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COMPARISON OF AGE-RELATED CHARACTERISTICS OF CEPHALOMETRIC INDICATORS: FRONTAL CHORD (N–B) AND PARIETAL CHORD (B–L) IN ARTIFICIALLY DEFORMED AND NORMAL SKULLS

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This study aimed to compare the age-related characteristics of two cephalometric indicators – frontal chord (n–b) and parietal chord (b–l) – in artificially deformed and normal human skulls. A total of 254 skulls (200 non-deformed and 54 with artificial cranial deformation) from the craniological collection of Azerbaijan Medical University were analyzed. Measurements of the n–b and b–l chords were performed using digital and sliding calipers. Across all age intervals, skulls with artificial deformation showed consistently higher average values for both cephalometric parameters: in the second adulthood group, the mean frontal chord in deformed skulls was 112.3 mm, compared with 108.6 mm in non-deformed skulls. Similarly, the mean parietal chord in deformed skulls was 110.1 mm compared to 108.2 mm in the non-deformed group. This trend was evident across all age categories, with particularly strong differences observed in the elderly group.

Key words: cephalometry, cranial deformation, frontal chord, parietal chord, skull morphology, age-related changes, anthropometry, craniology.

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ПОРІВНЯННЯ ВІКОВИХ ОСОБЛИВОСТЕЙ ЦЕФАЛОМЕТРИЧНИХ ПОКАЗНИКІВ: ЛОБНОЇ ХОРДИ (N-B) І ТІМ'ЯНОЇ ХОРДИ (B-L) ПРИ ШТУЧНО ДЕФОРМОВАНИХ І НОРМАЛЬНИХ ЧЕРЕПАХ

Метою даного дослідження було порівняти вікові характеристики двох цефалометричних показників – лобової хорди (n–b) і тім'яної хорди (b–l) – у штучно деформованих і нормальних черепах людини. Всього було проаналізовано 254 черепи (200 недеформованих і 54 зі штучною деформацією черепа) з краніологічної колекції Азербайджанського Медичного Університету. Вимірювання хорд n–b і b–l проводилися за допомогою цифрового і розсувного штангенциркуля. У всіх вікових інтервалах черепи зі штучною деформацією показали стабільно вищі середні значення обох цефалометричних параметрів: у другій зрілій групі середня лобна хорда у деформованих черепів склала 112,3 мм проти 108,6 мм у недеформованих черепів. Аналогічно, середня тім'яна хорда у деформованих черепів склала 110,1 мм проти 108,2 мм у недеформованій групі. Ця тенденція спостерігалася у всіх вікових групах, особливо виражені відмінності спостерігалися в групі літніх людей.

Ключові слова: цефалометрія, деформація черепа, лобова хорда, тім'яна хорда, морфологія черепа, вікові зміни, антропометрія, краніологія.

Cephalometry remains an essential methodology for studying human cranial morphology, enabling systematic assessment of cranial and facial dimensions across populations, age groups, and biological conditions [1, 4, 11]. Among commonly used linear measurements, the frontal chord (n–b) and parietal chord (b–l) are particularly valuable for evaluating anterior-posterior development of the neurocranium. These indicators are helpful not only in biological anthropology but also in forensic investigations and reconstructive surgery [6, 8, 9].

One of the most striking anthropogenic factors influencing skull morphology is artificial cranial deformation – a deliberate cultural practice in which the shape of an infant's head is modified using bindings, boards, or wrappings. This procedure, practiced across multiple ancient civilizations in the Americas, Eurasia, and Oceania, produces long-lasting structural changes to the cranial vault and base [10, 14]. These deformations are not merely superficial but can affect underlying bone growth, cranial suture patterns, and intracranial volume [3].

In addition to cultural modifications, biological aging also influences cranial dimensions. As individuals age, the skull undergoes a series of developmental and degenerative changes influenced by endocrine factors, bone remodeling, and sexual dimorphism [2, 6]. These age-related changes include variation in bone density, cranial thickness, and suture closure. Such changes can complicate anthropological interpretations if deformation effects are not separately accounted for [11, 12].

Despite growing research on cranial deformation, relatively few studies have comprehensively examined how such artificial changes interact with natural cranial development across age. Specifically, investigations comparing frontal and parietal chord measurements in deformed vs. non-deformed skulls across defined age intervals remain limited in the scientific literature. Yet, such comparative studies are critical for understanding how cultural and biological factors converge to shape cranial morphology throughout life [4, 13].

The present study aims to fill this gap by analyzing age-specific differences in the frontal chord (n–b) and parietal chord (b–l) in a large sample of artificially deformed and non-deformed human skulls. Drawing from a well-documented osteological collection and applying standardized cephalometric techniques alongside robust statistical analysis, this research seeks to clarify how early cultural practices and natural aging processes jointly affect cranial form. Such findings have implications not only for anthropology and archaeology, but also for forensic sciences and evolutionary biology.

The purpose of the study was to compare the age-related characteristics of various cephalometric indicators, such as n–b and b–l, between artificially deformed and normal skulls.

Materials and methods. The study was conducted at the Department of Human Anatomy and Medical Terminology of Azerbaijan Medical University during 2020–2023.

To fulfill the primary objective of this research, a cephalometric analysis was conducted on 200 human skulls, comprising 108 male and 92 female specimens. All samples were derived from the craniological collection housed at the Museum of Anatomy of the Department of Human Anatomy and Medical Terminology, Azerbaijan Medical University. The collection was formed through systematic osteological acquisitions conducted in the late nineteenth and early twentieth centuries, primarily from burial sites across different regions of present-day Azerbaijan and adjacent territories of the South Caucasus. The majority of specimens belong to individuals of Caucasian (South Caucasian) anthropological affiliation, representing indigenous ethnic groups historically inhabiting the territory of Azerbaijan (Azerbaijanis, Tats, Talysh, Lezgins, and related populations). Ethnic attribution was determined based on archival documentation, anthropological records, and craniometric typology maintained in the museum registry.

According to archival data, most individuals died of natural causes typical for the respective historical periods, including infectious diseases, nutritional deficiencies, and age-related conditions. No specimens were derived from victims of violent death, executions, or forensic investigations. In many cases, precise causes of death could not be established and were recorded as "natural causes" or "unknown" in archival documentation. All skulls represent adult and adolescent individuals with complete cranial vault preservation sufficient for standardized craniometric analysis.

Inclusion criteria: originated from the official museum craniological collection of Azerbaijan Medical University; had documented age-at-death allowing reliable assignment to one of the standardized age groups; demonstrated sufficient anatomical integrity of the frontal and parietal regions to allow accurate identification of craniometric landmarks; belonged either to individuals with clearly documented artificial cranial deformation or to non-deformed (normal) skulls with preserved natural cranial morphology.

Exclusion criteria: evidence of traumatic injuries of the cranial vault (fractures, penetrating defects, post-traumatic deformities); signs of pathological bone remodeling (tumors, severe osteomyelitis, Paget's disease etc.); congenital cranial malformations unrelated to intentional deformation; postmortem damage affecting the frontal or parietal regions; uncertain or undocumented age-at-death.

Age classification followed the standardized framework proposed during the VII All-Union Conference on Problems of Age Morphology, Physiology, and Biochemistry (1965, USSR). This system stratifies developmental stages into the following categories: adolescence, youth, first adulthood, second adulthood, and old age, with sex-specific age boundaries:

Males:
– Adolescence: 13–16 years,
– Youth: 17–21 years,
– First adulthood: 22–35 years,
– Second adulthood: 36–60 years,
– Old age (Elderly): 61–74 years.

Females:
– Adolescence: 12–15 years,
– Youth: 16–20 years,
– First adulthood: 21–35 years,
– Second adulthood: 36–55 years,
– Old age (Elderly): 56–74 years.

These intervals reflect physiological and biochemical distinctions between sexes. The skulls in this study were categorized accordingly.

Historically, numerous extrinsic factors – including cultural traditions, environmental conditions, and ethnic practices – contributed to intentional cranial shaping in early infancy through specialized headgear or binding. Such interventions frequently led to artificial cranial deformations that remained evident into adulthood, manifesting in measurable cephalometric alterations.

For analytical purposes, the sample was divided into two principal groups:

1. Skulls exhibiting artificial cranial deformation.
2. Non–deformed (normal) skulls.

Each group was subsequently subdivided based on the above-mentioned age classifications. Within every subgroup, the following cephalometric dimensions were measured in millimeters: frontal chord (n-b) and parietal chord (b-l).

The present study was conducted in full compliance with the principles of bioethics. The authors were guided by the following national and international regulatory and ethical frameworks: Declaration of Helsinki of the World Medical Association (2013); Council for International Organizations of Medical Sciences, International Ethical Guidelines for Biomedical Research Involving Human Subjects; and National regulatory acts of the Republic of Azerbaijan governing scientific research and the use of museum-based human biological collections. Before the initiation of the study, official written permission was obtained from the Director of the Museum of Anatomy of Azerbaijan Medical University for the scientific use of osteological materials from the museum collection (since the Museum of Anatomy is under the jurisdiction of the Azerbaijan Medical University, and this study was conducted at the Department of Human Anatomy and Medical terminology of Azerbaijan Medical University, it was carried out based on the relevant permission). All examined specimens were anonymized museum osteological samples, and no personal identifying information was available, thereby ensuring compliance with confidentiality and human rights protection requirements.

To assess the reproducibility and reliability of craniometric measurements, intra- and interobserver variability analyses were conducted.

A randomly selected subsample of 44 skulls (21 % of the total sample), representing both deformed and non-deformed groups and all age categories, was remeasured. Intraobserver variability was assessed by the primary investigator, who repeated all n-b and b-l chord measurements on the same skulls two weeks later under identical conditions, blinded to the original results. Interobserver variability was assessed by a second qualified anthropologist, who independently performed the exact measurements on the same subsample without access to the primary observer's data.

Measurement error was assessed using technical measurement error and relative technical measurement error. The analysis demonstrated good reproducibility for both parameters, with relative measurement errors not exceeding 2.0 %, within acceptable limits for osteometric studies. The results confirm the high measurement accuracy and minimal observer bias in this study.

Measurements were carried out using a digital caliper with a resolution of 0.01 mm and an accuracy of ±0.02 mm, along with a standard sliding caliper to ensure precision. A digital caliper determines area geometrically by measuring maximum (D_{max}) and minimum (D_{min}) diameters, dividing them in half to obtain the semi-axes (a, b), and substituting them into the formula ($S= \pi \times a \times b$). Statistical analyses included calculations of: mean values (M); standard deviation (SD); standard error of the mean (SEM); 95 % confidence intervals (CI) for the mean (lower and upper bounds).

These computations were applied to each subgroup to assess both intragroup and intergroup variation in cranial dimensions.

Results of the study and their discussion. In this study, among the 200 skulls without signs of artificial cranial deformation from the department's collection, 20 (10.0 %) belonged to individuals in the youth age category, 68 (34.0 %) to the first adulthood group, 72 (36.0 %) to the second adulthood group, and 40 (20.0 %) to the old age group. Of the 54 artificially deformed skulls included in the analysis, 2 (3.7 %) belonged to the youth group, 20 (37.0 %) to the first adulthood group, 25 (46.3 %) to the second adulthood group, and 7 (13.0 %) to the old age group.

Regarding sex distribution, 86 of the 200 non-deformed skulls were male (43.0 %) and 114 were female (57.0 %). Among the 54 deformed skulls, 22 (40.7 %) were male and 32 (59.3 %) were female.

Frontal chord (n–b) measurements revealed that, in the youth subgroup without cranial deformation (n=20), the mean value was 109.1±1.9 mm, with a minimum of 92.21 mm and a maximum of 122.21 mm. In contrast, the youth subgroup with artificial deformation (n=2) showed a mean n–b length of 110.5±5.5 mm, with individual values of 105.0 mm and 116.0 mm. The 95 % confidence interval (CI) for the non-deformed subgroup ranged from 105.2 mm to 113.1 mm. Although the calculated CI for the deformed subgroup extended from 40.6 mm to 180.4 mm, this result lacks statistical reliability due to the very small sample size.

In the first adulthood group, the frontal chord in non-deformed skulls (n=68) ranged from 93.21 mm to 121.21 mm, with a mean of 109.0±0.7 mm. The 95 % CI for this subgroup was between 107.2 mm and 110.4 mm. In the corresponding deformed subgroup (n=20), measurements ranged from 101.0 mm to 121.0 mm, with a mean of 112.0±1.2 mm. The 95 % CI for this group was calculated as 109.5 mm to 114.5 mm.

In the second adulthood age interval, among skulls without signs of artificial deformation (n=72), the minimum, maximum, and mean values for the frontal chord (n–b) were recorded as 91.46 mm, 123.39 mm, and 108.6±1.0 mm, respectively. In the corresponding subgroup of artificially deformed skulls (n=25), the values ranged from 103.0 mm to 123.0 mm, with a mean of 112.3±1.1 mm. The 95 % confidence interval (CI) for the non-deformed subgroup extended from 106.7 mm to 110.6 mm, while for the deformed subgroup, the CI ranged from 110.0 mm to 114.7 mm.

In the elderly age interval, the frontal chord (n–b) measurements in skulls without deformation (n=40) showed a minimum of 94.90 mm, a maximum of 120.60 mm, and a mean of 109.6±1.0 mm. The corresponding 95 % CI ranged from 107.6 mm to 111.6 mm. Among skulls with artificial deformation in the same age category (n=7), the minimum, maximum, and mean values were calculated as 105.0 mm, 121.0 mm, and 111.9±2.2 mm, respectively. The 95 % CI for this group extended from 106.4 mm to 117.3 mm.

When analyzing all skulls without artificial deformation across all age intervals combined (n=200), the frontal chord (n–b) ranged from 91.46 mm to 123.39 mm, with a mean of 109.0±0.5 mm. In contrast, in the group of skulls with artificial deformation across all age intervals (n=54), the minimum and maximum values were 101.0 mm and 123.0 mm, respectively, with a mean of 112.1±0.7 mm. The 95 % CI for the non-deformed group ranged from 108.0 mm to 110.0 mm, while the CI for the deformed group ranged from 110.6 mm to 113.6 mm (Table 1).

Table 1

Frontal chord (n–b) measurement results in skulls without artificial deformation and skulls with artificial deformation

Cephalometric parameter	Age periods	N	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Frontal chord (n–b) (skulls without artificial deformation)	Youth	20	109.1	8.5	1.9	105.2	113.1	92.21	122.21
	I adulthood	68	109.0	5.9	0.7	107.2	110.4	93.21	121.21
	II adulthood	72	108.6	8.2	1.0	106.7	110.6	91.46	123.39
	Elderly	40	109.6	6.2	1.0	107.6	111.6	94.90	120.60
	Total	200	109.0	7.1	0.5	108.0	110.0	91.46	123.39
Frontal chord (n–b) (skulls with artificial deformation)	Youth	2	110.5	7.8	5.5	40.6	180.4	105	116
	I adulthood	20	112.0	5.4	1.2	109.5	114.5	101	121
	II adulthood	25	112.3	5.7	1.1	110.0	114.7	103	123
	Elderly	7	111.9	5.9	2.2	106.4	117.3	105	121
	Total	54	112.1	5.5	0.7	110.6	113.6	101	123

In the phase of the study where Parietal chord (b–l) measurements were assessed in skulls with and without artificial deformation, the subgroup of non-deformed skulls within the "youth" age interval (n=20) showed a minimum value of 98.71 mm, a maximum of 121.0 mm, and a mean of 108.5±1.3 mm. The 95 % confidence interval (CI) for the mean in this subgroup ranged from 105.7 mm to 111.3 mm. In contrast, in the subgroup consisting of two skulls from the same age category with signs of artificial deformation (n=2), the minimum, maximum, and mean Parietal chord (b–l) measurements were 112 mm, 115 mm, and 113.5±1.5 mm, respectively. The 95 % CI for this group extended from 94.4 mm to 132.6 mm; however, this wide interval reflects the small sample size and should be interpreted with caution.

In the "first adulthood" age group, cephalometric analysis of non-deformed skulls (n=68) revealed a minimum Parietal chord (b–l) of 94.40 mm, a maximum of 129.66 mm, and a mean of 107.8±0.8 mm. In the corresponding subgroup of skulls with artificial deformation (n=20), the measurements ranged from 91.0 mm to 146.0 mm, with a mean of 111.1±2.5 mm. The 95 % CI for the non-deformed subgroup was calculated to be 106.3–109.3 mm. For the deformed subgroup, the 95 % CI ranged from 105.9 mm to 116.3 mm.

In the subgroup of skulls from the "second adulthood" age interval without signs of artificial deformation (n=72), cephalometric measurements revealed that the minimum, maximum, and mean values of the Parietal chord (b–l) were 97.72 mm, 133.48 mm, and 108.2±0.8 mm, respectively. In comparison, the corresponding subgroup with artificial cranial deformation (n=25) exhibited minimum, maximum, and mean values of 94.0 mm, 123.0 mm, and 110.1±1.5 mm, respectively. It is noteworthy that the 95 % confidence interval (CI) for the mean in the non-deformed subgroup ranged from 106.5 mm to 109.9 mm, while in the deformed subgroup, the CI extended from 107.0 mm to 113.2 mm.

In the "elderly" age interval, cephalometric assessment of skulls without artificial deformation (n=40) revealed Parietal chord (b–l) values ranging from 96.16 mm to 127.96 mm, with a mean of 107.6±1.1 mm. In the subgroup of deformed skulls from the same age category (n=7), the minimum, maximum, and mean values were 105.0 mm, 126.0 mm, and 112.8±2.6 mm, respectively. The 95 % CI for the mean in the non-deformed elderly subgroup was calculated to be 105.5–109.8 mm. For the deformed subgroup in this age range, the CI was broader, ranging from 106.4 mm to 119.2 mm (Table 2).

Table 2

Parietal chord (b-l) measurements in skulls without artificial deformation and with artificial deformation

Cephalometric parameter	Age periods	N	Mean	Std. Deviation	Std. Error	95 % Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Parietal chord (b-l) (skulls without artificial deformation)	Youth	20	108.5	5.9	1.3	105.7	111.3	98.71	121.0
	I adulthood	68	107.8	6.4	0.8	106.3	109.3	94.40	129.66
	II adulthood	72	108.2	7.2	0.8	106.5	109.9	97.72	133.48
	Elderly	40	107.6	6.7	1.1	105.5	109.8	96.16	127.96
	Total	200	108.0	6.7	0.5	107.1	108.9	94.40	133.48
Parietal chord (b-l) (skulls with artificial deformation)	Youth	2	113.5	2.1	1.5	94.4	132.6	112	115
	I adulthood	20	111.1	11.1	2.5	105.9	116.3	91	146
	II adulthood	25	110.1	7.5	1.5	107.0	113.2	94	123
	Elderly	7	112.8	6.9	2.6	106.4	119.2	105	126
	Total	54	110.9	8.7	1.2	108.6	113.3	91	146

In the final phase of the study, when all subgroups of skulls without artificial deformation across the "youth," "first adulthood", "second adulthood," and "elderly" age intervals were combined (n=200), the minimum, maximum, and mean values for the parietal chord (b–l) were recorded as 94.40 mm, 133.48 mm, and 108.0±0.5 mm, respectively. When the corresponding subgroups of skulls with artificial deformation across the same age intervals were considered collectively (n=54), the minimum, maximum, and mean values were 91.0 mm, 146.0 mm, and 110.9±1.2 mm, respectively. Based on these combined measurements, the 95 % confidence interval for the mean Parietal chord in non-deformed skulls ranged from 107.1 mm to 108.9 mm, whereas for deformed skulls, the CI was calculated as 108.6 mm to 113.3 mm.

Currently, many new methods have been proposed to improve cephalometric measurements [4, 9, 13].

Thus, Dolci C, et al (2023) in their study presented a new cephalometric analysis aimed at simplifying biomechanical modeling by identifying the complex relationship between craniofacial morphology, size and inclination of the masseter muscle taking into account its parameters. the authors used a different method from ours and studied other parameters (the line of action drawn between the Gonion and Orbital points relative to dental and skeletal landmarks (occlusal and Frankfurt planes)). It was found that age affects the angles between key reference points, while the skeletal-cutaneous class does not show age- or gender-specific trends. However, these results do not have features in common with our study, since the authors' goals did not coincide with our work and, thus, they did not evaluate artificially deformed skulls [7].

Chae R, et al (2020) measured 14 anatomical characteristics of the right temporal bone from 10 dry skulls. Each skull was 3D scanned using structured light scanning to create virtual models, which were measured using mesh processing software. Measurements from each virtual and 3D printed model were compared with measurements of the temporal bone. Significant differences between physical skulls and virtual models were observed for 11 of the 14 parameters, with the largest mean difference in petrous ridge length (2.85 mm) and the smallest difference in stylomastoid foramen diameter (0.67 mm). The authors concluded that 3D technologies can facilitate the creation of individualized and highly accurate reconstructions of cranial structures, which may be useful for anatomy teaching, clinical training, and preoperative planning [5].

Torres-Rouff C. (2020) noted that because the practice of head shaping is classified as a pathological condition in synthetics and is potentially confounded with other head shape changes, it is interesting to note that research into the health effects of the practice itself is few and far between, particularly in the last twenty years. Morphological studies have also noted changes in cranial shape that may have health consequences. For example, changes in the shape and symmetry of the eye sockets, the presence of adrenal pits, and even severe plagiocephaly resulting from uneven pressure on the bones may have associated health effects that have not been clearly documented in the skeletal remains [14]. The differences we found, which persist into old age and indicate the long-term impact of early cranial correction techniques, are consistent with the author's view that cephalometric data are important for assessing future outcomes in cranial deformities.

Conclusions

1. Across all age intervals, skulls with artificial deformation showed consistently higher average values for both cephalometric parameters (in the second adulthood group, the mean frontal chord in deformed skulls was 112.3 mm versus 108.6 mm in non-deformed skulls). Similarly, the mean parietal chord in deformed skulls was 110.1 mm compared to 108.2 mm in the non-deformed group.

2. This trend was evident across all age categories, with particularly strong differences observed in the elderly group. However, some confidence intervals for small samples, such as in deformed youth skulls, were too wide to be statistically reliable.

Artificial cranial deformation results in measurable increases in both frontal and parietal chord lengths across the lifespan. These differences persist into old age and highlight the long-term impact of early cranial shaping practices. Cephalometric analysis of age-specific cranial measurements provides valuable insight into the morphological consequences of artificial deformation.

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