Effect of head orientation on posterior anterior cephalometric landmark identification

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The basis of cephalometrics in orthodontic diagnosis is the use of a standardized, reproducible head position in relation to the x-ray source and film. The cephalostat ear rods prevent the head from rotating about the vertical and anterior-posterior axes. A third reference may be positioned against the nose preventing rotation about the transverse axis.[1] These head positioning devices contact soft tissue, causing distortion and resulting in patient-positioning errors. Improper positioning of the cephalostat ear rods within the external auditory meati and individual variability in the vertical or anteroposterior positioning of the external auditory meati will result in rotations of the head.

Van Aken[2] performed calculations to determine the effects of head rotation and distance from the midsagittal plane would have on the projected length of a particular object. From his results it was determined that objects located closer to the film than the midsagittal plane have less error due to magnification but are more subject to the effects of head rotation. Although Van Aken's paper dealt only with the lateral cephalogram, the same principles can be applied to posterior-anterior cephalometrics. In posterior-anterior cephalometrics, the patient faces the film and most of the landmarks of concern are close to the film, which would increase the error introduced by head rotation.

Eliasson et al. presented a mathematical formula that could be used to calculate the two-dimensional image distortion produced in cephalometric projection. In a second paper the

Abstract

This study examined the effect of head rotation about the vertical and transverse axes on posterior anterior cephalometric landmarks. Radiographs were taken on 25 skulls, first in a normal position, then in four positions each rotated 5° from normal. The identification errors of 52 bilateral and midline landmarks were determined in the horizontal and vertical dimensions. The landmark identification errors for each of the five orientations were compared and those landmarks affected by 5° rotation were identified. Landmarks with significantly larger identification error in a rotated position were: nasal cavity, mandible/occiput, foramen rotundum and orbitale. Best fit vertical and horizontal reference lines were determined, and the effect of head rotation on the choice of best fit reference lines was assessed. Rotation about the transverse axis did not affect the relationship of landmarks to the best vertical or horizontal lines. Rotation about the vertical axis did not affect the relationship of landmarks to the best horizontal line but did affect their relationship to the best vertical line.

Key Words

Cephalometrics • Posterior anterior cephalometrics • Landmark reliability • Identification error

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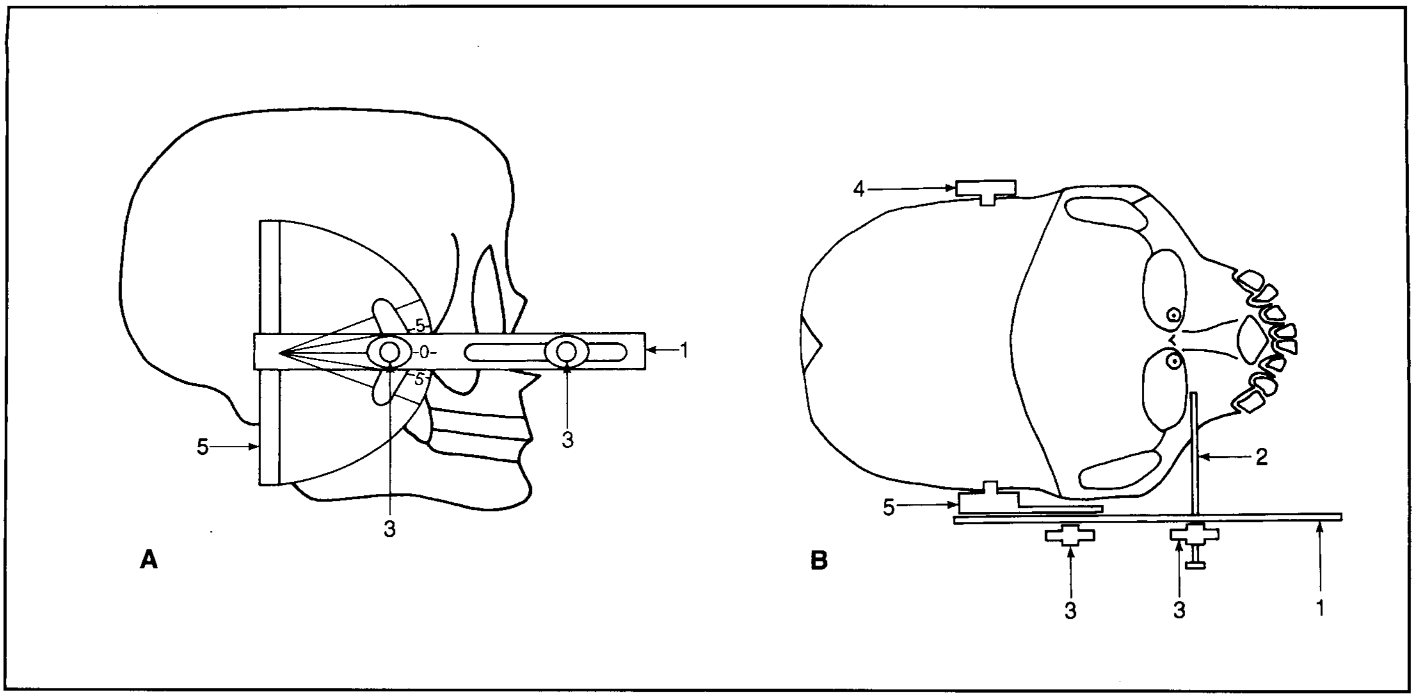

Figure 1

Figure 1A-B Orientation device. (A) side view, and (B) top view. (1) vertical adjustment arm, (2) pointer, (3) adjustment screw, (4) ear rods, (5) protractor.

same authors considered the effects of misalignment between the source, the object, and the film.[4] Their research demonstrated that for the posterior-anterior cephalogram, rotation of the head about the vertical axis (left and right) will have a small effect on vertical measurements but a much greater effect on horizontal measurements. Rotation about the transverse axis (up and down) was not specifically discussed, but it is anticipated that the effects would be the opposite, with vertical measurements affected to a much greater extent than horizontal measurements.

Ahlqvist et al.[5] reported that the error introduced by head rotations of 5° or less results in an insignificant amount of error (less than 1%) 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. A line parallel to the axes will be least affected and a line perpendicular will be most affected. They stated that head rotations of greater than 5° should not occur with careful patient positioning. Ishiguro et al.[6] stated that head rotation of 10° 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 objective of this study was to examine the effects of 5° rotations of the head about the vertical and transverse axes on posterior-anterior cephalometric landmarks. The impact these rotations have on the ability to identify the landmarks and the relationships of landmarks to one another has not been reported for posterior anterior cephalograms.

Materials and methods

A sample of 25 adult skulls from the University of Alberta collection with intact dentition and no gross asymmetry were chosen. The source-to-film distance was a constant 160 cm and the distance from the middle of the ear rods to the film was 17.5 cm. Each skull was stabilized in the cephalostat, and a skull orientation device was used to align Frankfort horizontal parallel to the floor (Figure 1A-B). The removable pointer was referenced to an indelible mark placed on each skull at or near the level of the infraorbital rim.

Five radiographs were taken of each skull. The initial radiograph was taken with the skull not rotated (normal view). Radiographs were then taken with the skull rotated 5° to either side about a vertical axis (left and right views). Two additional radiographs were taken with the skull rotated 5° up and down about a transverse axis (up and down views) (Figure 2A-B).

Rotation about the transverse axis was accomplished by changing the angulation of the orien-

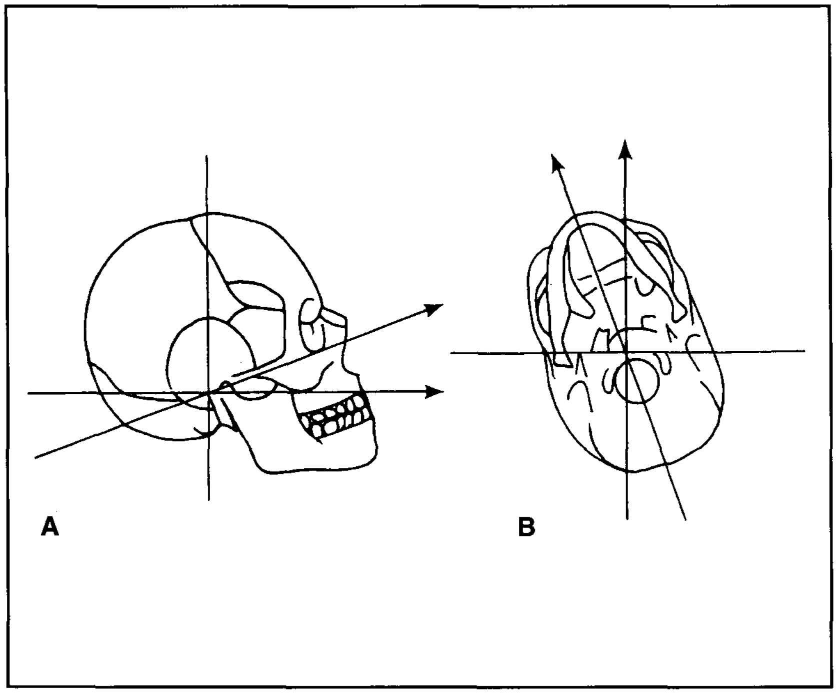

Figure 2

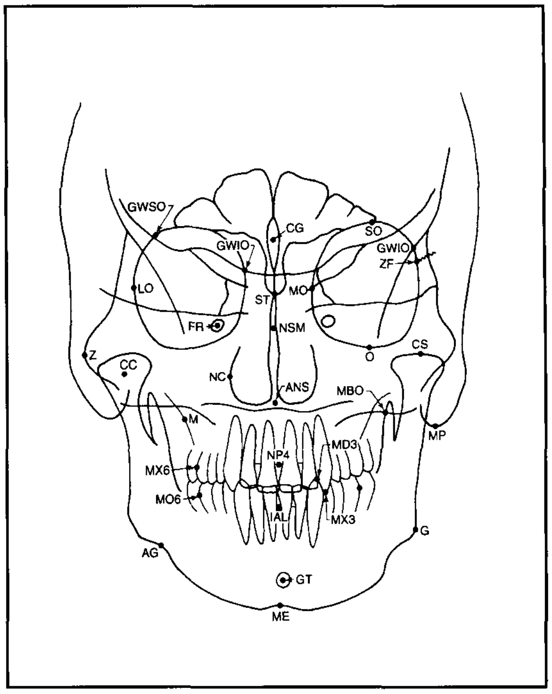

Figure 3

Figure 2A-B
Axes of rotation. (A) rotation about the transverse axis. (B) rotation about the vertical axis.

Figure 3
Posterior-anterior cephalometric landmarks.

tation device pointer by 5° up and down, and then rotating the skull about the cephalostat ear rods to realign the pointer with the infraorbital reference marks. Rotation about the vertical axis was accomplished by rotation of the cephalostat itself about a vertical axis centered between the two ear rods. In order to minimize any movement of the skull within the cephalostat, the normal view was always taken first, followed by the left and right rotated views. The up and down projections were taken last. Lead markers signifying skull number and skull orientation were projected directly onto the film during exposure.

Landmarks were digitized directly from the radiographs using a GP6 Sonic Digitizer in conjunction with an IBM-compatible computer and a program developed using Quick Basic. An individual coordinate system was established for each radiograph by including two fiducial points in the digitizing procedure. The fiducial points consisted of two pinholes placed at the superior and medial corners of the earrod markers on each radiograph. These two points, which were digitized first, enabled the digitization program to calculate the slope of the line between the two pinholes. This line was used as the X-axis of a Cartesian coordinate system. The Y-axis was calculated as the line perpendicular to the X-axis originating at the midpoint of the line between the two pinholes. This coordinate system eliminated the orientation of the viewbox as a variable. Fifty-two commonly used landmarks[6-15] were then digitized, including 36 bilateral skeletal, 8 midline skeletal, and 8 bilateral dental landmarks. The data were stored as Cartesian coordinates in ASCII files. All linear measurements were in tenths of millimeters.

The following landmarks (Figure 3) were identified on each radiograph:

(a) Upper third bilateral skeletal landmarks

1. Greater wing superior orbit (GWSO) - the intersection of the superior border of the greater wing of the sphenoid bone and lateral orbital margin.
2. Greater wing inferior orbit (GWIO) - the intersection of the inferior border of the greater wing of the sphenoid bone and the lateral orbital margin.
3. Lesser wing orbit (LWO) - the intersection of the superior border of the lesser wing of the sphenoid bone and medial aspect of the orbital margin.
4. Orbital (O) - the midpoint of the inferior orbital margin.
5. Lateral orbit (LO) - the midpoint of the lateral orbital margin.
6. Medial orbit (MO) - the midpoint of the medial orbital margin.
7. Superior orbit (SO) - the midpoint of the superior orbital margin.
8. Condyle superior (CS) - the most superior aspect of the condyle.
9. Center condyle (CC) - the center of the head of the condyle.
10. Mastoid process (MP) - the most inferior point on the mastoid process.

Table 1
Landmark identification error (mm) of upper third bilateral skeletal landmarks

	Orientation									
	Normal		Up		Down		Left		Right	
Landmark	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy
GWSOL	0.45	0.26	0.39	0.32	0.76	0.42	0.47	0.36	0.46	0.32
GWSOR	0.52	0.33	0.37	0.37	0.90	0.53	0.45	0.35	0.45	0.32
GWIOL	0.37	0.36	0.36	0.46	0.49	0.57	0.36	0.40	0.43	0.51
GWIOR	0.33	0.35	0.39	0.43	0.47	0.48	0.40	0.48	0.43	0.44
LWOL	0.75	0.39	0.73	0.39	0.81	0.61	1.00	0.49	0.76	0.41
LWOR	0.93	0.42	0.84	0.52	1.18	0.84	0.75	0.42	1.05	0.54
OL	0.93	0.80	1.27	0.85	1.11	*1.24	0.98	0.97	1.32	0.85
OR	1.23	0.68	1.20	0.95	1.04	*1.38	1.31	0.87	1.18	0.82
LOL	0.59	1.04	0.63	1.07	0.66	1.25	0.67	1.01	0.65	0.98
LOR	0.54	0.94	0.66	1.11	0.67	1.16	0.61	1.02	0.72	1.07
MOL	0.99	0.91	0.87	1.03	0.79	1.25	0.80	0.98	0.88	0.98
MOR	1.02	1.01	0.86	1.11	0.76	1.32	0.98	1.04	0.76	1.08
SOL	0.56	0.24	0.80	0.31	0.96	0.39	0.79	0.34	0.70	0.29
SOR	0.90	0.26	0.96	0.31	0.90	0.44	0.92	0.27	0.82	0.30
CSL	1.01	1.42	0.83	1.47	0.89	1.26	0.83	1.14	0.84	1.15
CSR	0.93	1.09	0.91	1.41	0.96	1.37	0.75	1.12	1.05	1.08
CCL	0.86	1.25	0.91	1.30	1.02	1.56	0.85	1.25	0.90	1.23
CCR	1.01	1.02	0.89	1.19	0.88	1.31	0.88	1.16	0.99	1.14
MPL	0.43	0.26	0.44	0.28	0.55	0.34	0.54	0.26	0.42	0.29
MPR	0.47	0.27	0.87	0.32	0.55	0.47	0.45	0.30	0.51	0.32

* significantly different from the normal orientation p<0.05
L and R have been added to landmark abbreviations to represent left and right

(b) Middle third bilateral skeletal and dental landmarks

1. Zygomatic frontal (ZF) - the intersection of the zygomaticofrontal suture and the lateral orbital margin.
2. Zygomatic (Z) - the most lateral aspect of the zygomatic arch.
3. Foramen rotundum (FR) - the center of foramen rotundum.
4. Malar (M) - the deepest point on the curvature of the malar process of the maxilla.
5. Nasal cavity (NC) - the most lateral point on the nasal cavity.
6. Maxillary cuspid (MX3) - the tip of the maxillary cuspid.
7. Maxillary Molar (MX6) - the midpoint on the buccal surface of the maxillary first molar.

(c) Lower third bilateral skeletal and dental landmarks

1. Mandible/occiput (MBO) - the intersection of the mandibular ramus and the base of the occiput.
2. Gonion (G) - the midpoint on the curvature at the angle of the mandible.
3. Antegonial (AG) - the deepest point on the curvature of the antegonial notch.
4. Mandibular cuspid (MD3) - the tip of the mandibular cuspid.
5. Mandibular molar (MD6) - the midpoint on the buccal surface of the mandibular first molar.

d) Midline skeletal and dental landmarks

1. Crista galli (CG) - the centre of the crista galli.
2. Sella turcica (ST) - the most inferior point on the floor of sella turcica.
3. Nasal septum (NSM) - the midpoint of the nasal septum between crista galli and the anterior nasal spine.
4. Anterior nasal spine (ANS) - the center of

Table 2
Landmark identification error (mm) of middle third bilateral skeletal and dental landmarks

Landmark	Normal SDx	Normal SDy	Up SDx	Up SDy	Down SDx	Down SDy	Left SDx	Left SDy	Right SDx	Right SDy
ZFL	0.67	2.12	0.50	*1.63	0.63	*1.17	0.62	*1.64	0.60	*1.68
ZFR	0.69	2.37	0.62	*1.95	0.62	*1.41	0.59	*1.89	0.57	*1.85
ZL	0.24	0.36	0.43	0.46	0.45	0.49	0.33	0.44	0.30	0.53
ZR	0.32	0.36	0.39	0.44	0.49	0.42	0.34	0.48	0.29	0.39
FRL	0.85	0.53	0.55	0.70	*1.22	0.56	0.85	0.48	0.76	0.48
FRR	0.62	0.50	0.70	0.78	*1.16	0.71	0.93	0.50	0.80	0.53
ML	0.38	0.61	0.45	0.67	0.53	0.81	0.39	0.98	0.52	0.71
MR	0.45	0.61	0.48	0.73	0.56	0.72	0.40	0.71	0.47	0.83
NCL	0.89	1.11	0.87	1.61	1.10	1.11	0.97	1.09	*1.88	1.29
NCR	0.99	1.04	0.92	1.54	1.03	0.88	*1.68	0.96	1.34	1.07
MX3L	0.66	0.37	0.75	0.43	0.85	0.53	0.97	0.48	0.79	0.40
MX3R	0.82	0.41	0.88	0.42	0.95	0.49	1.22	0.50	0.87	0.43
MX6L	0.70	0.91	0.74	0.63	0.89	0.89	0.67	0.74	0.54	0.69
MX6R	0.84	0.84	0.67	0.59	0.56	0.91	0.76	0.79	1.28	0.68

(Orientation: Normal, Up, Down, Left, Right)

* significantly different from the normal orientation $p<0.05$
R and L have been added to landmark abbreviations to represent left and right

the intersection of the nasal septum and the palate.

5. Incisor point (IPU) - the crest of the alveolus between the upper incisors.
6. Incisor point (IPL) - the crest of the alveolus between the lower incisors.
7. Genial tubercles (GT) - the center of the genial tubercles of the mandible.
8. Menton (ME) - the midpoint on the inferior border of the mental protuberance.

Radiographs were coded and digitized five times in a random order by the principal investigator. No radiograph was digitized more than once in a day. The raw data were examined for any single digitization which differed from the average of the other four by more than 10 mm. The digitization of any such radiograph was repeated. This procedure effectively eliminated any instances where the wrong landmark was digitized by mistake.

Results

The reliability of the method used in this study has been previously reported.[16] The very high level of reliability (Rx = .9995, Ry = .9992) indicates that the relative contribution of multiple digitizations to the total variance is very low.

The error associated with the identification of each landmark was calculated for each of the five skull orientations (normal, up, down, left, and right) in both the horizontal and vertical dimensions (Tables 1-4). The results show that there was a wide range of identification error both between landmarks and between the vertical and horizontal error for a particular landmark. Multiple comparisons, using the Student Newman-Keuls test for significance, were performed to see if significant differences existed between the normal orientation and the rotated skull positions for each of the landmarks. The results show that 5° rotation of the skull caused very few differences in identification error.

Table 3
Landmark identification error (mm) of lower third bilateral skeletal and dental landmarks

	Normal		Up		Orientation Down		Left		Right	
Landmark	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy
MBOL	0.38	0.42	0.41	0.31	0.65	0.74	0.64	*1.03	0.52	0.35
MBOR	0.57	0.51	0.47	0.37	0.97	0.99	0.63	0.65	0.42	*1.22
GL	0.39	0.72	0.42	0.76	0.53	1.00	0.41	0.76	0.46	0.83
GR	0.36	0.89	0.43	0.80	0.44	0.87	0.39	0.70	0.36	0.63
AGL	0.54	0.58	0.49	0.40	0.63	0.70	0.47	0.56	0.50	0.42
AGR	0.61	0.56	0.49	0.40	0.66	0.62	0.72	0.66	0.54	0.48
MD3L	0.71	0.31	0.74	0.44	0.61	0.46	0.73	0.35	0.76	0.36
MD3R	0.66	0.38	0.74	0/36	0.68	0.51	0.95	0.49	0.64	0.45
MD6L	0.96	0.61	0.96	0.96	1.26	0.97	0.82	0.70	1.28	0.79
MD6R	0.85	0.85	0.76	0.76	0.84	0.84	0.91	0.91	0.65	0.65

* significantly different from the normal orientation $p<0.05$
R and L have been added to landmark abbreviations to represent left and right

Table 4
Landmark identification error (mm) of midline skeletal and dental landmarks

	Normal		Up		Orientation Down		Left		Right	
Land-mark	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy	SDx	SDy
CG	0.39	0.78	0.37	1.05	0.53	0.67	0.37	0.76	0.40	0.65
ST	0.41	1.75	0.44	1.56	0.50	*1.20	0.57	*0.73	0.55	*0.89
NSM	0.49	2.83	0.47	*2.36	0.50	*1.75	0.82	*1.44	0.81	*1.95
ANS	0.32	0.36	0.32	1.58	0.40	0.41	0.43	0.35	0.38	0.40
IPU	0.31	0.34	0.31	0.45	0.38	0.56	0.26	0.36	0.59	0.39
IPL	0.31	0.45	0.34	0.93	0.44	0.45	0.52	0.43	0.33	0.38
GT	0.32	0.75	0.34	0.77	0.38	0.94	0.33	0.77	0.35	0.89
ME	0.50	0.23	0.44	0.28	0.59	0.41	0.48	0.26	0.51	0.32

* significantly different from the normal orientation $p<0.05$

Left skull rotation resulted in increased horizontal identification error for landmark nasal cavity right (NCR), and increased vertical identification error for landmark mandible/occiput left (MBOL). Similarly, right skull rotation resulted in increased horizontal error for landmark nasal cavity left (NCL), and increased vertical identification error for landmark mandible/occiput right (MBOR).

Upward skull rotation did not increase horizontal or vertical identification error for any landmarks. Downward skull rotation did increase the horizontal identification error for landmarks foramen rotundum right (FRR) and foramen rotundum left (FRL). Downward skull rotation also resulted in increased vertical identification error for landmark orbitale right (OR) and orbitale left (OL).

Landmark identification error was reduced with skull rotation around both the vertical and transverse axes, for zygomatic frontal right (ZFR), zygomatic frontal left (ZFL), sella turcica (ST) and nasal septum (NSM). Dental landmark identification error was not affected by skull rotation.

A best fit horizontal line through the skull was determined by a least squares difference method, using all of the bilateral landmarks. A deviation analysis was performed to determine the magnitude of variance between the slope of the line through each pair of bilateral landmarks and the best fit horizontal line. An analysis of variance for the slope of the lines through bilateral landmarks with respect to orientation showed no significant differences ($p <.05$). Five degree rotation of the skull about the vertical and transverse axes did not affect the reliability of bilateral landmarks in relationship to a best fit horizontal reference line.

A best fit vertical midline through the skull was determined by a least squares difference method using all the midline landmarks and the bisectors of all the bilateral landmarks. A deviation analysis was then performed to determine the magnitude of horizontal variance for each midline landmark and bisector of bilateral landmarks with respect to the best fit midline. The results of an analysis of variance comparing overall variance of bisectors of bilateral landmarks and midline landmarks with respect to orientation (Table 5) showed that there was no significant difference ($p<.05$) between the normal orientation and the up and down orientations. There were significant differences ($p<.05$) between these three orientations and the left and right orientations.

Table 5
Multiple comparison of variance of bisectors of bilateral and midline landmarks from the best midline

Orientation	Mean Variance	Right 0.190	Left 0.181	Down 0.097	Up 0.091	Neutral 0.088
Neutral	0.088	*	*			
Up	0.091	*	*			
Down	0.097	*	*			
Left	0.181			*	*	*
Right	0.190			*	*	*

* - significant difference $p<0.05$

Discussion

The reliability of posterior-anterior cephalometric landmark identification has been compared in dried skulls and live patients.[16] In general, landmark identification is less reliable on patient radiographs where soft tissue reduces the sharpness of the hard tissue image. Keeping these differences in mind, the information regarding the effect of head rotation determined in this study can be applied to the clinical setting.

Normal orientation of the skulls in the cephalostat was with the ear rods in the external auditory meatii and Frankfort horizontal plane parallel to the floor. Five degrees of rotation would create an 8.7 mm movement of a structure located 10 mm from the axis of rotation, which should be clinically observable. Since head rotations less than 5° are possible, if not probable, in the clinical setting, it is important that the clinician as well as the researcher have an understanding of this potential source of error.

The effects of head rotation on identification error can be explained by the superimposition of structures within the skull. Structures located farther from the axis of rotation will move more than structures closer to the axis of rotation. Structures located on opposite sides of the axis of rotation will move in opposite directions. In some instances the rotation of the skull is such that it resulted in increased superimposition. The reduced clarity of the landmarks resulted in an increased magnitude of identification error. Identification errors in the horizontal and vertical dimensions were affected independently. For example, left head rotation resulted in increased horizontal landmark identification error for nasal cavity right (NCR) and increased vertical error for mandible/occiput left (MBOL). With left and right head rotations, bilateral landmarks were affected differently on either side of the skull. In some cases skull rotation moved the structure in question into an area of less superimposition, making it easier to identify.

The clinical significance of the magnitude of landmark identification error will depend on the level of accuracy required. The landmark identification errors reported in this study represent the standard deviation of error. Landmark identification errors greater than 1.5 mm should probably be avoided and landmarks with identification error greater than 2.5 mm should definitely be avoided.[16] Tables 1-4 reveal a trend

Figure 4
Rotation about the anterior-posterior axis

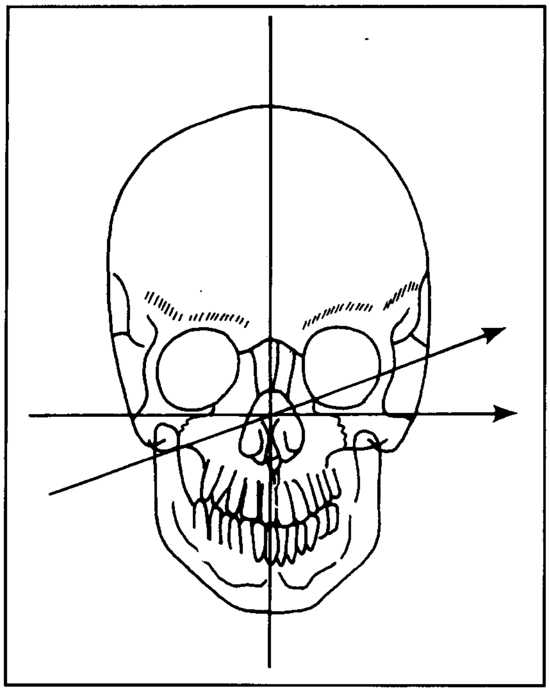

Figure 4

for greater identification error in rotated orientations, but in only a few instances is the increase significant. When only the landmarks that showed increased identification error were considered, only nasal cavity (left and right) showed an identification error greater than 1.5 mm in a rotated view but not in the normal view. If an identification error up to 1.5 mm is considered clinically acceptable, the other landmarks showing increased identification error with skull rotation are not a concern. Landmarks with reduced identification error in a rotated position all had large vertical identification errors in the normal position (1.75 - 2.0 mm). These landmarks (zygomatic frontal, nasal septum and sella turcica) are not reliable as vertical reference points.

In order to effectively identify and quantify transverse and vertical asymmetries, both a horizontal and a vertical reference line are required. The choice of landmarks used in the construction of these reference lines should be based upon the location of the landmarks and the error associated with their identification. Those landmarks used in the establishment of the vertical reference line should also be representative of the true midline of the skull. The landmarks for establishing the best horizontal reference may not be the best for a vertical reference, and vice versa. For the purpose of this study the ideal horizontal reference line was defined by analyzing the slope of the lines between pairs of all the bilateral landmarks. The ideal vertical reference line was defined as a compilation of the bisectors between bilateral landmarks along with all midline landmarks.

The design of the cephalostat places all landmarks used in posterior-anterior cephalometrics between the film and the axis of rotation. When a rotation occurs about the transverse or vertical axes, each landmark moves in the same direction in relation to the film. Each landmark is located at a unique distance from the axis of rotation and those landmarks furthest from the axis of rotation will move a greater distance on the projected image than those closer to the axis. This will change the relationship of the landmarks to one another on the cephalogram.

Rotation about the transverse axis will affect the relationship of landmarks vertically but not horizontally, as landmarks on both sides of the skull move the same amount. The relationship of landmarks to the best vertical midline is not affected, as no change in horizontal relationships take place. The true vertical distance between landmarks will change, depending on each landmark's distance from the rotational axis, but the vertical assessment of symmetry will not be affected.

Rotation about the vertical axis has the opposite effect, with horizontal relationships being affected while vertical relationships remain unchanged. This creates a potential problem because assessment of symmetry for bilateral landmarks involves relating them to a midline reference plane. If the midline reference plane is constructed from landmarks not located at the same antero-posterior position within the skull, any rotation about a vertical axis (left and right) will change the relationship between the bilateral landmarks and the midline reference line. Ideally, to eliminate the effects of rotation about a vertical axis, each pair of bilateral landmarks should be measured with respect to a midline reference located at the same anteroposterior position within the skull.

Rotation about the anterior-posterior axis (Figure 4) will not distort the image. This is because rotation is parallel to the central ray and will alter only the overall image position on the film, not the relationship between landmarks. Rotation about the anterior-posterior axis was not part of this study.

Summary and conclusion

The effect of 5° skull rotation about the vertical and transverse axes on posterior-anterior cephalometric landmark identification error was determined. Landmarks with significantly larger identification error in a rotated position were: nasal cavity right (NCR), nasal cavity left (NCL), mandible/occiput right (MBOR), mandible/occiput left (MBOL), foramen rotundum right (FRR), foramen rotundum left (FRL), orbitale right (OR) and orbitale left (OL). Rotation about the transverse axis did not affect the relationship of landmarks to the best vertical midline. Skull rotation did not affect the relationship between landmarks and the best fit horizontal reference line.

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