

# Relationships of Reference Points, Planes and Skull Symmetry on Posterior-anterior Cephalograms in Healthy Young Adults

REINHARD E. FRIEDRICH<sup>1\*</sup>, GEORG CHRIST<sup>1\*</sup>, HANNAH T. SCHEUER<sup>2</sup> and HANNA A. SCHEUER<sup>2,3</sup>

<sup>1</sup>Department of Oral and Craniomaxillofacial Surgery,  
Eppendorf University Hospital, University of Hamburg, Hamburg, Germany;

<sup>2</sup>Private Praxis for Orthodontics, Hamburg-Lokstedt, Hamburg, Germany;

<sup>3</sup>Department of Orthodontics, Eppendorf University Hospital, University of Hamburg, Hamburg, Germany

**Abstract.** *Background: Radiological cephalometry is an important diagnostic tool for analyzing the shape and proportions of the skull. Standardized telerradiography of the skull in posterior-anterior (PA) projection provides orientation data on the symmetry and vertical relations of the skull. The comparison of individual findings with normal values places high demands on the selection of a control group. The aim of this study was to characterize a group to be used as a standard for cephalometric comparisons. Patients and Methods: PA telerradiographs of 23 healthy young adults were analyzed. Distances from reference measuring points to the median sagittal plane and the orbital horizontal plane were made. All individuals showed ideal occlusion. None of the participants had been subjected to orthodontic therapy or craniomaxillofacial surgery. Results: The measurement results showed a high degree of lateral symmetry of the skeletal reference points and planes. Comparison of the vertical reference lines confirmed the symmetrical constitution of the facial skeleton. Conclusion: The study group is suitable for comparison with the cephalometric evaluations of other study groups.*

Skull examinations are an essential part of anthropological studies (1). Standardized radiological skull examination is an

essential tool for determining normal skeletal values and deviations from the norm both in living individuals for diagnostic and treatment purposes and in applied sciences (2, 3). Radiographic cephalometry provides data based on standardized technical conditions and skull reference points (4-7). However, most clinical cephalometric data are based on profile analyses performed on lateral cephalograms (6, 8). Applying standardized examination conditions, posterior-anterior (PA) skull radiography enables further statements to be made about the skull, e.g., the shape as seen from the front, vertical relationships of bone segments, and bone symmetry in relation to the median sagittal plane of the body (9). Every current cephalometric examination compares its results with normative standards (6, 7, 10). However, the examination technique used has a considerable influence on the examination results (7, 11-20). The basis of a meaningful comparison of data is that the defining parameters for the calculation of standard values are appropriately determined and the examined material is selected as representative for the calculation of the standard (21-23). Therefore, as a basis for further symmetry analyses of the skull, a study group is first analyzed, which offers physical prerequisites for standardization of symmetry analyses.

The aim of this study was to establish cephalometric reference values feasible for determining skull symmetry on PA cephalograms.

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\*These Authors contributed equally to this study.

*Correspondence to:* Professor Reinhard E. Friedrich, MD, DMD, Ph.D., FEBOMFS, Department of Oral and Craniomaxillofacial Surgery, Eppendorf University Hospital, University of Hamburg, Martinistr. 22, D-22046 Hamburg, Germany. Tel. +49 741053259, e-mail: rfriedrich@uke.de

**Key Words:** Cephalometry, posteroanterior cephalograms, symmetry, skull, normal values, measurement precision, human.

## Patients and Methods

*Characterization of the study group.* The PA skull radiographs were examined of individuals who had voluntarily undergone cephalography in a previous study (24, 25). The study group consisted of 21 individuals (male: 15, females: 6; mean age=25.9 years, range=18-30 years). We chose this archival group to define potential basic values of cephalometric parameters in a study group of individuals who fulfilled criteria assigning idealized cephalometric relations (2). The suitability of these cephalograms for comparative studies of the skull relationships has already been shown in an earlier study (26). The use of this archive material was

Table I. Reference points of posterior-anterior cephalograms.

Reference point	Abbreviation	Definition
Antegonion, right	AGR	Point located at the greatest concavity of the antegonial notch of the mandible
Antegonion, left	AGL	Point located at the greatest concavity of the antegonial notch of the mandible
Menton	Me	The most caudal point of the bony chin
Juga, right	JR	Point located most medial and cranial at the outside of the maxillary tuberosity/zygomatic buttress on the right side
Juga, left	JL	Point located most medial and cranial at the outside of the maxillary tuberosity/zygomatic buttress on the left side
Mastoid process, right	MaPR	Caudal tip of right mastoid process
Mastoid process, left	MaPL	Caudal tip of left mastoid process
Zygomatic arch, right	ZAR	Point located most lateral on the right zygomatic arch
Zygomatic arch, left	ZAL	Point located most lateral on the left zygomatic arch
Spina nasalis	Sp	Frontal projection of the tip of the anterior nasal spine, located in the middle of the skull, below the nasal concavity
Crista galli	Cg	A cockscomb-like protrusion of the upper edge of the perpendicular plate of the ethmoid bone
Z-point, right	ZR	Point on the inner side (towards the orbital) of the right zygomatico-frontal suture
Z-point, left	ZL	Point on the inner side (towards the orbital) of the left zygomatico-frontal suture
Orbit lateral, right	OrlaR	Point on the right outer lateral bony orbital boundary
Orbit lateral, left	OrlaL	Point on the left outer lateral bony orbital boundary.
Orbit medial, right	OrmeR	Point at the right inner medial bony orbital boundary
Orbit medial, left	OrmeL	Point at the left inner medial bony orbital boundary

based on the following criteria: i) All participants had an ideal occlusion without ever having undergone orthodontic treatment. ii) Individuals with facial skull trauma and developmental disorders that could have had an impact on skull growth were excluded. iii) The dental and orthodontic characteristics of the study group have been analyzed in detail elsewhere (24, 25). iv) There is no medical justification for an X-ray of the skull in young adults without the need for diagnostic tests. The use of a historical group for defining cephalometric standard values was justified by the fact that the X-ray examination of a new reference group of adults would have meant an unacceptable radiation exposure. v) Many cephalometric analyses are intended for supporting orthodontic treatment of children and adolescents. In this age group, variable growth effects can influence the skeletal findings. The examination of skull X-rays of adults is advantageous in determining cephalometric data of the fully developed body.

**Ethics.** All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Data were anonymized prior to analysis, and the investigators studying the radiographs were blinded for diagnosis and the identity of individuals. The investigations of anonymized data were performed in accordance with Hamburgisches Gesundheitsdienstgesetz (Hamburg Healthcare Act). This type of investigation does not require the approval of the local Ethics Committee.

**Measurement. X-Ray technique:** The X-ray examinations were carried out using a Lumex® cephalostat (B. F. Wehmer Co., Inc., Franklin Park, IL, USA, and Siemens, Erlangen, Germany). The object-focus distance of the cephalostat was 3.98 m. The magnification factor of the X-ray examination was 4.7%. The X-ray

voltage was 71.5-73 kV at 56 mAs. Radiological equipment and performance of cephalometries met the required technical standards (27) and have been described in detail elsewhere (26).

**Data registration and measurement:** Anonymized personal data were registered in Ortho Express® (Computerforum, Elmshorn, Germany). All radiographs were scanned and processed in Dental Vision® software (Computerforum). Dental Vision® realizes the processing and analysis of radiographs from different sources. The individually assigned and digitized data are merged into a database which is controlled via a graphical user interface. A distinctive feature of radiographs prepared for registration in Dental Vision® is the attachment of a transparent foil measuring 5x5 cm<sup>2</sup> onto the radiograph. The foil is imprinted with a metric scale allowing the calibration of the length measurement on the scanned radiographs. Angles are recorded in degrees. The software was modified for the requirements of this study by means of special programming. The process of digitizing the X-ray images and the digital measurement and evaluation of the data have been described in detail elsewhere (26).

**Definition of landmarks:** Definition of cephalometric landmarks and principles of analysis are detailed elsewhere (28). All lines and angles were defined by reference points. Line segments were designated by the acronyms of their anatomically defined endpoints. Angles were defined and designated by the constitutive line segments as shown in Table I and Figures 1-3.

**Determination of the main planes (Z-plane, M-plane):** In this investigation, the median sagittal reference plane (M-plane) of the skull was constructed as being perpendicular to the center of an anthropological horizontal plane defined by orbital wall reference points that can be reliably found on PA cephalograms. Both radiological reference points (Z-points) were defined as the

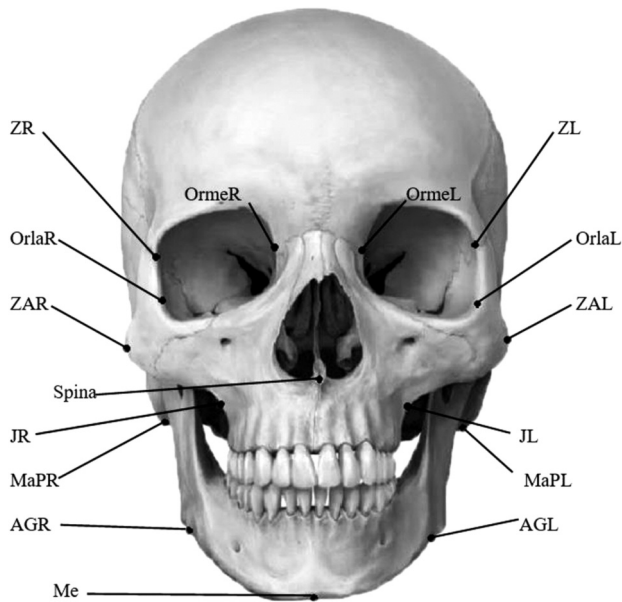


Figure 1. Reference points of the skull on posterior-anterior radiograph illustrated on a skull model, view en face. The drawing addresses the measurement points on the three-dimensionally displayed skull surface, which are identified on the two-dimensional summation x-ray image. Measurement point 'Crista galli' is defined as an intracranial measurement point and, therefore, is not assigned. AGR: Antegonion right; AGL: antegonion left; Me: menton; JR: juga point on the right; JL: juga point on the left; MaPR: caudal tip of right mastoid process; MaPL: caudal tip of left mastoid process; ZAR: zygomatic arch, most lateral point on the right; ZAL: zygomatic arch, most lateral point on the left; Spina: anterior nasal spine; ZR: Z-point right; ZL: Z-point left; OrlaR: most lateral point orbit on the right; OrlaL: most lateral point of the orbit on the left; OrmeR: most medial point orbit on the right; OrmeL: most medial point orbit on the left. Skull graphic from karlwesker.de, with the permission of the manufacturer to GC.

medial demarcation of the orbital margin in the zygomaticofrontal suture on each side (ZR and ZL). The connection of the reference points defines with empirical accuracy a plane parallel to the horizontal plane and is termed the Z-plane. The median sagittal plane was defined by a line starting from the point 'center of crista galli' and intersecting rectangularly with the Z-plane. Distances to the median sagittal plane of skeletal reference points were measured as distances that met the line from these points at right angles.

**Further planes:** Lines between the bilateral measuring points defined horizontal skull planes on the PA-cephalogram (Figures 2 and 3). The distances defined by bilateral points were calculated by adding the two distances to the M-plane. Deviations of the measuring points in the vertical dimension defined lines that cross the extended Z-plane on one side of the body at an acute angle. The smaller this angle, the better the parallel alignment of the planes relative to the Z-plane in *norma frontalis*. The angle between the Z-plane and the extended connecting lines of bilateral measuring points was evenly distributed on both sides of the body.

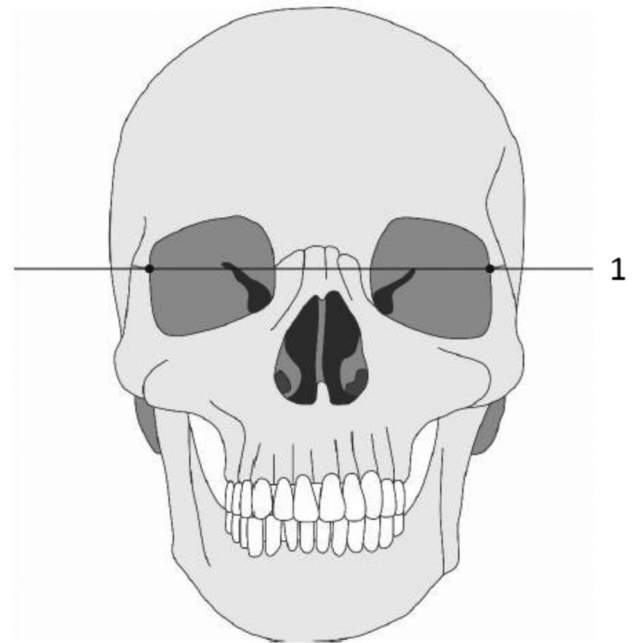


Figure 2. Illustration of Z-plane on skull model, view en face. Inner margin of right and left frontozygomatic suture define reference points (ZR, ZL). The connection of both points constitutes a plane (marked 1) crossing both orbits horizontally.

**Orbit:** The ratio of the distance between the two inner orbit limits (OrmeR-OrmeL) and the maximum orbit width (OrlaR-OrlaL) was determined. The mean value was calculated as a percentage.

**Statistical analysis.** The arithmetic mean and standard deviation are reported; statistical tests used were paired and unpaired *t*-test. The significance level was set at  $p < 0.05$ . All calculations were carried out with SPSS™ (Statistical Package for the Social Sciences, IBM Corp., Armonk, VA, USA).

## Results

**Error analysis of the measurements.** The calculation of errors in the determination of the measured values was carried out according to Dahlberg (29) and Houston (30). Reliability coefficients greater than 0.9 indicate a high level of reproducibility of the compared measuring points of an examination (30). The error analyses of the cephalometric measurements prove the precision of the measurements both in the inter-individual as well as in the intra-individual comparison of the measured values (Tables II, III and IV).

The distances between the symmetrically defined bilateral measuring points and the constructed interorbital reference plane (Z-plane) are almost identical, so no statistically significant differences in these relationships can be demonstrated: The Z-plane is suitable as a reference plane in analyzing symmetry of skeletal landmarks in a vertical

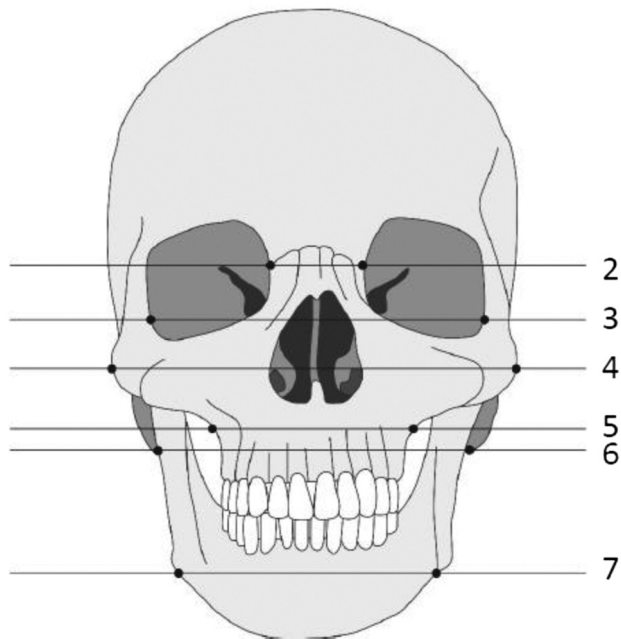


Figure 3. Illustration of horizontal lines crossing the face and defining horizontal lines of the skull on posterior-anterior radiographs. In addition to Z-plane (line no. 1 in Figure 2), the reference points identify the following lines: 2: Interorbital distance (OrmeR-OrmeL); 3: Maximum (horizontal) width of orbits (OrlaR-OrlaL); 4: Zygomatic arch to zygomatic arch distance, i.e., midfacial width (ZAR-ZAL); 5: Juga to juga distance, i.e., maxillary width (JR-JL); 6: Mastoid to mastoid distance, i.e., basal skull base width (MaPR-MaPL); 7: Antegonion to antegonion distance (AGR-AGL). The extensions of the lines beyond the defined points are lines which, if they are not parallel to the Z-plane, create an acute angle with the Z-plane. Some relevant angles of these lines with the Z-plane are listed in Table VI. Very small angles indicate a largely parallel alignment of the measuring points to the reference plane.

relationship. The test results also show that bilateral measuring points did significantly differ in the distances relative to the M-plane (intra-individual comparisons). The absolute values of sections to Z- and M-plane show differences in size between men and women, confirming the well-known sexual dimorphism of skull anthropometry ( $p < 0.05$ ).

**General symmetry.** Symmetry of the defined reference points to the median sagittal plane is evident. The presentation of results is limited to reference points and lines mainly used in PA cephalometric analysis (8). Table V provides an overview of the most relevant findings.

**Anterior nasal spine and menton.** Of particular interest was the analysis of the position of singular measuring points of the midface (*spina nasalis anterior*) and chin (*menton*) in relation to the M-plane. Both measurement points deviate slightly from the median sagittal plane. The quantified

Table II. Analysis of cephalometric measurement errors (angles): Measurement of distances to the Z-Plane. For abbreviations see Table I.

Comparison	Angle	Dahlberg error	Reliability coefficient (Houston, %)
Intraindividual	ZAR-ZAL to Z-plane	0.011	99.9
	JR-JL to Z-plane	0.052	99.7
	ABR-AGL to Z-plane	0.112	99.9
Interindividual	ZAR-ZAL to Z-plane	0.016	99.9
	JR-JL to Z-plane	0.024	99.9
	ABR-AGL to Z-plane	0.056	99.6

Table III. Analysis of cephalometric measurement errors (Lines): Measurement of distances to the Z-plane. For abbreviations see Table I.

	Distance	Dahlberg error	Reliability coefficient (Houston, %)
Intraindividual	ME-Z	0.142	97.8
	SP-Z	0.057	99.5
	AGR-Z	0.154	97.2
	AGL-Z	0.093	98.8
	JR-Z	0.064	99.4
	JL-Z	0.053	99.7
	MaPR-Z	0.046	99.8
	MaPL-Z	0.062	99.7
	ZAR-Z	0.460	99.8
	ZAL-Z	0.545	97.1
	OrlaR-Z	0.028	99.9
	OrlaL-Z	0.032	99.7
	OrmeR-Z	0.075	99.5
	OrmeL-Z	0.051	99.7
Interindividual	ME-Z	0.247	95.0
	SP-Z	0.055	99.8
	AGR-Z	0.013	98.7
	AGL-Z	0.069	99.7
	JR-Z	0.306	89.0
	JL-Z	0.285	92.4
	MaPR-Z	0.024	99.9
	MaPL-Z	0.058	99.8
	ZAR-Z	0.261	95.5
	ZAL-Z	0.202	95.7
	OrlaR-Z	0.022	99.9
	OrlaL-Z	0.113	99.2
	OrmeR-Z	0.014	99.8
	OrmeL-Z	0.026	99.9

deviations were small. The deviations were found to be numerically larger for the point 'menton' than for the 'spina' (nasal spine: mean $\pm$ SD=0.488 $\pm$ 0.70 mm, range=0.0-1.6 mm; menton: mean $\pm$ SD=2.07 $\pm$ 1.93 mm, range=0.30-6.30 mm).

**Orbit.** The mean $\pm$ SD value of the inner orbit distance for the entire group was 30.04 $\pm$ 2.32 mm (range=26.52-34.27). The



Table IV. Analysis of cephalometric measurement errors (Lines): Measurement of distances to the M-plane. For abbreviations see Table I.

	Distance	Dahlberg error	Reliability coefficient (Houston, %)
Intraindividual	ME-M	0.108	97.2
	Sp-M	0.007	99.9
	AGR-M	0.038	99.8
	AGL-M	0.089	99.3
	JR-M	0.002	99.8
	JL-M	0.107	98.3
	MaPR-M	0.198	98.5
	MaPL-M	0.165	98.2
	ZAR-M	0.068	99.3
	ZAL-M	0.106	99.1
	OrlaR-M	0.148	95.1
	OrlaL-M	0.150	96.8
	OrmeR-M	0.221	93.5
	OrmeL-M	0.082	97.8
Interindividual	ME-M	0.070	99.6
	Sp-M	0.042	99.5
	AGR-M	0.181	98.4
	AGL-M	0.360	93.3
	JR-M	0.217	96.6
	JL-M	0.030	99.8
	MaPR-M	0.339	95.1
	MaPL-M	0.270	94.4
	ZAR-M	0.139	97.5
	ZAL-M	0.222	94.5
	OrlaR-M	0.153	99.1
	OrlaL-M	0.246	90.0
	OrmeR-M	0.104	97.8
	OrmeL-M	0.147	94.5

distance was  $30.25 \pm 2.43$  mm for men and  $29.52 \pm 2.13$  for women ( $p=0.53$ ). The mean value of the outer orbital distance for the entire group was  $106.98 \pm 5.17$  mm (range= $95.60$ - $118.96$ ; male vs. female  $p=0.258$ ). The ratio of the medial orbital distance to the lateral orbital distance was 27%.

**Angles.** The line between two bilateral points defines a horizontal plane, which ideally runs parallel to the Z-plane (Figures 1-3). However, these planes are not completely parallel to the Z-plane. The angles of the reference planes (ZAR-ZAL, JR-JL, AGR-AGL) to the Z-plane are extremely acute and confirm the formation of a symmetrical facial skull considering the limitations of biological precision and technical limitations in radiography. The angle of three measured reference planes to the Z-plane was shown to increase slightly in the cranio-caudal direction (Table VI).

Comparison with data from the literature shows that radiological measurements are in the range of known anthropological data. On average, presented values are slightly higher. However, correction factors were considered

in the calculation in individual studies, which explain the differences in the results (Table VII).

## Discussion

This study provides normal values for measurements of reference points relative to the midsagittal plane on standardized PA skull X-rays. The comparison of bilateral distances did not achieve any statistical significance. The very small differences of measurement values are assessed as physiological variations (3) and do not influence the skeletal basis of perceiving a symmetrical face. Limitations of the technical equipment and application are to be assumed as further factors of the small differences in the measured values. Absolute differences in the measured values indicate the sexual dimorphism of skull formation. The results of measurements appear suitable to serve as a reference for cephalometric data from other test groups that have been generated with the same radiographic technique.

**Selection criteria of the reference group.** This research was conducted to generate normal measurement values on cephalograms that can be used to study skull symmetry in clinical practice. For this reason, X-rays were used from individuals who, thanks to a careful medical history, to the best of our knowledge had no known developmental disorders with an influence on skull growth (31). Influences such as head trauma or surgical intervention in the head and neck area were also excluded. An important inclusion criterion was the ideal occlusion of the permanent teeth, as well as the exclusion of orthodontic measures, and a complete set of teeth including the second molars. These dental criteria should ensure that no constitutive dental asymmetries influenced skull reference points that are assigned to the jaws (juga and antegonion).

Investigations of this kind present problems in accumulation of a suitable sample size (12). Many examinations are based on historical anthropological material or evaluate X-ray images that were made during orthodontic treatment. Performing cephalometric studies on living individuals that are healthy and show ideal occlusion, without any diagnostic prerequisite for radiological investigation, do not meet current ethical standards. Therefore, clinical data on healthy volunteers are rare and, in the few cases where such collections are available, usually numerically small. The change in the proportions of the skull during the growth phase must be considered (10, 32-34). Cephalometric analyses of fully grown individuals suggest that physiological bone remodeling has no significant influence on measurement results. An influencing factor not to be neglected for further application of cephalometric data is constant examination conditions for the comparability of the measured values (12, 35).

Table V. Side comparison of some reference group's cephalometric reference points (paired t-tests).

	Measurement	No. of individuals	Side	Mean±SD, mm	Difference of means, mm	Min, mm	Max, mm	p-Value
Zygomatic arch	To Z-plane	21	Both	28.37±3.65	-	22.62	35.95	-
		21	Left	28.62±4.08	0.682	22.97	37.74	0.395
			Right	28.13±3.66		20.66	34.16	
	To M-plane	21	Both	68.37±2.35	-	63.73	72.02	-
		21	Left	68.02±2.52	-0.721	57.84	72.19	0.396
			Right	68.74±3.46		63.24	74.83	
Mastoid process	Distance between measurement points	21	Total	136.77±4.73	-	127.44	144.16	-
	To Z-plane	21	Both	52.53±7.01	-	40.98	68.16	-
		21	Left	52.90±7.33	0.636	40.56	69.41	0.278
			Right	52.17±7.10		41.39	66.91	
Juga	To M-plane	21	Both	56.89±2.67	-	52.96	61.96	-
		21	Left	56.23±3.29	-1.32	50.08	63.38	0.293
			Right	57.56±4.40		51.85	66.81	
	Distance between measurement points	21	Total	111.35±5.24	-	103.77	121.85	-
Antegonion	To Z-plane	21	Both	57.09±3.61	-	50.70	63.31	-
		21	Left	57.14±3.93	0.95	50.08	64.17	0.764
			Right	57.04±3.42		51.17	62.44	
	To M-plane	21	Both	34.75±1.54	-	32.34	38.16	-
		21	Left	34.37±1.87	0.777	31.20	37.53	0.104
			Right	35.15±1.75		31.92	39.14	
Antegonion	Distance between measurement points	21	Total	69.54±3.08	-	64.67	76.35	-
	To Z-plane	21	Both	98.39±5.75	-	85.03	107.25	-
		21	Left	98.31±6.19	-0.167	84.20	107.00	0.749
			Right	98.47±5.55		85.81	107.54	
Antegonion	To M-plane	21	Both	46.02±2.94	-	42.11	53.93	-
		21	Left	46.00±4.11	-0.049	37.68	57.19	0.960
			Right	46.05±3.20		41.94	53.96	
	Distance between measurement points	21	Total	92.08±5.86	-	84.23	107.87	-

**Symmetry.** Absolute bilateral symmetry of the facial skull should be viewed as an ideal which, in a mathematical sense, is not adequately achieved in individuals (12, 36). In fact, skull asymmetries can be detected even in embryos and newborns (37). The skeleton plays an important part in the assessment of a symmetrical face. However, soft-tissue asymmetries can overlie an almost ideal skeletal symmetry and, conversely, existing skeletal asymmetries can be compensated for by the soft tissues (15). Definitions of facial asymmetry are variable. Some define asymmetry as any statistical deviation of the side difference from zero (11, 38), others identify asymmetries of the readings of a study population within statistically defined ranges (12, 32). Likewise, specifying the limit of perceptible facial symmetry as any difference with values greater than 2 mm in the sides of identical, bilateral measuring points (39) cannot be taken as an absolute value because the size of the skull is not considered (22, 37). Definitions of facial asymmetry are thus arbitrary (37). Some authors assume that mean lateral differences of 1-2 mm may not influence clinical

Table VI. Angle of three planes of the facial skeleton relative to the horizontal plane (Z-plane). Each angle is defined by intersection of the respective plane and the Z-plane.

Angle	Number	Mean±SD, ° error	Min, ° coefficient (Houston, %)	Max, °
Zygomatic arch-plane and Z-plane	21	0.85±0.59	0.01	2.17
Juga-plane and Z-plane	21	0.88±0.71	0.06	2.48
Antegonion-plane and Z-plane	21	1.09±0.93	0.14	3.55

decision-making (40). Changes in the position of individual compartments of the face seem to be more important for the visual assessment of asymmetry than others (15).

Table VII. Overview of selected study reports presenting cephalometric measurement values.

Authors/Year (Reference)	Country	No.	Age, years	Measurement (mean±SD), mm			Remarks
				AGL-AGR	JL-JR	ZAL-ZAR	
Cortella <i>et al.</i> , 1997 (23)	USA	22	18	79.1±4.1	59.1±2.7	-	Values corrected for radiographic enlargement
Al-Azemi <i>et al.</i> , 2012 (22)	Kuwait	159	13-14	82.4±5.39	62.7±4.88	125.8±7.43	Values corrected for radiographic enlargement
Athanasiou <i>et al.</i> , 1992 (33)	Austria	588	6-15	82.8±5.1	61.8±3.49	-	
Uysal and Sari, 2005 (21)	Turkey	46	Adult	90.2±7.36	61.3±4.85	128.4±7.25	
Hesby <i>et al.</i> , 2006 (34)	USA	36	26.4	83.04±4.42	61.57±3.92	-	
This study	Germany	21	18-30	92.08±5.86	69.54±3.08	136.77±4.73	

The determination of 'invariable' reference points has played a major role in the controversy about evidence for and the extent of asymmetry of the facial skull and the assessment of whether cephalometry is a suitable tool for examining skull symmetry (41, 42). In the quality assessment of skull examination, the competence of the examiner in determining the reference points is important. Repeating the measurement leads to more precise determinations of the measuring points. The agreement of the measured values is generally higher in the intra-individual than in the inter-individual comparison (31). Changing the examination equipment requires corresponding calibrations of landmarks (43). Some authors have rated the two-dimensional representation of the skull as a technique that is based on an impermissible reduction in the representation of skeletal relationships and therefore judged the findings derived from it to be of very limited use. It was claimed the deficiencies of two-dimensional skull measurements can be rectified by three-dimensional visualization of the skull and measurements on reconstructed bone surfaces. However, three-dimensional cephalometry also makes demands on the definition of landmarks and the reproducibility of the measured value (16-18, 44). Comparisons between two-dimensional and three-dimensional cephalometry [cone beam computed tomography (CBCT)] relate predominantly to data generated by plain radiographs in lateral projection (18). A recent review on studies evaluating the accuracy of measuring symmetry of bilateral bone landmarks using CBCT and PA cephalometry showed there to be no differences between the two examination techniques (20).

*Reliability of the cephalometric median sagittal plane to determine left/right skull symmetry.* Cephalometry is an established and valued tool in skull analysis used for almost 100 years (1-5). The discussion about the methodological limits of the radiological procedure has been going on for almost as long (1-5, 16-18, 20, 45). However, the discussion

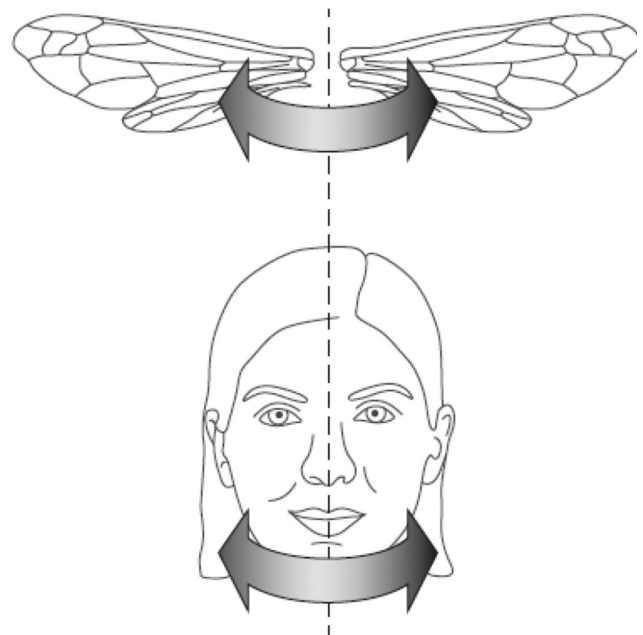


Figure 4. Bilaterians have an axis of symmetry to which individual limbs are arranged in mirror symmetry (top figure). In the case of object symmetry (lower figure), the plane of symmetry is part of the mirrored object. In this geometric constellation, the skull is like a unit within which a plane of symmetry is defined. However, defined bilateral parts of the skull having no intersection with the symmetry axis can be interpreted as mirror images of each other, for example the pinna or orbit. Illustration from Klingenberg *et al.* (44), slightly modified.

about potential individual and systematic errors in radiography of skulls does not contradict the successful clinical application of the technology in orthodontic planning and monitoring the treatment of dental, dentoalveolar and skeletal deformities (6, 7). Defining reference points of a skull radiograph is of particular importance for measurement accuracy. The determination of the reference plane is of

fundamental importance for the measurement process (6, 7). The assumption of object symmetry applies to skull measurement, *i.e.* the mirror image-like organization of the skull is oriented towards a fictitious plane that lies within the object and must be constructed (46). This reference plane is usually referred to as the median sagittal on the *en face* skull view (Figure 4). Single measuring points in the median region of the body are used to define the median sagittal plane. Asymmetry is rated by quantifying differences between bilateral measurement points from the constructed plane. If this reference plane is the yardstick for assessing symmetry, the optimized approximation of the defining measuring points of the median sagittal plane to the true center of the skull becomes the essential step in determining the validity of the measured values. Several studies have shown that the farther chosen center points deviate from the ideal of the median sagittal plane, the farther caudally these points were chosen. Therefore, numerous authors have advocated measurement points that can be identified in the upper third of the skull (12, 14). The radiographic measurement point '*crista galli*' is of particular importance as a central/median reference point (10, 13, 14). To obtain a valid second measuring point on PA radiographs that defines a median vertical line, the right-angled intersection of the connection between *crista galli* and the Z-plane was chosen in this study. The Z-plane (OrlaR-OrlaL) is a reliable horizontal plane of the skull X-ray in PA projection (6, 7). This cranial line is generally recognized to constitute an intrinsic reference line for which distances and angles can be measured with a precision sufficient for biological systems. The median sagittal plane (M-plane) is defined as a midline perpendicular to the orbital plane (Z-plane) running through its rectangular intersection with Z-plane and *crista galli*. The M-plane can reliably determine asymmetries of more caudal sections of the skull (5, 6). In addition, a symmetry plane of the skull base is far better suited to detecting asymmetries of the facial skull than those that are defined within the midface because skull symmetry decreases in the cranio-caudal direction (5, 6).

The test results presented here show that the unilateral skeletal point below the nose [anterior nasal spine (ANS), synonym: *spina*] is by no means stable in the center line but rather deviates from it measurably. Deviations of ANS from the median sagittal plane are relevant for determining maxillary developmental disorders, *e.g.*, patients with cleft lip and palate.

With the development of cross-sectional radiological examination techniques, namely CT and CBCT, cephalometric analyses based on the three-dimensional representation of the skull have become possible (43). However, these examination techniques are associated with a higher level of radiation exposure and their application so far has been reserved for specific diagnostics and scientific

questions. Furthermore, even in three-dimensional cephalometry, the accuracy of the reproduction of a measuring point remains a quality in need of improvement (47), including the definition of a median sagittal plane to determine skull symmetry (16, 48).

**Positioning errors.** The construction of vertical lines on PA cephalograms is influenced by positioning errors (49). However, in earlier studies it was shown that most vertical lines accurately represent quantitative values for determining true transverse symmetry. Only the connecting lines *crista galli*–ANS and nasion–ANS were unsuitable for assessing facial asymmetry (49). In this study, the variability of ANS in relation to the median sagittal was considered and, therefore, was not used as a measuring point to define a reference plane but rather as a variable in relation to the constructed median sagittal (*vide supra*). However, these distances were very small in the reference group. The influence of the skull symmetry on PA radiographs through positioning errors of the skull is apparently less with horizontal incorrect posture. There was an excellent agreement between true asymmetries and measured vertical asymmetries for all horizontal lines (49).

**Analysis of measurement errors.** All quantitative measurements are based on the application of instrumental technology and are therefore defined by the respective technology. An examination technique is used for as long as it meets the requirements. There is a high level of problem awareness of the artificial representation of anatomical conditions on cephalograms and influencing factors of incorrect measurements (41, 42, 45, 50).

A recently published study on identification of landmark errors in two-dimensional cephalometry describes high rates of agreement between measured values in an intra- and inter-observer comparison. Larger differences were only found for the definition of the *crista galli* measuring point, especially in the rate of the inter-examiner agreement. These differences were assessed to be insignificant if the measuring point is used for transverse analyses because the standard deviation of the measuring point determination was small in the X-axis (31). The *crista galli* reference point was used in the present study to determine the mid-sagittal line. The reproducibility of the location accuracy of the measuring point was very high.

**Comparison of radiographs and photography.** The symmetry of the face is assessed visually by the observer, *i.e.*, the surface of the face is assessed and not the skeleton. However, the skeleton determines the orientation of the soft tissue. On the other hand, asymmetries can occur both in the soft tissue and in the skeleton. Only the combination of the two components creates the respective face and any



deviations from the estimated symmetry (38). Analog measuring points are used in anthropological studies that are based on the physical examination of the subject. Direct measurements on the face or on photographs of faces use the point ‘subnasale’ to determine the midline. However, it has been shown that this measuring point can deviate considerably from the median sagittal. A current application of photographic analysis of faces to define symmetry is a recent study (19) aligning the midline at the point subnasale and the center between the eyes and eyebrows. The study was based on measurements and recommendations published by Grimmons and Kappeyne (9). The investigation confirmed the laterality of the face with a statistically non-significant dominance of the right side. Interestingly, parallel to the photographic documentation, the investigators made PA-cephalograms of the same individuals and checked these X-ray images for deviations in the symmetry of the facial skull. The center line was determined as the line from the center of the Z-plane through the ANS. The laterality of the face was the same in both examination techniques. However, it is very likely that a fixed point that is variable in relation to the base of the skull, such as the ANS, influences the determination of facial symmetry (38). In fact, the position of the nose plays a crucial role in three-dimensional perception of facial asymmetry (15). Interestingly, in this study, symmetry assessments agreed based on the soft tissue and bone measurement point. However, the question remains unanswered as to whether the caudal skeletal measuring point specifies a deviation from the median center line. The asymmetry inherent in the measurement process potentially increases the farther inferiorly the landmark which is used to construct the mid-line perpendicular to the horizontal plane is placed. In this way, significant lateral deviations of the skeleton can also be caused by the definition of the (most caudal) reference plane, *e.g.*, *menton* (51).

*Evaluation of some individual reference points as indicators of skull symmetry.* *Zygoma*: Current research shows a remarkable degree of skeletal symmetry for the three-dimensional configuration of the zygomatic bone on CBCT images. The measured deviations of individually mirrored zygomatic bones are on average 0.9 mm [CBCT, (52)] or even less [CT, (53)]. These deviations are considered acceptable, for example, for the design of orbital/zygomatic bone substitutes (52). The results confirm earlier assessments of craniofacial asymmetry using plain radiography and CBCT on skulls of anthropological collections. Other authors detected numerous asymmetries with quantitatively very low values and judged these deviations to be clinically insignificant (47). The comparison of our own study results with published data shows that a carefully defined control group provides the basis for further cephalometric studies applying this examination technique (Table VII).

*Juga*: The juga measuring point can be determined very easily and reproducibly and its identification is obviously largely independent of radiological technology (40). Analyzing J-J distance as a skull landmark, two studies revealed no statistical differences between PA radiography and three-dimensional skull radiography (CBCT vs. PA cephalometry) (20). In the study of Kilic *et al.* (54), facial symmetry of the control group was also demonstrated for the measurement point ‘jugular process’.

*Antegonial notch*: The side comparison of the antegonion measuring points on PA cephalograms are suitable for revealing surgically relevant asymmetries of the mandible, *e.g.*, occurring in some patients with class III malocclusion (54, 55). Interestingly, the distances of antegonion to the median sagittal plane did not statistically significantly differ from the control group of that study (54).

## Conclusion

Radiographic cephalometry of the skull in posterior-anterior projection is a diagnostic standard in many human sciences. The establishment of standards is defined by the respective instrument and research material. The cephalometric results of the study group are suitable for comparisons in further studies.

## Conflicts of Interest

All Authors state that there are no conflicts of interest regarding the publication of this study.

## Authors’ Contributions

REF and HAS conceptualized the study. GC, REF, HTS and HAS analyzed the radiographs. All Authors contributed to the article and approved the article in its final version for publication.

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