Landmark identification error in posterior anterior cephalometrics

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Since the introduction of a standardized method for obtaining skull radiographs,[1] cephalometrics has become one of the major diagnostic tools in orthodontics.

The posterior anterior cephalogram contains diagnostic information not readily available from other sources. This information allows the practitioner to evaluate the width and angulation of the dental arches in relation to their osseous bases in the transverse plane; evaluate the width and transverse positions of the maxilla and mandible; evaluate the relative vertical dimensions of bilateral osseous and dental structures; assess nasal cavity width; and analyze vertical and/or transverse facial asymmetries.[2-7] Regardless of the clinical or research application, it is critical to know the reliability of the reference landmarks.

Baumrind and Frantz[8] point out that there are two general classes of error associated with cephalometric measurements. The first class of errors are "projection" errors which arise from the geometry of the radiographic setup. The fact that the x-ray beam originates from a source which has a finite size leads to a penumbra effect or optical blurring.[9,10] The x-ray beam diverges as it moves away from the source, which results in an overall magnification of the object being radiographed and a radial displacement of all points which are not on the principal axis (central ray). The radiographic image is distorted as points closer to the film are magnified less than points farther from the film.

The second general class of landmark errors may be termed "errors of identification," and arise due to uncertainty involved in locating specific anatomic landmarks on the radio-

Abstract

This study was designed to quantify the intraexaminer and interexaminer reliability of 52 commonly used posterior anterior cephalometric landmarks. The horizontal and vertical identification errors were determined for a sample of 33 skulls and 25 patients. The results show that there is a considerable range in the magnitude of error with different horizontal and vertical values. Interexaminer landmark identification error was significantly larger than intraexaminer error for many landmarks. The identification error was different for the skull sample compared to the patient sample for a number of landmarks. The relevance of knowing the identification error for each landmark being considered in a particular application was discussed.

Key Words

Landmark identification error • Posterior anterior cephalometrics • Intraexaminer reliability • Interexaminer reliability

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Figure 1
Posterior cephalometric landmarks.

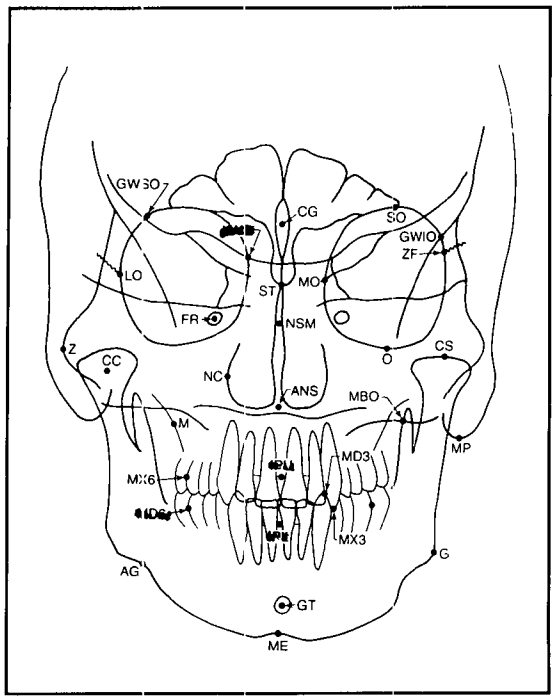

Figure 1

graph. The precision with which any landmark may be identified depends on a number of factors.[8,11,12] Landmarks lying on a sharp curve or at the intersection of two curves are generally easier to identify than points located on flat or broad curves. Points located in areas of high contrast are easier to identify than points located in areas of low contrast. Superimposition of other structures, including soft tissue over the area of the landmark in question, reduces the ease of identification. Precise written definitions describing the landmark reduces the chance of interpretation error. Operator experience is an important factor since increased knowledge of anatomy and familiarity with the radiographic appearance of the subject reduces interpretive errors.

A literature review concerning the reliability of landmark identification in posterior anterior cephalometrics revealed only one article, by El-Mangoury et al.,[12] which determined the horizontal, vertical and radial variability of 13 landmarks. They found that each landmark had its own characteristic noncircular envelope of error, and that the variability is different in the horizontal and vertical directions. Unfortunately, the majority of posterior anterior cephalometric analyses use landmarks whose identification error has not been independently reported.

The purpose of this study was to examine the reliability of posterior anterior cephalometric landmarks. Skeletal and dental landmarks to be investigated were chosen to include those most commonly used in published posterior anterior cephalometric analyses,[13,14-19] and those landmarks which can be recognized on the posterior anterior cephalogram.[20,21,22] Landmark reliability for cephalograms taken both on dry skulls and living patients were identified and compared.

Materials and methods

A sample of 33 dry adult skulls from the University of Alberta collection with intact dentitions and no gross asymmetries were radiographed with a standardized technique. The source-to-film distance was a constant 160 cm and the distance from the middle of the earrods to the film was 17.5 cm. A sample of 25 adult patient posterior anterior cephalograms based on the absence of obvious skeletal or dental asymmetries, was chosen from consecutive orthodontic records taken at a private radiology facility. All patient cephalograms were taken using a Siemans OP10 x-ray machine with standardized exposure and head positioning with Frankfort Horizontal parallel to the floor. Source-to-earrod distance was 60 inches and earrod-to-film distance was 5 inches.

Landmarks were digitized directly off the radiographs using a GP6 Sonic Digitizer R in conjunction with an IBM-compatible computer and a custom program developed using Basic TM. An individual coordinate system was established for each radiograph by including two fiducial points which consisted of a pinhole placed on each radiograph at the superior and medial corner of both earrod markers. These two pinholes were digitized first which enable the digitization program to calculate the slope of the line between the two pinholes. This value 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 radiograph on the viewbox as a variable. Fifty-two commonly used landmarks were then digitized including 36 bilateral skeletal landmarks.

The following landmarks (Figure 1) were identified on each radiograph:

A. 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 (GWI0) - 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. Orbitale (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. Zygomatic Frontal (ZF) - the intersection of the zygomaticofrontal suture and the lateral orbital margin.
9. Zygomatic (Z) - the most lateral aspect of the zygomatic arch.
10. Foramen Rotundum (FR) - the center of foramen rotundum.
11. Condyle Superior (CS) - the most superior aspect of the condyle.
12. Center Condyle (CC) - the center of the condylar head of the condyle.
13. Mastoid Process (MP) - the most inferior point on the mastoid process.
14. Malar (M) - the deepest point on the curvature of the malar process of the maxilla.
15. Nasal Cavity (NC) - the most lateral point on the nasal cavity.
16. Mandible/Occiput (MBO) - the intersection of the mandibular ramus and the base of the occiput.
17. Gonion (G) - the midpoint on the curvature at the angle of the mandible (gonion).
18. Antegonial (AG) - the deepest point on the curvature of the antegonial notch.

B. Midline skeletal landmarks

1. Crista Galli (CG) - the geometric center of the crista galli.
2. Sella Turcica (ST) - the most inferior point on the floor of sella turcica.
3. Nasal Septum (NSM) - the approximated midpoint on the nasal septum between crista galli and the anterior nasal spine.
4. Anterior Nasal Spine (ANS) - the center of the intersection of the nasal septum and the palate.
5. Incisor Point (IPU) - the crest of the alveolus between the maxillary central incisors.
6. Incisor Point (IPL) - the crest of the alveolus between the mandibular central 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.

C. Bilateral dental landmarks

1. Maxillary Cuspid (MX3) - the incisal tip of the maxillary cuspid.
2. Maxillary Molar (MX6) - the midpoint on the buccal surface of the maxillary first molar.
3. Mandibular Cuspid (MD3) - the incisal tip of the mandibular cuspid.
4. Mandibular Molar (MD6) - the midpoint on the buccal surface of the mandibular first molar.

To determine intraexaminer landmark reliability, each radiograph was digitized five times by the principle investigator. To avoid operator bias, radiographs were digitized randomly and no individual radiograph was digitized more than once in a day. The raw data was examined for any single digitization which differed from the average of the other four by greater than 10 mm. Digitization of that particular radiograph was repeated, effectively eliminating any instances where the wrong point was digitized by mistake. Deviations from each landmark mean value were analyzed to give the standard deviation of the mean, which was considered to be the landmark identification error in millimeters.

To determine interexaminer landmark reliability each radiograph was digitized one time by each of four operators with graduate level training in cephalometrics. Each operator was provided with written descriptions and diagrams of the landmark location for reference during digitization procedures. Data analysis was completed using the procedure outlined for intraexaminer landmark reliability.

The error of the method was established by repeated digitization of a precisely defined point which consisted of a pinhole in the radiograph.

Results

A. Reliability of the Method

Reliability is a measure of the reproducibility or, in this case, the closeness of the recorded coordinates for each particular landmark. In estimating the reliability of the method, four contributing factors were identified.

1. Radiograph (R) - differences in landmark

Table 1
Intraexaminer landmark reliability for bilateral skeletal and dental landmarks

Skeletal Landmark	Skull s.d.(mm) X	Skull s.d.(mm) Y	Patient s.d.(mm) X	Patient s.d.(mm) Y
Upper skeletal				
GWSO	0.48	0.30	0.64	0.56
GWIO	0.35	0.35	0.30	0.36
LWO	0.83	0.41	0.36	0.44
O	1.07	0.73	0.88	1.24
LO	0.56	0.99	0.65	0.79
MO	1.00	0.96	0.81	1.13
SO	0.75	0.25	0.94	0.84
CS	0.97	1.27	0.82	1.26
CC	0.93	1.14	0.70	1.17
MP	0.45	0.26	0.37	0.18
Nasomaxillary				
ZF	0.68	*2.23	0.50	*1.11
Z	0.28	0.35	0.41	0.57
FR	0.73	0.51	0.74	0.93
M	0.42	0.61	0.78	0.87
NC	1.03	1.10	0.97	0.99
MX3	0.74	*0.39	0.85	*1.30
MX6	0.76	0.86	0.37	0.54
Mandibular				
MBO	*0.48	0.46	*1.02	0.84
G	0.37	0.80	0.30	0.53
AG	0.58	0.56	0.41	0.38
MD3	0.68	0.34	0.72	0.71
MD6	0.91	0.61	0.59	1.08

* significantly different from the corresponding landmark in the same row, P<0.05

Table 2
Intraexaminer landmark reliability for midline skeletal and dental landmarks

Skeletal Landmark	Skull s.d.(mm) X	Skull s.d.(mm) Y	Patient s.d.(mm) X	Patient s.d.(mm) Y
Upper skeletal				
CG	0.40	*0.81	0.50	*2.20
ST	0.41	1.78	0.30	0.93
Nasomaxillary				
NSM	0.49	*2.82	0.37	*0.90
ANS	0.31	0.36	0.24	0.38
IPU	0.31	0.37	0.22	0.87
Mandibular				
IPL	0.30	0.45	0.53	0.36
GT	0.32	0.71	0.64	0.87
ME	0.50	0.23	0.66	0.20

* significantly different from the corresponding landmark in the same row, P<0.05

position between individual skulls or patients.
2. Position (P) - differences between positions of different landmarks within the same skull or patient.
3. Side (S) - differences in landmark position between the left and right sides of the skull or patient.
4. Case (C) - differences between successive digitizations of the same radiograph.

The reliability of the method was calculated using generalizability theory which uses an analysis of variance to separate the total variance into its component parts. The total variance is made up of the variation due to each factor plus the variation due to all combinations of factors. Since reliability is a measure of how reproducible the method is in repeated trials, any variance between successive digitizations is considered undesirable. To calculate the general reliability of the method, variance due to case and any other variance in combination with case were subtracted from the total variance, then this value was divided by the total variance.

$$R = \frac{VT - (Vc + VcRP)}{VT}$$

where: R = reliability; VT = total variance; Vc = variance due to case; VcRP = variance due to case in combination with radiograph position.

Because the sample was accepted on the criterion of good facial symmetry, the relative contribution of side as a variable was not considered in the estimation of reliability. The very high level of reliability [Rx(skull) = .9995, Ry(skull) = .9992, Rx(patient) = .9910, Ry(patient) = .9985] indicates that the relative contribution of multiple digitizations to the total variance is very low.

B. Method error

The magnitude of error associated with the equipment (SD_x = .13 mm, SD_y = .10 mm) was very close to the ± .1 mm accuracy of the digitizer claimed by the equipment manufacturer.

C. Intraexaminer landmark error

The error associated with the identification of each landmark was calculated for both the skull and patient samples (Tables 1 and 2). There was a wide variation in the amount of identification error between landmarks, as well as between the vertical and horizontal error for each particular landmark. Visual inspection of the results indicates that the identification errors for the skull and patient radiographs were

Table 3
Intraexaminer and interexaminer reliability of bilateral landmarks; x coordinate

Skeletal Landmark	Skull s.d.(mm) Number of examiners One	Skull s.d.(mm) Number of examiners Four	Patient s.d.(mm) Number of examiners One	Patient s.d.(mm) Number of examiners Four
Upper skeletal				
GWSO	0.51	0.80	0.53	0.83
GWIO	0.32	0.67	0.29	0.68
LWO	0.47	0.90	▼ 0.29	▼ 1.37
O	1.07	1.25	0.88	1.76
LO	0.55	*0.70	▼ 0.60	▼ *1.61
MO	0.96	1.36	0.88	1.30
SO	0.75	1.13	1.03	1.79
CS	1.00	1.81	0.83	1.63
CC	0.87	1.62	0.67	1.56
MP	0.41	0.69	0.38	0.55
Nasomaxillary				
ZF	❑ 0.61	❑ 1.79	▼ 0.46	▼ 2.47
Z	❑ 0.24	❑ 1.67	▼ 0.29	▼ 2.42
FR	0.27	*0.48	0.68	*1.28
M	❑ 0.43	❑ *1.01	▼ 0.77	▼ *2.60
NC	0.94	1.24	0.30	0.71
MX3	0.75	0.93	0.88	1.09
MX6	0.72	1.07	▼ 0.39	▼ 1.28
Mandibular				
MBO	❑ 0.38	❑ 2.10	▼ 0.42	▼ 1.66
G	0.37	0.63	0.31	0.52
AG	0.46	0.66	0.42	0.64
MD3	0.66	1.13	0.76	1.36
MD6	0.94	1.13	0.50	1.30

❑,*,▼ - significantly different from the corresponding landmark in the same row, P<0.05

Table 4
Intraexaminer and interexaminer reliability of bilateral landmarks; y coordinate

Skeletal Landmark	Skull s.d.(mm) Number of examiners One	Skull s.d.(mm) Number of examiners Four	Patient s.d.(mm) Number of examiners One	Patient s.d.(mm) Number of examiners Four
Upper skeletal				
GWSO	0.31	0.57	0.46	0.83
GWIO	❑ 0.35	❑ 1.10	▼ 0.35	▼ 0.95
LWO	❑ 0.42	❑ 1.07	▼ 0.36	▼ 1.60
O	❑ 0.76	❑ ○ 2.13	▼ 1.36	▼ ○ 3.37
LO	0.97	1.51	▼ 0.76	▼ 1.97
MO	0.89	1.97	1.20	2.40
SO	0.21	0.44	0.93	1.24
CS	❑ 1.35	❑ ○ 3.31	▼ 1.33	▼ ○ 4.70
CC	❑ 1.12	❑ 3.33	▼ 1.22	▼ 4.13
MP	0.23	0.45	0.18	0.70
Nasomaxillary				
ZF	*2.05	○ 3.36	▼ *0.98	▼ ○ 2.73
Z	❑ 0.36	❑ 2.88	▼ 0.51	▼ 3.49
FR	*0.19	○ 0.40	▼ *1.03	▼ ○ 2.04
M	❑ 0.66	❑ 2.08	▼ 0.93	▼ 3.06
NC	0.99	1.03	▼ 0.53	▼ 2.18
MX3	*0.39	○ 0.67	▼ *1.19	▼ ○ 2.46
MX6	0.90	1.04	▼ 0.55	▼ 1.83
Mandibular				
MBO	❑ 0.41	❑ 1.51	▼ 0.48	▼ 2.83
G	0.88	1.28	0.56	0.82
AG	0.46	0.71	0.39	0.64
MD3	0.36	0.48	0.70	1.07
MD6	0.63	0.78	1.16	1.62

❑,*,○,▼ - significantly different from the corresponding landmark in the same row, P<0.05

similar, with the values generally larger for the patient radiographs where soft tissue became a factor. Landmark identification error for the skull sample and patient sample were compared using a Student Newman Keuls comparison of means (P<.05). Horizontal identification error was significantly greater in the patient sample for Landmark Mandible/Occiput (MB0). Vertical identification error was significantly greater in the patient sample for Landmark Maxillary Cuspid (MX3) and Crista Galli (CG). Vertical identification error was significantly greater in the skull sample for Landmark Zygomatic Frontal (ZF) and Nasal Septum (NSM).

D. Interexaminer landmark error

The landmark identification errors for a single examiner and four examiners were determined for a selected sample of 20 skull and patient radiographs (Tables 3 to 6). The results indicate that landmark identification error was generally larger when four examiners were used, with the error for the patient sample larger than the skull sample.

A Student-Newman-Keuls comparison of means was used to compare the identification errors of each sample.

The results listed in Tables 3 to 6 show the comparison between groups. Horizontal interexaminer landmark identification error was significantly larger than the intraexaminer error for four landmarks in the skull sample, and 10 landmarks in the patient sample. Vertical interexaminer landmark identification error was significantly larger than the intraexaminer error for eight landmarks in the skull sample and 17 landmarks in the patient sample.

Horizontal interexaminer landmark identification error was larger in the patient sample compared with the skull sample for landmarks Lateral Orbit (LO), Foramen Rotundum (FR) and Malar (M). Vertical interexaminer land-

Table 5
Intraexaminer and interexaminer reliability of midline skeletal landmarks; x coordinate

Skeletal Landmark	Skull s.d.(mm) Number of examiners One	Skull s.d.(mm) Number of examiners Four	Patient s.d.(mm) Number of examiners One	Patient s.d.(mm) Number of examiners Four
Upper skeletal				
CG	0.29	0.48	0.52	0.67
ST	0.36	0.47	0.30	0.52
Nasomaxillary				
NSM	0.40	0.44	0.27	0.57
ANS	0.26	0.36	0.25	0.45
IPU	0.26	0.34	0.22	0.42
Mandibular				
IPL	0.29	0.31	0.59	0.99
GT	0.28	0.45	0.60	0.84
ME	0.45	0.66	0.69	0.96

* - significantly different from the corresponding landmark in the same row P<0.05

Table 6
Intraexaminer and interexaminer reliability of midline skeletal landmarks; y coordinate

Skeletal Landmark	Skull s.d.(mm) Number of examiners One	Skull s.d.(mm) Number of examiners Four	Patient s.d.(mm) Number of examiners One	Patient s.d.(mm) Number of examiners Four
Upper skeletal				
CG	* 0.60	❑ 1.35	* 2.07	❑ 2.17
ST	2.01	3.01	0.76	1.88
Nasomaxillary				
NSM	* 2.80	2.10	▼ * 0.82	▼ 2.04
ANS	0.39	0.69	0.37	1.20
IPU	0.39	0.56	0.93	1.53
Mandibular				
IPL	0.43	0.77	▼ 0.34	▼ 1.51
GT	0.71	❑ 1.08	1.10	❑ 2.11
ME	0.21	0.38	▼ 0.20	▼ 0.72

*,❑,▼ - significantly different from the corresponding landmark in the same row

mark identification error was larger in the patient sample compared to the skull sample for Landmarks Orbital (O), Condyle Superior (CS), Condyle Center (CC), Zygomatic Frontal (ZF), Foramen Rotundum (FR), Maxillary Cuspid (MX3), Crista Galli (CG) and Genial Tubercles (GT).

Discussion

There was a great deal of variability in the magnitude of horizontal and vertical landmark identification errors. This variability existed both within each landmark and between different landmarks. This is in agreement with the findings of other studies into landmark identification errors.[8,11,12,23-25] The range of values (in millimeters) for intraexaminer errors (0.28-2.23) was of similar magnitude as that reported by Vincent and West[11] (0.31-2.09) who also used five digitizations. The El Mangoury et al.[12] study into Posterior Anterior Cephalometric landmark identification error reported a range of error of 0.42 to 1.74. Her study used patient radiographs and when the same landmarks were examined in this study, the range of error was of similar magnitude (0.37-1.10).

The interexaminer identification errors showed a wide variation in magnitude in both horizontal and vertical dimensions. The range of values (0.31-4.79) was larger than in the intraexaminer portion of the study. This difference can be attributed to interpretive differences between operators. The study by El Mangoury et al.[12] used only one operator and did not report interexaminer error. The Baumrind and Frantz[8] study on lateral cephalograms used multiple operators and the range of error reported in their study was 0.34 to 3.71, which is similar to the range found in this study.

The choice of landmarks used in any analysis will depend on the objective of the analysis. Knowledge of the landmark identification error in both the horizontal and vertical directions is essential in establishing a valid analysis. Landmarks with a large horizontal

identification error should be avoided in transverse measurements. Similarly, landmarks with large vertical identification error should be avoided in measuring vertical structural relationships. Some landmarks will be useful for measurements in one dimension but not in the other. For example, landmark Nasal Septum (NSM) has a relatively small horizontal error (.49 in the skull sample) and large vertical error (2.82 in the skull sample). Caution must be exercised when comparing data taken from skull samples to patient samples. Most landmarks had similar identification errors but there were exceptions.

Some landmarks may be quite useful in research trials where one examiner takes repeated measurements, but less useful for clinical diagnosis where differences in interpretation may be large. For example, landmark Zygomatic (Z) had a relatively small intraexaminer error in both the horizontal (0.29) and vertical (0.51) dimensions, but large interexaminer errors in both the horizontal (2.42) and vertical (3.49) dimensions. This particular landmark may be very useful in research but would have limited value as part of a clinical diagnostic analysis.

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. Landmarks with identification errors greater than 1.5 mm should probably be avoided and landmarks with identification error greater than 2.5 mm are inappropriate.

The reliability of landmarks for dried skulls was compared to live patients. In general landmarks are less reliable on patient radiographs where soft tissue reduces hard tissue image sharpness. These differences should be kept in mind when applying data from dry skull studies to clinical settings.

The basis of cephalometrics in orthodontic diagnosis includes the use of standardized and reproducible head position in relation to the x-ray source and film. The cephalostat earrods minimize rotation about the vertical and transverse axis. A third reference may be positioned against the nose to prevent rotation about the anterior posterior axis.[1] Rotations of the head can potentially occur through soft tissue distortion or improper patient positioning. This study did not investigate the effect of head rotation on landmark identification.

Conclusion

The intraexaminer and interexaminer landmark identification errors associated with 52 posterior anterior cephalometric landmarks were presented. The magnitude of landmark identification error had a wide range with the horizontal error often being different from the vertical error. Some landmarks showed significantly different errors when taken from skull radiographs versus patient radiographs. Interexaminer landmark identification errors were generally larger and, in many cases, significantly larger, than intraexaminer errors. Many of the proposed posterior anterior cephalometric analyses use landmarks which have an unacceptable magnitude of landmark identification error.

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