ORIGINAL ARTICLE

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Reliability of cranial base measurements on lateral skull radiographs

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Structured Abstract

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Objective – To explore the reliability of identification of anatomic landmarks on lateral skull radiographs of young unaffected individuals that has conventionally been used to diagnose pathologic relationships in the craniovertebral junction.

Material and Methods – From the Helsinki longitudinal growth study, 20 randomly selected lateral radiographs were analyzed and re-analyzed by two examiners. Both located seven cephalometric landmarks based on which five measurements were calculated. The differences of results were compared. With similar method three radiographs were analysed by 11 examiners and results were compared.

Results – Some anatomic landmarks were easier to locate than others on lateral skull radiographs leading to differences in measurements based on them. We found the magnitude of the difference to be dependent on the landmark serving as reference. Inter- and intra-examiner errors were of similar magnitude, although intra-examiner error declined in the repeated landmark identification. Variation in a single landmark location had in general little effect on the measurement value.

Conclusion – Variations in landmark location lead to differences in numeric evaluation of the anatomic relationships in the skull base area. These differences were, however, shown to have little clinical significance. Hence, the documented methods are applicable for screening of basilar pathology.

Key words: basilar impression; cephalometry; craniovertebral junction; lateral skull radiograph; platybasia; skull base

Introduction

Cephalometric analysis from lateral skull radiographs is one of the major tools in studying morphology and growth of the head and face region. Longitudinal and cross-sectional studies have revealed how infant craniofacial morphology through differential growth proceeds to that of an adult. This baseline knowledge is used in orthodontic diagnosis and treatment planning as well as in analyses of abnormal growth particularly in association with genetic disorders. However, previous cephalometric studies on normal population have largely disregarded the junctional area between skull base and spine, i.e., basilar region. This area is highly significant because in diseases characterized by softness of bone, skull base deformity may result in a compression of the brainstem that is possibly lethal. This condition known as basilar impression, or basilar invagination if the uppermost vertebrae intrude the foramen magnum, has been described for instance in patients with osteogenesis imperfecta and achondroplasia (1–3).

To detect pathology in the basilar region, several measurements from lateral skull radiographs have been introduced (3–6). Although the actual diagnosis is nowadays most accurately carried out from computed tomography (CT) or magnetic resonance imaging (MRI) scans, lateral skull radiographs are still recommended for screening purposes as a simple, inexpensive, and low radiation method for patients at risk (3). Whereas population norms are available for basilar dimensions in non-growing individuals (3), data are lacking on the normal dimensions in this region on young children and on growth-dependent changes in anatomy. Adequate material to assess such data on a non-selected population is available in the form of traditional lateral skull radiographs. In this study our purpose was to test how reliably different examiners can identify cephalometric landmark points based on which the craniovertebral junction dimensions can be measured and to explore whether any of the commonly used measurements is superior to others in terms of inter- and intra-examiner reproducibility.

Materials and methods

Radiographic material

We randomly took 23 lateral skull radiographs from the material of Helsinki longitudinal growth study conducted between 1967 and 1993 at the Institute of Dentistry, University of Helsinki, Finland. The participants, 248 in number, were a non-selected sample of healthy ethnic Finns (Caucasians). They were aged between 4.5 and 24.9 at the time of the radiographs representing a sample of individuals at different growth stages.

Radiographs had been taken using a rigid cephalostat (Wehmer 517; BF Wehmer Co., Lombard, IL, USA) at the Department of Radiology, Institute of Dentistry, with the clinical Frankfurt horizontal plane parallel to the floor and the head position ascertained with ear rods. Central X-ray passed through the porion-porion axis. Magnification of the midsagittal plane was calculated for each image according to the distance of the subject from the film and X-ray tube. The Ethics Board of the Institute of Dentistry, University of Helsinki, had approved the Helsinki longitudinal growth study.

Cephalometric landmarks and measurements

Seven cephalometric landmark points situated at the mid-sagittal plane were identified (Table 1 and Fig. 1). Points nasion, sella, and basion were marked to measure the anterior cranial base angle because 'platybasia' – a flattened anterior skull base – is associated with basilar pathology (3, 4, 7). Other points were marked to measure the vertical distance from the processus odontoideus (dens) to four previously documented reference lines, described in Table 2, because an abnormal relationship would indicate basilar invagi-

Table 1. **Cephalometric landmarks used in this study**

Sella turcica (S)	Midpoint of the pituitary fossa as determined by inspection.
Nasion (N)	Most antero-inferior point on the frontal bone at the nasofrontal suture.
Posterior nasal spine (PNS)	Posterior extremity of the horizontal plate of palatine bone.
Basion (Ba)	Anterior margin of foramen magnum on the occipital bone.
Opisthion (Op)	Posterior margin of foramen magnum.
M point	Most caudal point of the posterior cranial bone.
Dens (D)	Most superior point of odontoid process.

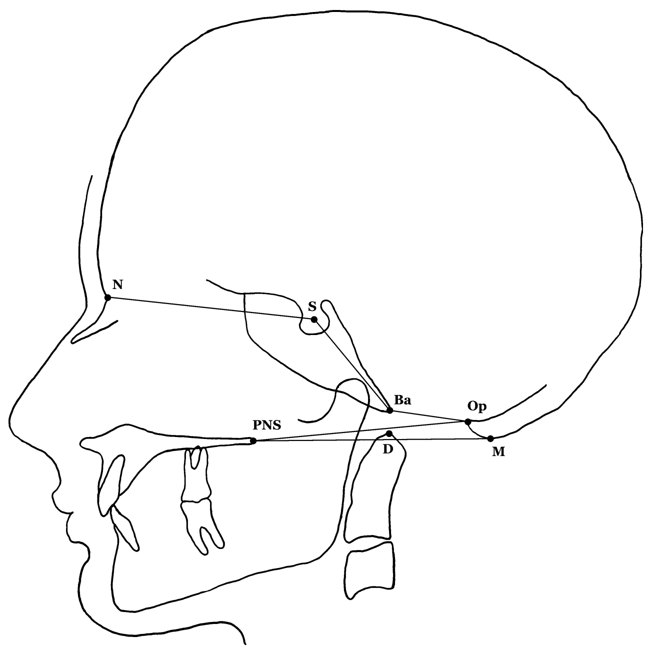

Fig. 1. Landmarks and variables analysed on the lateral radiographs. The description of the landmarks is given in Table 1 and the variables in Table 2.

Table 2. **Cephalometric measurements used in this study**

McRae measure	Perpendicular distance from D to Ba-Op line (foramen magnum line).
Chamberlain measure	Perpendicular distance from D to PNS-Op line.
McGregor measure	Perpendicular distance from D to PNS-M line.
D-M distance	Perpendicular distance from D to a line parallel to nasion-sella line passing through M point.
Anterior cranial base angle	Nasion-sella-basion angle.

PNS, posterior nasal spine; Ba, basion; OP, opisthion; D, dens.

nation or basilar impression (3–6, 8). To test the accuracy of landmark identification, 11 examiners marked the seven selected points independently on the same radiographs. The radiographs were placed on a light box in a dark room and each time covered with a new transparent acetate paper for marking of landmarks with a soft thin pencil. Orientation points to allow later superimposition of the tracings were also marked. Linear distances were measured using a hand ruler with 0.5 mm accuracy and corrected for radiographic magnification. The angular measurement was assessed with 0.5° accuracy. For the statistical analyses SPSS for Windows (version 13; SPSS Inc., Chicago, IL, USA) were used.

Assessment of inter- and intra-examiner variation

To assess the interexaminer variation in localizing the seven landmark points of interest we first conducted an experiment with 11 examiners. Ten first to third year postgraduate students studying orthodontics and dentofacial development as well as their mentor (JWS) at the Institute of Dentistry, University of Helsinki, marked the points on each of three randomly selected original radiographs. All of the students had previous general experience in tracing lateral skull radiographs and were briefly trained prior to the experiment by JWS to identify the landmarks in question.

To illustrate the differences in landmark identification we composed a scattergram with an *x-y* coordinate of the distribution of each point (Figs 2–8). The constructed Frankfurt horizontal plane (7° below the sella-nasion line through point S) served as the horizontal axis. For each point we placed origo at landmark point identified by JWS, which served as a reference to other observations. JWS is experienced in analyzing landmarks in question (3, 9). To further test inter- and intra-examiner variation we then randomly chose 20 cephalograms, which were independently analysed by two examiners, JWS and HA, and the process was repeated by both examiners a minimum of 3 weeks apart.

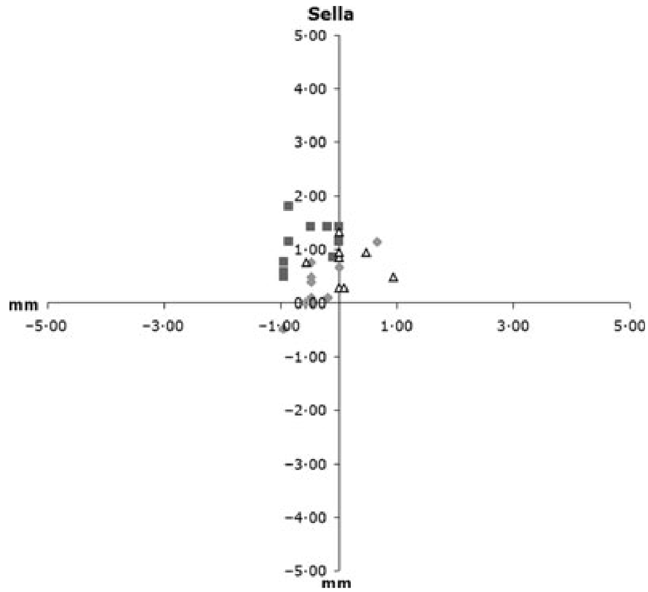

Fig. 2. Distribution of Sella landmarks. Each of the three symbols ◆, ■, and ▲ stands for one subject illustrating the different landmark identification profiles.

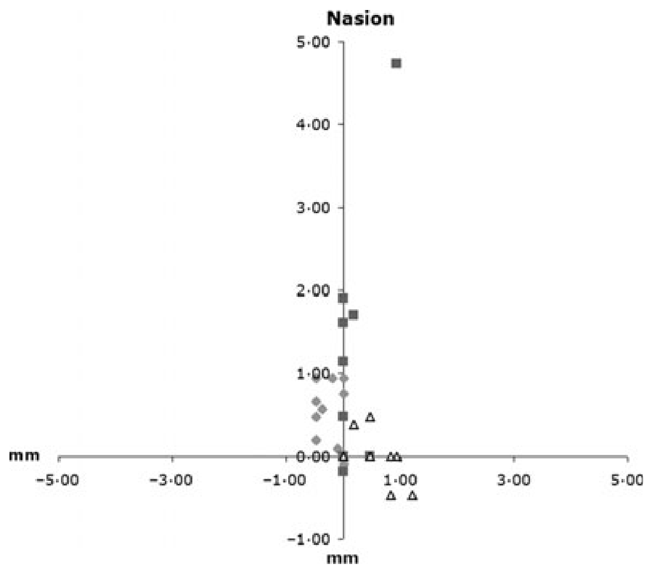

Fig. 3. Distribution of Nasion landmarks.

To evaluate how the differences in landmark identification would have affected the actual diagnostic

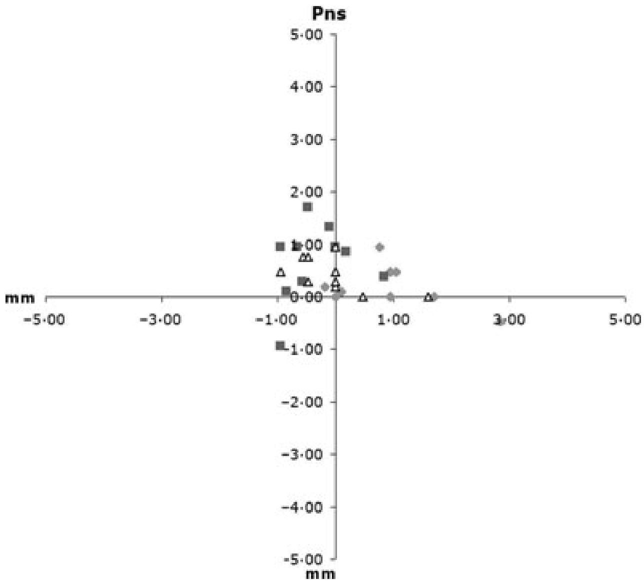

Fig. 4. Distribution of PNS landmarks. PNS, posterior nasal spine.

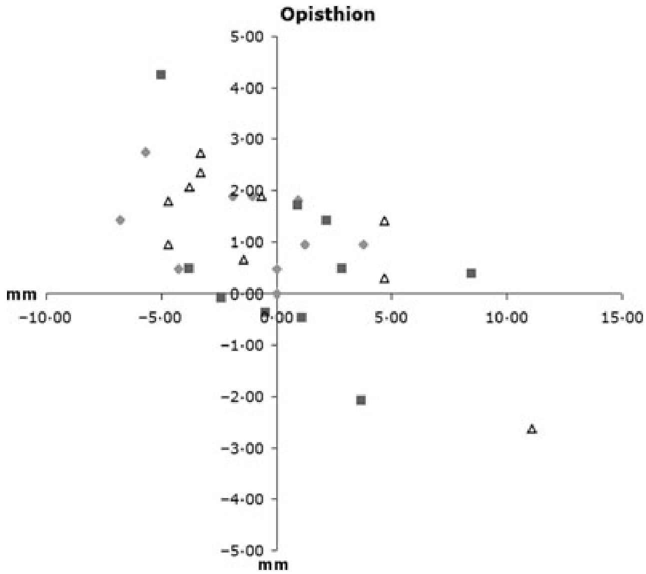

Fig. 6. Distribution of Opisthion landmarks.

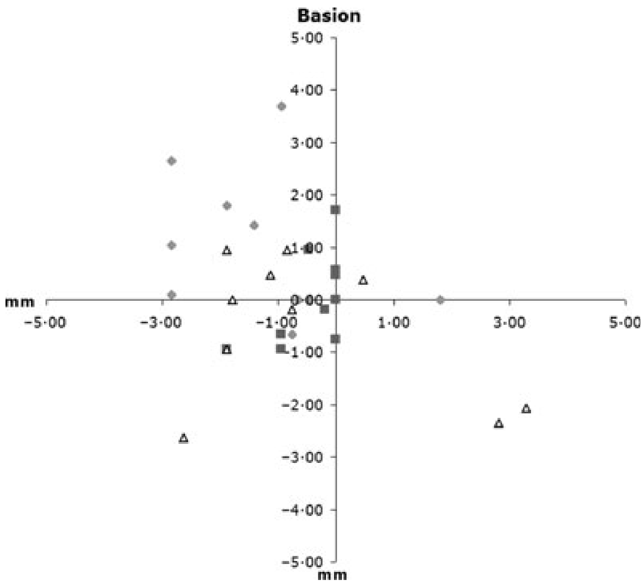

Fig. 5. Distribution on Basion landmarks.

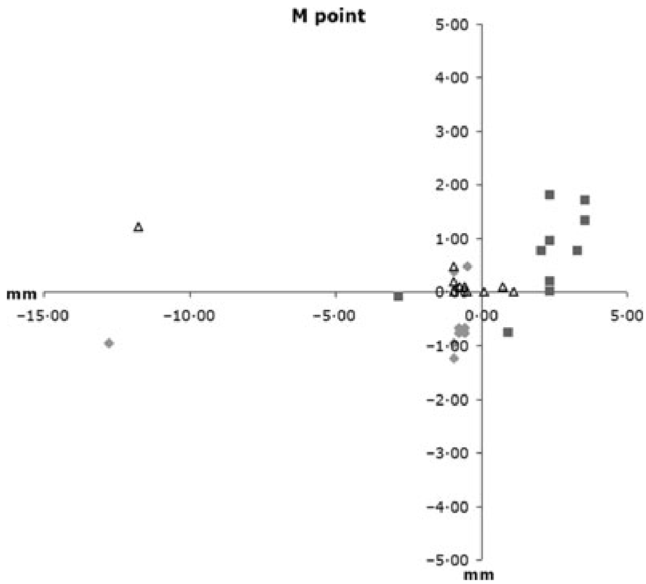

Fig. 7. Distribution of M-point landmarks.

measurements HA performed five measurements on all the tracings. To further test the impact of the difference in the location of a single landmark on the measurements, we constructed an experimental cephalometric model. It was carried out on the cephalometric tracing of a 15-year-old male (illustrated in Fig. 1) with a sella-nasion distance of 75 mm in line with the age mean (10, 11). We analyzed the amount of change in each measurement when the landmarks were positioned one by one 2.0 mm from the original position upwards, downwards, to the left, and to the right along an x-y coordinate, the constructed Frankfurt horizontal serving as x-axis. Linear measurements were carried out using manual sliding caliper to the closest 0.1 mm.

Statistics

For analyses of the results the primary statistical tools were mean, standard deviation (SD), median, and range. Measurement result differences between the radiographs were assessed using Friedman's test. We assessed the inter- and intra-examiner errors between the duplicated measurements using the Dahlberg's formula

$$S_e = \sqrt{\frac{\sum d^2}{2n}}$$

where S_e is the error variance, d is the difference between the two determinations of the same variable, and n is the number of determinations (12). Dahlberg's formula combines systematic and random components of the error, and includes assumption that the two determinations are carried out independently from each other. We tested the correlation between subject's age and magnitude of the random error using Spearman's rank correlation.

Results

Differences in landmark point identification

On each of the three radiographs analyzed by 11 examiners, sella (midpoint of sella turcica) demonstrated the narrowest distribution of the landmark points identified. The markings were scattered in a circular area with a maximum diameter of 1.8 mm (Fig. 2). The distribution of nasion (most anterior point of the frontonasal suture in the median plane) point markings was more vertical, following the outline of frontal and nasal bones. All excluding one marking lay vertically within a distance of 2.1 mm. The maximal horizontal distance between the markings was 1.2 mm (Fig. 3). Posterior nasal spine (PNS) (most posterior point on the hard palate) point distribution was horizontally scattered in an oval form with a distance of 3.0 mm at most between the markings horizontally and 2.6 mm vertically (Fig. 4). Basion (anterior margin of foramen magnum) demonstrated similar marking distribution along the posterior end of clivus, ranging 5.9 mm horizontally and 4.4 mm vertically (Fig. 5). Opisthion (most posterior point of the foramen magnum) had the greatest range of point distribution (15.8 mm horizontally and 6.3 mm vertically) following the anatomic form of posterior occipital bone (Fig. 6). M-point (most caudal point of the posterior occipital bone) distribution dispersed along the caudal occiput with a maximal distance of 12.9 mm between the markings horizontally, and 2.6 mm vertically (Fig. 7). Dens (most superior point of odontoid process) marking distribution ranged 4.3 mm horizontally and 1.4 mm vertically, excluding one radiograph presenting a more complex anatomic view of processus odontoideus that lead to a notable variation in landmark identification vertically (Figs 8 and 9). Anatomic view in this image might suggest presence of os odontoideum, which is an infrequently occurring odontoid abnormality where the tip of dens is incompletely fused with the body of processus odontoideus.

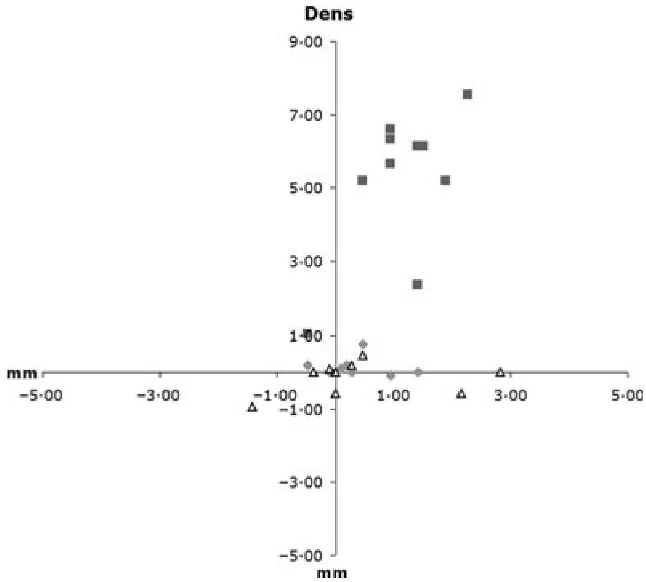

Fig. 8. Distribution of Dens landmarks.

Fig. 9. Radiograph presenting a complex anatomic view of processus odontoideus.

Cephalogram		McRae (mm)	Chamberlain (mm)	McGregor (mm)	D-M distance (mm)	Anterior cranial base angle (°)
1	Mean	−3.2	−0.9	0.7	−1.3	134.5
	SD	2.5	2.1	2.2	2.1	1.4
	Median	−2.4	0.5	1.9	−0.5	135.0
	Range	7.5	6.1	5.7	5.7	5.0
2	Mean	−6.9	−3.5	−1.8	−7.8	134.4
	SD	1.3	0.6	0.5	0.9	0.9
	Median	−6.6	−3.8	−1.9	−7.6	134.5
	Range	4.3	1.9	1.4	3.3	3.5
3	Mean	−6.5	0.3	2.3	−0.7	127.9
	SD	1.1	0.9	0.5	0.7	1.7
	Median	−6.6	0	2.3	−0.5	128.0
	Range	3.3	3.2	1.4	2.3	5.0

Table 3. **Comparison of the measurement result differences (millimeters or degrees) between the 11 examiners on three cephalograms (magnification corrected)**

Differences in cranial base measurements

On each of the 11 individual series of identified landmark points on the three test radiographs, we measured the cranial base angle and the distance of dens from the four reference lines as illustrated in Fig. 1 and described in Table 2. This was carried out to detect interexaminer variation in the actual measurement values. Table 3 summarizes the results. The present study found, that of the linear measurements, McRae measure gave the most unpredictable numeric values (SD on average 1.6 mm). McRae line runs between basion and opisthion points both of which were difficult to determine. All the results were, however, negative, indicating a normal position of the odontoid process below the foramen magnum level, and hence no false positive diagnostic results would have been obtained.

Of the linear measurements McGregor measures showed the smallest interexaminer variation (SD on average 1.1 mm). The points needed for the construction of McGregor line – PNS and M-point – are relatively easy to define vertically as shown by our scattergrams. This leads to vertical stability of the reference line. D-M measure and Chamberlain measure were equally reliable (SDs on average 1.2 mm for each). For the latter, identification of opisthion is needed, whereas construction of the former is complicated by the necessity of identification of four instead of three points. Standard deviation of the anterior cranial base angle was on the average 1.3°.

Landmark identification was not alike on the three test radiographs. This becomes apparent also on the scattergrams (Fig. 2–8), showing that landmark identification was more inaccurate on one of the images than on the other two, and this difference was statistically significant according to Friedman's test.

Sensitivity analyses

As the measurement results described above were all affected by variation in identification of three to four cephalometric points, HA made 480 additional measurements where the position of a single point was changed one by one, keeping the other ones unchanged (in a position assessed by JWS). This corresponds to a clinical situation where a sole analyst is uncertain of the position of a given landmark. We were interested in clarifying which of the measurements would be least sensitive to that uncertainty. We have listed the results of this sensitivity analysis in Table 4. It shows that SD for McRae measure was on the average 1.3 mm, for Chamberlain measure, 1.2 mm, similarly for D-M distance, 1.2 mm, and finally for McGregor measure, 1.0 mm. Thus, based on these results the order of preference of using these linear measurements would be the same as based on the original measurement results.

We also compared the mean results of this sensitivity analysis given in Table 4 to the original measurement values obtained by JWS (not listed). Values of JWS were

Table 4. **Sensitivity analysis results for the five measurements**

Cephalogram		McRae (mm)	Chamberlain (mm)	McGregor (mm)	D-M distance (mm)	Anterior cranial base (°)
1	Mean	−6.1	−3.3	−1.6	4.1	134.5
	SD	2.2	2.3	2.3	2.2	1.4
	Median	−7.1	−4.2	−2.8	5.2	135.0
	Range	7.0	8.0	6.6	7.0	5.5
2	Mean	−6.4	−3.1	−2.0	−7.7	134.0
	SD	0.8	0.5	0.4	2.5	1.5
	Median	−6.1	−2.8	−1.9	−8.0	134.0
	Range	4.3	1.4	1.4	17.5	7.5
3	Mean	−6.9	0.8	2.6	0.2	128.4
	SD	0.8	0.7	0.3	0.3	1.8
	Median	−7.0	0.9	2.8	0	128.8
	Range	4.3	3.7	1.4	1.8	9.5

chosen as a reference because of her previous experience in the field. Notably, the group mean values and JWS's results were all less than one SD apart. This suggests that, on the average, variation in the location of a single landmark affects little, the cranial base measurement values. In addition, we tested on an experimental model of the sensitivity analysis what impact a standardized 2 mm translocation of each reference point would have on the measurement results, to more precisely understand the effect of an error.

We found that the variation in the location of a landmark affects the linear measurement values generally less than the actual shift of 2.0 mm, and 2.0 ± 0.2 mm at most. McRae measure was originally 8.2 mm and after changes in the position of basion, opisthion, and dense points, it ranged from 6.0 to 10.3 mm yielding a maximum change of 2.2 mm. It was least sensitive to displacement of opisthion and most sensitive to vertical changes in positioning of dens. Chamberlain measure, originally 1.9 mm, ranged from 0.0 to 3.8 mm after changes in landmark positioning thus showing a maximum change of 1.9 mm. It was least affected by changes in PNS placement, but reacted equally strongly to inferior movement of opisthion and vertical changes in the position of dens. McGregor measure, originally 2.0 mm, was similarly least affected by PNS position, and alteration in M-point led to a maximum change of 1.3 mm. On the other hand, vertical displacements of dens in either direction lead to 2.0 mm alteration in the measurement. Of the linear measurements D-M was most sensitive to errors in landmark positioning. It was affected by vertical alterations in both nasion and sella but even more by vertical changes in both M and dens points, the difference of results reaching 2.7 mm. The anterior cranial base angle was originally 136° and in the experimental setting it ranged from 132 to 139°. It was least sensitive to horizontal movement of the nasion point and most sensitive to superior movement of sella. This experimental model is dependent of the subject's anatomy, and the results are not generally applicable. However, similar tendencies can be found universally.

Paired measurements

For the sample of 20 radiographs we found that the differences in errors, according to Dahlberg's formula, varied considerably between the five different measurements (McRae, Chamberlain, McGregor, D-M distance, Anterior cranial base angle). Table 5 lists these error values. When comparing the results between the two examiners, Dahlberg's values initially ranged from 0.62 to 2.62. At repeated measurements values ranged between 0.43 and 1.72. This indicates that with increasing experience the interexaminer variation generally diminished. In both series of observations McGregor measure performed best, and in defining the D-M distance there was a notable improvement. The intra-examiner variation profiles of the two examiners

Table 5. **Inter- and intra-examiner variation (Dahlberg's value) between two examiners (HA and JWS) in repeated measurements (t_1 and t_2) on 20 cephalograms**

Dahlberg	t1(HA-JWS)	t2(HA-JWS)	HA(t1-t2)	JWS(t1-t2)
McRae value	1.49	1.72	1.73	1.32
McGregor value	0.64	0.43	0.65	0.43
Chamberlain value	0.62	0.67	0.63	0.68
D-M distance	2.62	0.62	2.71	0.94
Anterior cranial base angle	1.74	1.61	1.18	1.71

were slightly different. In general, the more experienced examiner (JWS) gained more repeatable results. Spearman's rank correlation test results showed no relationship between age of the patient and magnitude of random error.

Discussion

Cranial base measurements in light of the present study

We have evaluated on lateral skull radiographs of young unaffected individuals, the reproducibility of cephalometric analyses that have previously been developed and used to detect pathologic conditions in the craniovertebral junction area. Those can be screened for inpatients with bone dysplasias and known risk for development of skull base anomalies by simple lateral skull radiography (3). Problematic is, however, that such cephalometric analyses have been applied for decades in epidemiologic studies of basilar region pathology without a comprehensive evaluation of the reproducibility of the different measurements.

The errors in cephalometric analysis comprise systematic and random errors; the latter include landmark identification (13). It is demanding to define the limits of acceptable random error within which the results can still be considered clinically reliable. In previous studies only basion and sella points on the x-coordinate and sella on the y-coordinate have been identified within suggested acceptable limits of error (14). Our findings support the previous observation that unambiguous identification of cephalometric landmarks in the basilar region is demanding (14). All the different experimental settings in this study implied that both basion and opisthion points are notably difficult to locate. Point basion affects the assessment of anterior cranial base angle and McRae line, and point opisthion that of the latter as well as Chamberlain line. These difficulties were well recognized by McGregor who already in 1948 introduced his method for detection of basilar impression. The method ignores both these difficult landmark points. The present results repeatedly demonstrate the usefulness of his method as being the most reproducible one of the linear measurements.

The effect of variation in landmark identification on the measurement results differs with each landmark. Our findings agree with those of Baumrind and Frantz (15) in that the distribution of identified landmarks is not random, but rather systematic, following the anatomic form of the structure identified. It should be noted, however, that for some points, such as PNS, its distribution horizontally leaves unaffected, the vertical location of the reference lines it marks, and thus the value of measurements remains unchanged. The experimental model showed that with the point that is most difficult to locate (opisthion in an antero-posterior direction), the effect of variation in landmark identification on the measurement result is relatively small. On the contrary, vertical changes in dens point location, which would strongly affect the linear measurements, are unlikely to occur. Hence our results show that the relationship between difficulties in landmark identification and their relative impact on the measurement results are favorable from a clinical perspective.

To detect basilar invagination, a true intrusion of uppermost vertebrae into the foramen magnum-locating anterior and posterior borders of the foramen is required. As opposed to the screening methods for basilar impression where the actual perpendicular distance of dens from a given reference line is essential, basilar invagination diagnosis simply requires that dens vertically exceeds McRae line. In our study, none of the linear measurements, despite of their interexaminer variation, lead to false-positive results. The same stands true for the measurement of the anterior cranial base angle which when being abnormally large would lead to a 'platybasia' diagnosis.

The radiographs used in this study were randomly chosen and represented average accepted radiographs for clinical use. If the radiographs were specifically chosen by their quality and representativeness, the landmark identification variation might have been smaller. However, selecting representative radiographs would have been misleading, as it would have poorly corresponded to average clinical settings.

Baumrind and Frantz (15) found significant interexaminer errors in cephalometric landmark identification, and as a solution to elimination of error they suggest replicate tracings. Repeated identification of landmarks, however, leaves unresolved the effect of intra-examiner error. Based on our results, for an experienced examiner replicating tracings does not markedly improve the reliability of landmark identification.

Major et al. (16), Williamson et al. (17), and Haynes and Chau (18) studied landmark identification errors associated with commonly used cephalometric landmarks. Our findings differ with theirs in that we found the intra-examiner error to be similar, not smaller than the interexaminer error. Combined with the results of the sensitivity analysis this suggests that noticeable advantage in accuracy of landmark identification could be achieved by having more than one examiner viewing radiographs together. Examining simultaneously several radiographs of the same individual would further improve accuracy in landmark identification.

The estimation of errors conducted in this study is based on simple statistical analysis of landmark positions, and variables calculated according to them. Of the different methods for assessing random error, Dahlberg's estimation has been shown to be mathematically the soundest one (19), although Dahlberg's statistics ignores the proportionate size of the error in relation to measurement value itself. We aimed at reducing the systematic error by similar education for all examiners in locating landmarks and using experienced examiners. The examiners were not calibrated, however, because we wanted the setting to mimic a clinical situation, where a new examiner starts applying the measurements.

General considerations of cranial base measurements from lateral skull radiographs

One source of error is projection, when three-dimensional (3D) structures are interpreted on two-dimensional (2D) images. Moyers and Bookstein (20), Baumrind (15), and Houston (21) have each commented on these projectional errors. Some cephalometric points such as opisthion and basion are projected under other structures and are therefore particularly difficult to locate. A number of studies have evaluated reproducibility of cranial and facial cephalometric landmarks with 2D and 3D images (15, 20–25). Kragskov et al. (26) found no evidence indicating that 3D CT images would be more reliable than traditional radiographs in locating standard cephalometric points. The landmarks used in this study are all located on the midsagittal plane, and thus the method is applicable to CT and MRI images of the same plane.

In comparing the reliability of cephalometric analysis from traditional radiographs and digital images, variation in the landmark identification has been shown to be a more significant factor than method (25). Therefore traditional radiographs can for this study be considered a reliable form of imaging. Turner and Weerakone (23) found direct landmark identification of X-ray images to be more accurate method than scanning images for computer-aided digitization as a scanning process might distort the images adding yet another error source.

Manual and digital measuring has been shown to give similar results, and therefore either method can be used as diagnostic tool with equal reliability and accuracy (24, 27). Manual measurement, as conducted in this study, carries a risk of misreading the measurement device and an error in registering data to a computer. We excluded from this study possible error of results brought on by measurement.

In a lateral radiograph, linear measurements and angles are affected by rotation of the head (28, 29). Our radiographs were taken with a rigid cephalostat with ear rods to minimize head rotation. Extension and flexion of the head, on the other hand, have been shown to leave unaffected the distance of dens point from foramen magnum line (5).

Cephalometric landmark identification is a skill greatly affected by examiner's experience. This becomes particularly evident when anatomic landmark points are to be defined in the demanding skull base area to detect possible pathologic relationship between skull base and spine. Fortunately, the difficulties in landmark identification and the effect of location errors on skull base measurements appear to be largely inversely related. Hence the inter- and intraexaminer variation in landmark identification remain clinically insignificant.

Conclusions

Bearing in mind the most likely sources of errors, the manual cephalometric analysis from traditional lateral skull radiographs, utilizing parameters studied, is an applicable method in evaluating relationships between cranial base structures.

Clinical relevance

Understanding the variation in normal anatomic relationships and the effect of growth in the craniovertebral junction is crucial for diagnosis of pathologic conditions of this area. Of these basilar impression and basilar invagination may emerge in skeletal disorders already in infancy. The analysis of such conditions based on cephalometric radiograph findings relies essentially on the reliability of observations.

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