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Determining the Length of the Human Body from the Size of the Skull

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Abstract

Using methods of mathematical modeling, the possibility of determining the length of the human body by the size of its skull was studied. The material for the study was a craniological series of Azerbaijani skulls in an amount of 120 (70 male, 50 female) from the museum collection of the Person of Public Law Association "Forensic medical examination and pathological anatomy" of the Ministry of Health of the Azerbaijan Republic. For each skull, the body length, sex, age, and anthropological type of the person to whom it belonged were known. A total of 120 craniometric features were studied on each skull. 80 features were taken from standard craniometric programs. The remaining 40 were suggested by us and represent single or total dimensions of various anatomical regions of the skull. The database of craniometric parameters and body length was subjected to statistical analysis. Using correlation and regression analysis, 71 multiple linear regression equations (34 for male skulls; 37 for female skulls) were developed to predict human body length from skull dimensions. Most of the equations developed have a standard prediction error value of +4-5cm and in certain practical situations can be used in expert examinations of personality identification. The article presents 10 equations of multiple linear regressions from the total number of developed equations.

Keywords: Craniometrical Parameters; Human Body Length Prediction; Regression Equations; Person Identification; Anthropological Type; Persons Missing in War

Introduction

Determining the lifetime length of a person's body based on his bone remains does not lose its relevance in the examinations of personality identification [1-3]. However, there are very few methods for calculating the length of the human body both by craniometric parameters and cephalometric parameters [4,5]. In one of our previous publications, we presented some data on our work in this context [6]. In this paper, we present new equations for calculating the lifetime length of a person's body based on the size of his skull and describe some of the nuances of the study that were not mentioned in the previous publication.

Materials and Methods

To achieve the goals set, a craniological collection of Azerbaijanis from 218 skulls was studied (information about the gender, height, age, and anthropological variant of each object was known in advance from the museum register). Information about this collection was introduced into scientific discussion as early as the 90s of the last centuries, and in subsequent years this series of skulls was also repeatedly studied [7,8]. Specifically, to solve our problem, 120 skulls (70 males; 50 females) were selected from this collection, considering the craniometric suitability (integrity of the skull) and population homogeneity (skulls belonging to the Caspian anthropological type). To register the sizes of skulls, standard craniometry techniques were used according to known recommendations [9,10].

According to the same recommendations, the corresponding craniometric programs were used, according to which 80 sizes were studied. Another 40 different sizes are either proposed by us or mentioned in studies by various authors as having a correlation with body length. For example, the height of the temporal bone was included in our study based on the data obtained by Galli G., Galli S. [11]. Various parameters on the squamous part of the occipital bone were included in the study due to the anatomical relationships of this part of the skull with the torso, and specifically the fixation of various back muscles here (it was assumed that the size of these muscles correlated with the size of the torso and indirectly with the total body length).

The dimensions of the natural openings of the skull base, as well as their various geometric ratios, were used based on the logic of a high probability of a correlation between the total dimensions of the human body and the dimensions of the great vessels. It should be noted that, in general, we went through a very large number of various metric characteristics of the skull, which made it possible to single out several craniometric indicators interconnected with body length. The technique for measuring most of these (i.e., selected by us) sizes was described in detail in our previous work [6]. However, some dimensions are used in the equations we present already in this article. They have not been presented before and therefore below we also present their measurement procedure:

S2 - The sum of the length and width of the foramen magnum.

P8 - Perimeter of the lower part of the facial skull. Caliper determined five parameters, which were then summarized. The distance between the points of the gnathion and the zygomaxillare (right and left), as well as between the zygomaxillary and the point of intersection of the zygomatic-maxillary suture with the lower edge of the orbit (also on the right and left) was determined. The fifth dimension was measured between the right and left points of intersection of the zygomatic-maxillary suture with the lower edge of the orbits.

P9 - Perimeter of the area of the openings of the base of the skull. The zone is limited by four geometric intervals (two lateral and two transverse) on the outer base of the skull. First, the lateral parameters are measured. The fixed leg of the caliper is inserted into the foramen ovale, and the movable leg into the stylomastoid foramen. Then the distance between the most distant points of the edges of the specified holes (left and right) is measured. The most distant points are marked and then the transverse segments are measured, which are limited by these landmarks (in front this is the distance between the oval holes, and behind the stylomastoid holes). The obtained values are summarized.

M7 - Length of the external occipital crest. The shortest distance along the surface of the skull from inion to opistion, which is measured with a curvimeter.

M13 - The smallest distance between the right and left foramen lacerum.

M10 - The largest diameter on the skull. With a morphological norm, this indicator is measured in the sagittal plane. A thick caliper is used, one leg of which is fixed on the gnathion point. Moving in the sagittal plane the other leg along the surface of the skull from the metopion point to the opistion point, we find the maximum value, which is the largest diameter.

S9 - The sum of the length and width of the posterior cranial fossa. The length of the fossa is measured from the base of the back of the sella turcica to the top of the internal occipital protuberance. The width of the fossa is defined as the distance between the bases of the two temporal pyramids (the point of intersection of the upper edge of the sigmoid sinus with the parietal mastoid suture was marked as a guide).

After selecting the skulls from the collection, the order of their distribution by age and body length was considered. Tables 1 and 2 present data on the distribution by sex, age, and height of the individuals whose skulls made up the studied craniological series. Age periodization and rubricating of body length in the tables are conditional and correspond to our conditional ranking (Table 1,2). We realized that a more representative sample was needed to develop statistically reliable criteria. So, for a population of 10 million inhabitants (the population of our country), representation is ensured with the number of 1320 studied skulls [12]. In this case, the probable accuracy of the conclusions is reached at the level of 97% with an error's confidence interval of ±3%. However, we do not yet have such several skulls, and therefore we considered the corresponding statistical relationships based on the available material (of course, without claiming the unconditional ness of our results). To analyze the results of craniometry, we used standard methods of variation statistics, as well as correlation and regression analysis [13]. Mathematical modeling and calculations were performed using the MATLAB statistical software package (version 8.6).

Table 1: Distribution of the Studied Material by Sex and Age.

Gender	Age								
	16-24	25-34	35-44	45-54	55-64	65-74	75-80	Total	Average age
Male	14	17	13	11	8	5	2	70	39
Female	13	10	10	7	4	3	3	50	38,2
Total	27	27	23	18	12	8	5	120	39,4

Table 2: Distribution of the Studied Material by Sex and Body Length.

Gender	Body length											
	140-144.9	145-149.9	150-154.9	155-159.9	160-164.9	165-169.9	170-174.5	175-179.9	180-184.9	185 and more	Total	Average body length
Male	0	0	2	4	11	19	17	10	4	3	70	169,7
Female	2	6	10	13	9	6	2	1	1	0	50	159,2
Total	2	6	12	17	20	25	19	11	5	3	120	166,4

Research Results

After the measurement procedure, the obtained numerical indicators of craniometric signs were grouped in tables separately for male and female. Statistical characteristics of the studied craniometric parameters on the skulls of men and women were presented by us in previous publications. Using the results of craniometry, we conducted a correlation analysis, which showed that among the sizes we studied, a considerable number of skull parameters had a good relationship with body length. At the same time, craniometric parameters that correlate well with body length in men did not always show the same relationship in the sample of female skulls. Having enough features that correlate with body length, we began to develop multiple linear regression equations (with their help it was supposed to predict the growth of an individual by the size of his skull). We used the method of stepwise linear regression, the essence of which is to sequentially introduce features into the regression model depending on the degree of their correlation with the predicted factor.

At the same time, the criterion for selecting features (regressors) in the format of a specific diagnostic model is their maximum correlation with the predicted parameter and weak among themselves. This condition in mathematical models similar in structure is necessary to reduce the phenomenon of multicollinearity. Without dwelling in detail on the relevant theoretical aspects, we note that compliance with this rule increases the accuracy and reliability of the created equations. Therefore, to develop equations, it was also necessary to calculate the correlation coefficients between all craniometric features that found a relationship with body length. Correlation coefficients between craniometric features in all possible combinations in pairs were determined for the skulls of men and women separately. In total, the values (r) for 2278 pairs of traits were obtained in the male sample, and for 2211 pairs of traits in the female series.

The analysis of correlation matrices to determine the compatibility of craniometric dimensions as part of a specific regression equation made it possible to construct many equations for predicting body length. However, then it was necessary to make a choice among the developed equations, considering their quality and accuracy. First, models were selected in the constructions of which there were many regressor signs (forecast efficiency is high when integrally considering factors interconnected with the reconstructed parameter). Another essential selection criterion was the focus on choosing such equations of multiple linear regressions, in which sizes from different anatomical regions of the skull would jointly act as predictors. This requirement was dictated by practical considerations regarding the examination of a fragmented skull since the presence of a defect automatically excludes some of the craniometric features from the general flow of potential determinants of body length. In case of fragmentation and extensive skull defects, the equations with regressors, which are measured in the perimeter of the skull destruction zone, jointly lose their service life. Considering the above limitations and requirements, we, using mathematical modeling, built regression equations separately for the skulls belonging to the male (total 34) and female (total 37) sex. After the procedure for calculating the statistical parameters of the equations and evaluating the forecast, the designed models were implemented into functioning ones. Some of the developed equations were presented by us in previous publications. In the same publication, we present the following 10 equations (five for each of the sexes) from our set of diagnostic models for predicting body length from the skull. Equations with the abbreviation K are intended for the study of male skulls, equations with the abbreviation Q for the study of female skulls:

K6. У = – 10,6749 + 0,2797xS3 + 0,1885xZ66 + 0,2392xZ3 + 0,056xM3 + 0,2301xZ67 + 0,3213xZ44 + 2,0926xM8 + 0,0795xS9 + 0,0288xM6 – 0,0592xZ35 + 3,865

K7. У = – 24,4835 + 0,2267xZ10 + 0,432xS2 + 0,1295xP9 + 1,828xM8 + 0,2042xM9 + 3,951

K8. У = – 1,3052 + 0,3923xS3 + 0,4365xZ46 + 0,6070xZ28 + 0,2972xZ43 + 1,5228xM8 + 0,0256xP8 + 0,0373xZ13 + 0,0627xM6 + 3,972

K9. У = 26,1981 + 0,1352xZ25 + 0,5237xS2 + 0,325xZ67 + 0,2129xZ15 + 0,234xZ7 + 0,1332xM7 + 4,374

K10. У = 8,5496 + 0,0847xS1 + 0,5739xS2 + 0,2198xZ24 + 0,5907xM13 + 0,2837xS7 + 0,0028Z70 + 4,588

Q6. У = – 84,4289 + 0,4977xM10 + 1,403xZ72 + 0,4384xM7 + 0,2407xZ15 + 0,3031xS7 + 5,144

Q7. У = – 123,4466 + 2,2363xZ72 + 1,1846xZ18 + 0,1422xS9 – 0,0051xP8 + 0,0058xM12 + 0,2965xZ5 + 0,1565xZ3 + 5,703

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Q8. $У = -98{,}6371 + 0{,}5976xM10 + 0{,}274xP9 + 0{,}572xM7 + 0{,}1515xZ15 + 0{,}1378xZ35 + 5{,}743$

Q9. $У = -43{,}7471 + 0{,}1807xZ12 + 2{,}2753xM13 + 1{,}1365xZ41 + 0{,}297xZ26 + 0{,}0737xZ5 + 5{,}786$

Q10. $У = -4{,}1474 + 0{,}3846xZ28 + 0{,}3167xZ26 + 0{,}5266xZ4 + 0{,}1592xZ1 + 1{,}3916xZ50 - 0{,}1963xZ35 + 6{,}106$

In equations, "L" is the parameter to be determined (i.e. body length), and the remaining numbers are the equation constant, as well as the regressor coefficients (craniometric features) and the standard error of the equation. The abbreviations M, P, Z and S denote various craniometric signs, the values of which are substituted into the equations for determining the length of a person's body from his skull. When developing our equations, we expressed the length of the body in centimeters, and the rest of the signs in millimeters. Therefore, the applied application of the formulas does not require the conversion of units - the dimensions of the skull are measured in millimeters (as is usually accepted in forensic anthropological examinations) and entered the corresponding model, while the value of the body length is obtained in centimeters.

Among all our equations, there are models that use 8 regressors (the minimum number of regressors is 5). The errors of the equations (the accuracy of predicting the length of an individual's body during life) range in these equations from 4 cm to 6.2 cm. To verify our equations, we used the cross-validation method. The skulls, which were submitted for examination of personality identification along with other parts of the skeleton, were also studied using the proposed equations. With a positive outcome of identification, we checked the accuracy of the coincidence of the real height of a person with the data obtained by our equations. We were able to conduct such cross-checking in 20 cases. Note that the correlation between real data on human height and predicted data was about r=0.8.

Discussion of the Research Results

When planning work to study the possibility of predicting the length of a human body from its skull, we, in addition to the messages listed above (see materials and methods), also relied on the features of the local anthropological type of the population. In previous studies [7,14] it was shown that most Azerbaijanis belong to the Caspian anthropological type (a local variant of the South-European race). Also, at the end of the last century, reliable methods for diagnosing local anthropological types of the population of the Caucasus by the skull were developed [7,15]. In the format of our study, we selected only skulls that belonged to the Caspian anthropological type. Diagnosis of the corresponding anthropological type was carried out according to the method of Professor Musaev Sh M [7]. It is known that each anthropological type also has characteristic features of the physique constitution. Therefore, we were guided by the logic that the search for relationships and modeling within a more permanent body configuration should have been more efficient.

Despite all the above arguments, we understood that our study would not have great prospects in view of the well-established (and already repeatedly proven) principles in anthropology about the best prediction of growth for long tubular bones. In the literature, we also found very few works that provide at least some information about determining the height of the skull, or the size of the head [4, 5, 16, 17]. Nevertheless, in our case there was an urgent need for such work since practice required at least some scientific data in the matter of determining the length of the body from the skull. Due to the presence of a military conflict on the territory of our country [16], 3890 people are listed as missing. When analyzing bone material from mass graves, considering the length of the body is very important in the segregation of skeletons. Our development was aimed at helping in this matter, since, in addition to a more reasonable set of skeletons, it would significantly help reduce the number of genetic examinations, which remain capital-intensive research.

Regarding the accuracy of the forecast using the proposed equations, we also note that our models were developed based on osteological material from people of average height (mostly). Table 2 above shows that the lifetime body length in the studied samples had an uneven distribution. The study sample consisted mainly of men and women of average height (their share was more than 75% of the total material studied). Therefore, it is possible that our diagnostic method will be less accurate when examining short or tall populations. The uneven distribution of skulls by age categories should also be pointed out. As can be seen from Table 1, the skulls of individuals whose age was in the range of 16-80 years were studied. But at the same time, there were very few skulls of elderly and senile age in general (in the combined group of men and women, the proportion of skulls corresponding to the age of over 60 did not exceed 14%). That is, the probability that in the study of skulls of elderly and senile age, the proposed equations will not detect the planned accuracy. However, it should be noted that senile skulls often have identification value. This is since in practice, missing people of young and middle age are more often searched for, and the discovery of the skull (or other bones) of an old person sharply narrows the circle of people suitable for the role of the "owner" of these bones.

However, speaking about the overall results of the work, we do not expect ideal results when using the proposed equations of multiple linear regression. It is possible that the use of all the equations we proposed for a specific forensic anthropological examination (a simple template for the simultaneous use of all equations when entering craniometry data is easily implemented in Microsoft Office Excel) and the determination of one average value from all the results obtained using these equations will be the most rational approach. Our practice shows that the average

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result for all equations is the closest to the true value of the lifetime length of the individual's body. In conclusion, we also note that our equations should be used in the study of skulls without anomalies (craniostenosis, deformities, etc.).

Conclusion

Some dimensional characteristics of the skull are interrelated by correlation-regression relationships with body length. This question was studied on the craniological collection from the territory of modern Azerbaijan. The results of the work showed that the relationship of some craniometric features with the length of the human body can be described using multiple linear regression equations. Considering these mathematical prerequisites, the corresponding diagnostic equations for practical application have been developed. However, these equations cannot be unconditionally recommended for general use due to certain limitations (statistical nuances in the development and insufficient level of verification). The proposed method is more focused on assisting in the examination of mass grave sites (for a more reasonable assembly of skeletons and reducing the number of genetic examinations). In some studies that do not have legal restrictions (anthropological studies, archaeological work, etc.), the proposed equations have applied value as an independent method for diagnosing lifetime body length.

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