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METHODS OF SEX ESTIMATION FROM THE CLAVICLES IN FORENSIC EXAMINATION OF BONE REMAINS

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ABSTRACT

One of the most complex problems in forensic medical expertise is the process of identification of unknown corpses and their parts, which very often include bone remains. Sometimes it is practically impossible to collect the data needed for police investigation because the most important parts of the skeleton such as skull, pelvic bones and long trabecular bones are absent. The aim of the study was to develop new methods for sex determination from the clavicle of an adult person based on the mathematical and statistical analysis of their osteometric properties. For this purpose bone samples from three skeletal collections were used: collection of the Department of Anthropology of Lomonosov Moscow State University; collection of the Department of Physical Anthropology of the Peter the Great Museum of Anthropology and Ethnography (St. Petersburg), and the The Robert J. Terry Anatomical Skeletal Collection stored at the Department of Physical Anthropology of the Smithsonian's National Museum of Natural History (Washington). The study demonstrated the possibility of correct sex determination from the clavicle using the five-interval diagnostic table suitable for quick sex assessment and multiple discriminant models with an accuracy of correct sex estimation between 85% and 97.5%. The methods described in the article can be applied not only in forensic context (especially when working with a limited set of isolated skeletal elements or their fragments), but also in the physical and medical anthropology for reconstructing an unidentified individual's biological profile.

Keywords – clavicle, sex estimation, multivariate discriminant analysis, forensic anthropology, human identification.

INTRODUCTION

Forensic examination of unidentified corpses and skeletal remains found in a variety of circumstances (e.g., mass disasters, homicide, infanticide etc.) present a significant problem for a medical examiner. The use of DNA analysis, osteological and radiological methods provides substantiated answers to a fairly wide range of questions related to the common and specific features of the victim's personality. The methods of forensic anthropology are widely used in forensic human identification around the world; unlike the methods of molecular genetics, they do not require complex equipment, expensive consumables, and much time for data processing. If bones are well preserved, sex determination generally does not pose significant difficulties. According to Iscan et al. [1], the accuracy of sex determination reaches almost 100% when all the skeletal elements are present. However, it should be noted that the forensic expert often has to deal with an incomplete set of fragmented remains, where such skeletal objects, significant for identification, as the skull, the pelvic bones, and even the long bones may be missing. In such cases, a valuable importance is given to the methods that involve teeth and such bones as vertebrae, ribs, hyoid bone, scapula, small bones of hands and feet. This list can be expanded if we mention the clavicle as one of the least studied (from the anthropological and forensic perspectives) human skeletal elements.

Currently, there is a significant increase in the number of research papers dedicated to sex identification from the clavicles, and most of them apply up-to-date mathematical statistics, which is of great importance for the forensic practice [2-7]. Thus, the accuracy of sex determination using the stepwise linear discriminant analysis in different populations varies from 70% to 95%.

THE AIM OF THE STUDY

was to develop new methods for sex determination from skeletonized clavicles using their osteometric measurements with subsequent mathematical and statistical processing of the measured data.

MATERIAL AND METHODS

Bone samples (right clavicles) from three skeletal series were used: series 1 – a collection of skeletons from the Department of Anthropology of Lomonosov Moscow State University (Russians, mid-20th century, N=83); series 2 – «Staraya Ladoga» (Russians, late 18th century, N=35) from the osteological collection belonging to the Department of Physical Anthropology of Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera); series 3 – The Robert J. Terry Collection (Caucasian Americans, 20th century, N=114) from the Department of Physical Anthropology of the Smithsonian's National Museum of Natural History, Washington, USA. The total number of bone samples examined was 232. The definitions of clavicle measurements follow the standard methodology [8]:

CLM-1. The total length of the clavicle: the distance between the most medial point of the sternal end of the clavicle and the most lateral point of its acromial end.

CLM-2. The length of the clavicle diaphysis at the posterior edge: the straight distance between the most medial point of the shoulder end at the posterior edge and the most dorsal point of the epiphysis.

CLM-3. The length of the diaphysis along the posterior surface: the length along the surface of the posterior edge of the bone from the most medial point of the humeral end to the most dorsal point of the epiphysis.

CLM-4. The length of the clavicle shaft: the distance from the sternal end of the clavicle to the most forward-protruding point of its diaphysis. The value is measured in parallel with the total length of the clavicle (CLM-1).

CLM-5. The clavicle circumference: the perimeter of the clavicle in the middle of the shaft. The measurement site is defined as half the total length of the clavicle.

CLM-6A. The sagittal diameter of the clavicle: the straight distance between the anterior and the posterior edges of the mid-shaft of the clavicle.

CLM-7A. The vertical diameter of the clavicle (clavicle thickness): the distance between the cranial and the caudal surfaces of the mid-body of the clavicle.

CLM-6. The largest diameter of the clavicle: the empirically determined maximum size at the mid-shaft of the bone.

CLM-7. The smallest diameter of the clavicle: the empirically determined minimum size at the mid-shaft.

CLM-8. The height of the clavicle shaft arc: the height of the most forward-protruding point of the anterior side of the clavicle shaft edge above the straight line connecting the most retracted points of the sternal and the acromial ends of the clavicle at its posterior side.

CLM-9. The height of the arc of the clavicle acromial end: the height of the most forward-protruding point of the anterior side of the clavicle acromial end above the straight line connecting the most retracted points of the sternal and the acromial ends of the clavicle at its posterior side.

CLM-8A. The depth of the sternal end arc: the projection distance from the deepest point of the sternal end arc to the tangent passing through the apex of the acromial end arc and the posterior edge of the sternal end.

CLM-9A. The depth of the acromial end arc: the projection distance from the deepest point of the acromial end arc to the tangent passing through the apex of the sternal end arc and the anterior edge of the acromial end.

CLM-10. The length of the deltoid tuberosity: the straight distance between the most anterior point of the clavicle acromial end to the most medial point of its deltoid tuberosity.

CLM-11. The width of the clavicle acromial end: the projection distance between the most protruding points of the ventral and the dorsal edges of the clavicle acromial end.

Osteometric measurements were collected using a standard sliding caliper, osteometric board, and millimeter measuring tapes. Computer data processing was performed using the StatSoft STATISTICA 10 and Microsoft Excel 2007.

RESULTS AND THEIR DISCUSSION

Sex determination using the univariate discriminant analysis. Univariate discriminant analysis (UDA) involves creation of a five-interval evaluation scale (chart) based on a certain number of differential osteometric parameters calculated by descriptive statistics using the following formulas:

1. Reliably male interval: $>X_{♀} + 3,3σ_{♀}$;
2. Probably male interval: $X_{♀} + 1,54σ_{♀} – X_{♀} ≤X +3,3σ_{♀}$;
3. Indefinite interval: $X_{♂} - 1,54σ_{♂} – X_{♀}+1,54σ_{♀}$
4. Probably female interval: $X_{♂}-3,3σ_{♂} – X_{♂}-1,54σ_{♂}$
5. Reliably female interval: $<X_{♂} - 3,3σ_{♂}$

Table 1 shows a one-dimensional model for sex determination, using 13 standardized measurements of the right clavicle. This model is configured as a simple-to-use diagnostic chart and can be regarded as a «quick» method, which does not require any time-consuming calculations. Sex determination using this model implies three types of solutions:

1. Practically reliable (correct classification accuracy – 85%): applies when one or more measurements fall within the reliable intervals of the scale, or when 9 and more measurements fall within one of the probable intervals of the scale.
2. Probable (correct classification accuracy<85%): applies if none of the requirements listed in clause 1 apply or if the difference between the number of measurements in the «probably male» and the «probably female» intervals is 4 and more. If all the measurements qualify as probable, the sex is determined based on their absolute count.
3. Indefinite: applies if all the measurements fall within the indefinite interval or if the difference between the number of measurements in the «probably male» and the «probably female» intervals is three and less. In this case, the model should be refused, and it is recommended to continue the procedure using a larger set of measurements or applying a multivariate discriminant analysis (MDA).

Table 1. Sex estimation from the clavicle using the univariate discriminant analysis

Measurements	Female		Undetermined intervals, mm	Male	
	Reliable intervals, mm	Probable intervals, mm		Probable intervals, mm	Reliable intervals, mm
CLM1	≤127,4	127,5-140,6	140,7-147,5	147,6-160,0	≥161,0
CLM4	≤33,9	34,0-44,9	45,0-57,0	57,1-67,1	≥67,2
CLM5	≤28,5	28,6-34,0	34,1-38,8	38,9-44,1	≥44,2
CLM6	≤9,2	9,3-11,6	11,7-13,3	13,4-15,4	≥15,5
CLM6A	≤7,6	7,7-10,4	10,5-12,8	12,9-14,9	≥15,0
CLM7	≤6,5	6,6-8,4	8,5-10,0	10,1-11,7	≥11,8
CLM7A	≤7,1	7,2-9,3	9,4-11,6	11,7-13,9	≥14,0
CLM8	≤19,5	19,6-25,7	25,8-32,0	32,1-37,3	≥37,4
CLM8A	≤9,3	9,4-14,1	14,2-21,2	21,3-26,3	≥26,4
CLM9	≤20,3	20,4-27,7	27,8-34,1	34,2-39,1	≥39,2
CLM9A	≤2,4	2,5-8,8	8,9-16,7	16,8-20,6	≥20,7
CLM10	≤30,0	30,1-38,9	39,0-50,8	50,9-60,0	≥61,0
CLM11	≤14,1	14,2-19,7	19,8-25,7	25,8-30,5	≥30,6

The data obtained supplement the available information on the individual variability of the clavicle osteometrics [6]. It should be noted that the accuracy of sex determination using the UDA method is lower than with the multivariate methods. However, if the skeletal remains are very fragmented, this method is the only available so far. To establish the degree of correlation between the sex constant and the measured osteometric parameters, a correlation analysis was conducted that showed a statistically significant correlation (P-value = 0.01) for all the measurements studied, except for CLM-9A. Later on, these measurements were selected to plot multi-dimensional diagnostic models.

Sex determination using the multiple discriminant analysis. Using the multiple discriminant analysis (MDA), 6 diagnostic models for sex determination were calculated. They can be divided into two groups: models with an extended and a reduced set of measurements that have the maximum achievable accuracy from 96.3% to 97.5%. In all cases, the models for which the Wilks' lambda value does not exceed 0.27 were selected. The coefficients of the discriminant functions (models) are presented in Table 2.

Table 2. Sex estimation from the clavicle using the multiple discriminant analysis

Measurements	Coefficients											
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
CLM-1	4,303	4,055	4,329	4,088	4,339	4,096	3,320	3,047	3,622	3,330	3,615	3,323
CLM-2	-1,082	-1,145	-0,941	-0,972	-0,960	-0,989						
CLM-3	0,178	0,216										
CLM-4	0,843	0,692	0,845	0,694	0,848	0,697	0,850	0,699	0,685	0,544	0,685	0,543
CLM-5	0,429	0,360	0,448	0,383								
CLM-6	-0,198	-0,577	-0,234	-0,622	0,416	-0,066	1,086	0,624	1,991	1,474	2,543	2,002
CLM-6A	-1,488	-0,994	-1,566	-1,089	-1,674	-1,182	-2,622	-2,157	-2,656	-2,190	-3,691	-3,179
CLM-7	8,833	7,974	8,882	8,034	9,418	8,492	9,585	8,664	9,339	8,433	10,048	9,111
CLM-7A	3,831	3,464	3,822	3,452	3,974	3,583	4,824	4,458	3,692	3,394	2,781	2,524
CLM-8	6,899	6,020	6,919	6,045	7,020	6,131	7,388	6,509	6,948	6,096	6,421	5,592
CLM-8A	-5,781	-5,106	-5,699	-5,006	-5,764	-5,061	-5,907	-5,209	-5,591	-4,912	-4,875	-4,227
CLM-9	1,613	1,304	1,644	1,341	1,642	1,339	1,563	1,258	1,684	1,372	2,713	2,356
CLM-9A	2,735	2,650	2,753	2,672	2,768	2,685	2,213	2,113	2,045	1,956		
CLM-10	0,587	0,543	0,582	0,537	0,602	0,555	0,732	0,688				
CLM-11	2,239	2,005	2,201	1,959	2,218	1,974	2,354	2,114	2,329	2,090	1,927	1,706
Constant	-494,562	-403,006	-494,502	-402,916	-494,351	-402,806	-487,752	-395,804	-483,737	-392,259	-474,957	-384,232
Correct classification accuracy, %	97,5						96,3					

To work with these models, the researcher needs to substitute the values of the measured variables into the equations and solve them. For example, the Model 1, written in a linear form, will look as: Y=CLM-1*4,303+CLM-2*(-1,082)+CLM-3*0,178+CLM-4*0.843+...+(-494,562). The highest value of the function determines the sex of the bone. The probability of referring the studied case to the male or the female population is determined by the value of the $Pl=1/(1+e^{-l})$ function relative to l. To do this, one should select the maximum of the two obtained values of the discriminant Y-function and subtract the minimum one from it. The resulting difference will correspond to l, knowing which it is possible to determine the reliability level of the solution by the table of P1 function values [9, *248-277*].

Expert conclusions can be formulated as one of three options:

1. The solution is reliable if: 1,0>Pl≥0,95
2. The solution is probable if: 0,95>Pl≥0,75
3. The solution is rejected if: Pl<0,75

Sex determination using canonical discriminant analysis. Calculations of diagnostic canonical functions (Table 3) were carried out on a combined sample of clavicles from Series 1 and 3. They solve the problem of discrimination within the same equation and are more labor-efficient. The probability of attributing an expert case to male or female groups is done in two stages: first approximately, focusing on the values of the group centroids (GC), then by the values of the Pl function. To do this, it is necessary to subtract the values of the indicator SP (Section Point, the value of the dividing plane of male and female groups) from the resulting function value, which is the arithmetic mean of two GC in each function. The resulting difference corresponds to l, by which the probability level of the Pl function is searched for and the corresponding expert conclusion is accepted (similar to the one described above).

Table 3. Sex estimation from the clavicle using the multiple canonic discriminant analysis

Measurements		**Diagnostic Coefficients**		
		CDA 1	**CDA 2**	**CDA 3**
CLM-1		-0,10675	0,0990	-0,10565
CLM-5		-0,19195	0,1386	-0,11495
CLM-8			0,1299	-0,22107
CLM-8A				0,13548
CLM-9		-0,11820	0,1386	-0,13424
Constant		26,15485	-27,5511	27,80095
Canonic correlation		0,808	0,829	0,837
Group centroids	♂ ≥	-1,276	1,383	-1,426
	♀ ≤	1,439	-1,560	1,608
Correct classification accuracy, %	♂	88,63	93,18	95,4
	♀	94,87	94,87	97,5

CONCLUSION

The study showed the possibility of sex determination from clavicles using osteometric approach. The methods described above make it possible to determine the sex using an extended or a reduced set of measurements, which is especially crucial when working with a limited number of bones or their fragments.

AUTHOR CONTRIBUTIONS

Dmitry Sundukov designed the study; Askold Smirnov collected, analysed, interpreted data and provided the tables. Askold Smirnov and Dmitry Sundukov prepared the manuscript for submission.

REFERENCES

1. Iscan M. Y., Steyn M. The Human Skeleton in Forensic Medicine. Charles C. Thomas Publishers, Springfield. 2013.
2. Akhlaghi M., Moradi B., Hajibeygi M. Sex determination using anthropometric dimensions of the clavicle in Iranian population // J. Forensic Leg. Med. – 2012. Vol. 19, No 7. – P. 381-385. DOI: https://doi.org/10.1016/j.jflm.2012.02.016
3. Demir U., Etli Y., Hekimoglu Y. , Kartal E., Keskin S., Yavuz A., Asirdizer M. Sex estimation from the clavicle using 3D reconstruction, discriminant analyses, and neural networks in an Eastern Turkish population // Leg Med (Tokyo) – 2022. Vol. 56. – P. 102043. DOI: 10.1016/j.legalmed.2022.102043
4. Koukiasa A.E., Eliopoulos C., Manolis S.K. Biometric sex estimation using the scapula and clavicle in a modern Greek population // Anthropol Anz. – 2017. Vol. 74, N3. – P. 241-246. DOI: 10.1127/anthranz/2017/0658
5. McCormick W.F., Stewart J.F.I., Greene I.T. Sexing of human clavicles using length and circumference measurements // Am. J. Forensic. Med. Pathol. – 1991. Vol 12, No 2. – P. 175-181. DOI: 10.1097/00000433-199106000-00017
6. Sehrawata J.S., Pathakb R.K. Variability in anatomical features of human clavicle: Its forensic anthropological and clinical significance // Translational Research in Anatomy. – 2016. Vol. 3–4, P. 5-14. DOI: https://doi.org/10.1016/j.tria.2016.08.001
7. Shirley N.R. Age and Sex Estimation from the Human Clavicle: An Investigation of Traditional and Novel Methods. Dissertation, University of Tennessee, Knoxville. 2009.
8. Voroncova E.L. Morfologicheskaja izmenchivost' kostej plechevogo pojasa i grudiny cheloveka. Avtoreferat dissertacii kand. nauk. M., 2005. [In Russ.].
9. Urbah V. Ju. Statisticheskij analiz v biologicheskih i medicinskih issledovanijah. M., 1975: 297 p. [In Russ.]

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