Original Article

Effect of Head Rotation on Posteroanterior Cephalometric Radiographs

Young-Jooh Yoon, DDS, MSD, PhD[a]; Dong-Hoon Kim, DDS, MSD, PhD[b]; Pil-Sik Yu, DDS, MSD[c]; Heung-Joong Kim, DDS, MSD, PhD[d]; Eui-Hwan Choi, DDS, MSD, PhD[e]; Kwang-Won Kim, DDS, MSD, PhD[f]

Abstract: The purpose of this study was to identify the potential projection errors of posteroanterior cephalometric radiographs due to head rotation in the vertical Z-axis. For this investigation, 20 human dry skull samples with permanent dentition were collected from the Department of Anatomy in the College of Medicine, Chosun University, Korea. They had no gross asymmetries and were well preserved. Each dry skull was rotated from 0° to ± 10° at 1° intervals. A vertical axis, the Z-axis, was used as a rotational axis for the exposure of 420 posteroanterior cephalometric radiographs. Most of the abscissa values of each landmark showed statistically significant differences in the head rotation from each rotational angle ($P < .05$), whereas the ordinate values were almost the same in all rotational angles regardless of the head rotation. The abscissa values of each landmark anterior to the vertical rotational axis displaced in the same direction as the head rotation, whereas those of other landmarks posterior to the vertical rotational axis displaced in the opposite direction. The mean differences of the abscissa values, per 1° of head rotation, were larger as the landmark was located further anteroposteriorly from the vertical rotational axis and smaller as the landmark was located nearer the vertical rotational axis. In view of the projection error, a posteroanterior cephalometric radiograph is a more valuable diagnostic tool when it is exposed with no head rotation about the vertical Z-axis. (*Angle Orthod* 2002;72:36–42.)

Key Words: Projection error, Head rotation, Posteroanterior cephalometric radiograph

INTRODUCTION

Posteroanterior cephalometric radiography is very valuable in evaluating transverse skeletal and dentoalveolar relationships, in spite of several limitations. These limitations include difficulty in reproducing head posture, difficulty in identifying landmarks because of superimposed structures or poor radiographic technique, and concern about exposure to radiation.[1–5] However, one of the perennial problems is the acquisition of an image that accurately reflects the object, the orofacial complex, and its component parts. It is essential to know whether the measurements accurately reflect the true dimensions and, if they do not, whether the error can be calculated and corrected.

Cephalometric radiography is based on the ability to use a standardized, reproducible head position in relation to the X-ray source and film. The ear rods of cephalostat prevent the head from rotating about the vertical and posteroanterior axes. A third reference, nasal positioner, may be positioned to prevent the nose from rotating about the transverse axis.[6,7] In spite of these head positioning devices, minor errors can arise from slight head rotation in the cephalostat and hence the midsagittal line of the head may not be positioned perpendicular to the central X-ray as desired.

Much research has been conducted to examine the reliability of posteroanterior cephalometric radiographs.[8–19] It is obvious that head rotations can introduce errors in posteroanterior cephalometric radiography. The situation becomes even more difficult when the aim is to measure the degrees of asymmetry in subjects with severe asymmetries of basic structures, because of the difficulty in finding a straight reference line in skulls. Therefore, unless the projection errors are precisely evaluated and perceived, pos-

[a] Associate Professor of Orthodontics, College of Dentistry, Chosun University, Gwang-Ju, Korea.
[b] Private practice, Eum-Sung, Korea.
[c] Resident in Orthodontics, College of Dentistry, Chosun University, Gwang-Ju, Korea.
[d] Assistant Professor of Oral Anatomy, College of Dentistry, Chosun University, Gwang-Ju, Korea.
[e] Associate Professor of Oral & Maxillofacial Radiology, College of Dentistry, Chosun University, Gwang-Ju, Korea.
[f] Professor of Orthodontics, College of Dentistry, Chosun University, Gwang-Ju, Korea.
Corresponding author: Dr Young-Jooh Yoon, Department of Orthodontics, College of Dentistry, Chosun University, 421, Seosuk-Dong, Dong-Ku, Gwang-Ju, 501-825, Korea
(e-mail: yjyun@mail.chosun.ac.kr).

Accepted: July 2001. Submitted: May 2001.

teroanterior cephalometric measurements may have only limited application in the diagnosis and treatment planning of malocclusion.

Unlike lateral cephalometric radiographs, attempts to evaluate the variability of the posteroanterior cephalometric radiographs have been limited to the investigation of errors relating to landmark identification and the literature lacks studies evaluating the extent of projection errors caused by head rotation in the vertical Z-axis. The purpose of this study was to identify the potential projection errors of posteroanterior cephalometric radiographs due to head rotation in the vertical Z-axis.

MATERIALS AND METHODS

For this investigation, 20 human dry skull samples with permanent dentition were collected from the Department of Anatomy in the College of Medicine, Chosun University, Korea. They had no gross asymmetries and were well preserved.

Before the radiographs were exposed, the landmarks were identified on the human dry skulls and 1.0 mm diameter steel balls were glued on the landmarks. The following landmarks were used: (1) crista galli (CG), (2) anterior nasal spine (ANS), (3) menton (ME), (4) zygomatic frontal, left (LFZ) and right (RZF), (5) foramen rotundum, left (LFR) and right (RFR), (6) nasal cavity, left (LNC) and right (RNC), (7) zygomatic arch, left (LZA) and right (RZA), (8) condylion, left (LCO) and right (RCO), (9) mastoid process, left (LMP) and right (RMP), and (10) antegonial notch, left (LAN) and right (RAN) (Figure 1).

Radiographs were exposed in centric occlusion using the same equipment and technique. The skull was tightly positioned with an ear rod, headrest, and rubber bands. The head rotational angle was marked on the upper part of the cephalostat and an indicator was attached so that the angle could be read more easily. A PM 2002 PROLINE cephalostat machine (Planmeca Co Ltd, Helsinki, Finland) was used for this investigation. The standard focus-median plane and film-median plane distances were 135.5 cm and 13.5 cm, respectively.

Each skull was rotated from 0° to ±10° at 1° intervals. A vertical axis, the Z-axis, was designated as a rotational axis, and 420 posteroanterior cephalometric radiographs were taken based on this axis. The code "+" means a left rotation, and "−" means a right rotation.

In order to establish the horizontal and vertical reference lines on posteroanterior cephalometric radiographs, those lines were marked on the outer surface of the film cassette with 0.016-inch stainless steel wires made with an x-ray impermeable substance. In order to expose the same horizontal and vertical reference lines on all of the developed films, the posteroanterior cephalographs were exposed after the x-ray films at the same place within the cassette, using only one cassette with lines.

Each landmark of the posteroanterior cephalometric radiographs was input in a preset order into a digitizer using a photo manipulation program (Adobe Photoshop 5.0, San Jose, Calif) after scanning on Power Mac G4 (Macintosh Apple Co, Cupertino, Calif). Centering at the intersecting point of the horizontal and vertical reference lines that were marked on the x-ray films, all of the landmarks were calculated so that each landmark would be the reference coordinate, the origin, from 0° as shown in Figure 1. Detailed measurements of the abscissa and ordinate values, with a length unit of 0.01 mm, were made. When measuring the abscissa values to each landmark from the reference coordinate, the code "+" means a right side, and "−" means a left side; when measuring the ordinate values, the code "+" means an up side, and "−" means a down side.

Paired *t*-tests were performed between the measurements from 0° to each rotational angle using the SPSS statistical program (SPSS Inc, Chicago, Ill) and statistical significance was determined in the abscissa and ordinate values for each landmark.

Intra-investigator reliability was evaluated using the correlation coefficient (r). One examiner (Dr Ko) traced and measured the records of 20 subjects twice with a 4-week interval. A high level of intra-investigator reliability was found ($r = 0.9$).

RESULTS

The changes in the abscissa and ordinate values of each landmark occurring with 0° to ± 10° rotational angles are presented in Tables 1 through 3.

No statistically significant differences were found in the ordinate values between 0° and each rotational angle for CG, ANS, ME, ZF, and FR, whereas all of these landmarks showed statistically significant differences in the abscissa values ($P < .001$). No statistically significant differences were found in the ordinate values between 0° and each rotational angle for NC and ZA, whereas both NC and ZA showed statistically significant differences in the abscissa values except at −1° for RNC, ± 1° for RZA, and −1° to −3° for LZA ($P < .05$).

No statistically significant differences were found in the ordinate values between 0° and each rotational angle for CO, MP, and AN, except at −3°, −5°, −7°, and −8° for RCO; +10° for RMP; −5° and −7° to −10° for RMP; +9° to +10° for LAN; and −5° to −10° for RAN. On the other hand, CO, MP, and AN showed statistically significant differences in the abscissa values, except at +1° for LCO and −1° for LMP and RMP ($P < .05$).

In the changes of the abscissa values on each landmark occurring with 0° to ± 10° most rotational angles displaced as straight lines with positive slopes toward the same direction of head rotation for each 1° rotation. The average displacements were: CG, 1.61 mm; ANS, 1.69 mm; ME, 1.55 mm; LZF, 1.35 mm; RZF, 1.37 mm; LFR, 1.36 mm;

TABLE 1. Comparison of the Abscissa Values for Each Landmark According to Head Rotation[a]

Measurement		−10°	−9°	−8°	−7°	−6°	−5°	−4°	−3°	−2°
Unilateral, mm										
CG	Mean	−15.97***	−14.04***	−12.40***	−11.22***	−9.18***	−7.66***	−6.10***	−4.51***	−3.00***
	SD	2.00	1.70	1.45	1.47	1.47	1.10	1.10	1.06	0.92
ANS	Mean	−16.68***	−15.03***	−13.28***	−11.70***	−9.89***	−8.29***	−6.50***	−4.95***	−3.25***
	SD	1.23	1.30	1.24	1.10	1.22	1.05	1.01	0.96	0.97
ME	Mean	−15.48***	−14.01***	−12.45***	−10.99***	−9.25***	−7.78***	−6.20***	−4.72***	−3.17***
	SD	3.43	3.10	2.80	2.59	2.25	1.96	1.70	1.29	1.13
Bilateral, mm										
LZF	Mean	−13.91***	−12.33***	−10.97***	−9.85***	−8.26***	−6.84***	−5.61***	−4.24***	−2.88***
	SD	1.12	1.05	1.00	0.87	1.01	0.82	0.86	0.90	0.75
RZF	Mean	−12.85***	−11.53***	−10.33***	−9.09***	−7.82***	−6.46***	−5.21***	−3.93***	−2.62***
	SD	1.05	1.06	1.20	0.85	0.95	0.92	0.91	0.85	0.71
LFR	Mean	−12.91***	−11.34***	−9.80***	−8.37***	−6.80**	−5.36**	−3.97*	−2.52**	−1.88***
	SD	0.91	1.08	1.05	0.99	1.10	1.00	1.01	−1.02	1.01
RFR	Mean	−14.10***	−12.68***	−10.94***	−9.96***	−8.23***	−7.05***	−5.61***	−4.13***	−2.71***
	SD	1.01	1.01	1.07	1.03	1.34	0.94	0.99	0.99	0.84
LNC	Mean	−15.62***	−13.92***	−12.24***	−10.59***	−9.06***	−7.51***	−5.95***	−4.36***	−3.10***
	SD	1.63	1.66	1.49	1.50	1.43	1.37	1.27	1.17	0.84
RNC	Mean	−15.66***	−13.82***	−12.26***	−10.89***	−9.18***	−7.66***	−6.15***	−4.59***	−3.07***
	SD	1.43	1.11	1.17	1.08	1.15	0.91	0.99	0.87	0.85
LZA	Mean	−9.72***	− 8.41***	−7.51***	−6.63***	−5.49***	−4.60**	−3.63***	−2.69	−1.79
	SD	2.56	2.36	2.10	1.76	1.57	1.34	1.01	0.97	0.66
RZA	Mean	−8.25***	−7.46***	−6.73***	−5.91***	−5.14***	−4.33***	−3.48***	−2.72**	−1.86*
	SD	0.79	0.74	0.75	0.67	0.82	0.62	0.57	0.62	0.62
LCO	Mean	−4.55***	−4.02***	−3.48***	−3.07***	−2.55***	−2.06***	−1.71***	−1.27***	−0.95***
	SD	2.91	2.73	2.32	2.09	1.88	1.44	1.26	1.08	0.77
RCO	Mean	−2.80**	−2.70**	−2.48***	−2.26***	−1.92**	−1.71***	−1.39**	−1.11**	−0.87**
	SD	2.63	2.51	2.28	1.93	1.82	1.41	1.22	0.98	0.74
LMP	Mean	1.64***	1.44***	1.41***	1.23***	1.18***	0.98***	0.78***	0.62***	0.35*
	SD	1.49	1.38	1.30	1.09	1.07	0.91	0.72	0.62	0.56
RMP	Mean	2.40***	1.99**	1.73**	1.32**	1.18**	0.90**	0.77*	0.49*	0.27*
	SD	1.51	1.44	1.31	1.19	1.04	0.83	0.69	0.45	0.38
LAN	Mean	−7.46***	−6.62***	−5.86***	−5.01***	−4.16***	−3.45***	−2.69***	−1.19***	−1.28***
	SD	2.73	2.58	2.27	2.01	1.87	1.61	1.45	1.09	0.98
RAN	Mean	−6.95***	−6.50***	−5.91***	−5.37***	−4.74***	−4.09***	−3.45***	−2.82***	−1.48***
	SD	2.60	2.37	2.06	1.90	1.72	1.48	1.28	0.99	0.83

[a] Reference group: 0°.

* $P < .05$, ** $P < .01$, *** $P < .001$.

RFR, 1.44 mm; LNC, 1.57 mm; RNC, 1.59 mm; LZA, 0.89 mm; RZA, 0.93 mm; LCO, 0.36 mm; RCO, 0.37 mm; LAN, 0.69 mm; and RAN, 0.74 mm. Only two rotation angles, LMP and RMP, displaced as straight lines with negative slopes toward the opposite direction of head rotation, displacing an average of −0.25 mm and −0.19 mm, respectively.

DISCUSSION

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 another on the cephalogram.[15,16,19] In the present study, the mean differences of the abscissa values per 1° interval of head rotation changed from ANS to CG, RNC, LNC, ME, RFR, RZF, LFR, LZF, RZA, LZA, RAN, LAN, RCO, LCO, LMP, and RMP. This means that the horizontal differences are larger as the landmark is located further anteroposteriorly from the vertical rotational axis and smaller as the landmark is located nearer the vertical rotational axis. In the changes of the abscissa values on each landmark occurring with 0° to ± 10° of rotational angle change, LMP and RMP were shown as straight lines with negative slopes and other landmarks were shown as straight lines with positive slopes. This shows that the abscissa values for each landmark changed at a certain interval according to head rotation and also the landmarks anterior to the vertical rotational axis moved in the same direction as the head rotation, whereas the landmarks posterior to the vertical rotational axis moved in the opposite direction.

The rotation on the vertical Z-axis affects the relationship of the landmarks horizontally, not vertically.[8] As a result, it is difficult to evaluate precisely the asymmetry of the face because their distances from the midline reference line to the bilateral landmarks are different as the positions of the

TABLE 1. Extended

−1°	0°	+1°	+2°	+3°	+4°	+5°	+6°	+7°	+8°	+9°	+10°
−1.71***	0	1.77***	3.38***	4.98***	6.72***	8.32***	9.99***	11.35***	12.96***	14.56***	16.19***
1.07	0	0.97	1.07	1.18	1.60	1.80	2.05	2.17	2.30	2.36	2.50
−1.55***	0	1.74***	3.55***	5.29***	7.10***	8.77***	10.48***	12.12***	13.76***	15.54***	17.06***
0.86	0	0.64	0.64	0.63	0.78	0.84	0.81	0.71	0.76	0.73	0.83
−1.55***	0	1.41***	3.18***	4.65***	6.31***	7.84***	9.38***	10.97***	12.58***	14.10***	15.45***
0.76	0	0.61	0.78	0.91	1.04	1.13	1.35	1.89	2.11	2.46	2.63
−2.35***	0	1.55***	2.91***	4.22***	5.61***	6.82***	8.32***	9.53***	10.79***	11.99***	13.09***
0.57	0	0.87	0.90	1.08	1.44	1.58	1.67	1.73	1.70	1.78	1.85
−1.38***	0	1.44***	2.83***	4.32***	5.78***	7.31***	8.74***	10.09***	11.52***	13.01***	14.47***
0.49	0	0.77	0.91	1.02	1.33	1.52	1.67	1.57	1.74	1.77	1.93
−1.36***	0	1.43***	2.99***	4.41***	6.00***	7.40***	8.92***	10.19***	11.60***	13.02***	14.31***
0.79	0	0.95	0.86	0.99	1.34	1.41	1.46	1.35	1.51	1.44	1.57
−1.34***	0	1.58***	3.07***	4.59***	6.17***	7.63***	9.12***	10.50***	12.01***	13.49***	14.65***
0.56	0	0.87	0.94	1.03	1.35	1.37	1.46	1.41	1.51	1.45	1.60
−1.59***	0	1.67***	3.34***	4.92***	6.52***	8.15***	9.70***	11.24***	12.77***	14.27***	15.74***
0.60	0	0.62	0.61	0.65	0.88	0.89	0.89	0.66	0.85	0.72	0.81
−1.55	0	1.63***	3.33***	5.01***	6.86***	8.28***	9.91***	11.38***	13.09***	14.54***	16.10***
0.59	0	0.58	0.56	0.66	0.83	0.92	0.91	0.74	0.83	1.06	0.83
−0.88	0	0.98*	1.87**	2.67**	3.58***	4.34***	5.10***	5.84***	6.60***	7.33***	8.08***
0.49	0	0.59	0.86	1.05	1.16	1.40	1.70	1.90	2.07	2.29	2.64
−1.11	0	1.08	2.20***	3.26***	4.35***	5.37***	6.49***	7.40***	8.42***	9.44***	10.44***
0.50	0	0.39	0.56	0.53	0.51	0.61	0.55	0.55	0.59	0.58	0.65
−0.44**	0	0.23	0.63**	0.95**	1.22**	1.50**	1.82***	1.97**	2.28**	2.48**	2.69**
0.59	0	0.59	0.81	1.08	1.34	1.58	1.85	2.20	2.46	2.80	3.13
−0.42*	0	0.36*	0.80***	1.20***	1.61***	2.12***	2.62***	3.09***	3.61***	4.12***	4.66***
0.57	0	0.60	0.80	1.12	1.36	1.57	1.79	2.14	2.40	2.69	2.94
0.10	0	−0.40**	−0.73***	−0.99***	−1.38***	−1.70***	−1.96***	−2.44***	−2.63***	−3.06***	−3.40***
0.45	0	0.62	0.69	0.65	0.68	0.90	0.88	1.14	1.22	1.42	1.69
0.11	0	−0.31**	−0.63***	−0.76***	−1.06***	−0.97***	−1.05**	−1.14**	−1.26***	−1.34***	−1.42***
0.45	0	0.37	0.46	0.57	0.58	0.85	0.89	0.97	1.00	1.29	1.33
−0.63**	0	0.72***	1.64***	2.05***	2.74***	3.38***	4.05***	4.61***	5.38***	5.83***	6.30***
0.70	0	0.49	0.59	0.73	0.97	1.08	1.25	1.65	1.83	2.11	2.17
−0.68***	0	0.73***	1.46***	2.26***	3.02***	3.87***	4.65***	5.48***	6.46***	7.13***	7.88***
0.55	0	0.49	0.71	0.82	0.91	1.01	1.11	1.56	1.87	1.94	2.06

midline reference line and the bilateral landmarks change according to the head rotation.

In the present study, the ordinate values of each landmark were almost the same in all angles regardless of the head rotation, whereas the abscissa values of LMP and RMP moved in the opposite direction as the head rotation and those of other landmarks moved in the same direction as the head rotation. This means that the landmarks anterior to the vertical rotational axis moved in the same direction as the head rotation, whereas the landmarks posterior to the vertical rotational axis moved in the opposite direction. Contrary to the results of the rotation on the vertical Z-axis, however, the rotation on the anteroposterior Y-axis causes no distortion of the image.[8–9] Although the head rotates on the anteroposterior axis, the location of head is parallel to the central ray. Only the location of the images on the film change, but this does not cause a change in the relationship between landmarks. The rotation on the transverse X-axis affects the relationship of the landmarks vertically, not horizontally.[11] As a result, it does not significantly affect the assessment of asymmetries of the face.

For effective analysis of facial asymmetry, the horizontal and vertical reference lines have to be established on the film.[18] Grummons et al[12] reported that a midsagittal reference line (MSR) was constructed 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 MSR line is to draw a line from the midpoint of Z-plane through either ANS or through the midpoint of both foramina rotundum (Fr-Fr line). In the present study, we used 0.016-inch stainless steel wires on the outer surface of the film cassette in order to establish the horizontal and vertical reference lines on the posteroanterior cephalometric radiographs. To expose the same horizontal and vertical reference lines on all of the developed films, we used the same cassette with lines for each exposure, and exposed posteroanterior cephalometric radiographs after the x-ray films were always at the

TABLE 2. Comparison of the Ordinate Values for Each Landmark According to Head Rotation[a]

Measurement		−10°	−9°	−8°	−7°	−6°	−5°	−4°	−3°
CG	Mean	0.13	0.02	0.04	0.08	0.16	0.13	0.09	0.09
	SD	0.30	0.25	0.38	0.33	0.34	0.34	0.36	0.39
ANS	Mean	0.25	0.13	0.17	0.15	0.28	0.19	0.28	0.30
	SD	0.36	0.34	0.36	0.33	0.35	0.28	0.41	0.44
ME	Mean	0.05	0.05	0.09	0.08	0.15	0.08	0.06	0.25
	SD	0.33	0.30	0.24	0.30	0.34	0.37	0.35	0.34
LZF	Mean	0.03	−0.09	0.00	−0.04	0.04	−0.02	−0.02	0.03
	SD	0.43	0.46	0.38	0.38	0.39	0.43	0.46	0.38
RZF	Mean	0.24	0.15	0.09	0.10	0.21	0.18	0.12	0.08
	SD	0.38	0.32	0.39	0.44	0.40	0.40	0.32	0.36
LFR	Mean	0.02	0.02	0.00	−0.02	0.02	−0.09	−0.01	0.03
	SD	0.28	0.29	0.30	0.33	0.29	0.38	0.35	0.29
RFR	Mean	0.11	0.02	−0.02	−0.04	0.04	−0.01	0.05	0.00
	SD	0.27	0.23	0.35	0.32	0.26	0.29	0.24	0.23
LNC	Mean	0.06	−0.09	−0.02	0.01	0.04	−0.03	−0.01	−0.02
	SD	0.36	0.41	0.39	0.44	0.45	0.39	0.40	0.38
RNC	Mean	0.08	−0.06	−0.03	0.01	0.07	−0.03	0.06	−0.02
	SD	0.35	0.36	0.38	0.41	0.44	0.37	0.32	0.38
LZA	Mean	0.12	0.02	0.01	−0.03	0.08	−0.02	−0.08	0.04
	SD	0.30	0.47	0.40	0.29	0.35	0.39	0.32	0.38
RZA	Mean	−0.07	−0.11	−0.14	−0.03	−0.04	−0.15	−0.06	−0.02
	SD	0.43	0.45	0.46	0.42	0.39	0.52	0.32	0.34
LCO	Mean	0.13	0.02	0.00	0.05	0.12	0.03	0.01	0.03
	SD	0.32	0.36	0.32	0.31	0.29	0.28	0.28	0.28
RCO	Mean	−0.06	−0.12	−0.14*	−0.12*	−0.03	−0.17*	−0.04	−0.15**
	SD	0.29	0.30	0.24	0.29	0.28	0.30	0.24	0.21
LMP	Mean	0.21	0.16	0.14	0.08	0.18	0.13	0.12	0.17
	SD	0.37	0.38	0.26	0.27	0.44	0.35	0.36	0.28
RMP	Mean	−0.27*	−0.34*	−0.31*	−0.30*	−0.17	−0.28*	−0.07	−0.09
	SD	0.42	0.34	0.34	0.37	0.42	0.46	0.35	0.46
LAN	Mean	0.39	0.23	0.24	0.30	0.27	0.16	0.25	0.19
	SD	0.32	0.29	0.42	0.28	0.39	0.34	0.32	0.30
RAN	Mean	−0.37**	−0.37**	−0.46**	−0.23**	−0.16*	−0.27**	−0.09	0.09
	SD	0.45	0.35	0.39	0.37	0.48	0.40	0.50	0.43

[a] Reference group: O°.
* $P < .05$, ** $P < .01$.

TABLE 3. Mean Differences of the Abscissa Values per 1° Interval of Head Rotation (mm)

CG	ANS	ME	LZF	RZF	LFR	RFR	LNC	RNC	LZA	RZA	LCO	RCO	LMP	RMP	LAN	RAN
1.61	1.69	1.55	1.35	1.37	1.36	1.44	1.57	1.59	0.89	0.93	0.36	0.37	−0.25	−0.19	0.69	0.74

same place within the cassette. Then we established geometric horizontal and vertical reference lines parallel with the reference lines of our reliable landmark.

Because each landmark is located at a different anteroposterior 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 since the distance from the rotational axis of the head to each landmark varies. Theoretically, it would be effective using the midline landmark that is located at the same anteroposterior distance on vertical rotational axis in order to solve these limitations. However, this may not be clinically possible.

The preciseness of the measurements in head films may be influenced by various errors such as the projection error, the landmark identification error, and the measuring technique error.[10] These errors lead to a wrong diagnosis in orthodontics and also, the real magnitude of such projection errors may not be considered in a study using a measuring technique.[8,9] Therefore, it is necessary to analyze these errors. In the present study, the potential projection errors of posteroanterior cephalometric radiographs were identified by analyzing the vertical and horizontal distances of 17 landmarks including bilateral landmarks due to head rotation in the vertical Z-axis.

TABLE 2. Extended

−2°	−1°	0°	+1°	+2°	+3°	+4°	+5°	+6°	+7°	+8°	+9°	+10°
0.16	0.01	0	0.00	−0.04	−0.08	−0.04	−0.02	−0.02	−0.04	−0.10	−0.02	0.05
0.32	0.32	0	0.35	0.31	0.34	0.42	0.38	0.27	0.35	0.38	0.40	0.40
0.31	0.26	0	0.22	0.32	0.25	0.16	0.20	0.17	0.09	0.10	0.18	0.00
0.43	0.33	0	0.34	0.65	0.44	0.42	0.42	0.40	0.38	0.37	0.32	0.00
0.12	0.12	0	0.01	0.01	0.07	−0.06	0.06	−0.05	−0.02	−0.01	−0.01	−0.15*
0.33	0.40	0	0.27	0.33	0.30	0.39	0.44	0.29	0.36	0.35	0.57	0.28
0.15	0.01	0	0.05	0.03	0.13	0.07	0.05	0.08	0.02	0.06	0.07	0.11
0.45	0.38	0	0.37	0.39	0.37	0.47	0.41	0.39	0.36	0.50	0.49	0.45
0.13	0.11	0	0.00	−0.02	0.03	0.01	−0.03	−0.04	−0.12	−0.15	−0.11	−0.09
0.28	0.35	0	0.34	0.29	0.37	0.35	0.33	0.37	0.34	0.37	0.37	0.40
0.06	0.00	0	−0.05	−0.03	−0.09	−0.06	−0.12	−0.05	−0.13	−0.14	−0.13	−0.13
0.40	0.28	0	0.25	0.23	0.21	0.25	0.31	0.25	0.22	0.29	0.32	0.32
0.05	0.03	0	−0.03	−0.08	−0.03	−0.04	−0.11	−0.02	−0.16	−0.17*	−0.05	−0.07
0.31	0.27	0	0.25	0.17	0.24	0.19	0.20	0.17	0.24	0.26	0.22	0.31
0.06	0.03	0	−0.01	−0.04	−0.03	−0.15	−0.08	−0.08	−0.14	−0.11	−0.13	−0.19
0.49	0.34	0	0.32	0.33	0.37	0.29	0.28	0.22	0.25	0.28	0.39	0.31
0.12	0.09	0	−0.01	0.04	0.08	0.01	0.00	0.05	0.03	−0.07	0.00	0.01
0.42	0.32	0	0.27	0.27	0.28	0.25	0.26	0.25	0.34	0.32	0.32	0.45
0.11	−0.12	0	−0.06	−0.05	0.01	−0.04	−0.01	−0.09	−0.04	−0.06	−0.06	−0.12
0.49	0.45	0	0.36	0.35	0.43	0.33	0.38	0.28	0.30	0.32	0.39	0.42
0.01	−0.11	0	−0.01	0.25	0.16	0.01	0.06	0.04	0.00	0.00	0.02	−0.01
0.34	0.27	0	0.29	0.57	0.36	0.29	0.36	0.30	0.24	0.32	0.26	0.38
0.05	0.03	0	0.01	−0.07	0.02	−0.05	0.01	0.06	−0.05	−0.03	−0.09	−0.11
0.38	0.29	0	0.26	0.28	0.21	0.23	0.21	0.21	0.30	0.39	0.43	0.33
−0.11	−0.11	0	0.03	−0.01	0.07	−0.11	−0.02	0.02	−0.02	−0.06	0.01	−0.03
0.28	0.26	0	0.21	0.25	0.23	0.20	0.21	0.16	0.14	0.24	0.30	0.35
0.12	0.03	0	−0.02	−0.10	0.02	−0.11	−0.08	−0.14	−0.14	−0.16	−0.14	−0.37*
0.30	0.37	0	0.27	0.18	0.29	0.28	0.34	0.27	0.27	0.41	0.39	0.37
−0.09	−0.05	0	−0.08	0.06	0.28	0.17	0.21	0.33	0.29	0.26	0.21	0.22
0.40	0.41	0	0.44	0.42	0.41	0.46	0.43	0.38	0.41	0.23	0.45	0.48
0.21	0.11	0	0.00	0.07	−0.04	−0.21	−0.13	−0.19	−0.23	−0.21	−0.28*	−0.48**
0.31	0.41	0	0.21	0.46	0.17	0.40	0.40	0.27	0.23	0.46	0.60	0.41
0.16	0.08	0	0.07	0.14	0.28	0.09	0.31	0.28	0.22	0.27	0.41	0.20
0.46	0.39	0	0.29	0.52	0.41	0.46	0.46	0.20	0.30	0.37	0.54	0.45

The radiographic images are magnified and do not radiate parallel to the whole part of the projected object. As the radiation beam diverges, image distortion can occur due to the magnification of different planes at different ratios.[8,9] As a result, the projection error could occur. Most of the landmarks used in posteroanterior cephalometric analysis are located at different distances anteriorly and posteriorly from the focal spot, and can affect the length of measurements due to these distortions. Moreover, head holding devices such as the ear rod, used to prevent head rotation at the vertical and anteroposterior axes, and head rests, such as a nasal positioner, are used to prevent head rotation at the transverse axis. These devices could result in head rotation by causing anteroposterior and vertical displacement when they touch the external auditory canal and soft tissue, resulting in a projection error.[7]

The ear rods placed into asymmetrical external auditory canals usually cause head rotation. In such a patient, only one ear rod should be inserted, and the midsagittal plane should be lined up perpendicular to the radiographic cassette. The second rod can then be placed lightly against the skin to give the patient a sensory reference. To insure correct head tilt when taking the radiograph, check the patient from the side to see that the Frankfort plane (from the infraorbital margin to the external auditory canal) is close to horizontal. The patient should be looking straight ahead or even slightly downward.[12] In order to minimize the projection errors and the identification errors when diagnosing and analyzing a patient's asymmetry using posteroanterior cephalometric radiographs, the film should be carefully processed and head positioning devices should be further developed.

CONCLUSIONS

In the present study, we demonstrated that (1) the abscissa values of each landmark showed statistically significant differences in the head rotation from each rotational angle, except −1° for RNC, ± 1° for RZA, −1° to −3° for LZA, +1° for LCO, −1° for LMP, and −1° for RMP ($P < .05$), whereas the ordinate values of each landmark were almost the same in all rotational angles regardless of the head rotation; (2) the abscissa values for each landmark changed at a certain interval according to head rotation.

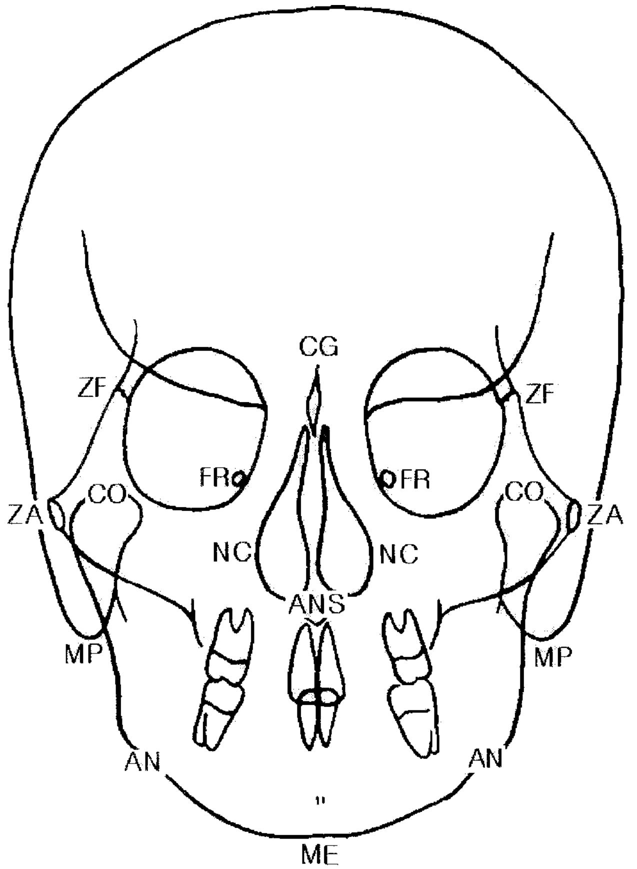

FIGURE 1. Posteroanterior cephalometric landmarks include: the geometric center of the crista galli (CG); the center of the intersection of the nasal septum and the palate referred to as the anterior nasal spine (ANS); the midpoint on the inferior border of the mental protuberance or menton (ME); the intersection of the zygomatic frontal suture and the lateral orbital margin(ZF); the center of foramen rotundum (FR); the most lateral point on the nasal cavity (NC); the most lateral aspect of the zygomatic arch (ZA); the most superior aspect of the condyle (CO); the most inferior point on the mastoid process (MP); the deepest point on the curvature of the antegonial notch (AN).

When this occurred, the landmarks anterior to the vertical rotational axis were displaced in the same direction as the head rotation, whereas other landmarks posterior to the vertical rotational axis displaced in the opposite direction, and (3) the mean differences of the abscissa values per 1° interval of head rotation were larger as the landmark was located further anteroposteriorly from the vertical rotational axis and smaller as the landmark was located nearer the vertical rotational axis. In view of projection error and in order for posteroanterior cephalometric radiography to be a valuable diagnostic tool, the films should be exposed with no head rotation about the vertical Z-axis.

ACKNOWLEDGMENTS

The authors would like to thank Drs Mee-Sun Hwang, Young-Hwan Kim, Seong-Jun Kwon, Dong-Ik Ko, and Sung-Nam Kang, Residents in Orthodontics, College of Dentistry, Chosun University, for their willing assistance in this investigation.

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