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The effect of head rotation on cephalometric radiographs

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SUMMARY The aim of this study was to identify the potential projection errors of lateral, postero-anterior (PA) and submentovertex (SMV) cephalometric radiographs due to head rotation in the vertical *z*-axis. For this investigation, a complete human dry skull of an adult was used. The skull was rotated from 0 to ±14 degrees at 2 degree intervals. A vertical axis, the *z*-axis, was used as the rotational axis to expose 15 lateral and 15 PA cephalometric radiographs. The skull was tilted on each side, again at 2 degree intervals, to expose the 15 SMV films. A series of linear and angular measurements was carried out on all cephalograms.

The results revealed that horizontal linear and angular measurements between the horizontal planes on lateral cephalograms were subject to changes from 16.1 to 44.7 per cent with a 14 degree rotation of the head position. For PA cephalograms, again horizontal linear measurements, particularly mandibular length, were subject to a projection error of up to 34.9 per cent with head rotation. On the other hand, projection errors were within the 3–4 per cent limit for SMV radiography.

The findings indicate that: (1) linear measurements and the measurement of angles between the horizontal planes are likely to be affected by head rotation in lateral cephalograms, (2) angular measurements demonstrate smaller variations with changing rotation of the head in PA cephalograms, (3) SMV radiographs are less vulnerable to head rotation. Vertical linear measurements of lateral cephalograms and angular measurements of PA radiographs are more reliable in minimizing the projection errors associated with head rotation.

Introduction

Lateral, postero-anterior (PA) and submentovertex (SMV) cephalometric radiographs are valuable in evaluating transverse and sagittal skeletal and/or dentoalveolar relationships, despite several limitations. These include difficulty in reproducing head posture, identifying landmarks because of superimposed structures or poor radiographic technique, and concern about exposure to radiation (Houston, 1983; Ahlqvist *et al.*, 1986, 1988; Baumrind and Frantz, 1971a, b; Na *et al.*, 1998). Another problem is the acquisition of an image that accurately reflects the orofacial complex, and its components. It is essential to know whether the measurements accurately reflect the true dimensions and, if not, whether the error can be calculated and corrected (Yoon *et al.*, 2002).

Cephalometric radiography is based on the ability to use a standardized, reproducible head position in relation to the X-ray source and film. Ear rods are used to prevent the head from rotating about the vertical, sagittal and transverse axes. A third reference, a nasal positioner, may be used to prevent the nose from rotating about the transverse axis (Broadbent, 1931; Broadbent *et al.*, 1975; Yoon *et al.*, 2001, 2002). However, when the device is used to contact the external auditory meatus and soft tissues of the patient, the head can be incorrectly positioned sagittally, antero-posteriorly, or vertically, as the head can be slightly rotated within the head-holding device. Due to these errors caused by different positioning of the head, cephalometric linear and angular measurements can vary depending on the different locations of anatomic structures against the central ray. Unless the projection errors are precisely evaluated and understood, cephalometric measurements may only have limited application in orthodontics (Baumrind and Frantz, 1971a, b; Yoon *et al.*, 2001, 2002).

Numerous studies conducted to evaluate the reliability of lateral, PA and SMV cephalometric radiographs (Baumrind and Frantz, 1971a, b; Bergersen, 1980; Forsberg *et al.*, 1984; Ahlqvist *et al.*, 1986, 1988; Ghafari *et al.*, 1995; Hsiao *et al.*, 1997; Na *et al.*, 1998) concluded that head rotation can introduce errors in cephalometric measurements. The situation becomes even more difficult when the aim is to determine the degree of asymmetry in subjects with severe asymmetries of basic structures, because of the difficulty in finding a straight reference line. Several investigators (Berger, 1961; Baumrind and Frantz, 1971a, b; Bergersen, 1980; Forsberg *et al.*, 1984; Na *et al.*, 1998) have used tracings of cephalometric radiographs to evaluate the reproducibility of cephalometric landmarks. The differences were found to be no greater than those attributable to intra-observer variability in landmark identification and concluded that the method error with repeated radiographic examinations was of minor importance. However, it is unclear whether they removed and repositioned the patients between radiographs (Kuntor *et al.*, 1993). No data have been published on the relationship between head rotation and SMV radiography.

The purpose of this study was to identify the potential projection errors on lateral, PA and SMV radiographs due to head rotation in the vertical *z*-axis.

Materials and methods

The material consisted of a series (45 exposures) of 15 lateral, 15 PA, and 15 SMV cephalograms. For this study, one complete dry human skull with a permanent dentition was used. The dry skull had no gross asymmetries and was well preserved.

Cephalometric method

Before the radiographs were taken, 11 anatomical landmarks were marked on the dry skull for lateral cephalometry, six for PA cephalometry, and seven for SMV radiography (Figures 1–3, Table 1). Steel balls, 1.0 mm in diameter, were glued to these landmarks. The Frankfort horizontal plane of the skull was placed parallel to the floor and was tightly positioned with an ear rod, headrest, and rubber bands for lateral and PA cephalometry and faced upwards for SMV radiography (Figure 4).

A PM 2002 Proline cephalometric unit (Planmeca Co. Ltd, Helsinki, Finland) was used for this investigation. A protractor was placed on the rotating base of the cephalostat against a mark on the fixed part to measure the rotation of the cephalostat so that the angle could be read more easily. The standard focus–median plane and film–median plane distances were 135.5 and 13.5 cm, respectively. The skull was rotated from 0 to ±14 degrees at 2 degree intervals.

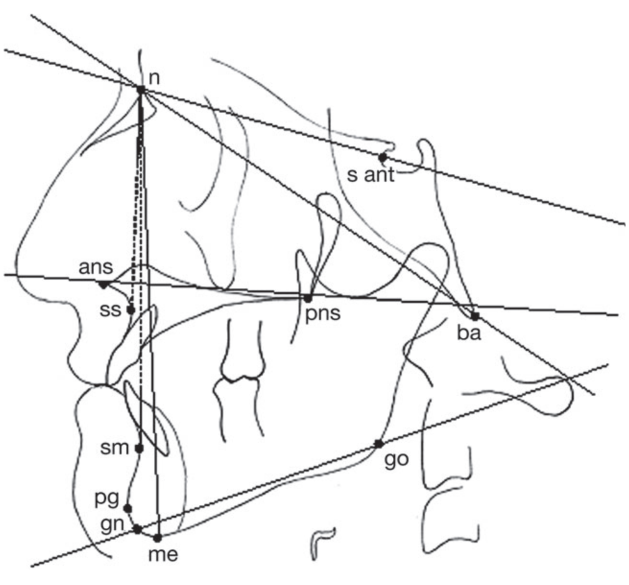

Figure 1 The lateral cephalometric landmarks and measurements used in this study.

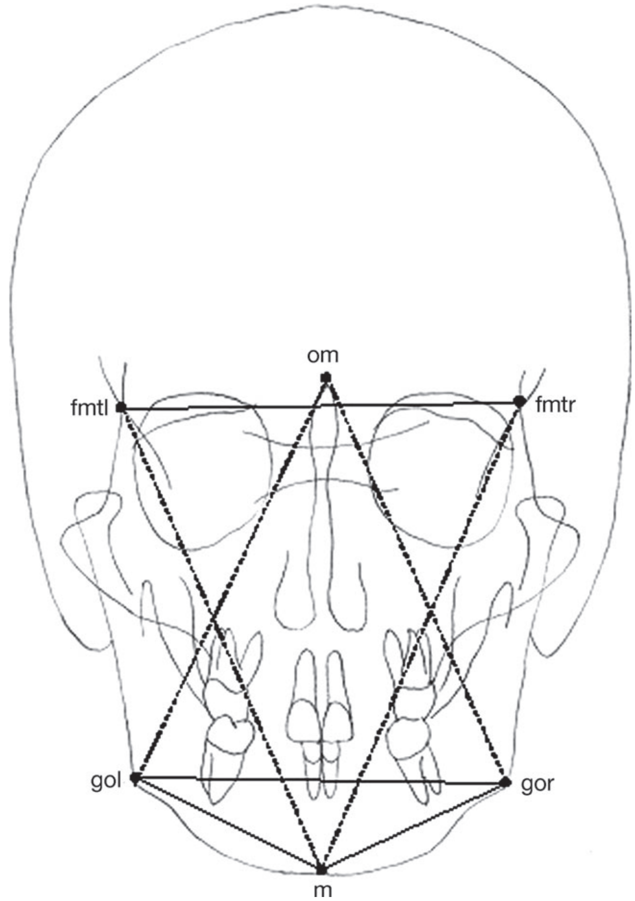

Figure 2 The postero-anterior cephalometric landmarks and measurements used in this study.

A vertical axis, the *z*-axis, was designated as the rotational axis connecting the centre of both ear rods in the direction of the SMV, and all radiographs (Figure 4) were taken based on this axis. The establishment of landmarks and measurements is shown in Figures 1–3 and described in Tables 1 and 2.

All measurements were undertaken twice in a darkened room by the same examiner (S.M.). Linear measurements were carried out directly on the radiographs with callipers to minimize tracing errors, and angular measurements on tracings on acetate paper by means of a protractor. A 0.2 mm diameter pencil was used for this purpose.

Intra-investigator reliability was evaluated using the Bland and Altman plot (Bland and Altman, 1999), which is a statistical method to compare two measurement techniques. With this graphical method, the differences (or alternatively the ratios) between the two techniques are plotted against the averages of the two techniques. Horizontal lines are drawn at the mean difference, and at the mean difference ±1.96 times the standard deviation (SD) of the differences. If the differences are within a mean of ±1.96 SD, they are not clinically important, and the two methods may be used

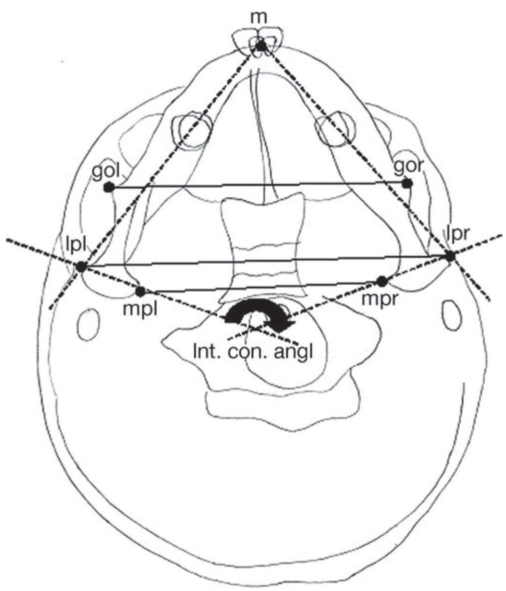

Figure 3 The submentovertex cephalometric landmarks and measurements used in this study.

interchangeably. The Bland and Altman plot may also be used to assess the repeatability of a technique by comparing repeated measurements using one single method on a series of subjects. One examiner (S.M.) traced and measured all radiographs twice with a 4 week interval. A high level of intra-investigator reliability was found (Figure 5).

Results

The changes in linear and angular measurements as a result of +14 to –14 degrees of head rotation are presented in Table 2.

Lateral cephalograms

No differences were observed in lower face height (ans–me), total face height (n–me), or s^{ant}nss and s^{ant}nsm measurements. Differences with a changing rotation of the head on the *z*-axis were found for the following parameters.

The anterior cranial base length (s^{ant}–n) was 64.5 mm at a position of 0 degrees. As the rotational angle towards the film increased, its length decreased, whereas it increased and then decreased as the rotational angle towards the focal spot increased. The differences were less than 1 per cent from 0 to –6 degrees and from 0 to +4 degrees of rotation. The maximum change was a 5.4 per cent reduction (3.5 mm) at +14 degrees of rotation.

Total face height (n–me) was 112.7 mm at 0 degrees. As the rotational angle towards the film increased, its length decreased, whereas it increased as the rotational angle towards the focal spot increased. The degree of these changes was similar regardless of the direction of rotation. The difference was less than 1 per cent from 0 to –6 degrees and from 0 to +8 degrees of rotation. The maximum magnification was 2.2 per cent (2.5 mm) at ±14 degrees of rotation.

Mandibular body length (go–me) was 77.5 mm at 0 degrees. As the rotational angle towards the film increased, its length decreased, whereas it increased as the rotational angle towards the focal spot increased. The maximum reduction was 16.1 per cent (12.5 mm) at –14 degrees of rotation. The maximum increase was 13.5 per cent (10.5 mm) at +14 degrees of rotation.

The growth direction (go–gn/s^{ant} –n) measurement was 24 degrees at 0 degrees. As the rotational angle towards the film increased, it also increased, but decreased as the rotational angle towards the focal spot increased. The maximum reduction was 12.5 per cent (3 degrees) at +14 degrees of rotation. The maximum increase was 25 per cent (6 degrees) at –14 degrees of rotation.

The maxillo-mandibular angle (ans–pns/go–gn) was 19 degrees at 0 degrees. When the rotational angle towards the film increased, it also increased, but decreased as the rotational angle towards the focal spot increased. The maximum reduction was 5.2 per cent (1 degree) at +14 degrees of rotation. The maximum increase was 44.7 per cent (8 degrees) at –14 degrees of rotation.

PA cephalograms

The bifrontmalar distance (fmtl–fmtr) was 95 mm at a position of 0 degrees. When the rotational angle towards the right increased, its length decreased. It decreased further, but to a lesser extent, as the rotational angle increased towards the left. The maximum reduction was 6.3 per cent (6 mm) at +14 degrees of rotation and 3.2 per cent (3 mm) at –14 degrees of rotation.

The bigonial distance (gol–gor) was 116 mm at 0 degrees. When the rotational angle towards the right increased, it decreased. It again decreased, but to a lesser extent, as the rotational angle towards the left increased. The maximum reduction was 5.2 per cent (6 mm) at +14 degrees of rotation and 2.6 per cent (3 mm) at –14 degrees of rotation.

Mandibular length (gol–m and gor–m) increased with head rotation towards the contralateral side and decreased with head rotation towards the ipsilateral side. The maximum increase was 33 per cent (19 mm) and the maximum reduction 34.9 per cent (17 mm).

The frontmalar–midpoint mandibular (fmtl–m–fmtlr) and gonial–orbital midpoint (gol–m–gor) angles decreased with head rotation in both directions. However, the rotation did not affect the measurement until at a position of +10 and –12 degrees.

SMV cephalograms

The bimedial pole (mpl–mpr), bilateral pole (lpl–lpr), and bigonial (gol–gor) distances and the medial pole–mandibular midpoint angle were decreased with head rotation in both

Table 1 The cephalometric landmarks and identification.

Symbol	Landmark	Description
Lateral cephalometry		
s^{ant}	Anterior wall of sella turcica	Anterior wall of sella turcica
n	Nasion	Intersection of the internasal and frontonasal sutures in the midsagittal plane
ss	Subspinale	Deepest point on the pre-maxilla between anterior nasal spine and prosthion
sm	Supramentale	Deepest point in the concavity between infradentale and pogonion
ans	Anterior nasal spine	Apex of anterior nasal spine
pns	Posterior nasal spine	Most posterior point on the hard palate
me	Menton	Most inferior point on the mandibular symphysis in the midsagittal plane
ba	Basion	Median point of the anterior margin of foramen magnum
go	Gonion	Constructed point of intersection of the ramus and mandibular planes
gn	Gnathion	Most antero-posterior point on the symphysis of the chin
Postero-anterior cephalometry		
om	Orbital midpoint	Top of the nasal septum at the base of crista galli
m	Mandibular midpoint	Mental spine on the lower mandibular border
ftml	Left frontmalar temporale	Most laterally placed point on the left zygomatico-frontal suture
ftmr	Right frontmalar temporale	Most laterally placed point on the right zygomatico-frontal suture
gol	Left gonion	Left gonion point
gor	Right gonion	Right gonion point
Submentovertex cephalometry		
m	Mandibular midpoint	Mental spine on the lower mandibular border
gol	Left gonion	Left gonion point
gor	Right gonion	Right gonion point
mpl	Left medial pole	Most prominent medial point of the left mandibular condyle on the axial plane
mpr	Right medial pole	Most prominent medial point of the right mandibular condyle on the axial plane
lpl	Left lateral pole	Most prominent lateral point of the left mandibular condyle on the axial plane
lpr	Right lateral pole	Most prominent lateral point of the right mandibular condyle on the axial plane

directions. However, the decreases were within the 3–4 per cent limit. The intercondylar angle measurement was not affected by this rotation.

Discussion

A major source of random errors in cephalometric investigations is usually the identification of landmarks. This source of error was markedly reduced in the material used in the present study, due to the availability of placed sets of metallic markers (steel balls of 1.0 mm diameter) at the defined anthropometric points.

The reliability of measurements on cephalograms has been investigated previously (Baumrind and Frantz, 1971a, b; Bergersen, 1980; Stabrun and Danielsen, 1982; Ahlqvist *et al.*, 1986). The result of those studies revealed different conclusions, which highlights that caution should be taken when measurements are transferred to reality. The resultant images are magnified, because X-rays do not radiate parallel to the whole part of the projected object. The ratio of magnification varies in the different planes, and hence the image is distorted. In cephalometric radiography, each landmark is not located at the same distance from the focal spot. As a result, possible changes may be caused by the relationship of the landmarks to one and another on the cephalogram (Major *et al.*, 1994, 1996).

Rotation at the antero-posterior axis affects landmarks vertically, not horizontally. The bilateral structures are moved equally and the vertical distance between landmarks changes depending on the distances of the landmarks from the rotational axis. Rotation on the vertical axis influences the horizontal measurements, not the vertical measurements, in a different manner from rotation on the anteroposterior axis. Unless landmarks are located equidistant from the midsagittal plane, any rotation on this axis changes the relationship between the midsagittal line and bilateral landmarks. Therefore, bilateral landmarks equally placed against the midsagittal plane within the skull should be measured to remove the adverse effects of rotation on the vertical axis (Eliasson *et al.*, 1982; Ahlqvist *et al.*, 1983; Yoon *et al.*, 2001).

For projection errors on linear measurements, Ahlqvist *et al.* (1986) found that the effects of rotations on the antero-posterior and vertical axes may be identical. In that study, using a computer model similar to a dry skull, they reported that head rotations of 5 degrees or less resulted in an insignificant error (less than 1 per cent) in lateral cephalometric distance measurements. The inclination of the line being measured with respect to the axis of rotation will affect the amount of distortion. Those authors stated that a line parallel to the axes will be least affected and a line perpendicular most affected and that head rotations of greater than 5 degrees should not occur with careful patient positioning.

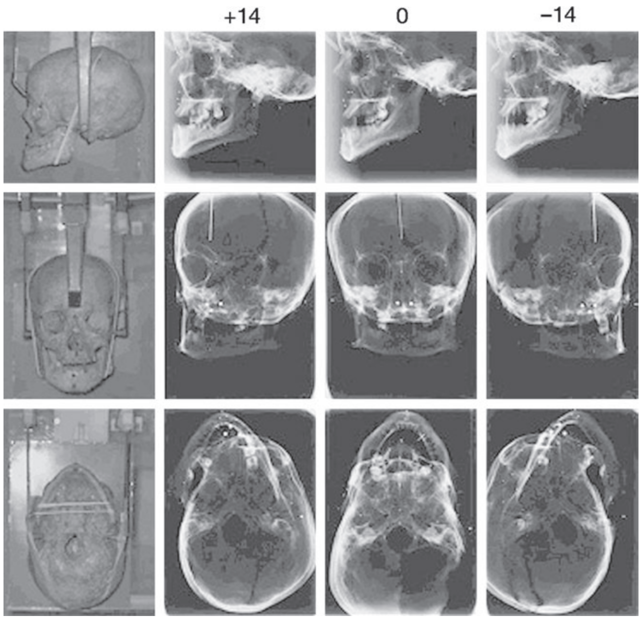

Figure 4 Positioning of the dry skull for lateral, postero-anterior (PA) and submentovertex (SMV) cephalometric radiography at a rotational angle of +14, 0 and –14 degrees. '+' indicates a rotation towards the focal spot, and '–' a rotation towards the film for lateral cephalograms and towards the right and left, respectively, for PA and SMV cephalograms.

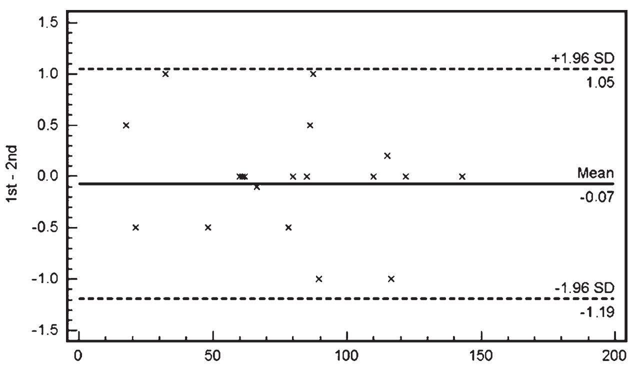

Figure 5 A Bland and Altman plot for the assessment of measurement error.

Ishiguro *et al.* (1974) found that head rotation of 10 degrees or less, either up–down or left–right, was a negligible factor in width measurements, but did, however, affect height measurements to a greater extent. It is apparent that patient positioning can introduce errors in cephalometric radiography and that the magnitude of the error depends not only on the amount of malpositioning, but also on the type of measurement and the relative positions of the structures being measured. The projection error found in the present study was different depending on the direction of rotation, contrary to the results of Ishiguro *et al.* (1974) and Ahlqvist *et al.* (1986).

For the PA and SMV cephalometric radiographs, the landmarks anterior to the vertical rotational axis moved in the same direction as the head rotation, whereas those posterior to the vertical rotational axis moved in the opposite direction. Contrary to the findings for the rotation of the vertical z-axis, the rotation on the antero-posterior y-axis causes no distortion of the images (Eliasson *et al.*, 1982; Ahlqvist *et al.*, 1983). The fact that mandibular length was significantly distorted when measured on the PA cephalograms (3 mm distortion produced by 2 degrees of rotation) was a particularly important finding. Because head rotations of less than 5 degrees are possible, if not probable, in the clinical setting, it is important that clinicians and researchers have an understanding of this potential source of error (Major *et al.*, 1996).

For effective analysis of facial asymmetry on PA and SMV radiographs, the horizontal and vertical reference lines need to be established on the film (Sharad, 1978). Grummons *et al.* (1987) constructed a midsagittal reference line from crista galli through the anterior nasal spine to the chin area. If anatomical variations in the upper and middle facial regions exist, an alternative way of constructing the midsagittal reference line is to draw a line from the midpoint of the z-plane through either anterior nasal spine or the midpoint of both foramina rotundum (frl–frr line). In the present investigation, 1 mm diameter stainless steel balls were used on the outer surface of the film cassette in order to establish the horizontal and vertical reference lines for PA radiographs.

In the present study, the measurement values were different according to the direction of rotation because different planes have different magnifications in different ratios. Moreover, the direction of rotation, i.e. towards the film or towards the focal spot, should also be considered as it changes the mutual relationship of an anatomical point with the focal spot and the film differently. This effect is clearly seen for the angles that indicate growth direction (go–gn/s^{ant}–n and ans–pns/go–gn). Both of these angles increased significantly with head rotation towards the film, while the changes were more limited with head rotation towards the focal spot.

Because each landmark is located at a different PA distance from the rotational axis, and the moving pattern on the film increases as the distance from the rotational axis increases, the relationship of each landmark between the reference position and rotational angles can change. In other words, the correlation among the landmarks on the film according to magnification changes as the distance from the rotational axis of the head to each landmark varies.

It should be borne in mind that the conclusions of this study are based on measurements from films taken of one particular human skull and it may be considered that skull morphology plays a part in the nature of any distortions produced by rotation and whether the same angular/linear distortions would take place if the measurements were obtained from a series of skulls exhibiting variations in

Table 2 Comparison of measurements at 2 degree intervals from +14 to –14 degrees for each rotational angle for the lateral, postero-anterior and submentovertex cephalograms.

	+14	+12	+10	+8	+6	+4	+2	0	–2	–4	–6	–8	–10	–12	–14
Lateral cephalograms															
s^{ant}nss (degrees)	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
s^{ant}nsm (degrees)	89.0	89.0	89.0	89.0	89.0	89.5	88.5	89.0	88.5	89.0	89.0	89.0	89.0	89.0	89.0
go–gn/s^{ant}–n (degrees)	21.0	22.0	22.0	22.0	22.0	23.0	23.0	24.0	25.0	23.0	25.0	26.0	27.0	29.0	30.0
ans–pns/go–gn (degrees)	18.0	18.0	18.0	18.0	19.0	19.0	19.0	19.0	19.0	19.0	21.0	23.0	25.0	26.0	27.0
s^{ant}–n (mm)	61.0	63.0	62.0	63.0	63.0	64.0	64.0	64.5	64.0	64.5	65.5	65.0	65.0	64.0	64.0
go–me (mm)	88.0	86.5	85.0	83.0	82.5	81.5	79.0	77.5	76.0	75.0	72.5	70.0	68.0	66.5	65.0
ans–me (mm)	66.4	66.2	66.1	65.8	65.6	65.3	65.2	65.0	64.9	64.7	64.2	63.9	63.8	63.6	63.3
n–me (mm)	115.2	114.8	114.2	113.9	113.5	113.0	112.8	112.7	112.5	112.1	111.7	111.5	111.1	110.6	110.2
Postero-anterior cephalograms															
fmtl–fmtr (mm)	89.0	93.0	94.0	94.0	95.0	95.0	96.0	95.0	95.5	95.0	95.0	94.0	93.0	91.0	92.0
gol–gor (mm)	110.0	111.0	112.0	113.0	114.0	115.0	116.0	116.0	116.5	116.0	115.0	113.0	114.0	113.0	113.0
gol–m–gor (degrees)	62.0	63.0	63.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	64.0	63.0
fmtl–m–fmtlr (degrees)	48.0	49.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	49.0	48.0
gol–m (mm)	80.0	78.0	76.0	73.0	71.0	69.0	66.0	63.0	60.0	57.0	54.0	51.0	45.0	43.0	41.0
gor–m (mm)	33.0	37.0	39.0	44.0	47.0	50.0	53.0	56.0	58.0	61.0	65.0	68.0	71.0	73.0	75.0
Submentovertex cephalograms															
mpl–mpr (mm)	78.0	79.0	80.0	80.0	81.0	81.0	80.5	80.5	81.0	80.5	80.0	79.0	78.5	78.0	77.0
lpl–lpr (mm)	122.0	122.5	123.0	124.0	124.5	124.0	124.0	124.0	124.5	124.0	122.5	122.0	120.5	119.0	118.0
gol–gor (mm)	116.0	118.0	118.5	119.5	120.0	121.0	121.0	121.0	121.0	120.0	119.5	118.5	118.0	116.5	115.0
Int.Con.Ang (degrees)	143.0	143.0	143.0	144.0	142.0	144.0	143.0	143.0	144.0	142.0	142.0	143.0	140.0	142.0	153.0
mpl–m–mpr (degrees)	60.0	62.0	61.5	62.0	62.0	62.0	62.0	62.0	62.0	62.0	60.0	60.0	60.0	60.0	60.0

skeletal pattern. As the observed distortions in the cephalometric measurements are a result of the geometric relationships of the focal spot, the object (skull) and the film, this may not be likely or the differences may not be significant.

Conclusion

The findings indicate that:

1. Linear measurements and the measurement of angles between horizontal planes are likely to be affected by head rotation in lateral cephalograms.
2. Angular measurements demonstrate smaller variations with changing rotation of the head in PA cephalograms.
3. SMV radiographs are less vulnerable to head rotation.
4. Vertical linear measurements of lateral cephalograms and angular measurements of PA radiographs are more reliable in minimizing the projection errors associated with head rotation.

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