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Effect of Head Position on Linear Cephalometric Measurement Accuracy of Cone-Beam Computed Tomography

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Objective This study aimed to assess the effect of head position on linear cephalometric measurements by cone-beam computed tomography (CBCT).

Methods: CBCT scans of four human dry skulls were obtained by NewTom 3G volume scanner with alarge (15 x15 cm)field of view in 1 centric and 18 eccentric positions: 10°, 20°, and 30° tilt (right and left), 10°, 20°, and 30° rotation (right and left), 10°, 20°, and 30° extension and 10°, 20°,and 30° flexion. The distances between the selected landmarks namely the Nasion (N), Sella (Se), anterior nasal spine (AN S), Menton (Me), Gnathion (Gn), Gonion (Go), and Condylion (Co) were measured by two observers on maximum intensity projection reconstructions using the NNT Viewer software, and compared with the actual measurements (gold standard). The inter-class correlation coefficient (ICC) and the student's t-test were used for statistical analysis.

Results The mean inter-rater agreement was excellent for all head positions (ICC=96.89%). The maximum error in absolute mean measurements was 2.56 mm (P=0.03) The minimum error was for the N-Me line, which is a vertical line closest to the midline.

Conclusion The greatest error was observed in 30° left ward rotation for the left CoGn linear measurement. Although this level of error may not be of clinical significance, it is suggested that clinicians acquire the scans in ideal head position to minimize distortion and errors.

Keywords Cephalometry; Cone-Beam Computed Tomography; Patient positioning

Introduction

Clinical success of orthodontic treatment largely relies on the ability of the clinician to determine the relationship between dental structures, soft tissue, and bone. In the recent decade, several methods were introduced for the assessment of the maxillofacial region. Development of the cone-beam computed tomography (CBCT) technology revolutionized dental science. This technology is commonly used for diagnostic purposes, orthodontic and maxillofacial analyses and assessment of orthopedic anomalies.[1]Many studies have assessed the influence of patient position and other inherent factors on image quality.[2,3] An accurate evaluation of the dental, skeletal, and soft-tissue relationships through the normative values of three-dimensional (3D) cephalometric parameters, specifically palatal and alveolar bone thickness, mandibular body, maxillary basal curve length, and basal arch form is pivotal for linear measurements.

An ideal radiographic examination is one that enables the clinician to obtain highly accurate and reliable measurements for optimal treatment planning. However, problems such as image distortion pose limitations to this task. Image distortion refers to alterations in the size and shape of the imaged structure and can compromise the accuracy of measurements made on a radiograph. One important factor that can result in distortion, especially in extraoral radiography, is improper patient positioning during image acquisition. To mitigate this problem, many imaging manufacturers incorporate accessories to assist with ideal patient positioning. The accuracy of CBCT is less commonly affected by erroneous patient positioning.[4-6], however, there is controversial evidence in the literature in this regard.

Numerous studies have documented that head position can affect the CBCT image quality, but there is little evidence on the influence of head position on linear cephalometric measurements.[1-7]The aim of this in vitro study was to evaluate the effect of deviated head positions from the centric position on linear cephalometric measurement on CBCT scans.

Methods and Materials

This was an analytical diagnostic study evaluating the effect of 19 different head positions on cephalometric measurement accuracy of CBCT studies of human dry skulls. The study was performed on four human dry skulls provided by the Anatomy Laboratory at Shahid Beheshti University of Medical Sciences in 2018-2019. The skulls with fractures, asymmetry or pathological defects were excluded.

The landmarks that were considered for cephalometric measurements were as follows: Nasion (N), Sella (Se), anterior nasal spine (ANS), Menton (Me), Gnathion (Gn), Gonion (Go), and Condylion (Co) (Table 1). The 10 linear measurements which were measured included SeN, NMe, right and left CoGo, right and left CoANS, right and left CoGn, and right and left GoGn.

Table 1- Cephalometric landmarks that served as reference points for linear measurements

Me	Menton: Most inferior midpoint of the chin on the outline of the mandibular symphysis
Co	Condylion: Most superior point of the mandibular condyle
Go	Gonion: Point midway along the curvature of the angle between the inferior and posterior borders of ramus
Gn	Gnathion: Most inferior point on the mental symphysis
Se	Centre point at the entrance of Sella turcica (pituitary fossa of sphenoid bone)
N	Nasion: Junction of the frontonasal suture
ANS	Anterior nasal spine

The landmarks were confirmed by an orthodontist and marked on the dry skulls using a 1-mm #40 gutta-percha point. The measurements were subsequently made using a digital caliper (Catyam, China), with + 0.02 mm/0.001 in. accuracy as shown in Figure 1 to serve as the gold standard. For the centric position, the skulls were fixed on horizontal and vertical plates and placed inside the scanner with the horizontal and vertical laser lights parallel to the Frankfurt plane and the midsagittal plane, respectively. To obtain reproducible centric and eccentric skull angulations i.e. flexion, extension and head tilt, resembling clinical situations, we designed three wooden platforms (10 cm x 10 cm) with 10°, 20° and 30° slopes. The eccentric positions were: 10°, 20° and 30° tilt (right) 10°, 20°and 30° tilt (left), 10°, 20° and 30° rotation (right), 10°, 20° and 30° rotation (left), 10°, 20° and 30° flexion, and 10°, 20° and 30° extension. In the tilted position, the mid-sagittal plane of the skulls was tilted to the right and left sides. In the rotated position, the skulls were rotated towards the right and left sides and for extension and flexion, the skulls were tipped upward and downward, respectively (Figure 2).

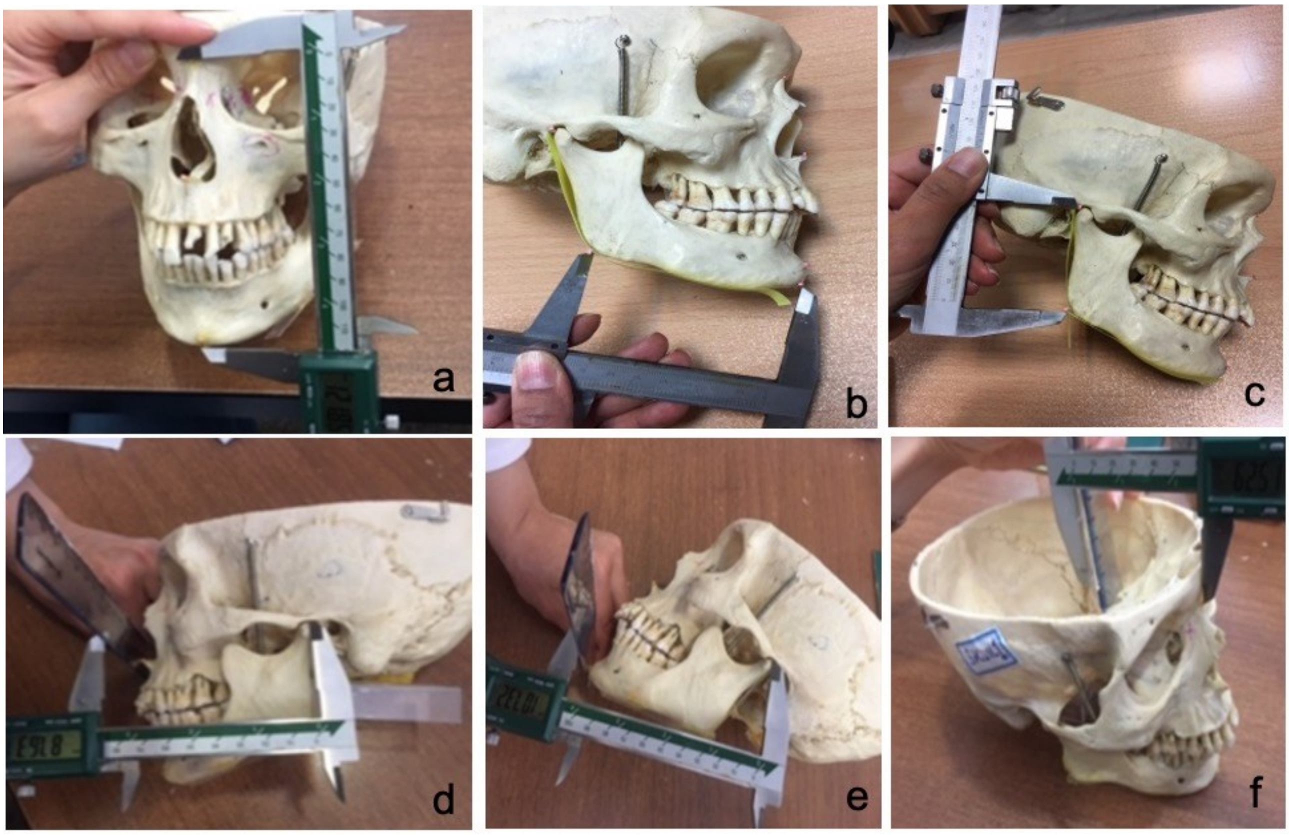

Figure 1- Measurements made by a digital caliper (gold standard)
a. NMe, b. GoGn, c. CoGo, d. CoANS, e. CoGn, f. SeN

The CBCT scans were acquired using the NewTom 3G volume scanner (QR SRL, Verona, Italy) with the exposure settings of 110 kVp, 2.8 mA, 3.6 s and 15 x 15 cm field of view and imported into the NNT viewer software program version 23 (QR SRL, Verona, Italy) for processing and analysis. Due to enhanced visualization of landmarks on maximum intensity projection images, the observers used this reconstruction for cephalometric measurements. The measurements were made by two observers independently by identifying the landmarks and measuring the distance between them (Figure 3).

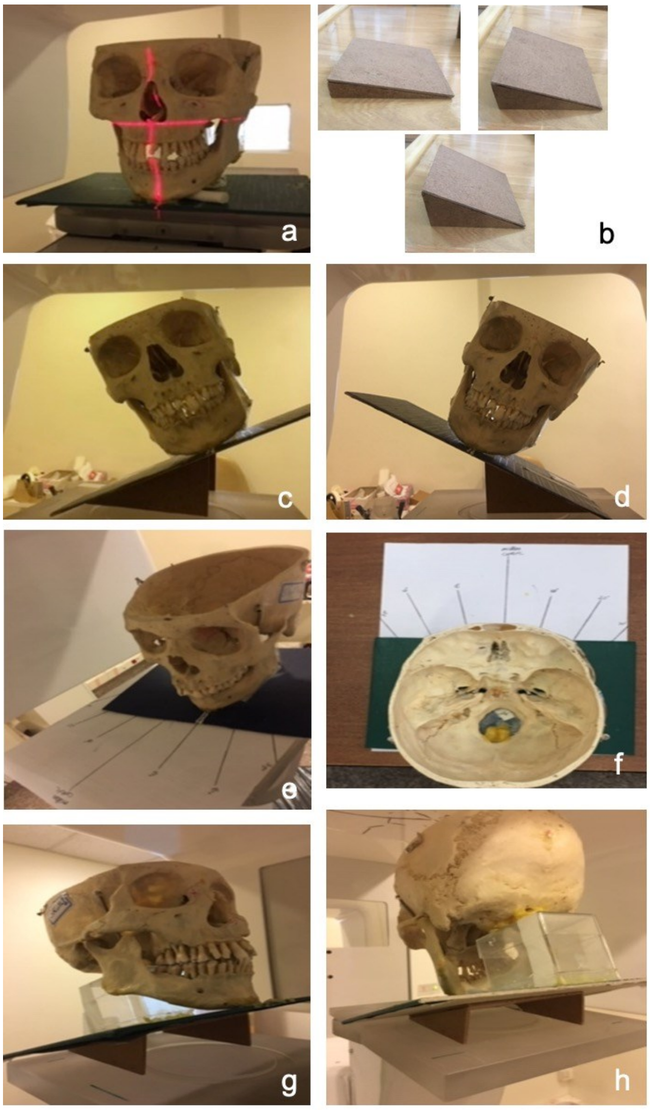

Figure 2- Centric and eccentric positions of the skull. a- Central position, red light was adjusted to the mid-sagittal plane and the Frankfort plane. b- Wooden platforms were designed to simulate eccentric positions at 10°, 20° and 30°. c, d- 30° right and leftward tilted position of the skull. e, f- 10° rotation g- Extension f- Flexion position

Figure 3- Right (a) and left (b) cephalometric measurements in 30° leftward tilt

The measurements were recorded and compared with the actual values measured by a digital caliper.[2, 5, 7, 11-13] Statistical analysis was performed using the SPSS software version 22 (SPSS Inc., IL, USA). For inter-rater reliability, mean-rating, absolute-agreement and 2-way random-effects model were used to calculate the inter-class correlation coefficient (ICC) for each head position. and one sample t-test was used to analyze the data.

Results

The Mean ICC values for each head position are presented in Table 2. The mean ICC between the two observers for all head positions was 96.89%. Due to high inter-rater reliability, it was deemed acceptable to utilize the mean measurements (mean absolute errors) between the two observers for comparison with the gold standard.

Table 2:-Mean ICC values for assessing the inter-rater reliability between the two observers

Position	Gold Standard	Centric	Tilt 10º Right	Tilt 20º Right	Tilt 30º Right	Tilt 10º Left	Tilt 20º Left	Tilt 30º Left	Rotate 10º Right	Rotate 20º Right	Rotate 30º Right
ICC	95.9%	98.3%	96.65%	95.55%	98.4%	98.2%	94.8%	95.6%	97.8%	97.6%	98.1%
Position	**Rotate 10º Left**	**Rotate 20º left**	**Rotate 30º left**	**Extension 10º**	**Extension 20º**	**Extension 30º**	**Flexion 10º**	**Flexion 20º**	**Flexion 30º**		
ICC	94.1%	94.8%	96.7%	99.0%	95.6%	97.64%	97.3%	97.6 %	98.25%		

Mean and standard error for the absolute errors in each position were compared with the gold standard values (one tailed test Ha=μ>0). The maximum error was observed in the left CoGn at 30° leftward rotation (2.56 mm). Tables 3-5 show the position-oriented absolute mean errors and P values.

Table 3- Mean± standard deviation of absolute error (mm) and P value for each tilted position

Landmark	Tilt 10° right	Tilt 20° right	Tilt 30° right	Tilt 10° left	Tilt 20° left	Tilt 30° Left
Se N	0.75±0.41 P=0.05	0.57±0.16 P=0.02	0.81±0.28 P=0.03	0.92±0.08 P=0.001	0.77±0.27 P=0.03	0.53±0.15 P=0.02
N Me	0.26±0.06 P=0.01	0.40±0.17 P=0.05	0.60±0.24 P=0.04	0.43±0.19 P=0.05	0.09±0.04 P=0.05	0.51±0.16 P=0.02
Co Go right	1.06±0.26 P=0.02	0.65±0.12 P=0.01	1.26±0.44 P=0.03	1.07±0.26 P=0.01	1.43±0.19 P=0.00	1.23±0.39 P=0.03
Co Go left	0.76±0.23 P=0.02	0.77±0.23 P=0.02	1.06±0.38 P=0.04	1.06±0.31 P=0.02	1.05±0.31 P=0.02	1.09±0.43 P=0.04
Co ANS right	0.70±0.23 P=0.03	0.99±0.35 P=0.03	1.46±0.57 P=0.04	1.45±0.81 P=0.03	1.30±0.55 P=0.05	1.37±0.41 P=0.048
Co ANS left	1.43±0.61 P=0.05	0.99±0.35 P=0.03	1.46±0.57 P=0.04	1.14±0.54 P=0.06	1.30±0.55 P=0.05	1.21±0.67 P=0.08
Co Gn right	0.49±0.26 P=0.08	2.03±0.92 P=0.06	1.13±0.52 P=0.06	0.49±0.26 P=0.08	0.36±0.20 P=0.08	0.59±0.32 P=0.08
Co Gn left	1.37±0.25 P=0.02	1.43±0.91 P=0.04	1.94±0.80 P=0.05	1.08±0.02 P=0.03	1.02±0.03 P=0.03	1.39±0.09 P=0.01
Go Gn right	1±0.12 P=0.10	0.53±0.17 P=0.13	0.31±0.12 P=0.08	0.52±0.23 P=0.12	0.65±0.15 P=0.07	1.03±0.13 P=0.08
Go Gn left	1.13±0.87 P=0.003	1.33±0.02 P=0.06	0.93±0.06 P=0.10	1±0.02 P=0.03	0.82±0.07 P=0.02	1.88±0.21 P=0.06

Table 4- Mean ± standard deviation of absolute error (mm) and P value for each rotated position

Landmarks	Rotation 10° right	Rotation 20° right	Rotation 30° right	Rotation 10° left	Rotation 20° left	Rotation 30° left
Se N	0.96±0.27 P=0.02	0.68±0.14 P=0.01	0.82±0.23 P=0.02	0.33±0.13 P=0.04	0.61±0.12 P=0.01	0.77±0.30 P=0.04
N Me	0.66±0.14 P=0.01	0.74±0.30 P=0.04	0.50±0.17 P=0.03	0.33±0.13 P=0.04	0.29±0.07 P=0.01	0.46±0.06 P=0.001
Co Go right	0.85±0.20 P=0.01	1.11±0.26 P=0.01	1.45±0.46 P=0.02	0.33±0.09 P=0.03	0.87±0.31 P=0.03	1.05±0.49 P=0.04
Co Go left	0.38±0.06 P=0.00	0.29±0.1 P=0.2	0.66±0.27 P=0.04	1.06±0.31 P=0.04	0.27±0.31 P=0.03	0.36±0.43 P=0.02
Co ANS right	1.61±0.99 P=0.10	1.70±0.35 P=0.004	0.75±0.19 P=0.01	1.15±0.56 P=0.06	1.60±0.38 P=0.01	1.27±0.43 P=0.03
Co ANS left	2.08±0.92 P=0.05	1.02±0.31 P=0.02	0.75±0.19 P=0.01	1.20±0.42 P=0.03	2.16±0.38 P=0.01	1.11±0.37 P=0.045
Co Gn right	1.76±0.65 P=0.04	0.72±0.30 P=0.05	1.03±0.4 P=0.04	1.58±0.68 P=0.05	0.93±0.37 P=0.04	2.12±0.77 P=0.04
Co Gn left	2.40±0.09 P=0.10	1.81±0.11 P=0.02	2.23±0.09 P=0.04	1.81±0.19 P=0.08	1.28±0.34 P=0.00	2.56±0.09 P=0.04
Go Gn right	2.55± P=0.245	0.61±0.56 P=0.119	0.85±0.89 P=0.09	0.43±0.78 P=0.08	0.74±0.29 P=0.004	0.7±0.89 P=0.054
Go Gn left	1.48±1.57 P=0.10	1.81±0.9 P=0.02	2.23±0.02 P=0.04	1.81±0.42 P=0.08	1.28±0.73 P=0.00	2.56±0.02 P=0.04

Table 5- Mean± standard deviation of absolute error (mm) and P value in each extension/flection position

Landmarks	10° extension	20° extension	30° extension	10° flexion	20° flexion	30° flexion
Se N	0.66±0.15 P=0.01	1.07±0.30 P=0.02	0.92±0.37 P=0.04	0.77±0.19 P=0.01	0.88±0.26 P=0.02	0.95±0.30 P=0.03
N Me	0.52±0.20 P=0.04	0.41±0.15 P=0.03	0.50±0.18 P=0.03	0.21±0.12 P=0.09	0.24±0.12 P=0.07	0.11±0.04 P=0.03
Co Go right	0.81±0.46 P=0.09	1.33±0.48 P=0.03	1.52±0.54 P=0.03	0.96±0.48 P=0.07	1.37±0.28 P=0.01	1.13±0.44 P=0.04
Co Go left	0.87±0.26 P=0.02	0.91±0.34 P=0.04	0.74±0.24 P=0.03	0.76±0.54 P=0.13	1.18±0.72 P=0.10	1.20±0.44 P=0.04
Co ANS right	0.66±0.20 P=0.02	0.69±0.20 P=0.02	1.86±0.74 P=0.04	1.36±0.41 P=0.02	1.64±0.56 P=0.03	2.19±0.79 P=0.03
Co ANS left	0.66±0.20 P=0.02	0.69±0.20 P=0.02	1.86±0.74 P=0.04	1.36±0.41 P=0.02	1.64±0.56 P=0.03	2.10±0.70 P=0.03
Co Gn right	0.73±0.29 P=0.04	1.57±0.69 P=0.05	1.46±0.64 P=0.05	1.09±0.55 P=0.07	1.02±0.29 P=0.02	1.63±0.59 P=0.04
Co Gn left	1.23±0.34 P=0.00	1.88±0.86 P=0.04	2.13±0.88 P=0.045	0.66±0.42 P=0.04	0.67±0.39 P=0.04	1.66±0.28 P=0.00
Go Gn right	0.71±0.78 P=0.17	1.01±0.87 P=0.35	1.14±0.53 P=0.02	1.13±0.16 P=0.15	0.68±0.39 P=0.04	1.36±1.25 P=0.12
Go Gn left	1.08±0.66 P=0.05	1.75±0.95 P=0.035	1.75±0.95 P=0.035	0.74±0.59 P=0.09	0.59±0.55 P=0.12	1.15±0.87 P=0.08

Table 6- Mean absolute errors (mm), standard deviation (SD), and P value for each acentric deviated position

	Extension			Flexion			Rotate left			Rotate right			Tilt left			Tilt right		
	Mean	SD	P-value	Mean	SD	P-value	Mean	SD	P-value	Mean	SD	P-value	Mean	SD	p-value	Mean	SD	P-value
SENabs	0.884	0.547	0.000	0.867	0.471	0.000	0.738	0.541	0.001	0.821	0.416	0.000	0.742	0.372	0.000	0.709	0.473	0.001
N_Me_abs	0.479	0.327	0.001	0.186	0.190	0.012	0.367	0.216	0.000	0.633	0.400	0.000	0.308	0.296	0.008	0.422	0.347	0.003
CoGo_R_abs	1.220	0.953	0.002	1.155	0.760	0.001	0.711	0.657	0.006	1.034	0.670	0.000	1.245	0.551	0.000	0.803	0.637	0.002
Co_Go_l_abs	0.840	0.514	0.000	1.044	1.070	0.012	0.715	0.837	0.026	0.582	0.572	0.009	0.853	0.745	0.004	0.903	0.693	0.002
Co_ANS_R_abs	1.072	1.014	0.007	1.730	1.156	0.001	1.221	0.836	0.001	1.243	1.326	0.016	1.218	1.073	0.005	1.051	0.809	0.002
Co_ANS_L_abs	0.945	0.826	0.004	1.503	1.601	0.015	1.153	1.416	0.033	1.337	1.735	0.044	1.182	1.314	0.020	0.948	0.917	0.009
Co_Gn_R_abs	1.252	1.141	0.006	1.248	0.940	0.002	1.544	1.246	0.003	1.169	1.035	0.005	0.481	0.489	0.012	1.319	1.252	0.008
Co_Gn_L_abs	1.459	1.096	0.002	0.995	0.675	0.001	1.880	1.821	0.009	2.147	1.961	0.006	1.163	0.647	0.000	1.530	1.151	0.002
G0_Gn_R_abs	0.954	1.090	0.023	1.054	0.965	0.006	0.621	0.342	0.000	1.338	2.108	0.100	0.733	0.603	0.003	0.612	0.612	0.011
G0_Gn_L_abs	1.371	0.927	0.001	0.825	0.671	0.003	1.038	0.598	0.000	1.108	1.012	0.006	1.233	0.905	0.001	1.137	0.674	0.000

As shown in Tables 3-5, the exact degree of deviation (10º, 20º, 30º) in eccentric positions was not the main factor affecting the measurements; therefore, we took the mean degrees as shown in Table 6.

As seen in Table 6, the P value of most positions was smaller than 0.05 showing that the mean errors were significant.

Central landmarks (NMe; vertical, SeN; horizontal) had the minimum mean errors in all positions.

Standard deviation of the mean errors varied from 0.216 mm (in NMe landmark/rotation positions) to 2.10 mm (in GoGn right/rotation positions).

The eccentric position responsible for the maximum mean error among all eccentric positions was the rotation (2.147 mm/ CoGn left).

Discussion

Accurate diagnosis and successful orthodontic and surgical treatment planning of orthodontic anomalies rely on precise and reliable imaging of the craniofacial complex.[8-13]

Incorrect patient positioning and the associated image distortion is a common error in imaging examinations.[12,14, 15]

This study aimed to assess the effect of tilting, rotation, and tipping of the head position on the accuracy of maxillofacial linear cephalometric measurements made on CBCT scans.

The present study revealed that deviations in the head position can result in statistically significant cephalometric measurement inaccuracies (maximum absolute error of 2.56 mm). The two observers had excellent inter-rater agreement (average ICC=96.89%).

The maximum mean absolute error in our study was for the CoGn-L in 30º leftward rotation (2.56 mm). The maximum mean absolute errors for other cephalometric measurements were as follows: GoGn-R in 10º rightward rotation (2.55 mm), CoANS-R in 30º flexion (2.19 mm), CoANS-L in 20º leftward rotation (2.16 mm), CoGn-R in 30º leftward rotation (2.12 mm), GoGn-L in 30º leftward tilt (1.88 mm), NMe in 20º rightward rotation (1.74 mm), CoGo-R in 30º extension (1.52 mm), GoGn-L in 30º leftward tilt (1.20 mm), and SeN in 20º extension (1.07 mm). The majority of them were deemed statistically significant; however, the agreements in all cases were high indicating excellent agreement with the gold standard.

Our results were in line with those of Sabbah et al.[5] and Shokri et al.[7] who also reported that head position affects linear measurement accuracy on CBCT scans. Furthermore, Kamburoglu and Kursun[21] compared the accuracy of linear measurements made on CBCT (Accuitomo3D) with physical measurements made on dry human skulls and revealed that CBCT measurements were highly accurate.

The maximum absolute error in the present study was for the left CoGn line in 30º leftward rotation (2.56 mm). However, in other studies by Sabban et al.[5] and Adibi et al.[2] the maximum absolute error was reported for extension and tilting positions, respectively.

It is documented that head position plays an important role in landmark identification and cephalometric measurements.[7] To maintain a stable centric position, we used a plate and a box and the skulls were fixed by wax on the box for image acquisition. Cheung et al.[12] used screws and springs for fixing the skull position; these screws and springs were not inserted into the anatomical areas of interest.

Previous studies demonstrated relatively high rate of error in landmark identification. Jae Joon Hwang.[10] reported a very low level of agreement among observers and reproducibility for landmark identification. In the present study, we used gutta-percha markers to assist with landmark identification which resulted in high accuracy. Additionally, presence of wires, springs and screws in a previous study attributed to metal artifacts which decreased the accuracy of measurements.[12]

Several authors have proposed that differences in the examiners' perception of each landmark could lead to deviations in angular and linear measurements.[8, 12, 13] Nonetheless, even in severe deviations from centric head position, the accuracy of cephalometric analysis was not affected. Some authors have argued that landmark identification errors of less than 1 mm are clinically acceptable.[14-16]. It has also been suggested that errors of less than 2 mm would most likely not make a significant difference in treatment.[15]

This study revealed that patient head position has a statistically significant effect on linear measurement accuracy with the greatest error being 2.56 mm. Based on a study, which suggested that errors less than 2 mm would most likely not make a significant difference in treatment planning[15, 16] errors in our study are clinically acceptable and would not influence the treatment plan.

The minimum error in the present study was for the NMe line in 20º rotation (0.74 mm), which was a vertical parameter and closest to the midline. But the mean error was the lowest in flexion positions. (0.18 mm). The error was less than 1 mm and deemed insignificant. This finding was in contrast to those of Sabban et al.[5] and Panjnoosh et al.[10]which demonstrated that head orientation could significantly affect vertical measurements made on CBCT scans. Our findings suggest that head position affects horizontal measurements more significantly compared with vertical measurements (NMe).

In 2017, Adibi and colleagues[3] reported the mean error in all head positions to be less than 0.5 mm, while in our study the errors were greater than 0.5 in eccentric position, probably due to greater variations in head position.

Stamatakis et al.[17] performed color mapping to analyze the effect of head orientation and voxel size on the accuracy of surface-rendered 3D models. They used a specially manufactured platform for precise positioning of the skull and tested 13 head orientations (20º, 10º, 0º, -10º, and -20º roll and 15º, 7.5º, 0º, -7.5º, and -15º pitch). They concluded that head position can affect the accuracy of the segmented 3D model, but the inaccuracies did not exceed the clinically relevant levels, which was in agreement with our results.

Conclusion

This study revealed that head position can affect the accuracy of linear measurements made on CBCT scans. The most noticeable absolute error was 2.56 mm for the left CoGn line in 30º leftward rotation. While this level of error does not seem to be of clinical significance for orthodontic and orthognathic surgery treatment planning, clinicians and radiologists should make every effort to adjust the patient's head position with minimal deviation from the centric position to minimize any measurement error.

The mean of all positions in each group showed that deviation in eccentric head position had minimum effect on NMe in flexion positions.

Conflict of Interest

No Conflict of Interest Declared ■

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