Clinical Oral Investigations (2023) 27:2747–2761
https://doi.org/10.1007/s00784-022-04852-9

RESEARCH

Effect of head rotation on two-dimensional cephalometric measurements using cone beam–computed tomography

Emilie El Hayeck[1] · Nayla Bassil-Nassif[2] · Alexandre Khairallah[3] · Terry El Wak[4] · Joseph Bouserhal[1,4,5]

Received: 1 April 2022 / Accepted: 28 December 2022 / Published online: 12 January 2023

Abstract
Objective The purpose of this study was to identify the variation of bi-dimensional cephalometric measurements following real head rotation.
Material and methods Thirty cone beam–computed tomography (CBCT) head films were oriented according to three axes: horizontal Frankfort plane, transverse bi-orbital plane, and Opisthion-Nasion median plane. Axial rotation of 2°, 4°, 6°, and 8° from the Odontoïdale point were performed. Horizontal and vertical linear and angular measurements were studied on lateral cephalograms derived from each rotation T0, T2, T4, T6, and T8. A paired *t*-test was applied to compare the measurements between T0 and each rotational angle.
Results Of the 18 measurements, 55% showed statistically significant differences ($P < 0.05$) and 22% showed clinically significant differences, mostly at T6 and T8. Horizontal linear measurements Ba-A and N-Ba decreased, and vertical linear measurement G-Sn increased gradually, as the angle of head rotation increased. Angular measurements studied did not vary.
Conclusions Head malpositions during X-ray acquisition should be avoided and rotated lateral CBCT cephalograms should be corrected and recentered to prevent any variation in linear measurements.

Keywords Cone beam–computed tomography · Axial rotation · Lateral cephalograms · CBCT

Introduction

Cephalometric analyses are an essential diagnostic tool for orthodontic and ortho-surgical treatments and precision in cephalometric measurements is considered essential in research studies. These cephalometric analyses contain measurements based on landmarks whose location depends on head orientation.

✉ Terry El Wak
terry.wak@hotmail.com

1 Department of Orthodontics, School of Dental Medicine, Saint Joseph University, Beirut, Lebanon

2 Private Practice, Paris, France

3 Department of Oral and Maxillo-Facial Imaging, School of Dentistry, Lebanese University, Beirut, Lebanon

4 Craniofacial Research Laboratory, Saint Joseph University, Beirut, Lebanon

5 Department of Orthodontics, School of Dentistry, Beirut Arab University, Beirut, Lebanon

The study of reference points and cephalometric measurements variations following different orientations of dry skulls was the subject of several researches on lateral cephalograms between the years 1993 and 2016. [1, 11] Tng et al. [1] were the first to question the cephalometric variations as a result of change in head orientation. By varying the Frankfort plane of 30 Chinese skulls by ± 30° from the horizontal, they found that skull modification upwards and downwards, produced significant differences for SNA, SNB, and SNPog angles. El Hayeck et al. [6] studied the variations of these sagittal angular measurements, SNA, SNB, and SNPog according to two different orientations: Natural head position and Frankfort anatomic plane, and no significant difference was found.

In order to ameliorate orthodontic treatment planning when additional information is needed, the use of three-dimensional imaging has increased during the last years. Cevidanes et al. [7] performed a retrospective study on cone beam–computed tomographies (CBCT) of 12 patients, to determine the reliability and systematic differences using two orientations: the visual axis to simulate natural head position, and intracranial reference planes. Significant differences were found between the two orientations for some angular and linear measurements, which may affect the diagnosis and the orthodontic treatment plan.

The head moves around three axes: horizontal, axial, and vertical. These movements are called: pitch, yaw, and roll.[11,12] Yaw movement and the variations of cephalometric measurements have interested some authors [2, 5]. They used a rotational axis connecting the center of both ear rods of the cephalostat, which does not represent the real axis of head rotation [2, 5]. The axial rotation has been described in functional anatomy as the axis passing by the odontoid process of the second cervical vertebrae [13, 14].

The combination of measurement variations with the real head movement according to functional anatomy is not yet studied. No study on cephalometric variations has been made considering measurable and precise variations of head orientations on CBCT images.

The purpose of this study was to determine the effect of yaw movement and real head rotation on two dimensional cephalometric measurements using CBCT.

Materials and methods

Sample selection

The 30 CBCT of the study subjects were obtained from the review of clinical records, taken for different purposes. The selection criterions were adults between 18 and 35 years old without craniofacial deformity or facial asymmetry or had undergone any maxillofacial surgery or facial trauma. The quality of radiographs was controlled and chosen without kinetic artifacts.

Facial symmetry was verified on the posteroanterior cephalometric radiograph, using the perpendicular to the bi-orbital plane passing through crista-galli point, as an axis of symmetry.

Methods

The CBCT scans have been acquired using a Kodak 9500 Cone Beam 3D System. (Care stream Health, Inc., Rochester, New York, USA) and according to the following technical specifications: Field of view (FOV) 206 mm × 184 mm, voxel size: $0.3 \times 0.3 \times 0.3 mm^3$, tube voltage: 60–90 kvp, tube current: 2-15 mA, frequency: 140 kHz, scanning time: 10.80 s. The focal spot size of the tube was 0.7 mm and the reconstruction time of one CBCT scan was 2 min. 20 s.

The 30 CBCT were initially taken in a standing position.

Head repositioning

3D scans were reoriented according to three axes:

- Horizontal axis in sagittal view: The anatomical Frankfort horizontal plane defined bilaterally by porion and orbitale skeletal landmarks (Fig. 1).
- Transverse axis in frontal view: The transorbital plane defined bilaterally by orbital skeletal landmarks (Fig. 2).

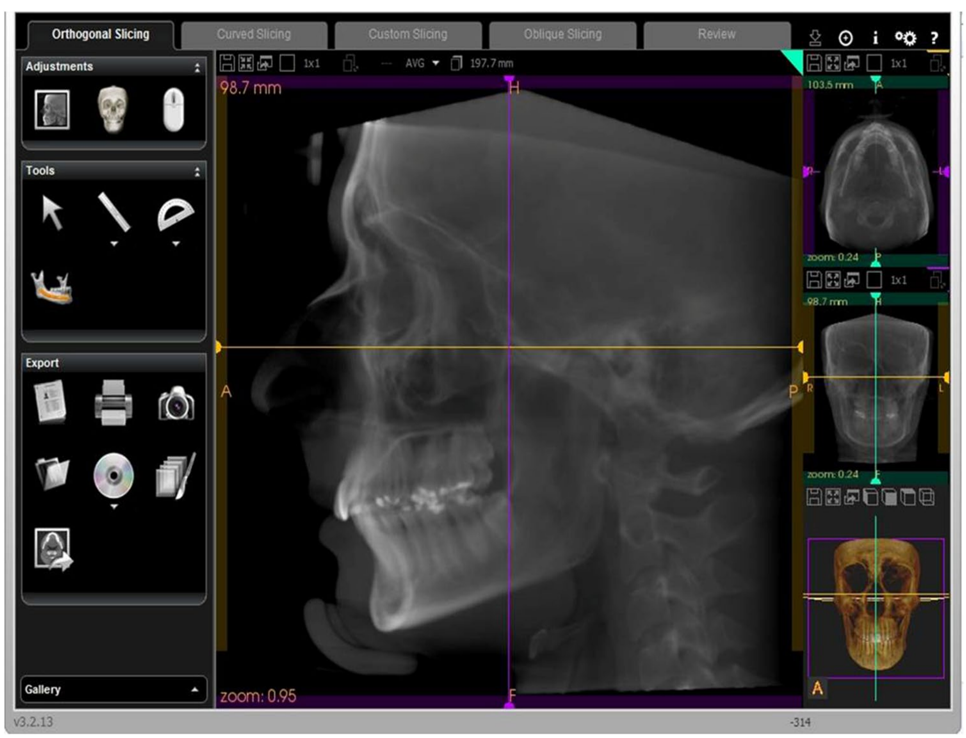


Fig. 1 Horizontal axis in sagittal view. The Frankfort horizontal plane

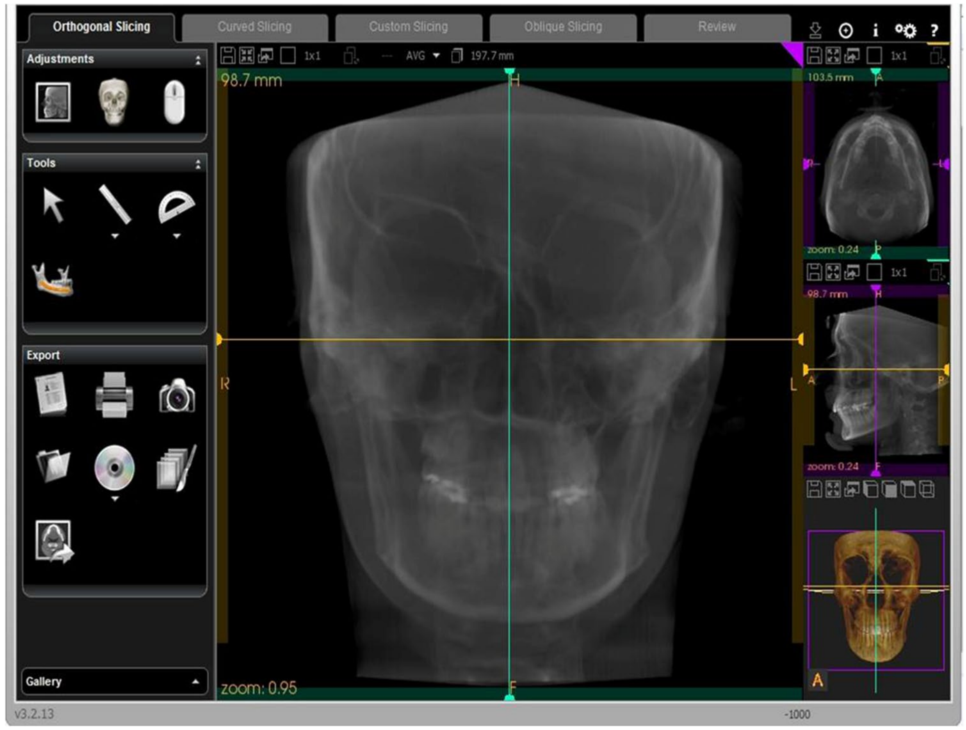


Fig. 2 Transverse axis in frontal view: The transorbital plane

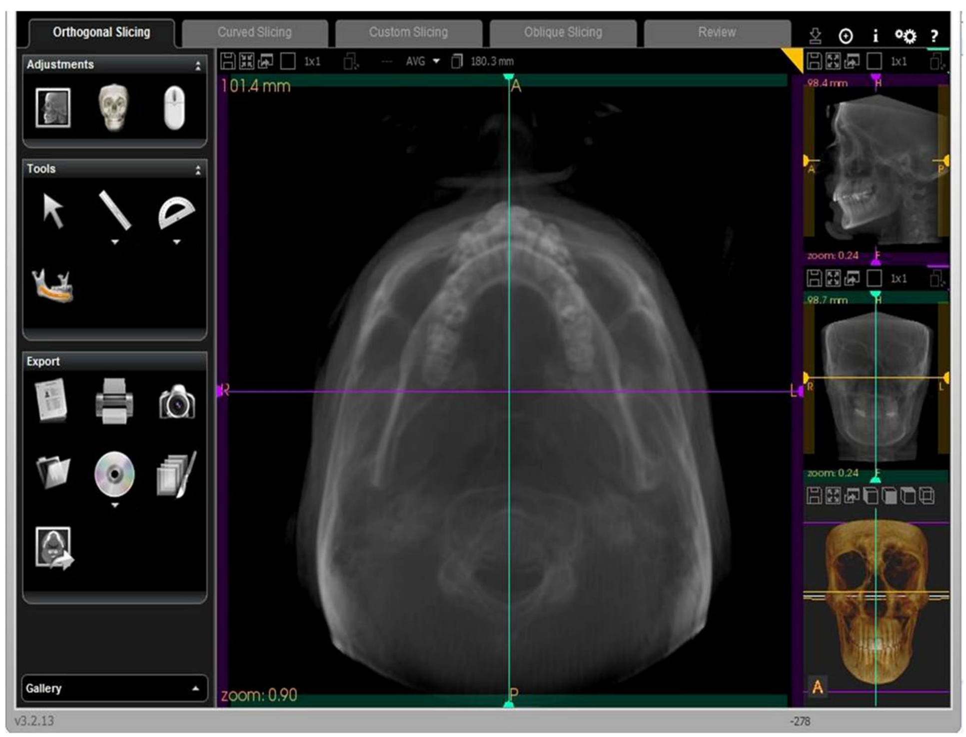


Fig. 3 Median axis in axial view. The midsagittal plane

- Median axis in axial view: The midsagittal plane defined by opisthion, the intermaxillary suture and Nasion point (Fig. 3). To verify its crossing through the Nasion point, the horizontal plane parallel to Frankfort plane was moved on the sagittal view in order to pass through Nasion point (Fig. 4). We verified the passage of the median axis through Nasion at 1.5 mm cut on the axial view (Fig. 5).

In sagittal, frontal, and axial views, the volume of the head was rotated until the Frankfort and transorbital planes

Fig. 4 The sagittal plane at the Nasion point

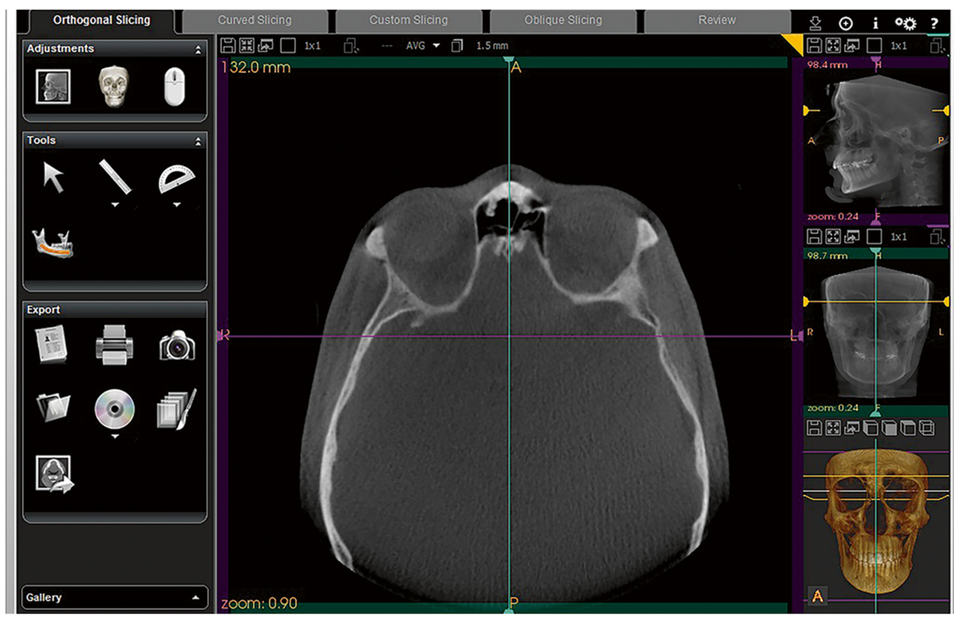


Fig. 5 Verification of median plane passing by Nasion point

were oriented horizontally, and the midsagittal plane was oriented vertically.

The data obtained after repositioning the head volume along the three axes were saved in a DICOM universal format. The 2D cephalograms obtained at this stage were named TR.

Axial rotation

Before axial rotation was performed, a millimetric ruler was introduced on the radiographs TR or T0 in order to be able to perform the linear measurements on Dolphin imaging software.

TR repositioning was followed by modifications in the axial view of each subject, which was initially oriented along the midsagittal plane (Opisthion – Nasion). Odontoïdal point: the most superior point of the odontoid process was chosen as the point of intersection of the two axes: the midsagittal plane and the transversal plane. This point was chosen to reproduce the natural rotation of the head, which is normally done around the odontoid process of the axis.

In order to locate this point in the axial view, the sagittal Frankfort horizontal axis was moved on the sagittal view to meet the top of the odontoid process (Fig. 6). Navigation at

Fig. 6 The sagittal plane at the level of the odontoid process

Fig. 7 Navigation at different axial sections to locate the Odontoid point

the different sections in axial view was performed to locate the most superior point of the odontoid process (Fig. 7).

The heads were rotated 2°, 4°, 6°, and 8° from the odontoid point, to the right side of the screen (Fig. 8). New lateral cephalograms T0, T2, T4, T6, and T8 were obtained for each position (Figs. 9, 10, 11, 12, 13).

Measurements

T0, T2, T4, T6, and T8 cephalograms were transferred to Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, California, USA).

The tracings were executed by the observer (EH), having 19 years' experience in cephalometrics. Lateral structures were drawn by tracing the middle of the duplication after rotation.

The landmarks used in this study are defined in Table 1.

Skeletal and soft tissue measurements of the most commonly used cephalometric analyses were performed, including angular and linear measurements that are divided into vertical and horizontal.

Horizontal linear skeletal measurements were chosen grouping:

Fig. 8 Head rotation

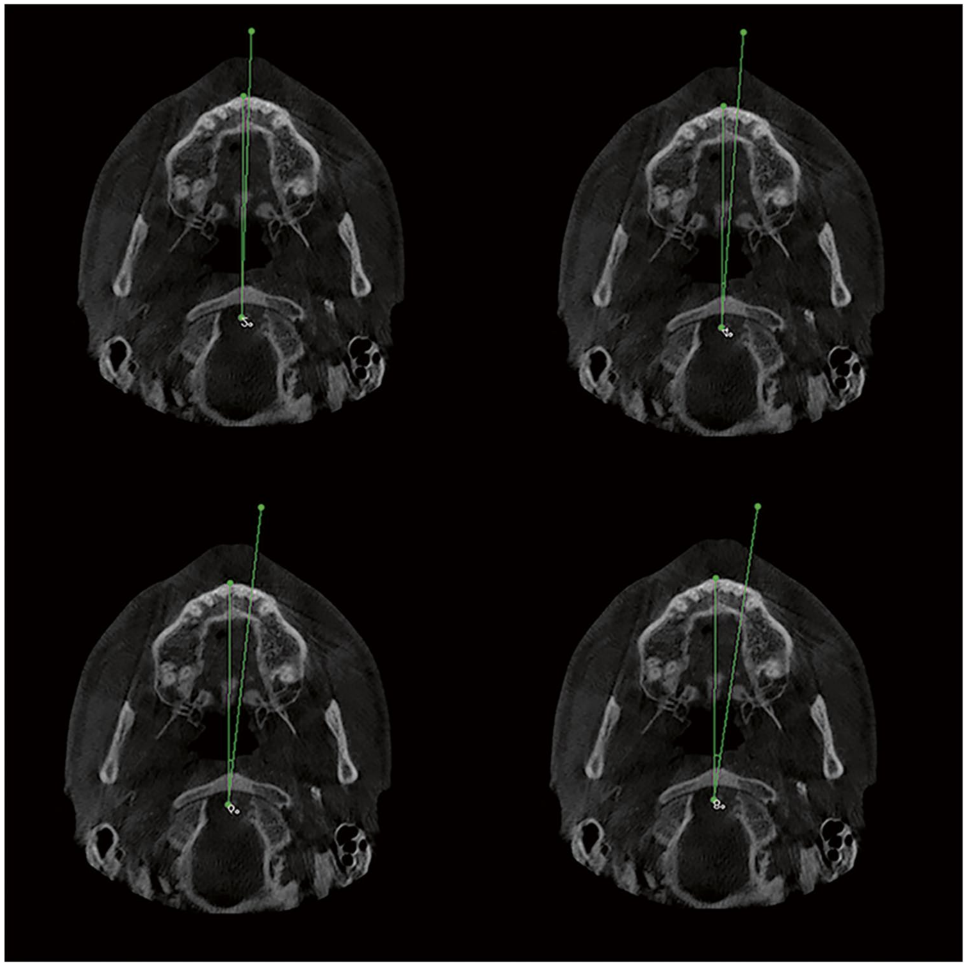
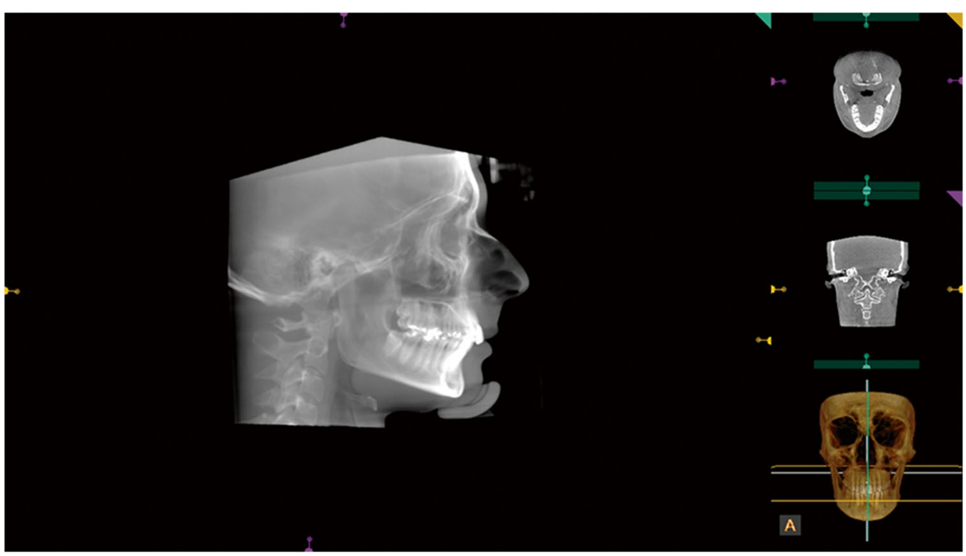


Fig. 9 Lateral cephalogram T0



- A midpoint located near the center of rotation and another point on the periphery: Ba-A, Ba-Pog, and N-Ba.
- A midpoint and a lateral point: GoGn.
- A midpoint of the profile and another point resulting from the projection on a vertical line: A-Na Perp. and Pog-Na Perp.

Fig. 10 Lateral cephalogram T2

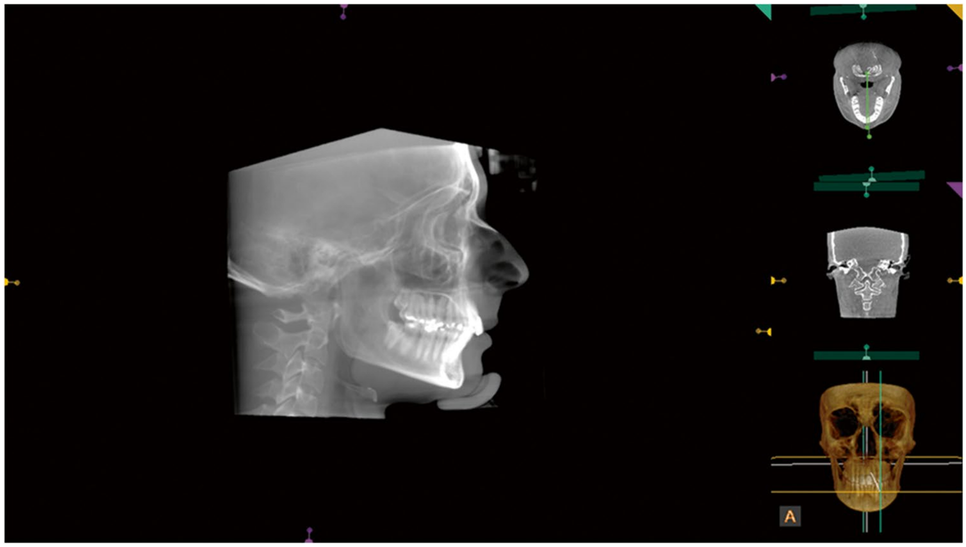


Fig. 11 Lateral cephalogram T4

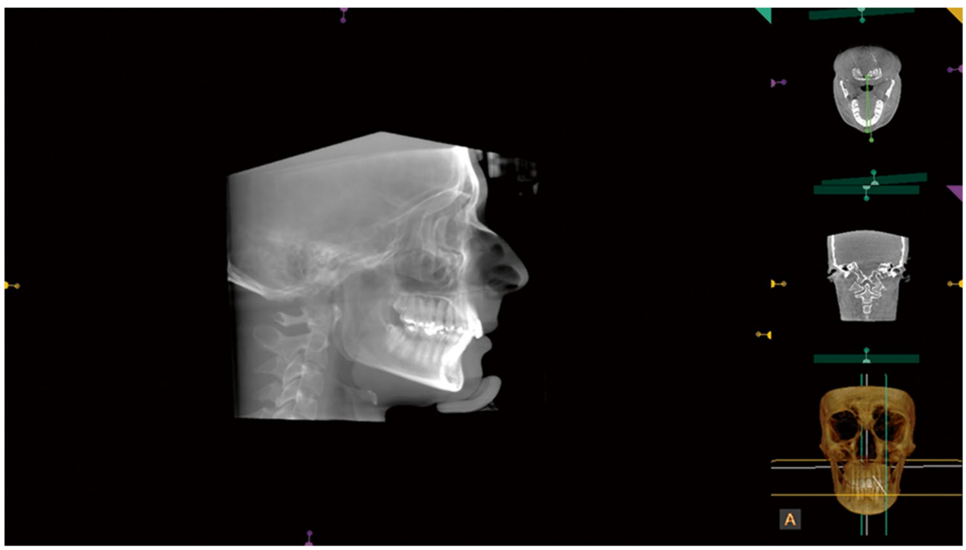
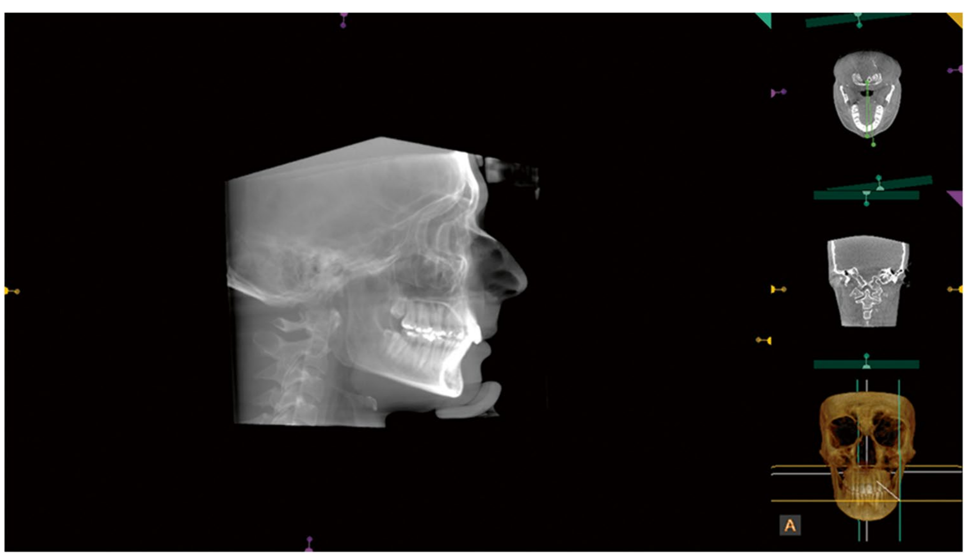


Fig. 12 Lateral cephalogram T6



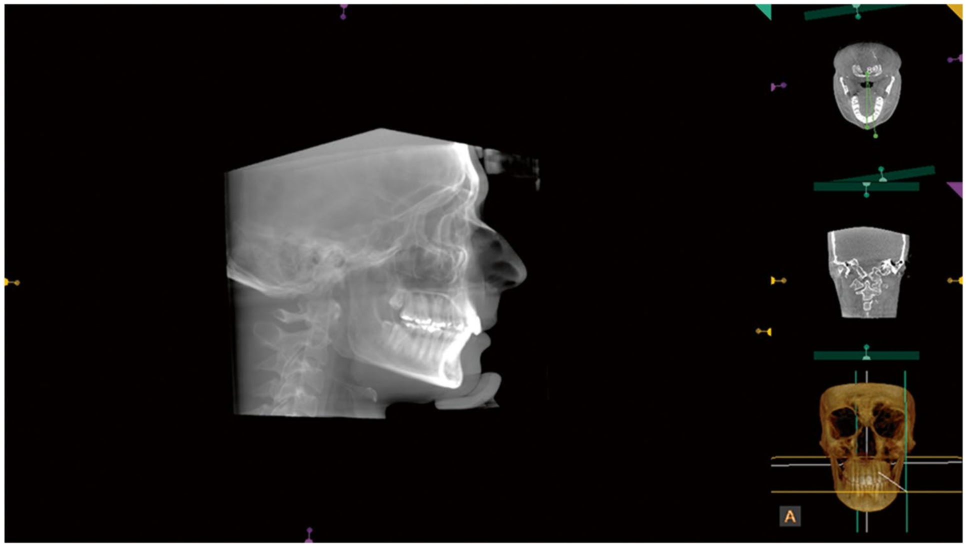


Fig. 13 Lateral cephalogram T8

Table 1 Landmark definitions

Landmarks	Definitions
Nasion (N)	Craniometric point where the midsagittal plane intersects the most anterior point of the nasofrontal suture
Sella turcica (S)	The center of the sella turcica
Skeletal porion (Po)	The highest point on the skeletal external auditory meatus
Basion (Ba)	The most inferior point on the anterior margin of the foramen magnum in the midsagittal plane
Orbitale (Or)	The lowest point on the lower margin of each orbit
Point A	Deepest point on the curve of the bone between the anterior nasal spine and dental alveolus
Point B	Deepest midline point on the mandible between infradentale and pogonion
Pogonion (Pog)	Most anterior point on the symphysis of the mandible
Menton (Me)	Most inferior point on the symphysis of the mandible
Gnathion (Gn)	The midpoint between the most anterior and inferior points of the symphysis
Gonion (Go)	The equidistant point between the most posterior and the most inferior points on the mandibular angle
Soft tissue Glabella (G)	The most anterior soft tissue point in the midsagittal plane of the forehead
Columella (Cm)	The most anterior and inferior point of the nose
Subnasale (Sn)	Point at which the base of the nose meets the upper lip

Angular skeletal measurements were chosen grouping:

- Angles having as reference a median plane: SNA, SNB, and SNPog.
- Angles having as reference a plane passing through two lateral points, such as the Frankfort plane: FH-NA and FH-NPog.

Cephalometric measurements used in this study:

- Sagittal angular skeletal measurements: FH-NA, FH-NPog, ANB, SNA, SNB, and SNPog.
- Vertical angular skeletal measurement: FMA.
- Horizontal linear skeletal measurements: Ba-A, Ba-Pog, A-NPog, A-Na Perp., Pog-Na Perp., N-Ba, and Go-Gn.
- Vertical linear measurement: N-Me.
- Angular soft tissue measurement: Col-Sn-UL.
- Horizontal linear soft tissue measurement: Sn-G.
- Vertical linear soft tissue measurement: G-Sn.

Cephalograms T0, T2, T4, T6, and T8 of 10 subjects were randomly selected. These cephalograms were retraced once again 1 month later. All landmarks were relocated, and measures were repeated by the first observer (E.H), in order to test intra-observer variance.

Cephalograms T0, T2, T4, T6, and T8 of 12 subjects were randomly selected and retraced by a second observer (N.N), having 10 years' experience in cephalometrics. Eight of 11 skeletal landmarks were relocated: Porion, Orbitale, Nasion, A point, B point, Pogonion, Menton, and

Gonion. These are among the most commonly used points. 4 corresponding measures were remeasured, in order to estimate the inter-observer variance in localizing the landmarks. These measures included facial angle, ANB, FMA, and anterior facial height.

Table 2 Mean variations and standard deviations of measurements after rotation

Measurements	T0	T2	T4	T6	T8
Skeletal angular measurements					
FH-NA(°) Mean	90.9	90.5	90.5	90.7	90.5
SD	3.0	3.0	2.8	2.8	2.6
FH-NPog(°) Mean	88.8	88.6	88.6	88.9	88.6
SD	3.4	3.5	3.6	3.6	3.6
ANB Mean	3.2	2.9	3.0	2.9	2.9
SD	2.2	2.1	2.2	2.3	2.2
FMA(MP-FH)(°) Mean	24.4	24.4	24.4	23.9	24.2
SD	5.2	4.9	4.9	5.0	4.8
SNA(°) Mean	81.0	80.8	81.2	80.9	81.1
SD	4.7	4.5	4.1	3.8	4.4
SNB(°) Mean	77.8	77.9	78.2	78.0	78.1
SD	4.9	4.7	4.6	4.4	4.8
SNPog(°) Mean	78.8	79.0	79.3	79.1	79.3
SD	5.0	4.8	4.6	4.5	5.0
Skeletal horizontal linear measurements					
Ba-A(mm) Mean	91.4	90.8	90.6	90.2	88.9
SD	5.7	5.0	5.2	5.7	5.3
Ba-Pog(mm) Mean	107.4	107.2	107.2	106.9	106.3
SD	7.2	7.1	7.7	7.2	7.2
A-NPog(mm) Mean	2.2	1.9	2.0	1.9	1.8
SD	2.6	2.5	2.5	2.6	2.5
A-NaPerp(mm) Mean	0.9	0.5	0.5	0.7	0.4
SD	3.1	3.1	2.8	2.9	2.7
Pog-NaPerp(mm) Mean	-2.5	-2.7	-2.7	-2.2	-2.6
SD	6.9	7.0	7.1	7.2	7.0
N-Ba(mm) Mean	103.6	103.0	102.3	101.8	100.5
SD	5.8	5.4	5.9	6.6	6.3
Go-Gn(mm) Mean	78.7	78.7	78.8	78.7	78.8
SD	6.5	7.0	7.6	6.3	6.1
Skeletal vertical linear measurement					
N-Me(mm) Mean	131.2	131.1	131.2	130.9	130.7
SD	9.8	10.0	10.2	10.0	9.9
Soft tissue angular measurement					
Col-Sn-UL(°) Mean	110.2	110.1	110.4	110.5	109.4
SD	11.6	11.4	11.1	11.2	11.4
Soft tissue horizontal linear measurement					
Sn-G(mm) Mean	-8.9	-8.8	-8.6	-7.9	-7.8
SD	4.5	4.4	4.1	5.2	4.3
Soft tissue vertical linear measurement					
G-Sn(mm) Mean	65.4	65.7	66.4	66.6	67.0
SD	4.5	4.8	4.9	5.0	4.5

Statistical analysis

Statistical analysis was performed using Minitab Software V 21.1. Variables were studied using means ± standard deviations. The sample normality was verified by the ANOVA—one-way test. Paired *t*-test was used to compare the patients' measurements from 0° to each rotational angle T2, T4, T6, and T8. Intra- and inter-observer variances were evaluated using the Attribute Agreement Analysis. The inter-observer variance was assessed using the Bland–Altman Plots test. $P < 0.05$ was considered statistically significant.

Results

Table 2 resumes the mean variations of measurements after head rotation.

Comparisons of measurements between T0 and T2, T4, T6, and T8 are presented in Table 3.

Table 3 Comparisons of measurements between initial position (T0) and different degrees of rotation (T2, T4, T6, and T8)

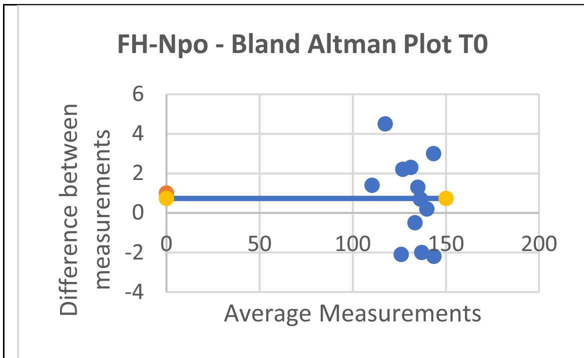
Measurements	T0 vs T2 *P* value	T0 vsT4	T0 vsT6	T0 vsT8
Skeletal angular measurements				
FH-NA (°)	0.048	0.155	0.243	0.047
FH-NPog (°)	0.444	0.397	0.525	0.554
ANB (°)	0.018	0.159	0.016	0.024
FMA (MP-FH) (°)	0.990	0.908	0.072	0.611
SNA (°)	0.572	0.635	0.935	0.714
SNB (°)	0.616	0.288	0.359	0.316
SNPog (°)	0.560	0.258	0.234	0.156
Skeletal horizontal linear measurements				
Ba-A (mm)	0.069	0.036	0.012	0.000
Ba-Pog (mm)	0.525	0.613	0.173	0.005
A-NPog (mm)	0.029	0.095	0.003	0.010
A-Na Perp (mm)	0.048	0.140	0.231	0.045
Pog-Na Perp (mm)	0.523	0.573	0.301	0.725
N-Ba (mm)	0.035	0.007	0.002	0.000
Go-Gn (mm)	0.954	0.812	1.000	0.798
Skeletal vertical linear measurement				
N-Me (mm)	0.715	0.856	0.342	0.027
Soft tissue angular measurement				
Col-Sn-UL (°)	0.908	0.474	0.499	0.086
Soft tissue horizontal linear measurement				
Sn-G (mm)	0.878	0.174	0.015	0.000
Soft tissue vertical linear measurement				
G-Sn (mm)	0.362	0.012	0.003	0.000

$P<0.05$ is considered statistically significant

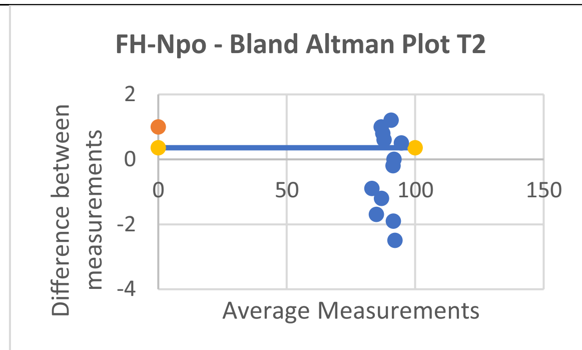
The results in Table 2 show that skeletal sagittal angular measurements FH-NPog, SNA, SNB, SNPog, and skeletal vertical angular measurement FMA, have no statistically significant differences between degrees of rotation and the initial head position. The only angular measurements with a statistically significant difference are FH-NA and ANB. Table 2 shows that angular variations are not clinically significant.

Skeletal horizontal linear measurements Ba-Pog, A-NPog, A-Na Perp., Ba-A, and N-Ba show statistically significant differences between angles of rotation and T0 (Table 3). Table 1 shows a gradual clinical significant decrease of Ba-A and N-Ba measurements as the angle of head rotation increases. The skeletal vertical linear measurement N-Me shows a statistically significant difference at T8 (Table 3).

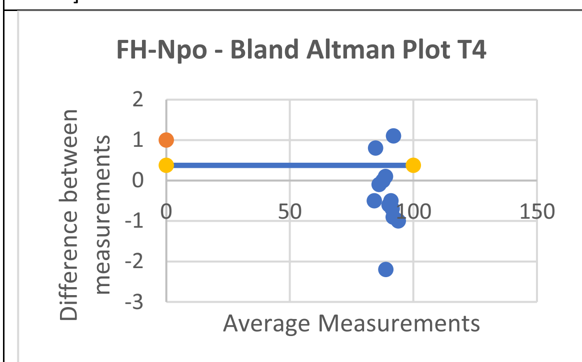
Table 4 Inter-observer variance. Bland–Altman Plots to compare the measurements achieved by two observers



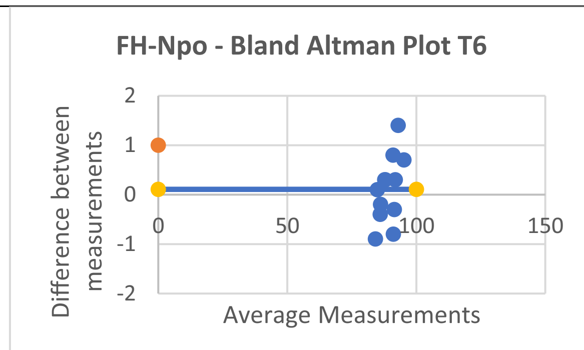
The average difference turns out to be -0.283 and the 95% confidence interval for the average difference is [-1.884, 1.317].



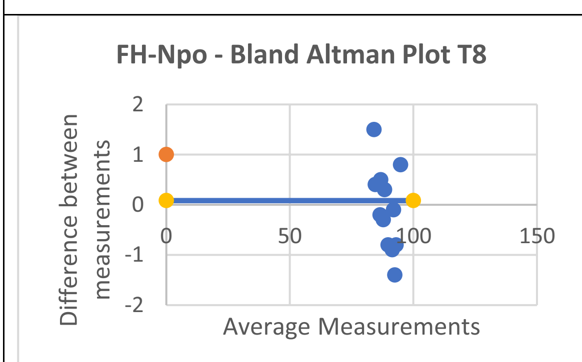
The average difference turns out to be −0.358and the 95% confidence interval for the average difference is [-2.808, 2.092].



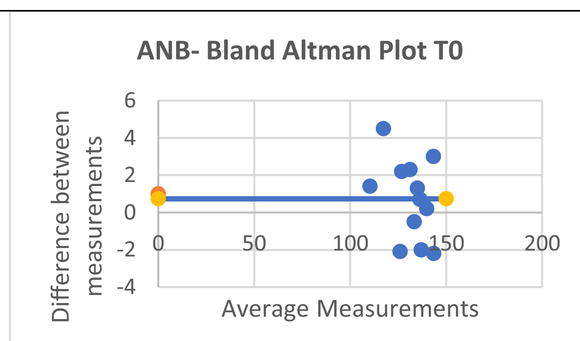
The average difference turns out to be −0.375 and the 95% confidence interval for the average difference is [-2.065, 1.315].



The average difference turns out to be 0.108 and the 95% confidence interval for the average difference is [-1.209, 1.426].

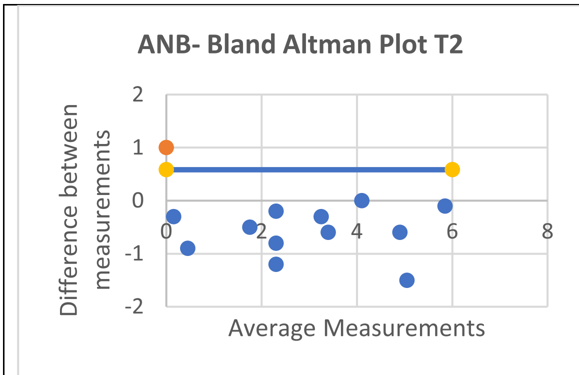


The average difference turns out to be -0.083 and the 95% confidence interval for the average difference is [-1.701, 1.535].

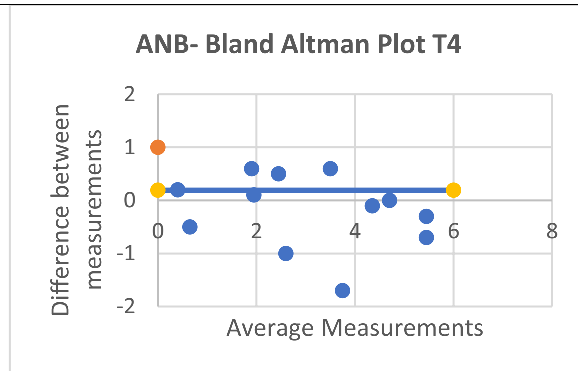


The average difference turns out to be -0.2 and the 95% confidence interval for the average difference is [-1.704, 1.304].

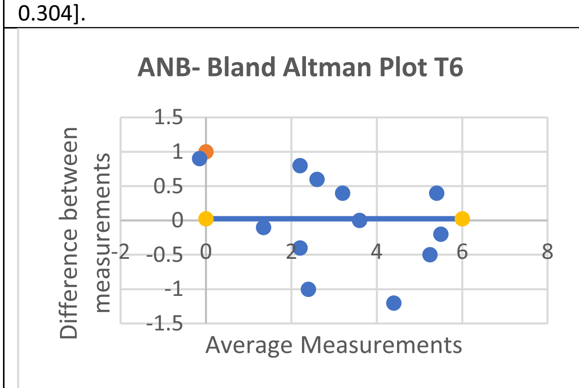
Table 4 (continued)



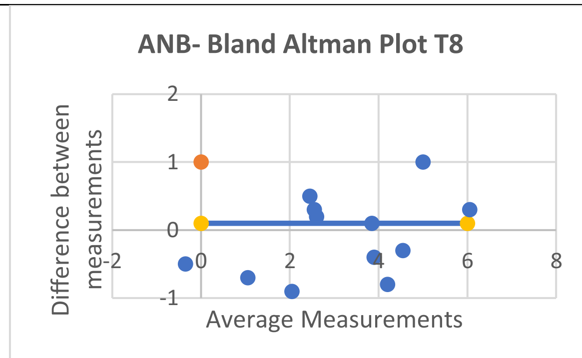
The average difference turns out to be -0.583 and the 95% confidence interval for the average difference is [-1.471, 0.304].



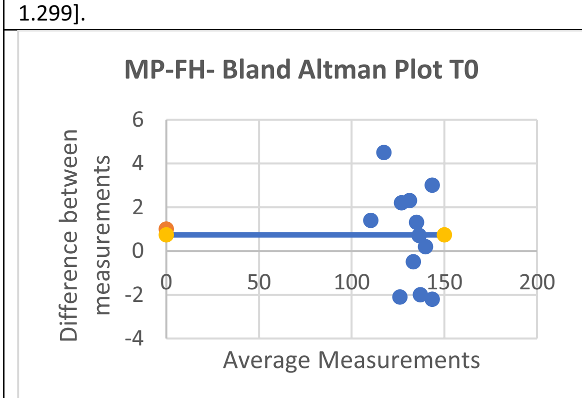
The average difference turns out to be -0.192 and the 95% confidence interval for the average difference is [-1.553, 1.170].



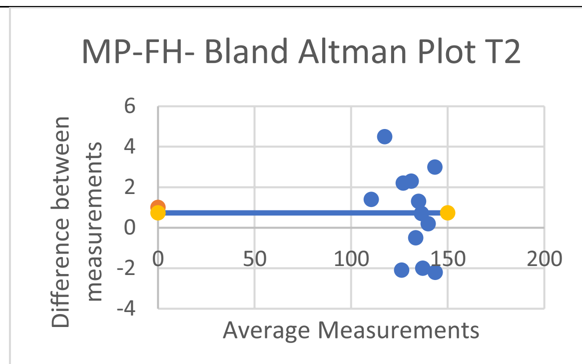
The average difference turns out to be -0.025 and the 95% confidence interval for the average difference is [-1.349, 1.299].



The average difference turns out to be -0.1 and the 95% confidence interval for the average difference is [-1.252, 1.052].



The average difference turns out to be 0.492 and the 95% confidence interval for the average difference is [-0.988, 1.971].



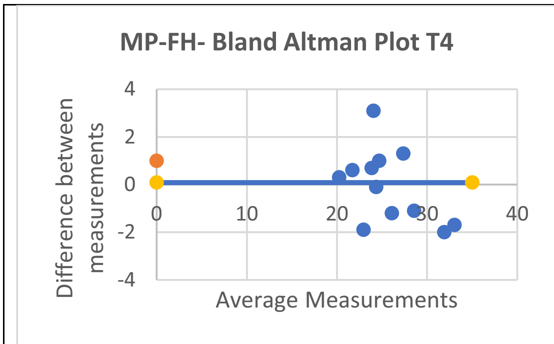
The average difference turns out to be -0.675 and the 95% confidence interval for the average difference is [-3.381, 2.031].

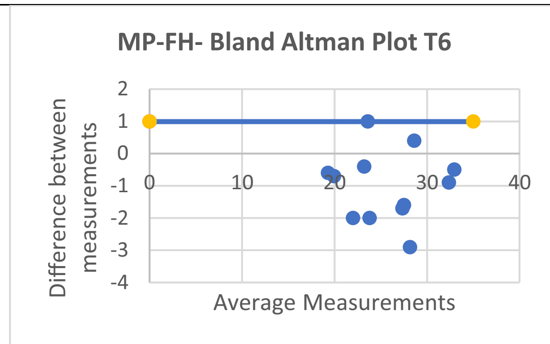
Table 3 indicates a statistically significant difference of the horizontal linear measurement Sn-G at T6 and T8, and the vertical linear measurement G-Sn at T4, T6, and T8. G-Sn increases gradually as the angle of head rotation increases (Table 2). Col-Sn-UL cutaneous angular measurement shows no significant difference between angles of rotation.

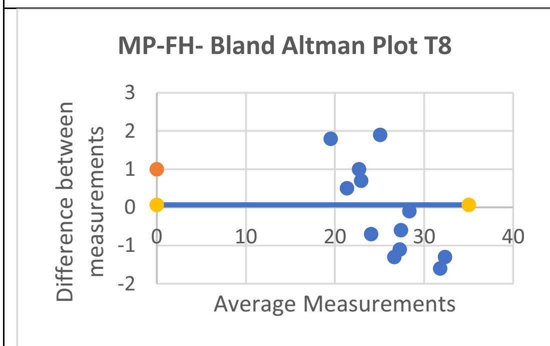
The intraobserver agreement is strong for the FH-NPog, ANB, FMA, and N-Me measurements at different angles ($P > 0.05$).

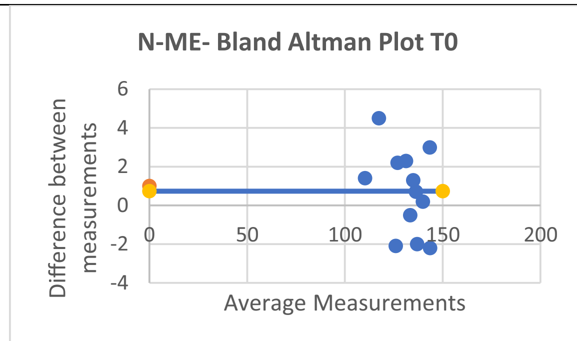
The interobserver agreement is found strong for all measurements. The average difference between measurements achieved by the two operators is shown in Table 4.

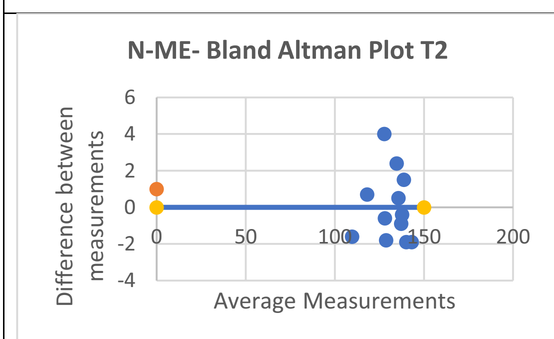
Table 4 (continued)

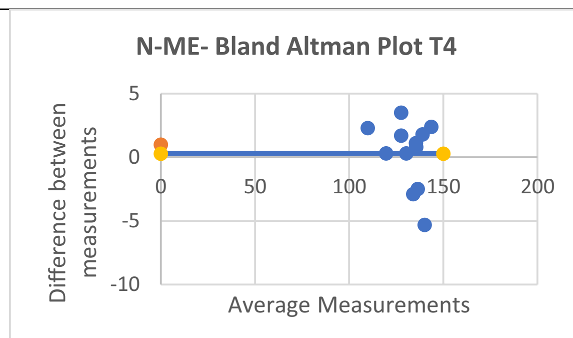
<table>
<tr>
<td>


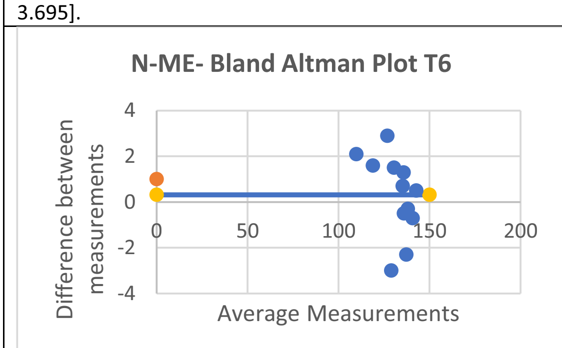
The average difference turns out to be -0.083 and the 95% confidence interval for the average difference is [-3.115, 2.948].
</td>
<td>


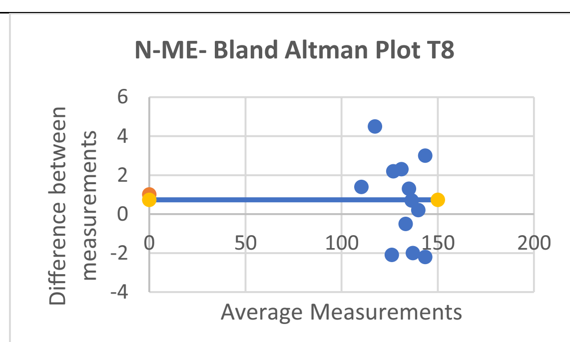
The average difference turns out to be -0.992 and the 95% confidence interval for the average difference is [-3.146, 1.163].
</td>
</tr>
<tr>
<td>


The average difference turns out to be -0.067 and the 95% confidence interval for the average difference is [-2.471, 2.337].
</td>
<td>


The average difference turns out to be 0.583 and the 95% confidence interval for the average difference is [-4.333, 5.499].
</td>
</tr>
<tr>
<td>


The average difference turns out to be 1.184 and the 95% confidence interval for the average difference is [-3.695, 3.695].
</td>
<td>


The average difference turns out to be 0.292 and the 95% confidence interval for the average difference is [-4.764, 5.347].
</td>
</tr>
<tr>
<td>


The average difference turns out to be 0.317 and the 95% confidence interval for the average difference is [-3.128, 3.761].
</td>
<td>


The average difference turns out to be 0.733 and the 95% confidence interval for the average difference is [-3.471, 4.937].
</td>
</tr>
</table>

Discussion

The aim of this study was to determine the effect of yaw movement and real head rotation on two dimensional cephalometric measurements using CBCT.

The center of rotation used in our study, to perform rotation movement of the head, is defined by the most superior point of the odontoid process. This process located at the level of the axis vertebrae and articulating with the anterior arc of the atlas, has been described in functional anatomy, like an axis allowing the head's rotation [13, 14]. Several studies conducted in order to study the variations of cephalometric measurements following rotation movement used as rotational axis, on dry skulls, the axis passing through both ear rods [2–5, 8]. But the displacement of the cephalometric reference points depends on the center of rotation and it is proportional to the distance between each reference point and the center of rotation according to the measure of arcs in geometry. It is important to use a center or axis of real anatomical rotation for better accuracy in point variations.

In our study, the landmarks were chosen at different rotation angles, after simulating real head rotation. We tend to think that these landmarks may not be the same at real head rotation when taking the radiographs for the patient, as the radiation path is not the same, and this may affect the measurements. But we have to consider, during a CBCT scan, the X-ray tube and detector rotate along a circular trajectory. During the rotation, a cone-shaped X-ray beam results in several hundred 2D X-ray projections in all rotating directions.

Variations of linear measurements

Horizontal linear measures have been described in several studies as having the greatest variation following head rotation [3, 5]. These studies used a radio-opaque material in their methodologies to locate initially the reference points on the skulls following therefore the displacement of these points with the rotating motion and thus the variation of cephalometric measures. These points do not vary deliberately in their choice but vary with rotation. Their location on lateral cephalograms taken at different degrees of rotation is none other than their projection on the cephalogram's plan.

Horizontal linear measurements having at their extremities the center of rotation or a point near the center of rotation and another point that is deliberately unchanging; in this case, study of the linear variation is none other than the displacement of this point on the trigonometric circle and its projection on x-axis which is the cosine of the angle, which decreases with the increase of the angle. This is true if the X-ray beam is perpendicular to the object and the receiver screen.

Yoon et al. [3] found in their study on error projections of horizontal linear measurements following skull rotation, a difference according to the direction of rotation. The base of the skull length (S–N) and mandibular length decreased as the skulls turn towards the film plane. Similar results to those of Ahlqvist et al. [15]. They considered that the reduction is due in part to the rotation itself, and in the other, to the effect of the enlargement resulting from the rotation towards the film. However, their results are different from those of Ahlqvist et al. for a rotation to the focal point [3, 15]. They found that the measurements increase then decrease following a rotation of 0° to 12° towards the focal point. This is explained by an increase in the projection enlargement following skull rotation towards the X-ray source, and a decrease in the projection after the rotation itself. According to Yoon, the length increases if the enlargement is greater, and decreases if the effect of rotational reduction is greater [3]. Ahlqvist et al. [15] found that a rotation to the film caused a decrease in the length of S–N, while a rotation towards the focal point caused an increase in this measurement. The reduction or increase of the projection by enlargement is none other than the effect of the angle that forms the incidence radius with the subject and the distance between subject and receiver screen.

In our study, rotations of the head were conducted in one direction to the right side of the head and the screen, using the lateral cephalograms derived from cone beam tomography. These cephlometric images are accurate and without enlargement according to the "ray–sum" method.[15] We found that almost all linear measures are reduced and some measures do not vary between 0° and 8° (Tables 2, 3).

The landmarks used were not chosen in advance as in other studies. Reference points were selected for the first time at T0 and were spotted again on the cephalogram for each angle of head rotation. Considering that the chosen point on the cephalogram after rotation, by its definition, is not necessarily the same point selected on the initial cephalogram T0.

Ahlqvist et al. [15] found in their computer-based virtual cephalometric study, that the rotation of an object by 5° from its original position, led to errors in linear measurements of less than 1%, which may increase with increasing rotation.

Our study shows that horizontal linear measurements have many variations after head rotation. These variations are statistically significant for the measurements N-Ba and Ba-A from T2 and T4 respectively (Table 3). But they are considered clinically significant from T8 with respective decrease of 3.1° and 2.5° from the initial values at T0 (Tables 2, 3). Although Ba-Pog is comparable to Ba-A and N-Ba, measurements that include the median point Ba which is close to the center of rotation and the points N, A, and Pog located on the periphery; Ba-Pog provides only a statistically significant difference at T8. This can be explained by a less variation of the Pogonion point compared to points A and Nasion during rotation.

The vertical cutaneous measurement G-Sn is the only measure that increases during the rotation from 0° to 8° in our study. The difference is statistically significant from T2 to T8 (Table 3), but it is clinically significant between T0 and T8. The skeletal facial height measure N-Me shows a statistical significant difference between T0 and T8 but non-significant clinically.

Variations of angular measurements

Tng et al.[1] were the first to study the variations of landmarks and cephalometric measurements following head orientation change in pitch direction. They considered that measurements depend on the location of landmarks, which are defined anatomically by head orientation. They found that skull rotation up or down and Frankfort plan modification relative to the horizontal produced significant differences for the angles SNA, SNB, and SNPog. [1] A study on the variations of the angles SNA, SNB, and SNPog following two different orientations in the sagittal plane showed that the difference is not significant [6].

Cevidanes et al. [7]. have studied changes in cephalometric measurements using some cephalograms deriving from CBCT, following different orientations in the sagittal plane. They found that 3 angular measures among 9 studied represent statistically significant differences.

Several studies take into account a fixed localization of reference points with the performed movement. The specificity of our study lie in determining the variation of certain angular and linear measurements, following a head rotation, and considering that reference point's localization can vary with its orientation. Only the ANB and FH-NA angles present statistically significant differences; however, they are not clinically significant (Table 3).

Studies conducted by Ahlqvist [3] and Yoon [17], using previously fixed landmarks, showed that angular values are almost invariable. Baumrind [18] considers that any malposition of the patient at the cephalostat produces a distortion for the linear and angular measurements. Even if the points are considered fixed in these studies, they undergo different displacements depending on the distance between each point and the rotation axis.

We studied the effect of pure rotation of the head on two-dimensional cephalometric measurements. Using three-dimensional MRI, Ishii et al. [19] studied the kinematics of the upper cervical region in rotation and found that this movement is associated with an intervertebral movement of extension at the atloido-occipital and atlanto-axial joints, and a lateral inclination movement in the direction opposite to the rotation of these two joints. Similar results were also found in other studies [20]. Even an inadequate positioning of the head, during conventional cephalogram or CBCT, may associate the three movements.

Conclusion

Considering the limitations of our study to examine the effect of rotational movement of the head on two-dimensional cephalometric measurements using CBCT, we may conclude the following:

- Head rotation caused a decrease in N-Ba and Ba-A horizontal linear measurements, and an increase in the vertical measurement G-Sn. No variation of the angular measurements studied was observed.
- The inadequate positioning of the head while taking the X-ray should be avoided.
- For better accuracy in linear measurements, the CBCT-rotated volume should be repositioned and corrected, before creating lateral cephalograms.

Author contribution Emilie El Hayeck wrote the main manuscript and prepared figures and tables. All authors made substantial contribution to the conception and design of manuscript. All authors drafted the work and revised it critically for important intellectual content. All authors agree to be accountable for all aspects of the study design and its content. All authors approved the final submitted version.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval Approval of the institutional Review Board was waived since this is research using a pre-existing radiological database and no patient identification was included.

Competing interests The authors declare no competing interests.

References

1. Tng TTH, Chan TCK, Cooke MS (1993) Effect of head posture on cephalometric sagittal angular measures. Am J Orthod Dentofac Orthop 104:337–341
2. Major PW, Johnson DE, Hesse KL (1996) Effect of head orientation on posterior anterior cephalometric landmark identification. Angle Orthod 66(1):51–60
3. Yoon Y-J, Kim K-S, Hwang M-S (2001) Effect of head rotation on lateral cephalometric radiographs. Angle Orthod 71:396–403
4. Yoon Y-J, Kim D-H, Yu P-S (2002) Effect of head rotation on posteroanterior cephalometric radiographs. Angle Orthod 72:36–42

5. Malkoc S, Sari Z, Usumez S (2005) The effect of head rotation on cephalometric radiographs. Eur J Orthod 27:315–321
6. El-Hayeck E, Bou Assi S, Bouserhal J (2005) Etude critique des plans d'orientation et de référence en céphalométrie. Orthod Fr 76:217–227
7. Cevidanes L, Oliveira AEF, Motta A (2009) Head orientation in CBCT-generated cephalograms. Angle Orthod 79(5):971–977
8. Naresh V, Lokesh NK, Pratapvarma KVV (2013) Cephalometric assessment of effect of head rotation toward focal spot on lateral cephalometric radiographs. J Contemp Dent Pract 14(2):202–207. https://doi.org/10.5005/jp-journals-10024-1300
9. Gaddam R, Shashikumar HC, Lokesh NK (2015) Assessment of image distortion from head rotation in lateral cephalometry. Journal of International Oral Health 7(6):35–40
10. Kim JH, Jeong H-G, Hwang JJ (2016) The impact of reorienting cone-beam computed tomographic images in varied head positions on the coordinates of anatomical landmarks. Imaging Sci Dent 46:133–139
11. Shokri A, Miresmaeili A, Farhadian N (2017) Effect of changing the head position on accuracy of transverse measurements of the maxillofacial region made on cone beam computed tomography and conventional posterior-anterior cephalograms. Dentomaxillofacial Radiol 46.
12. Ackerman JL, Proffit WR, Sarver DM (2007) Pitch, roll and yaw: describing the spatial orientation of dentofacial traits. Am J Orthod Dentofacial Orthop 131:305–310
13. Rouvière H (1962) Anatomie Humaine Descriptive et Topographique. Tome I. Masson. Libraires de l'académie de Médecine. 125–132.
14. Baqué P (2008) Manuel Pratique d'Anatomie Descriptive, Topographique, Fonctionnelle, Clinique et Embryologique. Ellipses, Paris, pp 52–56
15. Ahlqvist J, Eliasson S, Welander U (1986) The effect of projection errors on cephalometric length measurements. Eur J Orthod 8:141–148
16. Richmond S, Kau CH (2010) Three-Dimensional Imaging for Orthodontics and Maxillofacial Surgery. Wiley-Blackwell 59–60.
17. Ahlqvist J, Eliasson S, Welander U (1988) The effect of projection errors on angular measurements in cephalometry. Eur J Orthod 10:353–361
18. Baumrind S, Frantz RC (1971) The reliability of head film measurements, II: conventional angular and linear measures. Am J Orthod Dentofacial Orthop 60:505–517
19. Ishii T, Mukai Y, Hosono N (2004) Kinematics of the upper cervical spine in rotation. In Vivo Three-Dim Anal Spine 29(7):139–144
20. Panjabi MM, Crisco JJ, Vasavada A et al (2001) Mechanical properties of the human cervical spine as shown by three-dimensional load-displacement curves. Spine 26:2692–2700

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.