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Changes in parameters of skulls from different historical periods and the use of these data by Azerbaijani anthropologists in practice

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Method Article

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Abstract

This article presents the results of the work on the analysis of metric indicators of various craniological series from the territory of modern Azerbaijan. These craniological series belong to different historical periods in the range from the first century CE to the twentieth century inclusive. In total, craniometric indicators of 335 skulls were studied (196 male skulls, 139 female skulls). We compared a large array of craniometric data of skulls from different historical periods and found that 12 metric features, as well as 9 indicators, tend to change over time (i.e., they reveal epochal morphodynamics). Craniometric features from different craniological series were compared with each other using the analysis of variance, as well as the two-sample t-test. The results of the cluster analysis of the entire studied sample divided it into four parts: 1) skulls of the 1st-7th centuries; 2) skulls of the 8th-9th centuries; 3) skulls of the 14th-17th centuries; 4) skulls of the 20th century. Mathematical modeling using canonical discriminant analysis allowed us to develop discriminant functions for diagnosing the chronological typicality of a skull. By measuring the skull and using these functions, the anthropologist can make a preliminary conclusion (express-diagnosis) about the approximate chronological period to which this skull belongs (i.e., to which craniological series from different eras the skull under study most corresponds).

Introduction

It has long been known that human morphology tends to change over time during stages of evolution. Regarding the size and configuration of the skull, these changes are associated with encephalization, which developed rapidly among hominids and accelerated especially after the emergence of Homo habilis (1, 2). There is an opinion that encephalization is a characteristic feature of the evolution of hominids (3).

However, epochal changes in craniometric traits (and therefore in skull shape), as well as in other morphological parameters, can also be traced within shorter historical periods. These include processes such as brachycephalization and debrachycephalization (4, 5), gracilization (6), secular trends, and other complex yet essentially similar phenomena, which are united by one term – morphodynamics (7, 8).

In the context of the epochal variability of the skull, we examined almost all available craniological collections from various historical periods from the territory of modern Azerbaijan. We established certain facts of changes in craniometric sizes, angles, indices, and ratios that occurred over time. The potential applied use of these patterns is the subject of this work. Our specific goal was to explore whether it is possible to differentiate skulls from different epochs using methods of mathematical modeling. In our view, having a methodology for rapid diagnostics that allows distinguishing contemporary skulls from craniological material of earlier epochs would not only be useful for routine forensic anthropological practice but also of interest to anthropologists and archaeologists working in historical anthropology.

Materials and Methods

The research material consisted of two craniological collections – one from the modern population and another from archaeological excavations of skulls dated to the 1st–17th centuries CE. The series from the modern (20th century) population of Azerbaijan (including 105 male and 51 female skulls) at the time of the study was stored at the Public Legal Entity “FME and PA” of the Ministry of Health of the Republic of Azerbaijan. This collection was gathered in various regions of Azerbaijan over the last 50 years and corresponds to the craniological characteristics of the modern population of this country. The collection of skulls discovered during archaeological excavations (including 91 male and 88 female skulls) was stored at the National Academy of Sciences of Azerbaijan at the time of the study. The distribution of craniological material by burial type and chronology is presented in Table 1.

Table 1

Table 1
Distribution of the studied craniological material by burial type, chronological period and sex

Type of burial	Chronological period (centuries, CE)	Men	Women	Total
1. Pitcher	I-III	4	0	4
2. Log (a)	I-III	8	6	14
3. Log (b)	III-V	1	1	2
4. Catacomb (a)	I-III	6	5	11
5. Catacomb (b)	III-V	21	36	57
6. Catacomb (c)	V-VII	15	24	39
7. Christian	VII-IX	21	7	28
8. Muslim	XIV-XVII	15	9	24
9. Modern	XX	105	51	156
Total	-	196	139	335

The procedures of craniometric studies followed the classical recommendations presented in the works of R. Martin (9), as well as V.P. Alekseev and G.F. Debets (10). The number of measured traits (if the skull had no extensive defects and was not fragmented) included 74 traits: absolute dimensions – 58, indices – 18. For measuring skulls (standard craniometric procedures), the following instruments were used: a digital caliper “Mutitouyo” with an accuracy of 10 microns, a sliding caliper (accuracy 0.1 mm), a measuring tape (accuracy 1 mm), a goniometer (accuracy 0.5°), a mandibulometer (accuracy 1.0 mm; 1°), and a coordinate compass (accuracy 0.1 mm). For analyzing the results of craniometry, simple methods of variation statistics and canonical discriminant analysis were used (11). Mathematical modeling procedures were carried out using the statistical software package “Statgraphics” (https://www.statgraphics.com).

Results and Discussion

The total number of skulls whose dimensions were analyzed was 335. The measurement results for each skull are presented in previous works. This is a craniometric database of skulls from the 1st–17th centuries discovered during Soviet-era archaeological excavations and is presented in the monograph of R.M. Kasimova (12).

The data on 20th-century skulls are the results of our own research conducted during dissertation work (13). However, it should be noted that during the dissertation, we remeasured skulls that had previously been studied by R.M. Kasimova and found almost no discrepancies between the results. Minor deviations were observed in the measurements of some skulls and concerned such dimensions as auricular height (No. 20 according to Martin), the alveolar part angle (am), and the zygomaxillary angle (zm). Nevertheless, for these parameters, we used our own measurements in the analysis.

Table 1 provides a combined classification of craniological series, both by chronology and by burial type. The classification by burial type was carried out by R.M. Kasimova (12) and corresponded to the tasks she solved as an archaeologist. In our case, only the chronological grouping of the material was significant.

As a result, we conditionally had six chronological groups: Skulls of the 1st–3rd centuries; Skulls of the 4th–5th centuries; Skulls of the 6th–7th centuries; Skulls of the 8th–9th centuries; Skulls of the 14th–17th centuries; Skulls of modern times (20th century). The metric data of these craniological series were compared with each other and with the craniometric indicators of 20th-century skulls.

In fact, it was possible not to include the skulls of the 14th–17th centuries in the study. According to historical data, starting from the first half of the 14th century, no mass migrations were observed in the territory of Azerbaijan, and only insignificant sub-local relocations took place (14, 15). That is, there were no strong triggers, such as migration waves, that could change the anthropological appearance of the inhabitants, and for at least the last 600 years, large-scale miscegenation can be excluded. Nevertheless, for greater reliability, we included in the study even the skulls belonging to the second half of the 17th century.

Thus, we compared a large array of craniometric data from different historical periods. In total, it was possible to compare all skulls using 58 metric traits and 18 indices. Only 12 traits (15.8%) and 9 indices (11.8%) showed a tendency of epochal variability.

However, we note that in the process of searching for craniometric traits affected by epochal changes, we tried to expand the array of studied dimensions. Unfortunately, apart from the noted 12 traits and 9 indices, no other parameters showed significant changes over time. Below, in Tables 2–5, we present the statistical characteristics of those craniometric traits in which we found characteristic changes during the chronological period covering the 1st–20th centuries.

Table 2

Craniometric features for which differences were established depending on their chronological period (1st-9th centuries, male skulls)

Craniometric signs and indicators (numbering according to Martin)	I-III centuries N = 18		IV-V centuries N = 22		VI-VII centuries N = 15		VIII-IX centuries N = 21	
	X(cm)	SD	X(cm)	SD	X(cm)	SD	X(cm)	SD
1.Longitudinal diameter	186.88	7.61	188.90	5.73	186.00	5.78	176.47	5.89
8.Transverse diameter	133.86	4.05	135.59	5.02	136.00	6.26	148.09	6.87
10.Greatest width of forehead	113.83	4.62	113.28	4.24	113.66	6.76	123.78	7.36
11.Width of skull base	119.16	5.44	122.25	4.25	121.96	5.56	131.42	5.48
24.Transverse arch	308.50	11.88	303.41	6.94	309.72	11.33	323.70	14.77
45.Zygomatic diameter	129.00	4.71	131.76	3.94	132.75	4.51	137.26	4.79
43.Upper face width	103.30	3.56	107.52	4.00	107.48	3.42	106.64	3.78
46.Average face width	91.53	3.09	98.58	4.88	97.20	4.61	97.17	3.56
61.Width of alveolar arch	61.83	3.48	65.35	3.55	65.11	2.84	64.67	2.80
51a.Width of orbit from dacryon	39.42	1.91	39.66	1.54	39.50	1.20	39.42	1.38
74.Angle of alveolar part	80.50	3.58	79.05	5.00	79.72	2/24	81.33	5.09
33(1). Angle of upper part of occiput	97.63	4.65	94.55	6.67	94.45	4.78	92.00	3.95
8/1 Transverse-longitudinal index	71.28	3.60	71.83	3.83	73.47	4.92	84.62	4.33
17/8 Altitude-transverse index	99.06	4.91	99.08	5.07	101.26	5.06	89.85	4.81
9/8 Fronto-transverse index	72.50	2.45	72.26	4.05	73.20	3.58	66.71	4.49
9/10 Fronto-latitudinal index	85.00	3.43	86.53	4.53	87.57	4.22	80.33	3.43
45/8 Transverse facio-cerebral index	96.06	3.12	97.16	3.56	97.50	5.22	92.28	3.45
48/9 Vertical-transverse facio-cerebral index	70.19	3.33	74.96	5.13	70.75	6.91	72.73	4.27

Craniometric signs and indicators (numbering according to Martin)	I-III centuries N = 18		IV-V centuries N = 22		VI-VII centuries N = 15		VIII-IX centuries N = 21	
	X(cm)	SD	X(cm)	SD	X(cm)	SD	X(cm)	SD
20/1 Altitude-longitudinal index	60.63	2.78	59.53	2.10	62.02	3.02	64.75	2.80
20/8 Altitude-transverse index	83.93	3.42	82.98	2.99	85.21	3.78	76.59	2.57
54/55 Transverse naso-zygomatic index	19.27	1.59	19.08	0.79	19.35	1.05	18.10	0,86

Table 3

Craniometric features for which differences were established depending on their chronological period (14th-20th centuries, male skulls)

Craniometric signs and indicators (numbering according to Martin)	**XIV-XVII centuries N = 15**		**XX centuries N = 105**	
	X(cm)	**SD**	**X(cm)**	**SD**
1.Longitudinal diameter	180.86	5.90	181.98	6.55
8.Transverse diameter	150.64	8.42	145.33	6.89
10.Greatest width of forehead	125.71	6.29	123.38	6.34
11.Width of skull base	131.42	6.61	127.40	6.72
24.Transverse arch	331.71	18.79	322.13	13.70
45.Zygomatic diameter	137.78	3.11	134.17	5.41
43.Upper face width	107.82	2.61	105.80	4.61
46.Average face width	96.13	4.62	94.21	4.86
61.Width of alveolar arch	65.75	3.30	60.98	3.95
51a.Width of orbit from dacryon	38.65	1.17	41.06	2.28
74.Angle of alveolar part	78.61	4.84	85.00	5.05
33(1). Angle of upper part of occiput	88.92	5.90	90.76	4.67
8/1 Transverse-longitudinal index	83.29	4.99	79.96	4.69
17/8 Altitude-transverse index	91.50	4.19	94.44	5.06
9/8 Fronto-transverse index	65.71	2.62	67.15	3.92
9/10 Fronto-latitudinal index	78.70	2.44	79.19	4.22
45/8 Transverse facio-cerebral index	91.65	3.99	92.34	3.49
48/9 Vertical-transverse facio-cerebral index	73.22	3.37	76.00	6.41
20/1 Altitude-longitudinal index	64.68	3.91	64.47	3.56
20/8 Altitude-transverse index	77.70	2.80	80.61	3.18
54/55 Transverse naso-zygomatic index	17.99	0.92	18.16	1.45

Table 4

Craniometric features for which differences were established depending on their chronological period (1st-9th centuries, female skulls)

Craniometric signs and indicators (numbering according to Martin)	**I-III centuries N = 11**		**IV-V centuries N = 37**		**VI-VII centuries N = 24**		**VIII-IX centuries N = 7**	
	X(cm)	**SD**	**X(cm)**	**SD**	**X(cm)**	**SD**	**X(cm)**	**SD**
1.Longitudinal diameter	176.00	5.44	177.68	5.77	179.67	5.37	173.83	3.71
8.Transverse diameter	135.85	7.88	131.03	5.70	131.41	5.46	144.06	9.57
10.Greatest width of forehead	111.71	7.36	110.95	5.45	110.90	6.12	120.36	7.12
11.Width of skull base	116.60	7.63	116.33	4.11	115.94	4.56	122.00	6.96
24.Transverse arch	301.80	12.87	299.51	12.50	301.42	12.43	316.40	16.56
45.Zygomatic diameter	128.80	5.02	125.13	3.07	123.92	4.80	127.00	5.09
43.Upper face width	100.50	6.85	101.18	3.89	100.23	4.59	103.91	3.56
46.Average face width	91.90	7.16	91.92	5.33	92.25	4.61	92.37	5.59
61.Width of alveolar arch	60.50	0.57	61.65	3.09	61.28	2.23	60.26	1.94
51a.Width of orbit from dacryon	37.20	1.92	37.93	1.98	38.08	1.35	38.80	1.30
74.Angle of alveolar part	76.00	6.16	77.47	5.51	80.61	5.22	82.40	2.60
33(1). Angle of upper part of occiput	92.00	6.97	96.17	5.94	103.50	6.06	94.80	4.08
8/1 Transverse-longitudinal index	77.19	3.69	74.00	3.43	73.10	2.69	83.84	5.52
17/8 Altitude-transverse index	95.66	5.43	100.40	5.88	100.05	4.68	90.51	6.02
9/8 Fronto-transverse index	69.43	1.97	71.60	3.44	71.74	4.06	66.01	3.54
9/10 Fronto-latitudinal index	84.38	2.78	84.99	3.85	85.66	4.43	79.79	4.39
45/8 Transverse facio-cerebral index	92.94	3.67	94.41	3.30	93.98	5.05	87.53	3.87
48/9 Vertical-transverse facio-	69.85	2.12	72.34	5.34	71.31	3.35	72.19	1.74

Craniometric signs and indicators (numbering according to Martin)	I-III centuries N = 11		IV-V centuries N = 37		VI-VII centuries N = 24		VIII-IX centuries N = 7	
	X(cm)	SD	X(cm)	SD	X(cm)	SD	X(cm)	SD
cerebral index								
20/1 Altitude-longitudinal index	63.18	1.37	63.23	3.86	63.28	3.15	65.19	3.23
20/8 Altitude-transverse index	81.37	5.33	85.36	4.49	85.90	3.26	77.89	3.98
54/55 Transverse naso-zygomatic index	19.32	1.55	19.62	1.50	19.24	1.39	18.75	0.73

Table 5

Craniometric features for which differences were established depending on their chronological period (14th-20th centuries, female skulls)

Craniometric signs and indicators (numbering according to Martin)	**XIV-XVII centuries N = 9**		**XX centuries N = 51**	
	X(cm)	**SD**	**X(cm)**	**SD**
1.Longitudinal diameter	170.87	7.06	174.60	6.49
8.Transverse diameter	144.87	3.52	142.18	6.00
10.Greatest width of forehead	121.42	3.82	120.01	6.27
11.Width of skull base	120.44	3.57	122.38	5.67
24.Transverse arch	316.75	10.09	313.86	11.84
45.Zygomatic diameter	125.87	3.72	125.69	5.26
43.Upper face width	102.50	1.69	100.51	3.57
46.Average face width	93.14	4.94	90.88	4.13
61.Width of alveolar arch	61.71	2.69	57.72	4.09
51a.Width of orbit from dacryon	38.55	0.72	39.36	1.95
74.Angle of alveolar part	78.37	3.11	85.94	2.19
33(1). Angle of upper part of occiput	86.00	6.00	90.85	4.20
8/1 Transverse-longitudinal index	84.89	3.75	81.57	4.36
17/8 Altitude-transverse index	90.59	2.54	92.74	4.58
9/8 Fronto-transverse index	66.74	3.00	66.12	3.60
9/10 Fronto-latitudinal index	79.57	3.19	78.44	4.99
45/8 Transverse facio-cerebral index	86.80	2.62	88.59	3.26
48/9 Vertical-transverse facio-cerebral index	71.13	4.25	73.64	4.34
20/1 Altitude-longitudinal index	66.66	3.49	66.44	3.00
20/8 Altitude-transverse index	78.50	1.78	81.07	2.97
54/55 Transverse naso-zygomatic index	19.17	1.04	18.32	1.36

The studied craniometric traits from different craniological series were compared with each other using analysis of variance, as well as the t-test when it was necessary to separately compare two groups with each other. All relevant procedures and the results of statistical analysis for this part of the work are

presented in the dissertation of Sh.M. Musayev (13). A detailed report of these results goes beyond the scope of this article; therefore, we present here only the interpretation of the obtained data.

First of all, we note that in general (for the overwhelming majority of craniological traits), all the studied craniological series from the territory of Azerbaijan, dated to the 1st–20th centuries, form a single whole. Differences by sex, as well as between neighboring Caucasian populations, were more significant than epochal changes over the past two millennia. For the indicated traits, the differences between the earliest series and skulls belonging to the 14th–17th centuries were significant. At the same time, each of these groups differed from the 20th-century craniological series not as strongly. Naturally, random factors played a role here, such as the number of studied objects by chronological periods and the level of diversity within the series (after all, archaeological series had a more limited location compared to the 20th-century skulls, which covered the entire geography of Azerbaijan). In any case, it would be illogical to argue that modern Azerbaijanis, by craniometric characteristics, occupy an intermediate position between the groups living in the 1st–3rd centuries and in the 14th–17th centuries. In the last chronological series, the range of trait variation was the greatest. In the late medieval craniological series (14th–17th centuries), there were only 24 skulls. However, this group also included skulls whose dimensional and craniological characteristics corresponded to earlier chronological periods. These results allow us to speak of the historical continuity of populations living in the territory of Azerbaijan over the last two millennia. It should also be noted that the results of cluster analysis of the entire studied sample divided it into four parts (unlike the six groups we conditionally distinguished by chronology). Thus, four groups were distinguished: Skulls of the 1st–7th centuries; Skulls of the 8th–9th centuries; Skulls of the 14th–17th centuries; Skulls of modern times (20th century). These data correspond to information about two major migration waves that took place in the early Middle Ages from the Middle Eastern and Central Asian geographical areas (16) and, apparently, reflect phenomena of minor miscegenation of the inhabitants of that period (17, 18). However, as we noted, in craniometric terms, more than 72% of the traits we studied remained relatively stable over the last millennia and did not show epochal shifts. Thus, the analysis of craniometric results confirms previous anthropologists' data (17, 19) on the weak influence of modern-era migration waves on the genetic and anthropological composition of the population of Azerbaijan. A relatively small number of craniometric traits that did show epochal variability were externally reflected in the cranial morphotype by the brachycephalization of the population. The female part of the population reacted to this process more conservatively. The process of brachycephalization most likely ended at the beginning of the 14th century, and for the last 500–600 years, relative stability of the cranial index has been observed. It should also be noted that craniometric features demonstrating epochal variability correlate poorly with age-related morphological changes in the skull. Considering that we studied skulls whose biological age corresponded to a period of relative morphological stability, the influence of age-related skull morphodynamics on the obtained results can be ruled out.

The above results were identified, as we mentioned, during the 1997 dissertation work, but they are directly related to the goals of this study. Reconsideration of these data showed us that it is possible to create a mathematical model for predicting the chronological typicity of a skull in relation to

craniological material from the territory of Azerbaijan. For the implementation of the corresponding classification, it was decided to use canonical discriminant analysis (20, 21). Mathematical modeling showed that of the 21 traits that showed signs of epochal variability, only 10 traits (5 measurement traits and 5 indices) were the most informative and least correlated with each other. Since measurement traits showed sexual dimorphism, it was necessary to introduce data on the sex of the skull into the developed model. The discriminant functions for diagnosing the chronological affiliation of the skull and the craniometric traits used for this are given in Table 6.

Table 6

A set of discriminant functions for differential diagnosis of the chronological groups of the population of Azerbaijan based on skull dimensions (for the period of the 1st–20th centuries)

Craniometric signs and indicators (numbering according to Martin)	**DF(x)**	**DF(y)**	**DF(z)**
9/10 Frontal-latitudinal	-0,07222	0,02578	-0,02808
51a. Orbital width from dacryon	0,14015	0,39499	0,14976
33(1). Angle of the upper part of the occiput	-0,06895	-0,04738	0,16076
61. Width of the alveolar arch	-0,03118	-0,15197	-0,04808
45/8 Transverse facio-cerebral index	-0,09477	-0,07472	0,07104
20/1 Altitude-longitudinal index (from porion points)	-0,00990	0,23370	-0,02717
48/9 Vertical-transverse facio-cerebral index	0,05217	0,04849	0,04230
24. Transverse arch	-0,00558	-0,00883	-0,02507
8/1 Transverse-longitudinal index	0,12231	-0,21724	0,16419
43. Upper face width	0,02347	-0,12218	0,02246
Sex (value "1" for male, value "2" for female)	-0,76468	-0,75030	-0,74137
Constant	4,78523	18,3344	-29,9349
Calculation results			
Canonical correlation	0,82203	0,70617	0,35058
Group centroids	X	Y	Z
Chronological group I-VII CE	-2,05246	0,00950	-0,03590
Chronological group VIII-IX CE	0,81198	-1,66304	0,59959
Chronological group XIV-XVII CE	1,16662	-1,04378	-0,74058
Chronological group XX CE	0,97219	1,02062	0,08373

When using this diagnostic method, the results of each of the three equations are calculated. The value of the craniometric feature or indicator is multiplied by the corresponding coefficient from the table, and then the resulting numbers are summed up with each other and with the constant value from the table. For example, for the result of the DF(x) equation, this will be the sum of the values obtained in lines 2–13 of the corresponding column of Table 6. It is important to know that the coefficients intended for the

"gender" feature are multiplied either by "1" if the skull being examined is male, or by "2" if the skull is female. For convenience, we've highlighted the "Calculation Results" row in the table. These empty cells allow the user to record the results obtained for each equation. These three numbers (the results of the DF(x), DF(y), and DF(z) equations) determine the coordinate of a certain point in three-dimensional space along the (x), (y), and (z) axes. The point determined in this way falls into one of the 8 octants into which the space is divided by three mutually perpendicular axes (x), (y) and (z). Four octants are occupied by points that are determined by the coordinates of the corresponding chronological group of skulls (numbers from the last four lines of Table 6). The division of chronological groups in this way (i.e. the discriminant analysis procedure) during mathematical modeling was carried out automatically by the statistical software package “Statgraphics”. According to mathematical premises, the occurrence of a point determined in the course of calculations in one of the octants corresponding to any of the chronological groups indicates that the skull under study belongs to this chronological group. If the coordinates obtained in the course of calculations place the obtained point in one of the empty octants, then the diagnostics is considered unsuccessful and no conclusions are made.

It should be noted here that classification models (graphs of centroids of several clusters based on two or more discriminant functions) similar to our method have been successfully used previously both in medical research (22) and in other fields of science (23, 24). The process of understanding the essence of the proposed diagnostic model is facilitated by the graphical visualization presented in Fig. 1.

As we can see in the graphic drawing, the octant sections corresponding to different chronological groups are marked with different colors (red – group of skulls of the 1st-7th centuries; green – group of skulls of the 8th-9th centuries; crimson – group of skulls of the 14th-17th centuries; blue – group of skulls of the 20th centuries). That is, for clarity, we have colored the sections that are cut off by the point of each chronological group (points A, B, C and D, respectively, according to the distance of the chronological group from the beginning of our era). It is simply easier to visually determine the corresponding octant in this way. We also note that for greater clarity, the scaling in the presented drawing is conditional. Our graphic drawing also contains point M, the coordinates of which we calculated according to our model using the craniometric parameters of a real male skull from a series attributed by Soviet anthropologists to the 4th-5th centuries (12). (According to our mathematical calculations, this series conditionally fell into the group allocated as the earliest cluster). As we can see, the coordinates of point M calculated by the discriminant functions determine it in the octant where the red parallelepiped is located, and this indicates that the model was not mistaken in its diagnosis. Theoretically, the results of the equations could determine "our point" with localization in another colored octant (erroneous diagnosis of the skull belonging to another chronological group). Or a certain point could even fall into an empty octant, and as we said, in such cases one should refuse any answer (the model is not capable of performing diagnostics for a specific skull).

Despite the apparent bulkiness and difficulty in practical implementation, the model can be easily used if you use the Excel software package. You only need to measure 12 craniometric features and enter the resulting figures into a pre-prepared Excel sheet, which already contains all the necessary coefficients

and constants. The program will automatically calculate the coordinates, and then, using the obtained coordinates, you can see where the point determined by our equations falls on the figure above. However, we note that our statistical processing of the actual craniometric material from the territory of Azerbaijan made it possible to identify a set of craniometric features, the values of which, when analyzed in aggregate, allow us to speak only about the probable disposition of a craniological object on a chronological tape. Of course, we are talking about the greatest correspondence of the craniometric data of the studied skull (in other words, the integral indicator of the craniometric individuality of the skull) to any of the craniological series that are characteristic of various chronological periods of the last two millennia. That is, we understand that unconditionally recommending such a method for applied use in archeology and forensic anthropology is a rash step. But at the same time, as a preliminary diagnostic method, this method of predicting the probable chronology of the skull can help an anthropologist in the field to approximately estimate the historical period of the found material. Of course, if during further excavations many additional interesting artifacts are discovered, then it will be necessary to conduct radiocarbon dating for the discovered skull.

In conclusion, we note that we tested the reliability of our functions on a test independent sample of 44 male skulls, which included 12 skulls belonging to the first and fourth selected chronological groups, and 10 skulls to the remaining two groups. In this case, the most accurate diagnosis was that of the skull belonging to the first chronological period (92%) and the last (83%). Less accurate was the diagnosis of skulls belonging to the second and third chronological groups (80% and 70% of the forecast accuracy, respectively). In this case, skulls from the first group did not erroneously fall into the third and fourth, and skulls from the fourth into the first. Skulls from the second group erroneously fell (one skull each) into the first and third chronological groups. And finally, from the third group of skulls, two skulls were mistakenly attributed to the skulls of the second chronological group and one skull to modern skulls (the last group). It should be noted that a forecast of this level of accuracy usually proves the high efficiency of the mathematical tool chosen for classification (25, 26). Perhaps, based on the results of these checks, it is appropriate to conclude (or at least assume) that each population (at least in the context of craniometric analysis) has a morphology most adequate to its chronological time with an insignificant admixture of neighboring chronological groups. Thus, it can be assumed that the complex of craniometric features of the human skull quite clearly reflects historical continuity, and also outlines possible morphodynamic trends in the future (more or less distant).

In addition, the authors believe that diagnostic methods similar to the one presented can be developed (if sufficient material is available) for other geographic areas. Of course, such methods play a supplementary role and are not proposed as a replacement for more objective methods, such as radiocarbon dating or analysis of artifacts, burial types, etc. At the same time, however, numerous examples demonstrate that discriminant analysis methods remain an effective method for differential diagnosis and classification (27, 28). On the other hand, it is known that statistical methods (including biostatistics) are the fundamental basis of machine learning (29, 30). Mathematical formulas from classical statistics are widely used in the algorithms of various computer programs, which in recent years have come to be called artificial intelligence. In this context, the integrated use of many diagnostic

methods (similar to ours in terms of the problem being solved) from various geographic regions in the format of a single application, which will have the functionality of artificial intelligence, can significantly increase the efficiency of forensic anthropologists and archaeologists.

Conclusions

The analysis of craniometric parameters studied across different craniological series from the territory of modern Azerbaijan, using statistical methods, shows that all known craniological series (if considered as a single dataset) can be divided into four groups: 1) skulls from the 1st–7th centuries; 2) skulls from the 8th–9th centuries; 3) skulls from the 14th–17th centuries; 4) skulls from the 20th century. At the same time, changes in values corresponding to historical periods were observed in 21 craniometric traits (12 measurements and 9 indices), which provides grounds to conclude that these traits are linked to morphodynamic changes in the skull. Mathematical modeling using discriminant analysis allowed the development of discriminant functions, which can be used to determine the chronological period to which a studied skull belongs (i.e., which craniological series from different eras it most closely corresponds to in terms of its metric characteristics). To make a prediction, it is sufficient to measure 12 craniometric parameters and determine the chronological period to which the skull most closely corresponds. This method can be very useful during archaeological fieldwork (pre-laboratory stage of anthropological research). The results of this study also demonstrate the effectiveness of an integrative approach in solving problems at the intersection of different scientific fields (forensic medicine and historical anthropology).

Abbreviations

CE
Common Era
FME and PA
Forensic Medical Examination and Pathological Anatomy
DF
discriminant function

Declarations

Ethical approval

Permission to conduct the study was obtained from the Ethics Committee of the Azerbaijan State Institute for Advanced Training of Medical Doctors.

Conflict of interest

There is no conflict of interest.

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Consent for publication

Not applicable.

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Figures

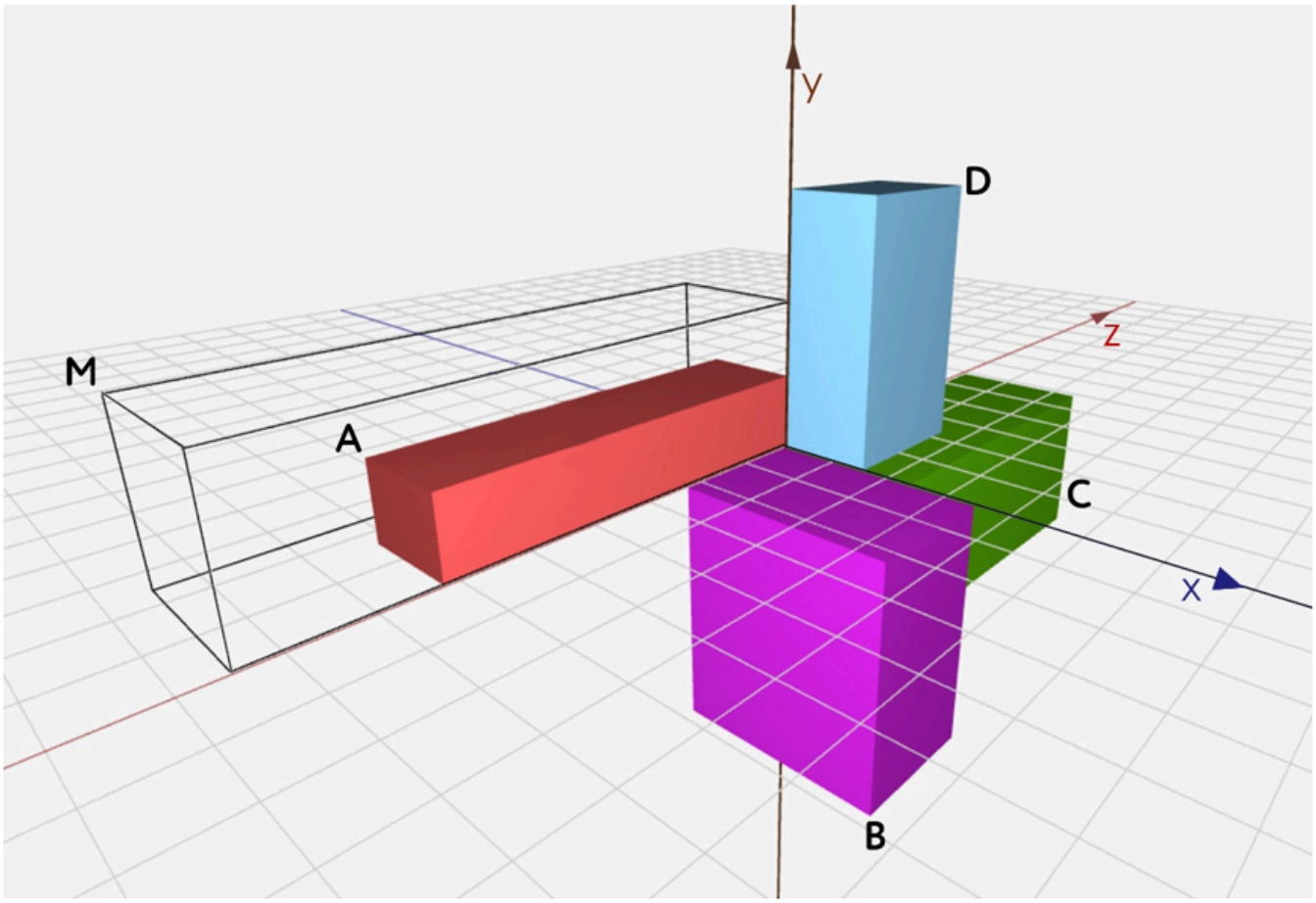


Figure 1

Visualization of diagnostics of chronological typicality of the skull (for the period of the 1st-20th centuries)