Institute of Experimental Morphology and Anthropology

Acta morphologica et anthropologica, 6
Sofia • 2001

Numeral Procedures for Stature Estimating According to Length of Limb Long Bones in Bulgarian and Hungarian Populations

K. Tenekedjiev, D. Radoinova***

* *Department of Economics and Management, TU, Varna*
** *Department of Forensic Medicine, MU, Varna*

The purpose of the current study is to create numerical procedures for assessment and predicting the human stature by the length of one of the three long pipe bones — humerus, fibula and tibia, as well as by a combination of humerus and tibia. The procedures are applied to our own corpse measurements, arranged in four samples: 129 Bulgarian women and 286 Bulgarian men, 84 women and 186 men of Hungarian origin. New formulas of stochastic dependence between the variables observed are derived. Six different approaches concerning age correction are applied. Based on single samples 96 cases of different regression dependencies are built (4 tasks times 4 samples times 6 correction methods). The outliers are rejected in each regression then the regression is tested for heteroskedasticity using 11 tests. Whenever we detect heteroskedasticity, we try to remove it by using a dispersion model. There are also built 144 cases of regression dependencies based on two samples united by sex, nationality and both (4 tasks times 6 couples of samples times 6 corrective methods). The stability of the coefficients is calculated by 4 tests according to 7 theories. The applicability of the best known formulas for the samples studied in both populations is evaluated.

Key words: stature estimation, long bones, forensic anthropology, human identification, multiple regression.

Introduction

One of the obligatory stages of forensic osteological expertise of bones and bone remains is determining the living stature of the individual. A lot of formulas and tables are known made for this aim, based on length measurements of different bones. The fundamental dependence on which all similar calculations stand is that long bones preserve a relatively constant correlation with the lengths of the limbs as well as with the length of the whole body [11, 17]. Moreover, it has been established that the correlation stature/bones length is stable for a given population and characterizes it [2, 14]. This makes possible to calculate and predict stature by the length of skeleton bones. There are numerous studies in this field, which do not give determined connection between the observed quantities since the development of human organs and systems has specific peculiarities in particular and various factors influence the phenomenon known as stature as a whole: social, economic, racial, hereditary, evolutionary, nutrition, standard of living et al. [12]. Researchers of different historical periods have worked with different basic data: human skeletons [14, 15], corpses [11, 19] or measurements of living humans [2]. In the opinion of the researchers the stature estimations are most precise when applied to individuals of the same population. The common use of these results for other peoples sometimes leads to considerable inaccuracies and deviations in height determining, because of population differences, acceleration et al. Apart from the anthropological significance these formulas have also practical application especially in the field of forensic medicine— in the personality identification expertise. The inaccuracies and deviations already mentioned are extremely undesirable in this case and may have serious consequences of legal nature.

In Bulgaria this problem has not attracted scientific interest apart from measuring of post mortem stature and lengths of right tibiae in 100 forensic cases done by [18]. Unfortunately the purpose of the investigation did not include large-scale observation; only the necessity of wide osteoanthropometrical investigations has been stressed.

For the needs of forensic osteological expertise and anthropology sciences we set ourselves the task of measuring the height of corpses parallel to the measuring of three limb long bones — humerus, fibula and tibia. The results are a base for creating regression equations of our own, but they also help us when compare them to other similar measurements. Along with this it is possible to make an evaluation for the applicability and exactness of some known formulas as regards to Bulgarian and Hungarian populations, as well as to examine the possibilities for calculation of dependencies about the two populations at the same time.

Material and Methods

All measurements were made on forensic corpses in the dissection hall of the department of forensic medicine, Medical University — Varna and at the University of Legal Medicine — Budapest, Hungary. The measurements were made before the autopsies the cases having been selected so that the cause of death should not affect body height and body part proportions. In this way we eliminated the cases caused by traumas and processes of different origin (railway-, auto- and agricultural traumas, falling from a great height, burns, etc). The age interval of the cases is between 20 and 66 years, and we relied on the fact that bones and body growth had been practically finished in the lower age border while at the upper border there do not exist any obvious deforming processes of the spine and joints of the limbs. Stature measurements were being made in supine position on the dissection table, which is adapted and ruled like an anthropometer. The lower elevated edge of the table, where the heels of the cadaver touch it, serves as a fixed shoulder, and the long part of the metallic schubler serves as an upper mobile shoulder. Before the measuring we cut off Achilles tendon. The reading of the stature is with an allowance of 5 mm. The arm and upper limb bones are measured with a metallic schubler 500mm long with an allowance of 0.1 mm. Whole or physiological length is measured of humerus and tibia and maximal or lateral length of fibula. Bone lengths are measured right and left so as to check for bilateral asymmetry.

It is known that after the age of 45-50 years the decline of maximal human stature begins, which depends on a number of factors, including maximal stature, bone-mineral status, inter-vertebral disc changes et al. [5]. In reading of the age loss of length we used data from many authors [1, 3, 4, 5, 6, 8, 16]. Summarizing these data, differentiated by sex, we include them in our procedure.

The “stature- limb long bones length” dependence is accepted as linear in all of the literature used. This approximation is confirmed by our results. The connections needed are searched using the regression analysis method. It is necessary to point out, that we use the mean lengths of the right and left bone as independent variables in the learning samples. Thus the practical use of the dependencies derived is improved and one can predict the stature by only the left, only the right bone as well as both of them. The predicted stature values concern the maximal stature of the individual aiming to minimize the influence noise factors. The regression analysis is made using modern original software in which the solving of the optimization task is searched by singular value decomposition (SVD). As mentioned in [10]: "SVD can be significantly slower than solving the normal equation, however, its great advantage, that it (theoretically) cannot fail...". The singular values are discriminated to zeroes and non-zeroes by specially developed algorithm that compares the direction and the magnitude of two vectors as generalization of the ideas in [13]. The estimation of the regression coefficients is the final purpose of the regression analysis task by minimization by the least square (LS) method. It is also necessary to: 1. Calculate: a) standard and adjusted coefficient of multiple determination (R^2; adjusted-R^2); b) predicted values of the model; c) LS residuals, predicted residuals and studentizied residuals; 2. Evaluate the confidence intervals: a) of the coefficients; b) of the standard deviation; c) of the predicted values; d) of the residuals. 3. Perform a series of statistical tests for: a) zero value of the individual coefficients; b) adequacy of the model compared to the constant one; c) testing if each observation belongs to the sample (outlier tests); d) heteroskedasticity tests; e) error model adequacy tests; f) heteroskedasticity tests of the homogeneous transformed model; g) coefficient stability tests when combining two different samples. Each of these tasks has many different solutions in literature [9]. The difficulty comes from the fact that the regression task is not solved in a holistic manner but partial solutions of different problems are suggested, for example heteroskedasticity testing in precondition of rejected outliers. The task of the experimentalist is to arrange the solving of the different tasks in the proper consequence. This requirement is often unrealistic because the experimentalist (forensic physician, anthropologist) is not a statistical specialist. Therefore we suggest two automatic procedures for structuring of regression dependence over one and over two samples.

A. One sample procedure :

I. *Sample formation.* A choice of one out of four types of regressions of stature of humerus, of stature of fibula, of stature of tibia or of humerus and tibia is made. One out of four samples is chosen: Bulgarian male, Bulgarian female, Hungarian male or female. One out of sixth methods for age correction of stature is selected: five according to the authors' cites and one with no correction. For each observation of the sample the stature is increased by the age correction calculated for each individual concerned to estimate its maximal height.

II. *Outliers' rejection.* Linear regression is built for each observation of the sample using the rest of the observations in the sample. Linear regression helps us to predict observation height value using a preliminary chosen significance level. After calculating the last regression we reject all the observations from the sample whose height value measured does not lie in the derived confidence interval. The procedure is repeated until either a predetermined number of loops are executed, or some loop does not reject any outliers.

III. *Heteroskedasticity tests.* Because there is not full unity of terminology we will use the one mentioned in [9].

1. Linear regression is built over the sample, and the residuals are calculated in each point of it.

2. Five types of tests are performed as follows: RESET (Ramsey) test, White-tests

(squared, linear), Glejser tests (linear, reciprocal and root), Goldfeld and Quadt tests with equations concerning two groups (with smaller and bigger standard error), Breusch and Pagan tests (squared, linear, reciprocal and root). These 11 sub-tests compare the calculated P-value with preliminary chosen significance level for heteroskedasticity. Goldfeld and Quadt test compares with F-test the divided into two parts sample at the bigger and smaller variances. Each of the other tests aims to build dependence between residual function and regressors function using linear in its parameter model. The so built models are tested for adequacy using the classical ANOVA test and the null hypotheses for homoskedastisity is equivalent to the hypothesis for adequacy of the constant model.

IV. *Heteroskedasticity removal*

1. If statistically significant heteroskedasticity is available, then four models (linear, squared, reciprocal and root type) of the residual module as function of the regressors are built (that cover the ANOVA test). The model with the biggest corrected multiple determination coefficient is selected of all adequate models (which must not be smaller than a preliminary chosen adjusted multiple determination coefficient).

2. If adequate residual model is available in each observation of the sample the module of the residuals is evaluated and a new regression dependence is built using the method of the weighted least squares (WLS) with reciprocal values of the modules evaluated used as weighting factors [7]. Otherwise it is considered that statistically significant heteroskedasticity is unexplainable using regressors and therefore neglected from the practical point of view.

3. In case of calculated WLS the tests for heteroskedasticity are repeated as in III.1 and III.2.

V. *Model building*

1. Regression dependence is built over the screened sample with removed heteroskedasticity if necessary.

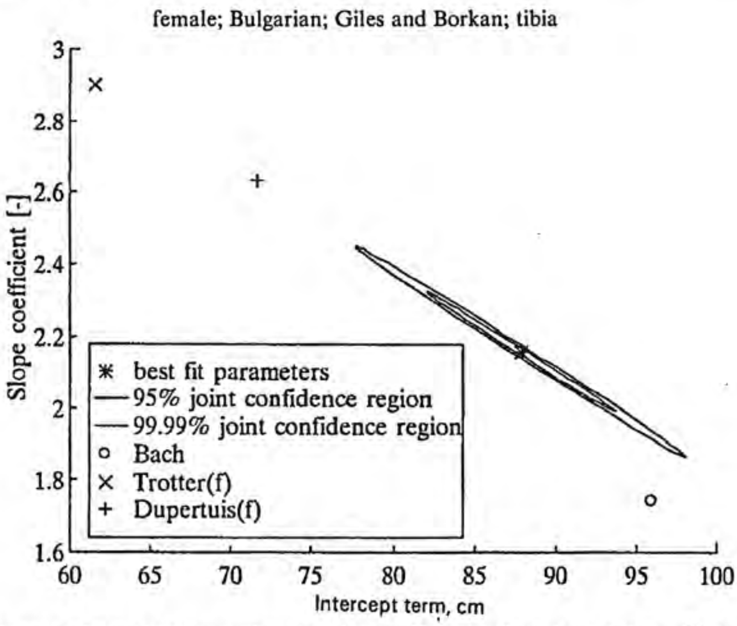

Fig. 1. Confidence regions of the regression equation coefficients of maximal stature of Bulgarian female by the tibia length with age correction using Giles and Borkan and comparison with some famous formulas

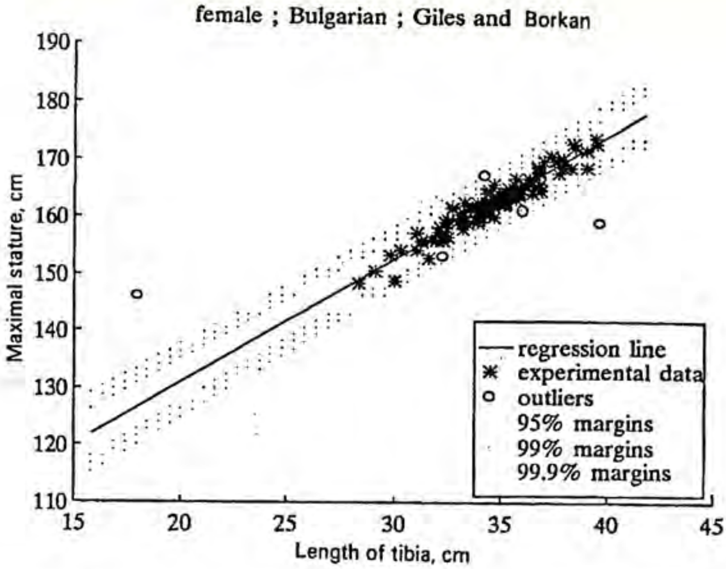

Fig. 2. Monogram of the maximal stature of Bulgarian female by the tibia length with age correction using Giles and Borkan

2. The coefficients of the model are calculated, as well as the standard deviation and one t-test for significance for each of the coefficients is performed. Assessment of the main standard error is calculated as well as a confidence interval for its margins. ANOVA test for adequacy of the model is also performed. The significance level is preliminary chosen.

3. Covariance matrix of model coefficients is calculated and the probabilities for each of the following famous formulae to describe adequately the sample observed [10]. We estimate the applicability and the accuracy of the following formulas: Trotter and Gleser - for humerus, fibula and tibia and humerus and tibia together in both sexes, Breitinger - for humerus and tibia in males and Dupertuis and Hadden - for humerus and tibia in both sexes. Multi-attributive confidence region for the model coefficients are built the significance levels being preliminary chosen (Fig.1). The last are visualized together with the points corresponding to the referative formulas mentioned before as projections over the coordinate planes of the coefficient space.

4. In case of one regressor a monogram is built including: a/ regression dependence; b/ sample observations over which the regression dependence is built; c/ rejected outliers and d/ confidence intervals (using different significance levels preliminary chosen) of the predicted values (Fig.2).

VI. *Model using.*

1. In case of given regressor(s) and age, the predicted value of maximal stature is calculated, as well as the basic level of the standard error in the point given using residuals transformational model. On its base a number of significance intervals are calculated using preliminary chosen significance level (Fig. 3).

2. The stature age correction is calculated according to the method chosen in the building of the sample.

3. The maximal stature and confidence intervals is decreased by the correction calculated and the actual height and its confidence intervals are estimated.

Predicting the stature using humerus and tibia length in 67 year old Bulgarian male with age correction using Giles and Borkan

Sample:

Nationality	Bulgarian
Sex	Male
Regression on	Humerus and Tibia
Age correction	Giles and Borkan

Individual:

Sex	Male
Humerus	36.2 [cm]
Tibia	39.8 [cm]
Maximal Stature	179.4 [cm]
Age	67.0 [years]
Age Correction	1.86 [cm]
Corrected Stature	177.5 [cm]

Confidence Margins:

	Lower Stature	Upper Stature
95.0% (maximal)	176.3 [cm]	182.4 [cm]
99.0% (maximal)	175.4 [cm]	183.4 [cm]
99.9% (maximal)	174.2 [cm]	184.5 [cm]
95.0% (corrected)	174.5 [cm]	180.5 [cm]
99.0% (corrected)	173.5 [cm]	181.5 [cm]
99.9% (corrected)	172.4 [cm]	182.6 [cm]

B. Two samples procedure

I. *Sample formation.*

1. A choice of one out of four types of regressions and one out of six age correction models is made as mentioned in A.I.1. One out of six couples samples are chosen: Bulgarian and Hungarian male, Bulgarian and Hungarian female, Bulgarian male and female, Hungarian male and female, Bulgarians and Hungarians or male and female.

2. For each observation of the sample the stature is increased by the age correction calculated for each individual concerned to estimate its maximal height.

II. *Outlier's rejection.* The outliers are rejected separately from the first and from the second sample (using the algorithm described in A.II).

III. *Heteroskedasticity testing and rejecting.* Using the algorithm described in A.III and A.IV over united sample.

IV. *Stability testing.* We use terminology of [8] here as well.

1. Three regressions of pooled sample are built as well as the two separate samples. If need of WLS (see point A.IV.1), then the residual model derived from the united sample is used in all three cases.

2. F-test for equality of the variances of the separate samples is performed using preliminary chosen significance level for this pre-test.

3. Three stability tests are made: ANOVA test for coefficient equality of the two models, predicted Chaw test based on the bigger sample and predicted Chaw test, based on the smaller sample. Result interpretation of these F-tests is not simple because all three tests may be viewed as a problem for selection of regressors using dummy variables. Except for the classical comparison with preliminary chosen significance level, six other types of answers of every one of the tests are given according

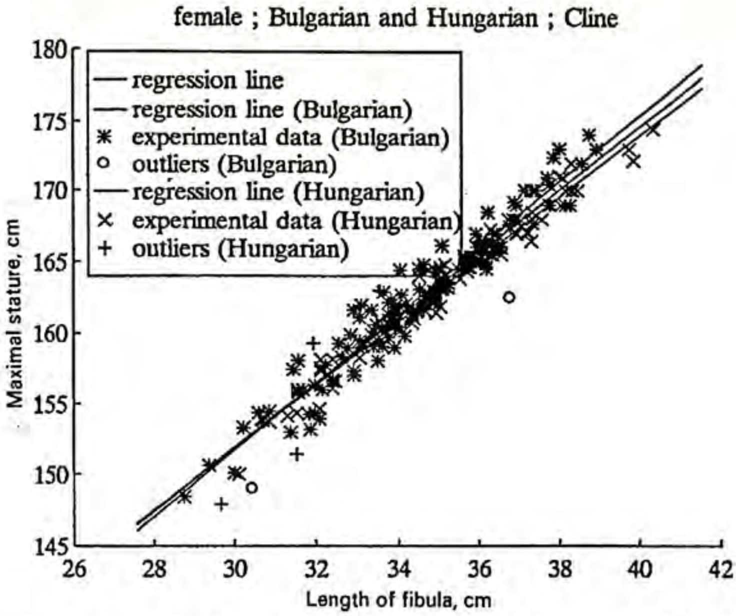

Fig. 3. Maximal stature regression in two samples of Bulgarian and Hungarian male by fibula with age correction using Cline

to different criteria, evaluating the problem for selection of regressors [8]: maximum of the adjusted multiple determination coefficient, three criteria minimizing the mean squared error of prediction (Cp of Mallows, Sp of Hockins and PC of Amemiya), information criteria of Akaike and Baeyes posterior relation of Leamer. The latter is most appropriate for the case observed because with a sufficiently large sample every null hypothesis can be rejected applying classical approaches.

4. In case of one regressor a visualization of stability tests is built by plotting: a) three regression dependencies from the two samples, and from the pooled data ; b) observations from the first sample over which regression dependency is built; c) rejected outliers from the first sample; d) the observations from the second sample over which regression dependency is built and e) rejected outliers from the second sample (Fig. 3)

V. Building and using the model: the algorithms from A.V and A.VI over the united sample are used.

Result and Discussion

A program system (written in MATLAB 4.2c1) is built based on the previously discussed algorithms which consists of 19 main and 3 auxiliary programs that interact using the 246 data files system. The so structured software can: 1) maintain the sample data base; 2) visualize the different methods for age correction of the stature; 3) linear model chosen. 2. The well known formulas have adequacy probability of the actual samples less than 10^{-5} which shows the necessity to read the population peculiarities as well as secular changes; 3. Heteroskedasticity in almost all cases is statistically significant, but practically negligible which shows stable variance regardless of the length of the bones. 4. High degree of multicollinearity is detected that indicates the necessity to use only one or two regressors in estimating the stature using the methods that are employed in the system 5. The stability of two arbitrary samples is low and just in case of unknown nationality the regressions built over Bulgarian and Hungarian males and over Bulgarian and Hungarian females are to be used as an exception. 6. In case of unknown sex it claims to be a better way to give conditional sex predictions compared to a method based on mixed sex sample. 7. Giles and Borkan give most adequate results for age correction of the stature.

Acknowledgements. I wish to thank all the colleagues of the Institute of Legal Medicine in Budapest, Hungary for the collaboration and to Natalia Nikolowa and to Damian Ialamov for the technical support.

References

1. Borkan, G. A., D. E. Hults, R. J. Glynn. Role of Longitudinal Change and Secular Trend in Age Differences in Male Body Dimensions. — Hum. Biology, **55**, 1983, No 3, 629-64.
2. Breitinger, E. Zur Berechnung der Körperhöhe aus den langen Gliedmassenknochen. — Anthropol. Anz., **14**, 1938, No 3/4, 249-274.
3. Cline, M. G., K. E. Meredith, J. T. Boyer, B. Burrows. Decline of Height with Age in Adults in a General Population Sample: Estimating Maximum Height and Distinguishing Birth Cohort Effects from Actual Loss of Stature with Ageing. — Hum. Biology, **61**, 1989, No 3, 415-425.
4. Friedlaender, J. S., P. T. Costa, Jr., R., Bosse, E. Ellis, J. G. Rhoads, H. W. Stout. Longitudinal Physique Changes Among Healthy White Veterans at Boston. — Hum. Biol., **49**, Dec. 1977, No 4, 541-558.
5. Galloway, A. Estimating Actual Height in Older Individual. — J. Forensic Sci., **33**, 1988, No 1, 126-136.
6. Giles, E. Corrections for Age in Estimsting Older Adults' Stature from Long Bones. — J Forensic Sci., **36**, 1991, No 3, 898-901.
7. Gujarati, D. N. Basic Econometrics. Third edition. McGraw-Hill, Inc., 1995.
8. Hertzog, K. P., S. M. Garn, H. O. III Hempy. Partitioning the Effects of Secular Trend and Ageing on Adult Stature. — Am. J. Phys. Anthropol., **31**, 1969, No 1, 111-115.
9. Maddala, G. S. Intoduction to Econometrics, Macmillan Publishing Company, 1988.
10. Press, W. et al., Numerical recipes in FORTRAN: the Art of Scientific Computing. Second Edition. Cambridge University Press, 1992.
11. Rollet, E. De la mesuration des os longs des membres dans ses rapports avec l'Anthropologie la Clinique et la Mèdicine judiciaire. Lyon, 1888.
12. Steckel, R.H. "Stature and Standard of Living". — J. Econ. Lit., **33**, 1995, 1903-1940.
13. Tenekedjiev, K., N. Karakatsanis, A. Bekiaris. FICTITIOUS COVARIANCE MATRICES. — In: Proc. of the Fourth International Conference, Adaptive Computing and Design and Magnifacture ACDM 2000, 23-26, Plymouth, UK, 20009.
14. Trotter, M., G. C. Gleser. Estimation of Stature from Long Bones of American Whites and Negroes. — Am. J. Phys. Anthropol., **10**, 1952, No 4, 463-514.
15. Trotter, M., G. C. Glassier. A Re-evaluation of Estimation of Stature Based on Measurements of Stature Taking During Life and of Long Bones after Death. — Am. J. Phys. Anthropol., **16**, 1958, No 1, 79-124.
16. Trotter, M., G. Gleser. The Effect of Ageing on Stature, Am. J. Phys. Anthropol., **9**, 1951, No 3, 311-324.
17. Бец, В. А. Об отношении величины костей человеческого скелета к длине его в различные возрасты. — Врач, 1886, 3, 64.
18. Дойчинов, И. К. Попов, И. Станева. Определяне на ръста по тибията при българското население.— В: IV нац. конф. съд. медици и криминалисти в Б-я, (С, 4-5.X.1986). Резюмета, 1986, с.21.
19. Найнис, И. -В. Идентификация личности по проксимальным костям конечностей, Вильнюс, Минтис.