tissue simulation using pink wax mounted on CBCT Planmeca ProMax 3D Mid machine.

Each skull was scanned twice with a fixed kilovoltage of 90 kVp, voxel size of 0.4 mm and 20×20 cm FOV. Meanwhile, the mA and the time were modified; first scan with 10 mA and 13.5 sec which is the standard dose protocol, and then a second scan with 7.1 mA and 4.5 sec which is the ULD protocol.

Anatomage software (version 5.01) was used to convert the dicom files into volumetric images. Multiplanar sagittal, coronal and axial projections were generated. To minimize the identification error and increase the accuracy, the reference landmarks were chosen and identified according to several considerations [12]:

1. Landmarks localization was done on axial, sagittal and coronal tomographic slices, and then checked on the 3-D rendering.

2. Landmarks located in areas of high-density contrast with adjacent structures or located on sharply curved or pointed structures.

For skull reorientation, the mid sagittal plane was set to be perpendicular to the floor while the Frankfort plane was set to be parallel to the floor.

Landmarks Identification:

For each skull, 17 landmarks were identified on the sagittal plane and 16 other landmarks were identified in the coronal plane. A total of 33 landmarks were identified and linear measurements were then taken on the CBCT reconstructed images; 10 on the lateral and 18 on the posteroanterior views.

Lateral cephalometric landmarks (fig. 2):

Sella: The center of the hypopheseal fossa.

Anterior clinoid: the anterior boundary of the superior surface of sphenoid bone

Posterior clinoid: the posterior boundary of the superior surface of sphenoid bone

Porion (Rt & Lt): Upper most point on the external auditory meatus on the right and left sides.

Nasion: Mid- point of frontonasal suture. Anterior most midpoint of the anterior contour, summit of the radiolucent suture, midpoint in the center of the radiolucency.

Basion: the most inferior point on the anterior margin of the foramen magnum in the mid sagittal plane.

Point A: The most posterior midline point in the concavity between the anterior nasal spine and the prosthion.

Point B: The deepest midpoint of the mandibular anterior surface.

Condylar point (Rt & Lt) The most postero-superior points on the condyles (Rt & Lt).

Coronoid point (Rt & Lt) The most superior points on the coronoid process (Rt & Lt).

PTM (Rt & Lt): apex of tear drop shaped pterygomaxillary fissure.

Pogonion: Most anterior point on the anterior curvature of the chin.

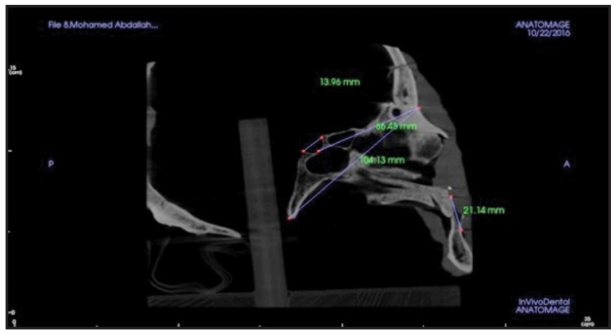

Figure (2) CBCT lateral reconstructed view showing landmarks (anterior and posterior clinoid, nasion, basion, point A, point B) and linear measurements.

Postero-anterior cephalometric landmarks (fig. 3):

Lateral frontal-zygomatic suture (Rt & Lt): The most external point of the lateral margin of the frontal-zygomatic suture (Rt & Lt).

Medial frontal-zygomatic suture (Rt & Lt): The most external point of the medial margin of the frontal-zygomatic suture (Rt & Lt).

Zygomatic arch (Rt & Lt): The central point of the root of the zygomatic arch, (Rt & Lt).

Jugal process (Rt & Lt): Intersection of the outline of the tuberosity of the maxilla and zygomatic buttress (Rt & Lt).

Nasal cavity (Rt & Lt): The most lateral points of the piriform aperture (Rt & Lt).

Orbitale (Rt & Lt): A point midway between the lowest point on the inferior margin of the two orbits.

Upper orbital ridge (Rt & Lt): A point midway between the highest point on the superior margin of the orbit.

Gonion Posterior and inferior most point on the angle of the mandible on the right and left sides.

Figure (3) Identification of the right and left nasal cavity points on the CBCT reconstructed posteroanterior view.

For inter-observer reliability, landmarks were identified by a radiologist (N.A) and an orthodontist (N.S) of 15 years' experience. Both observers were blinded to each group allocation

All data were presented as mean &standard deviation. Statistical analysis was performed with SPSS 16 ® (Statistical Package for Scientific Studies), Graph pad prism and windows excel.

Exploration of the given data was performed using Shapiro-Wilk test and Kolmogorov-Smirnov test for normality which revealed that the significant level (P-value) was insignificant as P-value > 0.05 which indicated that data originated from normal distribution (parametric data) resembling normal Bell curve.

Accordingly, comparison between different groups and between different observers was performed by using Independent t-test. All reliabilities were calculated and presented as Inter Class coefficient (ICC).

Moreover, Dalberg error was used for quantifying measurement error between group I and II using the following formula:

$$D = \sqrt{\sum_{i=1}^{N} \frac{d_i^2}{2N}}$$

Where *di* is the difference between the first and second measure; *N* is the sample size which was re-measured.

Sample size was calculated [13] and the minimally accepted sample size was 8 per group. When the response within each subject group was normally distributed with a standard deviation 0.16, the estimated mean difference was 0.24, when the power was 80 % and type I error probability was 0.05. Total sample size increased to 10 per group to compensate any possible (15%) drop outs.

RESULTS

Statistical analysis of the current study revealed no statistically significant difference between ULD CBCT protocol (group I) and standard dose CBCT protocol (group II) with P > 0.05. The intra-observer and inter-observer reliability revealed excellent reliability in both lateral and postero-anterior views with inter class correlation coefficient (ICC) >0.7 in group I and II (fig. 4,5).

On comparing, group I and II results, the mean Dahelberg Error (DE) recorded 0.85 in lateral view and 4.32 in postero-anterior view, while the ICC ranged from 0.86 to 0.98 in lateral view and 0.86 to 0.98 in postero-anterior view. The mean difference between both groups ranged between -0.12 to 0.51 in lateral view and -0.67 to 0.46 in postero-anterior view as shown in table 1 and 2.

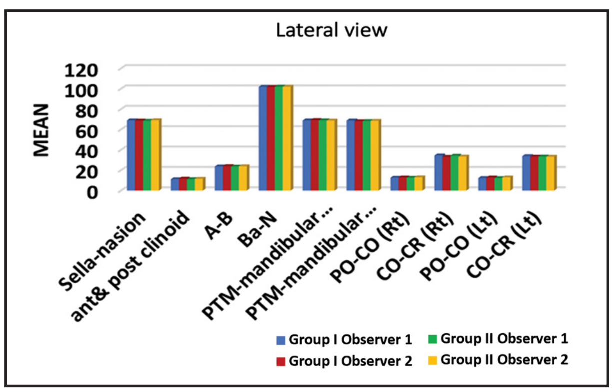

Figure (4): Bar chart representing observer 1 & observer 2 of group I and group II regarding measurements of lateral view.

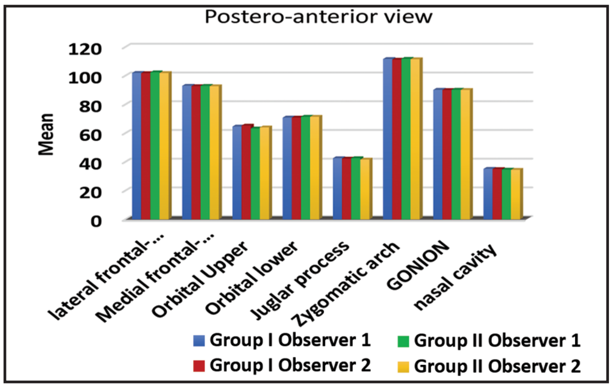

Figure (5): Bar chart representing observer 1 & observer 2 of group I and group II regarding measurements of postero-anterior view.

Table (1): *Mean and standard deviation of group 1 & group 2, comparison between them using Independent -test and ICC in the lateral view measurements:*

Lateral view	Group I		Group II		Independent t-test					ICC	Dalberg error
					MD	SD	CI		P value		
	M	SD	M	SD			L	U			
Sella-nasion	68.97	3.66	68.54	3.92	0.44	1.70	-3.13	4.00	0.80	0.95	0.803
ant& post clinoid	11.15	2.37	11.21	1.97	-0.06	0.97	-2.11	1.99	0.95	0.98	0.576
A-B	23.68	2.72	23.58	3.19	0.10	1.33	-2.69	2.88	0.94	0.94	1.432
Ba-N	101.90	3.31	102.02	3.94	-0.11	1.63	-3.53	3.30	0.95	0.97	1.092
PTM-mandibular point RT	68.92	6.92	69.04	7.22	-0.12	3.16	-6.76	6.53	0.97	0.96	0.466
PTM-mandibular point LT	68.79	5.83	68.28	5.85	0.51	2.61	-4.98	6.00	0.85	0.97	0.909
PO-CO (Rt)	12.60	1.94	12.61	2.05	-0.01	0.89	-1.89	1.86	0.99	0.92	0.594
CO-CR (Rt)	34.47	4.69	34.22	4.84	0.26	2.13	-4.22	4.73	0.91	0.95	1.292
PO-CO (Lt)	12.34	1.64	12.24	1.48	0.10	0.70	-1.36	1.57	0.89	0.86	0.547
CO-CR (Lt)	33.84	4.96	33.43	5.26	0.41	2.29	-4.40	5.21	0.86	0.98	0.741

M; mean *SD: standard deviation*
MD: mean difference *SE: standard error*
CI: confidence interval at 95%
ICC: Inter class correlation coefficient

Table (2): *Mean and standard deviation of group 1 & group 2 in postero-anterior view measurements:*

Postero-anterior view	Group I		Group II		Independent t-test					ICC	Dalberg error
					MD	SE	CI		P value		
	M	SD	M	SD			L	U			
Lateral frontal- zygomatic suture	101.97	4.54	102.40	4.76	0.17	2.12	-4.29	4.63	0.94	0.98	0.568
Medial frontal- zygomatic suture	93.00	3.36	92.96	3.98	0.25	1.44	-2.77	3.28	0.86	0.94	0.586
Orbital Upper	64.65	4.23	63.31	4.41	-0.67	1.75	-4.35	3.00	0.70	0.89	1.033
Orbital lower	70.86	3.00	71.45	3.29	0.01	1.34	-2.81	2.83	0.99	0.97	0.387
Jugal process	42.58	3.22	42.63	2.57	0.30	1.44	-2.72	3.33	0.84	0.92	0.414
Zygomatic arch	111.65	6.20	111.78	6.21	0.46	2.77	-5.35	6.28	0.87	0.98	0.307
GONION	90.23	6.96	90.30	6.82	0.14	3.05	-6.26	6.55	0.96	0.99	0.205
Nasal cavity	35.20	4.10	34.66	3.83	0.16	1.80	-3.61	3.94	0.93	0.86	0.823

M; mean *SD: standard deviation*
MD: mean difference *SE: standard error*
CI: confidence interval at 95% *ICC: Inter class correlation coefficient*

DISCUSSION

CBCT has gained a great acceptance among clinicians due to its precise 3D measurements compared to traditional 2D images. Additionally, CBCT decreases problems resulting from malposition of the patient's head leading to inaccurate measurements. Many researches have concluded that CBCT standard dose measurements are comparable to those obtained directly on skulls, thus validating its use in different dental fields [14, 15].

It is agreed among orthodontists that the use of CBCT constantly unveils new perspectives. Although CBCT imaging has been widely used over the last two decades in orthodontic diagnosis and treatment planning, it is still cautiously used to guard against any possible risks of ionizing radiation. Children were reported to be at a higher risk for radiation exposure where they were found to be more prone to developing radiation induced malignancy than adults [10,16,17].

Efforts were continuously made to decrease the effective radiation dose of CBCT while maintaining diagnostically acceptable image qualities. It was previously reported [18] that ULD protocols provided an average dose reduction up to 87 % compared to standard CBCT protocols. Lateral cephalometric x-rays are one of the essential diagnostic records that any orthodontist needs in the diagnosis of nearly all cases. Posteroanterior radiographs are requested in cases of facial asymmetries and midline discrepancies [19]. In the present study, the reliability of landmark identification using ULD CBCT was analyzed in comparison with standard dose CBCT for orthodontic diagnostic purposes. Various landmarks were chosen in both the lateral and posteroanterior views. Results of the current study showed that there was no statistically significant difference between the CBCT doses in landmarks identification in both views with $P > 0.05$. This agrees with a previous study [18] reporting no significant reduction in image quality despite dramatically reducing the dose used with the ULD protocol.

Another study [16] agrees with the present findings and recommended using ULD protocol in assessing impacted maxillary canines. The authors reported obtaining enhanced CBCT image quality which enabled diagnosis of impacted teeth with a radiation dose of 39% less than that of the standard protocol. Further agreement came from a study [5] comparing conventional lateral cephalogram scanned at 66 kV, 10 mA and for 6.79 s to ULD reconstructed lateral cephalometric images scanned by Planmeca ProMax 3D Mid with less milliamperage and time. Their results reported an interclass correlation (ICC) value of 0.88 to 0.99 for ULD reconstructed lateral cephalograms, and the authors recommended its use for orthodontic diagnostic purposes.

Although there is a gap of knowledge towards the safest imaging protocol used for orthodontic diagnosis, a previous trial [20] examined the effect of altering the exposure time by 40, 20 and 7 seconds on the accuracy of linear measurements. Iluma, Imtek Imaging CBCT unit was used with a fixed kVp of 120 and a large FOV. The results showed that the evaluation of the implant sites was reliable and accurate despite changing the exposure time. An additional previous study [9] was in agreement with the current results where the authors investigated the impact of altering kVp and mA on image quality. They reported no effect on image accuracy with the combination of the 80 kVp, 8 mA and 200 µm voxels size with mean and SD of 357:6 ± 146:1. On the other hand, the use of ULD radiation was previously recommended [21] in a former study in which the authors proposed the possibility of replacing the routine 2D views needed in orthodontic diagnosis by CBCT with significantly reduced radiation exposure.

Conclusively, results of this study suggest that the quality of ULD images in both the lateral and posteroanterior reconstructed views can be used efficiently in diagnostic purposes. In a step towards decreasing ionizing radiation hazards, this may encourage clinicians in the future to depend on lower doses CBCT images for collection of pretreatment diagnostic information.

CONCLUSION

Ultra-low dose CBCT protocol can be efficiently used in craniofacial imaging for orthodontic diagnosis purposes.

RECOMMENDATIONS

Further researches are required in this field with different machines and different exposure parameters to develop clear guidelines for the use of ULD-CBCT.

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Conflict of Interest Statement

The authors declare that they have no conflicts of interest.

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