Original Article

Effect of Head Rotation on Lateral Cephalometric Radiographs

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Abstract: The purpose of this study was to identify the potential projection errors of lateral cephalometric radiographs due to head rotation in the vertical Z-axis. For this investigation, 17 human dry skull samples with permanent dentition were collected from the Department of Anatomy in the College of Medicine, Chosun University. They had no gross asymmetry and were well preserved. Each dry skull was rotated from 0° to ±15° at 1° intervals. A vertical axis, the Z-axis, was used as a rotational axis to have 527 lateral cephalometric radiographs exposed. The findings were that: (1) angular measurements have fewer projection errors than linear measurements; (2) the greater the number of landmarks on the midsagittal plane that are included in angular measurements, the fewer the projection errors occurring; (3) horizontal linear measurements decrease gradually in length as the rotational angle toward the film increases, whereas a small increase and then decrease of the length occurs as the rotational angle toward the focal spot increases; (4) horizontal linear measurements have more projection errors than vertical linear measurements according to head rotation; and (5) projection errors of vertical linear measurements increase as the distance from the rotational axis increases. In summary, angular measurements of lateral cephalometric radiographs are more useful than linear measurements in minimizing the projection errors associated with head rotation on a vertical axis. (*Angle Orthod* 2001;71:396–403.)

Key Words: Projection error; Head rotation; Lateral cephalometric radiograph

INTRODUCTION

Lateral cephalometric radiography has limited orthodontic applications in the precise interpretation of a patient's craniofacial entity regardless of its standardization. Cephalographic projection is a central projection in which the object is projected onto the film by a beam that diverges from the radiation source, the focal spot. Only in the rarely occurring ideal case is the projection surface where the film is placed perpendicular to the central ray of the beam.[1,2]

Much research has been conducted into the reliability of the lateral cephalometric radiograph.[3–16] Cephalometric errors are divided into 3 categories:[4,5] (1) Identification errors occur in finding certain anatomic landmarks; (2) Projection errors are caused by the wrong positioning of the radiograph; (3) Mechanical errors occur in drawing lines between points on a tracing and in measuring the tracing with a ruler or protractor.

A head-holding device, consisting of an ear rod and nasal positioner, is used for lateral cephalometric radiographs to minimize the projection errors caused by head rotation in the vertical, transverse, and anteroposterior axes. However, when the device is used to contact the external auditory meatus and the soft tissue of the patient, the head can be incorrectly positioned sagittally, anteroposteriorly, or vertically, because the patient's head can be slightly rotated within the head-holding device. Because of such improper positions due to head rotation, an error can occur in cephalometric measurements. Because of the errors caused by the different locations of the head, cephalometric linear and angular measurements can vary depending on the different locations of anatomic structures against the central ray.[1,2] Therefore, unless the projection errors are precisely evaluated and understood, cephalometric measurements may have only limited application in orthodontics. The purpose of this study is to identify the potential projection errors of lateral cephalometric radiographs due to head rotation in the vertical Z-axis.

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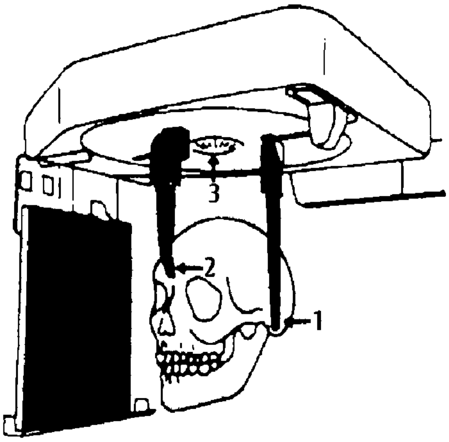

FIGURE 1. Positioning of the dry skull. 1. ear rod, 2. nasal positioner, 3. rotational scale.

MATERIALS AND METHODS

Materials

For this investigation, 17 human dry skulls with permanent dentition were collected from the Department of Anatomy in the College of Medicine, Chosun University. They had no gross asymmetry and were well preserved. Sex, occlusion, and skeletal pattern were not significantly considered.

Methods

Lateral cephalometric radiographs. Before the radiograph was taken, 8 anatomic landmarks were designated on the human dry skulls. Steel balls of 1.0-mm diameter were glued on each of 11 landmarks including bilateral landmarks. The FH (Frankfort horizontal) plane of the skull was placed parallel to the floor and was tightly positioned with an ear rod, headrest, and rubber bands (Figure 1). The 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 ±15° at 1° intervals. A vertical axis, the Z axis, was designated as a rotational axis connecting the center of both ear rods in the direction of the submentovertex, and 527 radiographs were taken based on this axis (Figure 2). The code "+" means a rotation toward the focal spot, and "−" means a rotation toward the film.

Establishment of landmarks and measurements.

A. Cephalometric landmarks
- S (Sella turcica): The midpoint of the sella turcica, determined by inspection.

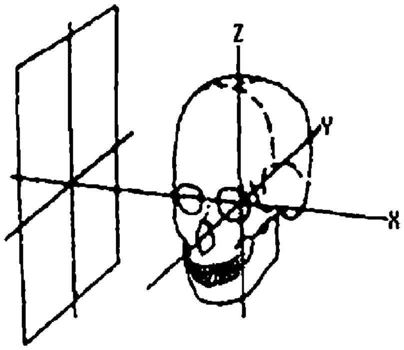

FIGURE 2. The rotational axes of skull.

- N (Nasion): The intersection of the internasal suture and the frontonasal suture in the midsagittal plane.
- A (Subspinale): The deepest point on the premaxilla between the anterior nasal spine and prosthion.
- B (Supramentale): The deepest point in the concavity between the infradentale and the pogonion.
- Me (Menton): The most inferior point on the mandibular symphysis in the midsagittal plane.
- Corpus left: The left point of a tangent of the inferior border of the corpus.
- Ramus down: The lower point of a tangent of the posterior border of the ramus.
- Ar (Articulare): The intersection of the posterior margin of mandibular condyle and temporal bone.

B. Cephalometric measurements
1. Linear measurements
   a. Horizontal linear measurements
      - Anterior cranial base length (S-N)
      - Mandibular body length (Gonion [Go]-Me)
   b. Vertical linear measurements
      - Anterior facial height (N-Me)
      - Posterior facial height (S-Go)
2. Angular measurements
      - SNA
      - SNB
      - Saddle angle (N-S-Ar)
      - Articular angle (S-Ar-Go)
      - Gonial angle (Ar-Go-Me)
      - AB to mandibular plane angle

Input of data. The point at which the steel balls on the landmarks including Corpus left, Ramus down, and Ar (Articulare) met the bone surface was marked on the film with a sharp metal pin. The results were input using a digitizer connected with a Macintosh computer. Detailed measurements—with length units of 0.01 mm and angular units of 0.01°—were made using Quick Ceph Image Pro™ Version 3.0 (Quick Ceph® Systems Co, San Diego, California). The same person recorded the data throughout the whole process to reduce measurement errors.

Reliability of digitizing. Each result was digitized 3 times

TABLE 1. Comparison of the Measurements From Zero to Each Rotational Angle Toward the Film[a]

Measurement		−15°	−14°	−13°	−12°	−11°	−10°	−9°
Linear, mm								
1. N-S	Mean	67.44***	67.74***	68.18***	68.44***	68.89***	69.23***	69.52***
	SD	4.81	4.67	4.67	4.69	4.72	4.66	4.69
	Error, %	−5.37	−4.95	−4.33	−3.97	−3.34	−2.86	−2.46
2. Go-Me	Mean	72.67***	73.07***	73.56	73.78***	74.15***	74.61***	75.15***
	SD	5.96	6.05	6.07	5.97	6.05	6.14	5.99
	Error, %	−5.78	−5.26	−4.63	−4.35	−3.86	−3.26	−2.57
3. N-Me	Mean	116.80***	116.91***	117.04***	117.19***	117.30***	117.44***	117.54***
	SD	8.80	8.82	8.72	8.79	8.83	8.75	8.77
	Error, %	−1.49	−1.40	−1.29	−1.67	−1.07	−0.95	−0.87
4. S-Go	Mean	85.66	85.73	85.76	85.72	85.88	85.73	85.78
	SD	9.39	9.44	9.47	9.52	9.61	9.51	9.49
	Error, %	−0.23	−0.15	−0.11	−0.16	0.02	−0.15	−0.08
Angular, °								
5. SNA	Mean	80.58	80.43	80.54*	80.61	80.50*	80.61	80.59*
	SD	5.55	5.31	5.24	5.29	5.28	5.14	5.12
	Error, %	−0.34	−0.51	−0.40	−0.31	−0.44	−0.31	−0.32
6. SNB	Mean	81.01	81.02	81.05	81.11	81.08	81.08	81.15
	SD	6.85	6.78	6.79	6.83	6.84	6.75	6.86
	Error, %	−0.35	−0.34	−0.43	−0.24	−0.27	−0.28	−0.19
7. N-S-Ar	Mean	132.53	132.52	132.71	132.71	132.75	132.88	133.05
	SD	8.62	8.61	8.40	8.46	8.40	8.36	8.44
	Error, %	−0.51	−0.52	−0.37	−0.37	−0.34	−0.25	−0.12
8. S-Ar-Go	Mean	136.89**	136.86**	136.68**	136.60**	136.46*	136.27*	136.27*
	SD	8.97	9.20	8.66	8.63	8.71	8.84	8.68
	Error, %	1.10	1.08	0.95	0.88	0.78	0.64	0.64
9. Ar-Go-Me	Mean	116.39	116.40	116.32	116.21	116.38	116.51	116.22*
	SD	6.13	6.23	6.09	5.97	6.05	6.08	6.14
	Error, %	−0.16	−0.16	−0.22	−0.32	−0.18	−0.07	−0.31
10. AB/Go-Me	Mean	75.99	75.95	76.15	76.06	76.21	76.08	76.05
	SD	7.38	7.63	7.55	7.60	7.65	7.60	7.63
	Error, %	0.09	0.03	0.30	0.18	0.38	0.21	0.16

[a] Reference group: 0°.
* $P < .05$; ** $P < .01$; *** $P < .001$.

to analyze the digitizing errors and to produce an average value for each angle. The coefficient constant (r) among the 3-time digitizing values was .9956, which may be considered very reliable.

Statistical analysis. Four linear and 6 angular measurements were taken from 0° to ±15° at 1° intervals. Paired *t*-tests were performed between the measurements from 0° to each rotational angle using the SPSS (SPSS Inc, Chicago, Illinois) statistical program.

RESULTS

The changes in the cephalometric linear and angular measurements occurring with 0° to −15° rotational angles are presented in Table 1 and those from 0° to +15° rotational angles in Table 2.

1. Linear Measurements
   a. Horizontal linear measurements
      • Anterior cranial base length

The anterior cranial base length was 71.27 mm at 0°. As the rotational angle toward the film increased, its length decreased, whereas its length increased and then decreased as the rotational angle toward the focal spot increased. The degree of these changes was not significant. There was a statistical difference between the measurements from 0° to each rotational angle toward the film ($P < .05$) and to rotations of more than +9° rotational angle toward the focal spot ($P < .01$). The difference was less than 1% from 0° to +12° and from 0° to −4° rotational angle. The maximum reduction was −5.37% at −15° rotational angle.

• Mandibular body length

The mandibular body length was 77.13 mm at 0°. As the rotational angle toward the film increased, its length decreased, whereas its length increased and then decreased as the rotational angle toward the focal spot increased. The degree of these changes was not significant. There was a statistical difference between the measurements at more than −2°, except at −13° rotational angle toward the film ($P < .01$) and more than +2°, except from +11° to +13° rotational angle toward the focal spot ($P < .05$). The difference was less than 1% from 0° to each rotational angle toward the focal spot and from 0° to −4° rotational angle

TABLE 1. Extended

−8°	−7°	−6°	−5°	−4°	−3°	−2°	−1°	0°
69.72***	70.12***	70.29***	70.45***	70.62***	70.84***	70.95***	71.13*	71.27
4.70	4.73	4.72	4.69	4.74	4.75	4.75	4.70	4.66
−2.17	−1.61	−1.38	−1.15	−0.91	−0.60	−0.46	−0.20	0.00
75.37***	75.74***	75.94***	76.18***	76.40***	76.64***	76.80**	76.81	77.13
6.18	6.14	6.14	6.26	6.21	6.25	6.26	6.19	6.26
−2.28	−1.79	−1.54	−1.23	−0.94	−0.64	−0.42	−0.41	0.00
117.71***	117.70***	117.81***	117.93***	118.12***	118.21***	118.29**	118.51	118.58
8.81	8.85	8.80	8.89	8.92	8.70	8.78	8.85	8.81
−0.73	−0.73	−0.64	−0.54	−0.38	−0.30	0.23	0.05	0.00
85.83	85.87	85.80	85.90	85.95	85.95	85.95	85.92	85.86
9.47	9.43	9.62	9.51	9.53	9.58	9.47	9.48	9.54
−0.03	0.02	−0.06	0.05	0.11	0.11	0.11	0.07	0.00
80.59*	80.62	80.72	80.77	80.67	80.74	80.83	80.75	80.86
5.13	5.12	4.98	5.09	4.90	4.98	5.04	5.03	4.98
−0.32	−0.29	−0.17	−0.10	−0.23	−0.15	−0.03	−0.13	0.00
81.15	81.16	81.25	81.27	81.25	81.28	81.32	81.26	81.30
6.78	6.87	6.78	6.90	6.83	6.90	6.88	6.91	6.94
−0.19	−0.17	−0.06	0.00	−0.07	−0.03	0.02	−0.05	0.00
133.18	133.17	133.12	133.21	133.31	133.32	133.38	133.45	133.21
8.07	8.26	8.17	8.22	8.21	8.10	8.07	8.18	8.13
−0.02	−0.03	−0.06	0.00	0.07	0.09	0.13	0.18	0.00
136.03	135.86	135.89	135.83	135.76	135.70	135.59	135.57	135.40
8.42	8.66	8.46	8.62	8.63	8.49	8.27	8.19	8.13
0.47	0.34	0.36	0.32	0.27	0.22	0.14	0.13	0.00
116.36	116.42	116.48	116.36*	116.41*	116.43	116.56	116.52	116.59
6.16	6.18	6.19	6.12	6.01	6.20	6.08	5.98	6.14
−0.20	−0.14	−0.09	−0.19	−0.15	−0.13	−0.02	−0.06	0.00
76.11	76.22	76.09	76.09	76.03	76.02	75.99	76.18	75.92
7.61	7.76	7.67	7.72	7.68	7.82	7.71	7.62	7.94
0.23	0.40	0.21	0.23	0.13	0.13	0.09	0.33	0.00

toward the film; the maximum reduction was −5.78% at −15° rotational angle.

b. Vertical linear measurements

- Anterior facial height

The anterior facial height was 118.58 mm at 0°. As the rotational angle toward the film increased, its length decreased, whereas its length increased and then decreased as the rotational angle toward the focal spot increased. The degree of these changes was similar regardless of the direction of rotation. There was a statistical difference between the measurements at more than −2° rotational angle toward the film ($P < .01$) and at each rotational angle, except at +2° rotational angle toward the focal spot ($P < .05$). The difference was less than 1% from 0° to ±10° rotational angle, and the maximum magnification was 1.51% at +15° rotational angle.

- Posterior facial height

The posterior facial height was 85.86 mm at 0°. The difference between the measurements from 0° to each rotational angle was a little larger toward the focal spot than toward the film, but the degree of these changes was minimal regardless of the direction of rotation. There was no statistical difference in the measurements from 0° to each rotational angle toward the film ($P > .05$), whereas a statistical difference was found in the measurements at +9°, +14° and +15° rotational angle toward the focal spot ($P < .05$). The difference was less than 0.5% from 0° to each rotational angle regardless of the direction of rotation.

2. Angular measurements

- SNA

SNA was 80.86° at 0°. There was a statistical difference in the measurements at −8°, −9°, −11° and −13° rotational angle toward the film ($P < .05$), but no statistical difference existed in the measurements from 0° to each rotational angle toward the focal spot ($P > .05$). The difference was less than 0.5% from 0° to each rotational angle regardless of the direction of rotation.

- SNB

SNB was 81.3° at 0°. There was no statistical difference in the measurements from 0° to each rotational angle toward the film ($P > .05$), but a statistical difference was found in the measurements at +11° and from +13° to +15° rotational angle toward the focal spot ($P < .05$). The difference

TABLE 2. Comparison of the Measurements From Zero to Each Rotational Angle Toward the Focal Spot[a]

Measurement		0°	+1°	+2°	+3°	+4°	+5°	+6°
Linear, mm								
1. N-S	Mean	71.27	71.29	71.23	71.34	71.38	71.30	71.29
	SD	4.66	4.72	4.74	4.75	4.80	4.79	4.72
	Error, %	0.00	0.03	0.06	0.10	0.15	0.04	0.03
2. Go-Me	Mean	77.13	77.18	77.37*	77.61**	77.64**	77.46*	77.61***
	SD	6.26	6.33	6.20	6.31	6.44	6.26	6.29
	Error, %	0.00	0.07	0.31	0.62	0.66	0.43	0.63
3. N-Me	Mean	118.58	118.69*	118.71	118.88*	118.88*	119.09***	119.29***
	SD	8.81	8.90	8.85	8.84	8.61	8.93	9.01
	Error, %	0.00	0.10	0.12	0.26	0.26	0.44	0.61
4. S-Go	Mean	85.86	85.88	86.00	85.95	85.89	86.01	86.02
	SD	9.54	9.52	9.51	9.39	9.50	9.59	9.60
	Error, %	0.00	0.03	0.17	0.11	0.04	0.18	0.19
Angular, °								
5. SNA	Mean	80.86	80.90	80.82	80.92	80.79	80.85	80.80
	SD	4.98	4.91	5.03	5.01	4.94	5.00	4.93
	Error, %	0.00	0.06	−0.04	0.09	−0.08	0.00	−0.07
6. SNB	Mean	81.30	81.39	81.44	81.39	81.30	81.33	81.32
	SD	6.94	6.94	6.84	6.80	6.97	6.99	6.90
	Error, %	0.00	0.12	0.17	0.11	0.00	0.03	0.03
7. N-S-Ar	Mean	133.21	133.16	133.37	133.26	133.29	133.28	133.39
	SD	8.13	8.04	7.96	7.83	8.01	8.23	7.87
	Error, %	0.00	−0.04	0.12	0.04	0.06	0.05	0.14
8. S-Ar-Go	Mean	135.40	135.45	135.53	135.73	135.82	135.82	136.03
	SD	8.13	8.13	8.01	8.09	8.18	7.99	8.04
	Error, %	0.00	0.03	0.10	0.25	0.31	0.31	0.46
9. Ar-Go-Me	Mean	116.59	116.65	116.60	116.70	116.77*	116.75	116.84
	SD	6.14	6.12	6.16	6.19	6.24	5.96	6.03
	Error, %	0.00	0.06	0.01	0.10	0.16	0.14	0.22
10.AB/Go-Me	Mean	75.92	75.87	75.69*	75.70	75.68**	75.63*	75.78
	SD	7.94	7.80	7.75	7.79	7.80	7.86	7.58
	Error, %	0.00	−0.08	−0.30	−0.29	−0.32	−0.39	−0.19

was less than 0.5% from 0° to each rotational angle regardless of the direction of rotation.

- Saddle angle

The saddle angle was 133.21° at 0°. There was no statistical difference in the measurements from 0° to each rotational angle regardless of the direction of rotation ($P > .05$). The difference was less than 0.5% from 0° to each rotational angle regardless of the direction of rotation.

- Articular angle

The articular angle was 135.40° at 0°. There was a statistical difference in the measurements at more than −9° rotational angle toward the film and more than +8°, except at +11° rotational angle toward the focal spot ($P < .05$). The difference was less than 1.0% from 0° to each rotational angle regardless of the direction of rotation.

- Gonial angle

The gonial angle was 116.59° at 0°. There was a statistical difference in the measurements at −4°, −5° and −9° rotational angle toward the film and at +4°, +7°, and from +11° to +15° rotational angle toward the focal spot ($P < .05$). The difference was less than 1.0% from 0° to each rotational angle regardless of the direction of rotation.

- AB to mandibular plane angle

AB to mandibular plane angle was 75.92° at 0°. There was no statistical difference in the measurements from 0° to each rotational angle toward the film ($P > .05$), but a statistical difference existed in the measurements +2°, +4°, +5°, +7° and from +10° to +15° rotational angle toward the focal spot ($P < .05$). The difference was less than 1.0% from 0° to each rotational angle regardless of the direction of rotation.

DISCUSSION

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 the present study, the measurement values are different according to the direction of rotation because different planes have different magnifications with different ratios.

Head rotation can occur in the anteroposterior axis, vertical axis, and transverse axis. However, standardization on the anteroposterior and transverse axes is actually hard to achieve. Rotation on the transverse axis causes no distortion of images. Although the head rotates on the transverse axis,

TABLE 2. Extended.

+7°	+8°	+9°	+10°	+11°	+12°	+13°	+14°	+15°
71.15	71.21	71.02**	70.89***	70.77***	70.59***	70.42***	70.11***	70.00***
4.78	4.72	4.75	4.73	4.68	4.65	4.58	4.63	4.62
−0.17	−0.08	−0.35	−0.53	−0.70	−0.95	−1.19	−1.63	−1.78
77.43*	77.62**	77.46*	77.45*	77.17	77.01	76.95	76.73*	76.38***
6.29	6.24	6.32	6.24	6.38	6.01	6.16	6.15	6.10
0.39	0.64	0.43	0.42	0.06	−0.15	−0.23	−0.52	−0.97
119.46***	119.57***	119.72***	119.79***	119.95***	119.99***	120.16***	120.30***	120.36***
8.94	8.91	8.90	9.01	9.01	9.02	9.11	9.06	9.08
0.75	0.84	0.97	1.03	1.17	1.20	1.34	1.46	1.51
86.17	86.09	86.17*	86.02	86.09	86.16	86.03	86.19*	86.27*
9.58	9.44	9.50	9.58	9.51	9.56	9.54	9.60	9.50
0.36	0.27	0.37	0.21	0.28	0.35	0.20	0.39	0.48
80.75	80.74	80.89	80.89	80.83	80.84	80.78	80.77	80.71
4.92	5.04	5.08	4.92	5.02	5.13	5.02	5.06	5.29
−0.14	−0.15	0.05	0.04	−0.04	−0.02	−0.10	−0.11	−0.18
81.31	81.21	81.16	81.21	81.13*	81.10	81.07*	81.02*	80.94*
6.97	6.96	6.93	7.01	7.04	7.00	7.08	7.02	7.05
0.02	−0.11	−0.17	−0.11	−0.21	−0.25	−0.28	−0.35	−0.43
133.49	133.42	133.34	133.33	133.38	133.28	133.40	133.17	133.08
7.87	7.93	7.66	7.83	8.08	8.03	8.05	7.96	7.96
0.21	0.16	0.10	0.09	0.13	0.05	0.15	−0.03	−0.10
135.85	136.37**	136.28*	136.44**	136.15	136.23*	136.51**	136.64**	136.75**
8.09	8.05	7.88	7.75	8.19	7.75	7.82	7.60	7.60
0.32	0.71	0.66	0.78	0.55	0.61	0.81	0.92	1.00
117.04**	116.86	116.89	117.01	117.09**	117.09*	116.96*	117.15*	117.36**
6.12	6.17	6.34	6.20	6.39	6.15	6.14	6.23	6.22
0.39	0.03	0.27	0.36	0.43	0.43	0.31	0.48	0.66
75.64*	75.62	75.66	75.53*	75.52*	75.49*	75.34*	75.39*	75.40*
7.78	7.69	7.75	7.83	7.77	7.72	7.62	7.76	7.65
−0.38	−0.40	−0.35	−0.52	−0.53	−0.57	−0.77	−0.70	−0.70

[a] Reference group: 0°.
* $P < .05$; ** $P < .01$; *** $P < .001$.

the location of the head is parallel to the central ray. Only the location of the images on the film changes, but this does not cause a change of the relationship between landmarks.[1,2] However, rotation in the anteroposterior axis affects landmarks vertically, not horizontally. The bilateral structures are moved equally and the vertical distance between landmarks changes depending on the distances of landmarks from the rotational axis.

Rotation on the vertical axis influenced the horizontal measurements, not the vertical measurements, in a different manner from rotation on the anteroposterior axis. Unless landmarks are located within the distance equidistant from the midsagittal plane, any rotation on this axis changes the relationships 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.[1,2]

Concerning the projection errors of linear measurements, Ahlqvist et al[17] supposed that the effects of rotations on the anteroposterior and vertical axes may be identical. In their study using a computer model similar to the real dry skull, they found that rotation of ±5° from the ideal position resulted in errors of less than 1%, a margin that is usually insignificant and difficult to distinguish from other errors. However, the errors became significant at even a few degrees of rotation more than ±5°. The projection error of the present study was different depending on the direction of rotation, contrary to the results of Ahlqvist et al.[17]

The anterior cranial base length and mandibular body length gradually decreased as the rotational angle toward the film increased. There was a statistical difference in the measurements from 0° to each rotational angle toward the film in the anterior cranial base length ($P < .05$) and to more than −2° rotational angle toward the film in the mandibular body length ($P < .01$). The difference was above 1% with an increase of more than −5° rotational angle, and the maximum reduction was −5.37% in the anterior cranial base length and −5.78% in the mandibular body length at −15° rotational angle. These were the same as the results of Ahlqvist et al.[17] This is thought to result because the nearer to the film the head rotates, the more the image decreases, and this decrease is gradual because the rotation itself causes the decrease of the images.

However, the anterior cranial base length and mandibular body length increased and then decreased as the rotational angle toward the focal spot increased. The difference was less than 1% from 0° to +12° rotational angle toward the focal spot in the anterior cranial base length and all rotational angles toward the focal spot in the mandibular body length, contrary to the results of Ahlqvist et al.[17] This is thought to be due to an offset, because the farther from the film the head rotates, the more the image is magnified, and the rotation itself causes the shortening of the images. That is, if the image magnification caused by the greater rotation from the film is larger than the image reduction caused by the rotation itself, the length may be increased, but in the reverse case, it will be decreased.

In the anterior facial height, there was a statistical difference in the measurements at more than −2° rotational angle toward the film ($P < .01$) and at each rotational angle, except at +2° rotational angle toward the focal spot ($P < .05$). The difference was above 1% at more than ±10° rotational angle. In the posterior facial height, the difference was less than 0.5% at all rotational angles regardless of the direction of rotation. The variation due to head rotation was the least among all the linear measurements.

The amount of rotational axis error was greater in the horizontal linear measurements than in the vertical linear measurements, especially in the mandibular body length. This may be because the landmarks of the mandibular body length are located farther vertically from the central ray and contain bilateral structures. In the case of the posterior facial height including bilateral structures, however, the difference was minimal, because it is near the rotational axis.

Concerning the projection errors of angular measurements, Ahlqvist et al[18] made various geometric computer models to find projection errors of angular measurements and rotated them on the anteroposterior and vertical axes. They demonstrated that rotations within ±10° of the modeled angles give rise to angle distortion less than ±0.6°. Thus, projection errors were insignificant as compared to the total error. In addition, in their study, computer models similar to the real dry skull were used. When heads were rotated 5° toward both the film and the focus, each distortion value was not above ±1°. Moreover, most of the distortion values were less than ±0.5°. When 10° rotation was made toward the film and the focus, the distortion increased, and the value was just within ±2°.

In summary, for the lateral cephalometric radiograph, 10° of head rotation to the film and the focus produced the largest value possible. In reality, even 5° of head rotation is hard to find in a clinical procedure. The projection error is insignificant when compared with the total of all the differences involved in the process. In the present study, SNA, SNB, and saddle angle showed less than 0.5% difference at all rotational angles regardless of the direction of rotation. Even the more distorted articular angle, gonial angle, and AB to mandibular plane angle showed less than 1% difference, and the projection errors of angular measurements were much smaller than those of Ahlqvist et al.[18] The projection errors of angular measurements did not exceed 1% difference at all rotational angles regardless of the direction of angle, and it was far less than those of the linear measurements.

In conclusion, angular measurements of lateral cephalometric radiographs are more useful than linear measurements to minimize the projection errors associated with head rotation on the vertical axis. For example, SUM—a combination of saddle angle, articular angle, and gonial angle—has greater diagnostic merit than facial height ratio as one of the linear measurements in the Jarabak Analysis.

Even a tiny error may change the prediction and the analysis of craniofacial growth in a lateral cephalometric radiograph. Considering that a projection error of 1% difference in the horizontal linear measurements is close to the 1.0 mm annual growth[19] of the anterior cranial base length (CC-N) and is half of the 2.0 mm annual growth[19] of the mandibular body length (Xi-pm), these projection errors should not be ignored even though they are very small.

Furthermore, considering the projection error caused by head rotation on the anteroposterior and transverse axes as well as the vertical axis, the lateral cephalometric radiograph may lead to an interpretation that is very different from the real condition of the patient. Therefore, in exposing films, the projection errors should be reduced as much as possible. The location of the patient's head should be represented consistently. In order to predict and analyze the change caused by orthodontic treatment and growth, the film should be exactly processed and should be accompanied by further development of head-positioning devices.

CONCLUSIONS

Angular measurements have fewer projection errors than linear measurements. The greater number of landmarks on the midsagittal plane that are included in angular measurements, the fewer the projection errors occurring.

Horizontal linear measurements decrease gradually in length as the rotational angle toward the film increases, whereas a small increase and then decrease of the length occurs as the rotational angle toward the focal spot increases. Horizontal linear measurements have more projection errors than vertical linear measurements according to head rotation.

Projection errors of vertical linear measurements increase as the distance from the rotational axis increases.

In summary, angular measurements of lateral cephalometric radiographs are more useful than linear measurements in minimizing the projection errors associated with head rotation on a vertical axis.

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