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3. Reconstruction of body height, body mass and body shape in fossil and historical human populations

Introduction

The problem of body size and shape in Homo sapiens and hominid evolution has been discussed in detail by many authors during last decade (see e.g. Holliday 1977, McHenry 1991, 1992 a, b, Porter 1999, Ruff and Walker 1993, Ruff et al. 1997, Vančata 1988, 1989, 1991, 1996, 1997, Vančata and Charvátová in press). There are numerous theoretical and methodological studies concerning body size and shape description demonstrating also different approaches to this problems that are in primatology and anthropology (c.f. e.g. Aiello and Dean 1990, Bogin 1993, Cieślik 1979, Falkner and Tanner 1985, 1986, Karlberg 1987, Kaczmarek 1995, McHenry 1992 b, Ruff 1991, 2000, Tanner 1962, Vančata 1996, 1997). One of the most important problem is not the reconstruction of the body size and shape but the reliability of the estimates of body height and body mass (c.f. e.g. Boldsen 1984, Formicolla 1983, 1993, Formicolla and Franceschi 1996, Formicolla and Giannecchini 1999, McHenry 1988, 1991, 1992 a, b, Ruff 1991, Vančata 1996, 1997).

After several years of a detail study of this problem and the detailed testing of individual methods of body height and body mass estimates we have proposed a new approach to the reconstruction of the body size and body shape (Vančata 1996, 1997, Vančata and Charvátová in press, see Tables 1, 2, 3) that does not depend on one method of reconstruction being based on the probabilistic approach. Before the detailed discussion of our approach and basic methods we should discussed problems and advantages of the body height and body mass estimates in general including a brief review of their history.

Methods of the body height estimates

Reconstruction of a body height of fossil hominids is in an important research topic of anthropologists for more then hundred years (Pearson 1899). Similarly, the forensic medicine and anthropology deals with this problem for many decades (e. g. Allbrook 1961, Breitinger 1937, Dupertius and Hadden 1951, Lorke et al 1953, Stevenson 1929, Trotter and Glasser 1952, 1958 as representative classical studies). Body height has been estimated by numerous authors using various regression methods for most various human, hominid, hominoid and general higher primates samples (e.g. Aiello and Dean 1991, Allbrook 1961, Bach 1965, Breitinger 1937, Dobisíková et al. 2000, Dupertius and Hadden 1951, Feldesman and Fountain 1996, Feldesman and Lundy 1988, Feldesman et al 1989, 1990, Formicolla 1983, 1993, Formicolla and Franceschi 1996, Formicolla and Giannecchini 1999, Geissman 1986, Genoves 1967, Helmuth 1968, Holland 1995, Jungers 1988 b, McHenry 1991 b, Olivier

1976 a, b, Olivier et al 1978, Rösing 1983, Schmid 1983, Scieulli and Giessen 1993, Sjøvold 1990, Telkä 1950, Trotter and Glasser 1952, 1958).

Unfortunately, there had not been any attempt to test a large sample of methods for the body height estimate *an block* on various human, hominid, ape and mixed samples,. Consequently, it had been difficult to evaluate advantages and disadvantages of individual methods and it was necessary to make such analysis for the purposes of studies of body size and shape reconstruction of fossil human, early hominid and ape samples. Naturally, this analysis has been the most important for the study of fossil and historical human skeletal samples.

We have revised on our sample of long bones of several thousands individuals of Homo sapiens, fossil hominids and apes more than 200 regression equations for the body height estimates (Tables 4 a, b, c represent about half of the examined equations, most of them belongs among the frequently used equations by paleoanthropologists and historical and forensic anthropologists). 70 most confident and reliable equations had been analysed in detail. We have examined variability, and random fluctuation of the result, variation and the degree of confidence of the estimates for the tall and small Homo sapiens populations. The results have been checked in recent, historical and fossil human skeletal samples and in recent apes.

Only some of the selected 70 equations gave us confident and representative results for various different samples and, the same time, they were sufficiently robust against random fluctuation (Feldesman and Fountain 1996, Feldesman et al 1989 and 1990, Jungers 1988b, Olivier 1976 b, Sjøvold 1990, see discussion e.g. Aiello and Dean, 1989, Feldesman 1993, Feldesman and Fountain 1996, Feldesman and Lundy 1988, Formicolla and Franceschi 1996, , Jacobs 1993, Jungers 1982, 1988b, McHenry, 1991 a, Sjøvold, 1990), which is especially important in small human samples and estimates of body height in early hominid and Miocene hominoids.

Least square regression has been the only method (with the exception of correlation methods published by French statisticians c.f. Olivier 1976a, b) of estimate of body height untill mid80[th]. In those times several studies using Major Axis method (e.g. Feldesman et al 1989, 1990, Feldesman and Fountain 1996) and Reduced Major Axis metod, which is basically first principal component of principal component analysis (c.f. Sjøvold 1990) have been published. Those methods are in the case of body height estimate much more precise with higher likelyhood of results in comparison with the classical methods that used Least Square methods that has been broadly used in paleoanthropology, historical and forensic anthropology.

Those classical method are still preferred by some authors and some new equations have been recently published for example by Knussmann (1988), Scieulli and Giessen (1993) and Dobisíková and co-authors (Dobisíková et al., 2000). However, the classical regression estimates are problematic and controversial from numerous reasons.

At first, LS regression methods overestimates body height of small individuals, or even whole population with a small body height, and underestimate tall individuals or even the whole population with a high body height. The over/under-estimating of individuals is caused by the fact that the correlation coefficient of any human population is far to be close to one and therefor the slope of regression equation is less than 90 degrees, i.e. identical with the axis of a cloud of XY points. The over/under-estimating of whole populations is caused by the fact that the equations are in most cases computed for populations that are average in recent terms and there is large fixed part in the equation.

At second, they also clearly decrease the variability of the sample which is clear if we compare variability of any recent living population and the estimates by LS methods. Comparing the variability based on measured body height in recent populations (e.g.

Cieślik et al. 1996, Evellett and Tanner 1990) and the results of estimates of body height by the regression methods then the variation coefficient computed on the basis of Major Axis or Reduced Major Axis methods is comparable while the variation coefficient based on Least Square methods estimates is much smaller, it can be even two times smaller.

The only exception is MA method published by Formicolla and Franceschi (1996) where the results of MA equation are not very different from those of LS methods published by the same authors (Formicolla and Franceschi 1996). The reason is very simple and it is a very good example that even more appropriate regression method can be less precise if the sample used for the computing formula is wrong. The authors have used the mixed Neolithic sample with anatomically reconstructed body height. The following problems have naturally appeared:

1) body height is imprecise (only smaller part of the relatively small examined sample was really suitable for the reconstruction),

2) the sample lack the whole scale of individuals that is possible only on the basis of random selection of individuals from large sample,

3) The Neolithic populations have small or medium small stature (Vančata 1997, Vančata and Charvátová in press) and very short tibia and radius (e.g. Vančata 1988, 1993, 1997, Vančata and Charvátová in press).

Another important problem is that the classical methods of body height estimates that used Least Square methods (c.f. e.g. Formicolla 1983, 1993, Knussman 1988, Scieulli a Giessen 1993, Dobisíková et al. 2000) have been usually based, because of the above mentioned problems, on two regression equations; one equation for males and the second one for females (Dobisíková et al. 2000 published also equations for the whole sample). Such approach is erroneous both theoretically and also from practical reasons.

The first problem is that the body height in males and females is a continuous parameter. It can potentially overlap in males and females and the body height significantly overlaps in many recent, historic and fossil populations. The second, theoretically even more important problem, is that the sex assessment is not sure in any historic or fossil population for most individuals of the examined population. The uncertainty of sex assessment increases with the historic age of the studied skeletal sample. We are far to be sure with sex determination even in Neolithic or Bronze samples and the sexing is much more complicated in Palaeolithic skeletal samples or in early hominid ones. Furthermore, the variability and the degree and pattern of sexual dimorphism of fossil human and hominid populations have been certainly not identical with those described in recent human or ape populations.

The most confident and the most robust equations have been published by Feldesman and co-workers (Feldesman et al 1989, 1990, Feldesman and Fountain 1996) and Sjøvold (1990). Consequently, those equations are the key ones for the estimates of body height in fossil human, hominid and hominoid populations (Vančata 1996, 1997, Vančata and Charvátová in press). The detailed analyses have shown that any of the above mentioned most confident equations has its theoretical and practical problems that follows from both type of the regression method used for the computing of equation and from the basic statistical characters of a sample used for the computing of an equation (see discussions e.g. Formicolla and Franceschi 1996, Sjøvold 1990).

The last problem is the bones used for the computing of equation for the body height estimate. Not any long bone is suitable for the estimate of body height. The reason is not only the various degree of correlation of body height and individual long bones but also the variability of bone proportions among various populations. As it has been shown by many authors (see discussions e.g. Formicolla and Franceschi 1996, Sjøvold 1990, Trotter and Glasser 1952, 1958) the estimates based on femoral length

are the most precise ones and those using the humerus length give also reasonable results. Tibia and radius or ulna are too variable to be suitable for the confident estimates of body height in any hominoid population. It seems to be more precise to reconstruct femoral length instead to use radius or tibia length.

As follows there is no optimal way how to estimate body height of fossil hominids from single regression equations. From this reason we started to estimate the body height from several estimates based on various human or hominid samples. We have used eight equations using femoral and humeral lengths in fossil and historic *Homo sapiens* samples or for other Homo species. For other hominoids only femoral length is used. Average value is computed from six or eight different equations in early hominids and from three equations in the Miocene apes (Vančata 1996, 1997). The details of our approach and used methods are explained in other part of the paper concerning the reconstruction of the body size and shape.

Methods of body mass reconstruction

Estimates of another important body parameter, body mass, is frequent in primatological studies (e.g. Conroy 1987, Hartwig-Scherer 1993, Hartwig-Scherer and Martin 1992, Jungers 1987, 1988 a, c, McHenry 1988, 1992, Rafferty et al. 1985, Ruff et al. 1989, Steudel 1980, Vančata 1997, Zihlman 1992) but quite rare in anthropological studies (e.g. Aiello and Dean 1990, Ruff, 1991, Ruff and Walker 1993, McHenry 1992 a, b, Stern and Susman 1983, Wolpoff 1983) and most of them concern early hominid or Homo erectus body mass. This is because the situation in the case of estimates of the body mass is very different from the estimates of body height. Until eightieth it had been generally judged on the basis of results of physiological and developmental research that the body mass is a simple function of the body height.

Due to supposed in-preciseness of the body mass estimates caused for example unpredicted amount of body fat and lean body mass (cf. e.g. Steudel 1980) this problem is too complicated or even without reasonable solution and the detailed study of body mass estimates in fossil and historical population has no practical meaning and estimate of the body mass from body height is fully sufficient in the case of necessity.

However, it has been proved during the studying of ethnical differences in correlation of body height and body mass (see e.g. discussion Wolpoff 1983 contra: Stern and Susman 1983) that the body mass is not the simple function of the body height even in very well studied recent human populations and that such approach is problematic for Lover Palaeolithic human skeletal samples and incorrect for early hominids or even Miocene apes (Aiello and Dean 1990, Jungers 1987, 1988 a, McHenry 1988, 1991, 1992 b, Ruff 1991, Ruff and Walker 1993, etc.). In estimates of body mass is important not only body height but also robusticity of the skeleton as such (Steudel 1980, Zihlman 1992), robusticity of individual epiphyses (Vančata 1996, 1997) and compact bones of diaphyses (Ruff 1991, 2000) as well as the overall body built (McHenry 1992 b, Ruff 1991, Ruff et al.. 1997, Vančata 1996, 1997).

The meaning of this approach could be demonstrated in estimating body height of populations with tall and slim stature and those with small and very robust stature. This is the case, for example, of aborigine Australian populations and the skeletal remains of Neanderthals. Using the estimates based on the body height only the body mass of Australian aborigines will be significantly overestimated and the body mass of small, very robust Neanderthals significantly underestimated. The detailed analysis of the equations for estimates of the body mass based on the body height are in most cases relatively not precise, with a low confidence of estimates. They also significantly decrease the variability of body mass in the examined populations because they are not able describe slim or robust individuals in principle.

Detailed studies of estimates of body mass in fossil hominids and apes have appeared as late as in mid-eighteenths. (Aiello and Dean 1990, Conroy 1987, McHenry 1988, Jungers 1977, 1988 a, etc.). In nineteenths the estimates of body mass has been systematically elaborated namely by McHenry (1991, 1992 a, b, 1994), Chris Ruff (Ruff 1991, Ruff and Walker 1993, Ruff et al 1989) a Hartwig-Scherer (Hartwig-Scherer 1993, Hartwig-Scherer and Martin 1992). Numerous discussions have shown the lower limb bones, femur and tibia are the most confident and most suitable for the body mass estimates. However, there is no definitive agreement which parameters of femur and tibia are the most appropriate ones. Ruff (1991, 2000) a Hartwig-Scherer (1993) that cross-sectional parameters (Ruff 1991, 2000) or specially designed, but non-standard, metrical traits (Hartwig-Scherer 1993, Hartwig-Scherer and Martin 1992) are the best and most precise parameters for the estimating of the body mass.

We can state on the basis of a detailed analysis the equations using the system of "classical metrical traits" proposed for the estimates of the body mass by McHenry (1988, 1992 a) gives comparable if not more confident results and those equations are designed on the basis of standardised widely used and precisely defined osteometric metric traits (see Table 1). This is undoubtedly in favour of the use of system of equations for the body mass estimated proposed by McHenry (1988, 1991, 1992 a). It uses the femoral head diameter and femoral and tibial products (i.e. multiplies of medio-lateral and antero-posterior diameters that are approximately 4/3 of surface of cross-sections McHenry op. cit), i.e. subtrochanteric product, distal femoral product, proximal tibial product and distal tibial product (see Table 1).

Similarly like in the case of body height it had been necessary to conduct the detailed analysis of regression equations for the estimates of body mass. Most examined equations with some detail information is presented in the Table 1. We have tested 60 equations for the body mass estimates (Aiello and Dean 1991, Jungers 1982, 1987, 1988 a, b, Jungers and Stern 1983, McHenry, 1988, 1991 d, 1992 a, Rafferty et al 1993, Ruff and Walker 1993, Wolpoff 1983). However, the confident ones are very different for individual studied ape and hominid groups. The major axis or reduced major axis type equations computed on the bases of gracile apes, namely chimpanzees, or on the mixed gracile apes – gracile humans samples we the best for the estimates of body mass in the Miocene apes. The major axis or reduced major axis type equations computed on the bases of mixed human or eventually mixed human – gracile apes samples were proved to be most precise for the estimates of body mass of early hominids (see McHenry 1991 d. 1992a). For Homo sapiens were relatively precise all types of regression equations based purely on human samples but it has appeared that use of one equation only could be seriously misleading for some individuals of the examined sample.

This is because of the same methodological problem like in the case of the body height but much more remarkable in body mass estimates. Similarly like in the case of the body height estimates it is almost impossible to judge which of the proposed equations is really precise and confident. One reason is that the results remarkably fluctuates even much more than in the case of body height which is caused by many factors, e.g. the correlation of any individual skeletal parameter and is generally much lower in comparison with the correlation of the length skeletal parameters and the body height. Second reason is that any of the proposed morphometric or cross-sectional trait has specific variability given by specific genetic, physiological, developmental and stress factors of an individual.

From these reasons the use of several equations for the estimate of body mass in fossil and historical human populations or fossil hominids or apes appears to be inevitable. Consequently, we propose to use from 22 up to 26 regression equations based on all the widely used regression methods (Least Square, log Least Square,

Major Axis and Reduced Major Axis), i.e. 23 equations based on gracile ape and mixed gracile ape hominid samples (Vančata 1997), 22 equations for early hominids (Vančata 1996) a 26 for the *Homo sapiens* skeletal remains (Vančata 1997, Vančata and Charvátová in press, Table 3). Selected equations based on the body height were also used as an feedback factor. The details are presented in the following chapters of the paper.

A reconstruction of body size and shape – probabilistic approach

Introduction and basic principles and rules

A reconstruction of body shape parameters is one of the most important goal of the recent evolutionary anthropological, paleoanthropological, paleoecological and paleodemographic studies. Accordingly, several important issues should be mentioned.

Body height and body mass are integral organism parameters defining general body size and shape. In this sense, the body height represents the long bones growth and the body mass then basic physiologic and biomechanic features of the body or its parts. Due to the different long bone proportions between different human populations body height cannot be represented by the individual long bones (e. g., Formicolla 1993, Formicolla and Giannecchini 1999, Piontek 1999, Porter 1999, Ruff et al. 1997, Vančata 1988, 1991, 1993, 1997). Similarly, specific allometric differences in proportions of individual epiphyses or diaphyses of long bones among sexes or different human groups do not allow to use these metric traits as simple indicators of body mass (McHenry 1992, Ruff 2000, Vančata, 1988, 1991, 1993, 1997).

The length of bones and other selected metrical traits and indexes on femur, tibia, humerus and radius were used for the reconstruction of body size and body shape (see Vančata 1981, 1988, 1991, 1997, Knussmann 1988, Holliday, 1995 for the definition of measurements, see Table 1 for the measurements used for estimates of body height and body mass). The body height, body mass and skeletal ponderal indexes were computed (Vančata, 1996, 1997) from the above mentioned metrical traits.

Body height and body mass were computed for each examined individual by various regression equations that were published earlier by several authors (e.g. Feldesman et al. 1990, Sjøvold 1990, McHenry 1992 a, Ruff and Walker 1993, Table 2, 4a).

In our opinion, as we have explained in previous parts, there is no ideal universal formula for computing of body height and/or body mass and the confidence of estimates cannot be precisely checked in fossil Homo sapiens skeletal remains (cf. also Vančata, 1996, 1997) and we have very limited possibility also in the historical human skeletal samples.

Therefor we recommend to keep the following principles in reconstruction of the body size and shape:

1) Use a stochastic approach in the body height and body mass reconstruction; it means a consistent system of formulas should used for the estimate of body height or body mass where the body height and body mass should be computed as an average value from the whole set, or as complete as possible set, of formulas for any examined skeleton,

2) Body height and body mass should be analysed together with their relation that is best expressed by skeletal ponderal indexes (Rohrer´s index and Body mass index has been used - formulas are mentioned below and in the Table 1),

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3) The body shape parameters should be related also to the individual limb lengths and their proportions.

From the above mentioned reasons we have computed the body parameters as mean values of several most reliable equations and they were computed by the same methods for any individual. In this point our approach differs with other studies (see e.g. Aiello and Wood 1994, Formicolla 1983, 1993, Formicolla and Franceschi 1996, Formicolla and Giannecchini 1999, Konigsberg et al. 1998, Sjøvold 1990; for the review) that usually recommend to use individual "best optimal" equation.

We principally do not prefer selection of one, or few, optimal equation published by one author for the estimates of stature and body mass from the following reasons:

1) A potential incompatibility of basic statistical parameters of a human sample on which basis the used equations had been computed with those of an examined fossil human skeletal sample,

2) Biological character of recent skeleton samples and fossil ones differ in many important parameters; recent skeletons represent relatively homogenous population from short time period while the fossil ones originate from larger time and regional range and, furthermore, skeletal sample is usually small and fragmentary,

3) Specific proportionality of long bones in the individual studied human samples (see e.g. Sjøvold 1990 for the discussion) can be very different in comparison with phylogenetically different human groups, e.g. Upper Palaeolithic Homo sapiens is typical by relatively very long tibia and radius while some Neolithic populations have very short tibia and radius,

4) Sufficiently robust methods should be used for the estimates because the estimates of body size parameters in fossil human populations is not possible to check precisely (see Formicolla and Franceschi 1996, Formicolla and Giannecchini 1999, Sjøvold 1990, Vančata 1996, 1997).

Our approach allows to be free of random errors of the estimates of body size for the individual and it is very suitable for the description of population body size variability. In any case we cannot state for sure which method is the best because individual methods are relatively precise for some populations only (see e.g. Aiello and Wood 1994, Feldesman et al. 1989, 1990, Feldesman and Fountain 1996, Formicolla 1983, 1993, Formicolla and Franceschi 1996, Formicolla and Giannecchini 1999, Scieulli and Giesen 1993, Sjøvold, 1990, Vančata 1996, 1997 for the discussion) and, consequently we have really no exact guideline for fossil human populations. We have very limited possibilities also in historical human populations.

Furthermore, the data computed by our method are fully statistically comparable because they all originated by the identical method and, consequently, such data are statistically very appropriate for any kind of comparative or evolutionary study.

Body height estimates

Body height of fossil and historic human and early hominids (Vančata 1996, 1997) samples has been computed by MA and RMA formulas only (Table 2) published by Feldesman and colleagues (Feldesman et al. 1989, 1990, Feldesman and Fountain 1996), Jungers (1988), Olivier (1976 a, b) and Sjøvold (1990). We strongly do not recommend to include Least Square methods into the system of computing of body height estimates.

For the estimate of body height of the Miocene apes is possible to use either universal equations (Feldesman et al 1989, 1990) and the equations for the low grown human populations (Vančata 1997, Table 4 a) have been used. It is worth to note that the equations based on the metric traits of Pan paniscus are much less confident in comparison with those based on common chimpanzee and human samples. We have

proposed to use average from eight universal equation for the body height estimate computed from various human ethnic groups for early hominids (Vančata 1996, 1997, Table 2 a).. For fossil and historic Homo sapiens populations we propose to compute mean values from six equations based on femoral length and two formulas for humeral length. Humeral formulas are less precise then the femoral ones (Sjøvold 1990) but they decrease the influence of random errors connected with unexpected values of femoral length of the individual.

It is very important to be sure up to which degree our system of body height estimates corresponds the "real" body height of fossil and historic human populations. Consequently, we have also used a calibration method for the estimate of confidence of method for body height computing as a mean of eight regression equations. On the basis of the longitudinal growth study from Poznan (Cieślik et al. 1994) we estimated that body height in the Upper Palaeolithic population, that is by the body height comparable to the recent Central European populations, can be also computed as a sum of femoral, tibial, humeral and radial length plus 20 % of the sum that should roughly represent height of foot and head and length of the neck. These 20% values represent approximation to the skeletal body height and need no rather problematic anatomical reconstruction of vertebral column.

This calibration method was designed for Upper Palaeolithic skeletal populations only. The difference of "anatomical" reconstruction and the probabilistic estimate is rarely larger then 2 cm. It has been slightly modified for the post-Palaeolithic human groups because they have significantly shorter tibial and radial limb segments. After the detailed analysis the coefficient has been increased up to 22 %. The results for post-Palaeolithic skeletal remains are slightly less precise, namely because of higher fluctuation of the differences, but the difference usually does not exceed 3 cm in most examined populations.

Body mass estimates

The confident body mass estimates describing reliably the population variability is a much more complicated. Body mass is then computed as an average value of the 26 equations. Consequently, the body mass was computed by the use of 22 formulas (Table 4) from the following metric traits: femoral head, the subtrochanteric product, the distal femoral product, the proximal tibial and distal tibial products (McHenry, 1988, 1991, 1992) and, in addition, by four formulas based on of body height (Jungers and Stern 1983, Ruff and Walker 1993, Wolpoff, 1983). These four formulas were also included to decrease the influence of random errors resulting from possible unusual morphology of individual epiphyses of the long bones.

Naturally there, is no objective and precise method how to calibrate methods of estimates of body mass because we are not able to describe the amount of fat and the lean body mass in a given population. In this sense the body mass estimates must be taken as rough estimates of body size and volume based on skeletal robusticity. Therefor, the most important rule is that the estimate must be strictly made by the same methods.

Relations of height and mass – skeletal ponderal indices

Ponderal indexes have been computed from the estimated body height and body mass. They can be taken as integral parameters expressing relations of body linearity and body volume and body mass as well as general body shape (Vančata, 1996, 1997). For this study skeletal Body mass index and skeletal Rohrer's index were computed (s - BMI = body mass [g] / height [cm] ^{2}, s - Rohrer = body mass [g] / height [cm] ^{3}) for all

the studied Upper Palaeolithic individuals. Due to the relatively large sexual differences in many human fossil skeletal populations in body height the s-Rohrer´s index is a more suitable for the estimate of body robusticity because it is less sensitive to random fluctuations of body mass estimates.

Conclusions

Naturally, we are not proposing the universal and definitive method describing body size and shape of fossil and historic humans and hominids. The study of description of the body size and body shape is in progress. The approach and methods must be checked on most various fossil and historic populations. This holds namely for the body mass estimates that must be analysed more in detail. Our approach and methods could be too complicated and too theoretical for some forensic purposes. However, our approach is the only proposed method that is able in principle to describe confidentially population variability in body height, skeletal body mass and skeletal ponderal indexes. It seems to be very proper for the paleoanthropological and evolutionary anthropological studies, for the comparison of different human fossil and historical populations. As such this approach could help us to learn more about ecology and demography of fossil and historical human populations.

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Table 1. Basic metrical traits and body size and shape parameters (Abbreviations: metric traits [*x – number of a measurement*] – K *x* – Kunssman 1988, VV *x* – Vančata 1988, MC *x* - McHenry and Corruccini 1978, VG – VanGerven 1972, TH – Holliday 1995)

Abbreviation	Definitions
FEMLNGMX	Biomechanical length of femur (K2),
TIBLNGMX	Maximal tibial length (K 1a),
HUTOLE	Maximum length of humerus (K 1),
RAMALE	Maximum length of radius (K 1),
HEADBRTH	Medio-lateral head breadth (M 19),
SUBTROAP	Anterio-posterior subtrochanteric diameter (K 10),
SUBTROML	Medio-lateral subtrochanteric diameter (K 9),
INTEREPI	Bicondylar width (MC 12),
DSTEPIMX	Anterio-posterior of the distal femoral shaft (MC 13),
DIAMDLAP	Anterio-posterior diameter of midshaft (MC 15),
DIAMDLML	Medio-lateral diameter of midshaft (MC 14),
PRXEPIML	Anterio-posterior diameter of proximal tibial epiphysis (VV 47),
PRXEPIAP	Medio-lateral diameter of proximal tibial epiphysis (K3),
DIEPIBRT	Medio-lateral diameter of distal tibial epiphysis (VV 67),
MALEMLBR	Medio-lateral breadth of maleolus medialis (VV 66),
ARTBRLAT	Lateral antero-posterior diameter of distal tibial joint surface (VV 70),
ARTBRMED	Medial antero-posterior diameter of distal tibial joint surface (VV 71),
TDML	medio-lateral diameter of distal tibial joint surface (TH), it can be also computed by subtracting of medio-lateral breadth of maleolus medialis from of medio-lateral diameter of distal tibial epiphysis,
TAPM	middle antero-posterior diameter of distal tibial joint surface (TH), it can be also computed as a mean of lateral antero-posterior diameter of distal tibial joint surface and medial antero-posterior diameter of distal tibial joint surface.
Products	
MIDSHAFT	Midshaft product – product of medio-lateral diameter of midshaft and anterio-posterior diameter of midshaft,
SUBTROCH	Subtrochanteric product – product of medio-lateral subtrochanteric diameter and anterio-posterior subtrochanteric diameter,
DISTFEM	Distal tibial products – product of bicondylar width and anterio-posterior of the distal femoral shaft,
PROXTIB	Proximal tibial product – product of anterio-posterior diameter of proximal tibial epiphysis and medio-lateral diameter of proximal tibial epiphysis,
DISTATIB	Distal tibial product - product of medio-lateral diameter of distal tibial joint surface and middle antero-posterior diameter of distal tibial joint surface (can be calculated from computed values or from measured values (Holliday, 1995).
Estimated traits	
Body height	mean body height estimate from 8 regression equations (Vančata 1996, 1997, *see Table 2 for details*),
Body mass	mean body height estimate from 26 regression equations (Vančata 1996, 1997 *see Table 3 for details*),
s – BMI	skeletal Body mass index (*s-BMI = body mass [g] /height [cm]^2*),
s – Rohrer	skeletal Rohrer's index (*s-Rohrer = body mass [g] /height [cm]^3*).

Table 2. Selected equations for estimates of body height in Homo sapiens (average values of body height were computed for each individual from the below listed eight equations for the estimate of body height from femoral length and humerus length)

Reference	Parameter	Equations
Feldesman et al 1989, 1990	Length of femur	BH = 3.745*Femur
Feldesman & Fountain 1996	Length of femur	BH = 3.01939*Femur + 31.26332
Sjøvold 1990	Length of femur	BH = 3.10*Fem2 + 28.82
	Length of humerus	BH = 4.74*Hum2 + 15.26
	Length of femur	BH = 3.01*Fem2 + 32.52
	Length of humerus	BH = 4.62*Hum2 + 19.00
Olivier 1976b	Length of femur	BH = 3.420*Fem2 + 17.1
Jungers 1988 b	Length of femur	BH = 3.8807*Fem – 51.0

Table 3. Selected equations for estimates of body mass in Homo sapiens (average values of body height were computed for each individual from the below listed 26 equations for the estimate of body mass from femoral and tibial parameters and the body height

Reference	Parameter	Equations
Ruff and Walker 1993	Stature	BM = 0.689*Stat - 53.1
Jungers and Stern 1983	Stature	BM = 0.00013*Stat^2.554
Wolpoff 1983	Stature	BM = 0.00011*Stat^2.592
	Stature	BM = 0.00062*Stat^2.241
McHenry 1988	subtrochanteric product	logBM = 0.624*log*Subtroch - 0.0562
McHenry 1991d	femoral head	logBM = 1.7125*logHead - 1.048
	subtrochanteric product	logBM = 0.7316*logSubtroch - 0.4527
	distal femoral product	logBM = 0.960*logDistFem - 1.5678
	proximal tibial product	logBM = 1.0583*logProxTib – 1.9537
	distal tibial product	logBM = 0.9005*logSubtroch - 0.8790
McHenry 1992 a	femoral head	logBM = 1.7125*logHead - 1.0480
		logBM = 1.7754*logHead - 1.1481
		logBM = 1.7538*logHead - 1.1137
	subtrochanteric product	logBM = 0.7927*logSubtroch - 0.5233
		logBM = 0.8069*logSubtroch - 0.5628
		logBM = 0.8107*logSubtroch - 0.5&33
	distal femoral product	logBM = 0.9600*logDistFem – 1.5678
		logBM = 0.9919*logDistFem – 1.6754
		logBM = 0.9921*logDistFem – 1.6762
	proximal tibial product	logBM = 1.0583*logProxTib – 1.9537
		logBM = 1.0689*logProxTib – 1.9903
		logBM = 1.0683*logProxTib – 1.9880
	distal tibial product	logBM = 0.9005*logDistTib - 0.8790
		logBM = 0.9227*logDistTib - 0.9418
		logBM = 0.9246*logDistTib - 0.9473

Table 4a. Selected equation s for the body height estimates from long bones
MA - regression method Major Axis type, RMA - regression method Reduced Major Axis type

Reference	Sample	Equation
Feldesman et al 1989, 1990	all groups	$BH = 3.745*Femur$
Feldesman and Fountain 1996	all groups	$BH = 3.01939*Femur + 31.26332$
All regression methods are Major Axis type		
Sjøvold 1990	Caucasians	$BH = 2.63*Fem1 + 49.96$
All regression methods are	Caucasians	$BH = 3.10*Fem2 + 28.82$
Reduced Major Axis typ	Caucasians	$BH = 3.02*Tib1 + 58.94$
	Caucasians	$BH = 4.74*Hum2 + 15.26$
	all ethnic groups	$BH = 2.71*Fem1 + 45.86$
	all ethnic groups	$BH = 3.01*Fem2 + 32.52$
	all ethnic groups	$BH = 3.29*Tib1 + 47.34$
	all ethnic groups	$BH = 4.62*Hum2 + 19.00$
Olivier 1976a	regression - negroes	$BH = 1.74*Fem2 + 84.5$
	correlation - negroes	$BH = 3.395*Fem2 + 17.9$
	regression - negroes	$BH = 1.85*Tib2 + 88.8$
	correlation - negroes	$BH = 3.25*Tib2 + 39.2$
	regression - negroes	$BH = 1.31*(Fem2 + Tib2) + 55.0$
	correlation - negroes	$BH = 1.61*(Fem2 + Tib2) + 32.8$
Olivier 1976b	correlation - pygmies	$BH = 3.420*Fem2 + 17.1$
	correlation - pygmies	$BH = 3.29*Tib2 + 37.8$
Jungers 1988 b	Human pygmy sample - regr.	$BH = 3.3496*Fem + 147.9$
	Human pygmy sample - MA	$BH = 3.8807*Fem - 51.0$
	Human pygmy sample - RMA	$BH = 3.6251*Fem + 44.8$
	Human pygmy sample - regr.	$lnBH = 0.9067*lnFem + 1.8732$
	Human pygmy sample - MA	$lnBH = 0.9784*lnFem + 1.4480$
	Human pygmy sample - RMA	$lnBH = 0.9802*lnFem + 1.4377$
	Pan paniscus sample - regr.	$BH = 3.9185*Fem + 3.8$
	Pan paniscus sample - MA	$BH = 5.8707*Fem - 568.9$
	Pan paniscus sample - RMA	$BH = 4.8317*Fem - 264.1$
	Pan paniscus sample - regr.	$lnBH = 1.0220*lnFem + 1.2432$
	Pan paniscus sample - MA	$lnBH = 1.2980*lnFem - 0.3246$
	Pan paniscus sample - RMA	$lnBH = 1.2403*lnFem + 0.0034$
Feldesman and Lundy 1988	negroes MA	$BH = 3.422*Fem + 0.102$
	negroes MA	$BH = 3.416*Fem + 0.002$
	negroes MA	$BH = 4.016*Tib + 0.222$
	negroes MA	$BH = 4.051*Tib + 0.127$
	negroes MA	$BH = 1.847*(Fem + Tib) + 0.185$
	negroes MA	$BH = 1.853*(Fem + Tib) + 0.072$
	negroes regression	$BH = 2.403*Fem + 45.721$
	negroes regression	$BH = 2.769*Fem + 27.424$
	negroes regression	$BH = 2.427*Tib + 60.789$
	negroes regression	$BH = 2.485*Tib + 55.968$
	negroes regression	$BH = 1.288*(Fem + Tib) + 46.543$
	negroes regression	$BH = 1.410*(Fem + Tib) + 34.617$

Sex (for all tables)**: M** - males, **F - **females**, A – **without sex, both males and females

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Table 4 b. Selected equations for the body height estimates from long bones
Regression methods are Least Square type – exceptions are marked – MA – Major axis type

Reference	Sample	Equation
Sciulli and Giesen 1993	prehist.Native Americans	BH = 2.497*Fem2 +41.403 + 10.5
	prehist.Native Americans	BH = 2.381*Fem2 +43.697 + 10.5
Dobisíková et al. 2000	Czech males	BH = 2.03*Femur + 79.047
	Czech females	BH = 1.59*Femur + 95.753
	Czech males and females	BH = 2.17*Femur + 71.983
	Czech males	BH = 2.51*Humerus + 90.601
	Czech females	BH = 2.13*Humerus + 99.335
	Czech males and females	BH = 2.88*Humerus + 77.566
Formicolla and Franceschi 1996	Neolithic mixed sample	BH = 2.23*Fem1 + 65.9
	Neolithic mixed sample MA	BH = 2.55*Fem1 + 52.08
	Neolithic mixed sample	BH = 1.22*(Fem + Tib) + 66.86
	Neolithic mixed sample MA	BH = 1.30*(Fem + Tib) + 60.42
	Neolithic mixed sample	BH = 3.31*Humerus + 60.87
	Neolithic mixed sample MA	BH = 4.04*Humerus + 38.05
Knussman 1988		BH = 2.42*Fem2 + 58.5
		BH = 2.1*Fem2 + 70.2
		BH = 2.61*Tib1b + 71.7
		BH = 2.30*Tib1b + 80.4
		BH = 1.31*Fem2 + 1.39*Tib1b + 57.3
		BH = 1.51*Fem2 + 1.27*Tib1b + 51.3
Rosing 1983	Calcutta	BH = 1.987*Fem + 78.00
	Calcutta	BH = 1.619*Fem + 86.02
	Calcutta	BH = 2.288*Tib + 79.55
	Calcutta	BH = 1.819*Tib + 88.69
	Calcutta	BH = 0.936*Fem +1.685*Tib+ 61.80
	Calcutta	BH = 0.851*Fem +1.073*Tib+ 80.37
Rosing 1983	Lucknow	BH = 3.499*Fem + 76.1
	Lucknow	BH = 4.019*Tib + 14.72
	Lucknow	BH = 3.021*Fem + 0.608*Tib + 64.8
Breitinger 1937	German	BH = 1.645*Fem + 94.31
Bach 1965	Middle Europe (German)	BH = 1.313*Fem + 106.69
Boldsen 1984	Danish	BH = 2.519*Fem + 52.85
	Danish	BH = 2.528*Fem + 50.76
Genovés 1967	Mesoamericans	BH = 2.26*Fem + 66.379 - 2.5
	Mesoamericans	BH = 2.59*Fem + 49.742 - 2.5

Table 4 c. Selected equations for the body height estimates from long bones
All regression methods are Least Square type

Reference	Sample	Equation
Helmuth 1968	white males	BH = 1.880*Fem + 81.308
	white females	BH = 1.945*Fem + 72.844
	white males	BH = 2.376*Tib + 78.664
	white females	BH = 2.352*Tib + 74.774
Lorke et al 1953	Western Europe	BH = 2.358*Fem + 61.34
Stevenson 1929	N-Chienese	BH = 2.4398*Fem + 61207 - 2.5
Telkkä 1950	Finnish	BH = 2.1*(Fem - 45.5) + 169.4 - 2.5
	Finnish	BH = 1.8*(Fem - 41.8) + 169.4 - 2.5
Trotter and Gleser 1952	US-White	BH = 2.38*Fem + 61.41
	US-White	BH = 2.47*Fem + 54.10
	US-White	BH = 2.52*Tib + 78.62
	US-White	BH = 2.90*Tib + 54.53
	US-White	BH = 3.08*Hum + 70.45
	US-White	BH = 3.36*Fem + 57.97
	US-Black	BH = 2.11*Fem + 70.35
	US-Black	BH = 2.28*Fem + 59.76
	US-Black	BH = 2.19*Tib + 70.02
	US-Black	BH = 2.45*Tib + 72.65
	US-Black	BH = 3.26*Hum + 62.10
	US-Black	BH = 3.08*Hum + 64.67
Trotter and Gleser 1958	US-White	BH = 2.32*Fem + 61.53
	US-Black	BH = 2.10*Fem + 72.22
	Mongoloid	BH = 2.15*Fem + 72.57
	Mexican	BH = 2.44*Fem + 58.67
	Puorto Rican	BH = 2.10*Fem + 72.61
Dupertuis and Hadden 1951	US-White	BH = 2.116*Fem + 77.048 - 2.5
	US-White	BH = 2.322*Fem + 62.872 - 2.5
	US-Black	BH = 2.540*Fem + 55.021 - 2.5
	US-Black	BH = 2.498*Fem + 54.235 - 2.5
	General formula	BH = 2.238*Fem + 69.089 - 2.5
	General formula	BH = 2.317*Fem + 61.412 - 2.5

Table 5. Selected equations for the estimates of body mass on the basis of long bones and stature

BM – body mass, Stat – stature, abbreviations – see Table 1

Reference	Sample	Parameter	Equation
Ruff and Walker 1993	world-wide adult	stature	BM = 0.689*Stat - 53.1
	world-wide adult	stature	BM = 0.888*Stat - 87.1
	world-wide adult	stature	BM = 0.659*Stat - 47.0
	black African	stature	BM = 0.637*Stat - 50.0
Jungers and Stern 1983	Pygmies	stature	BM = 0.00013*Stat^2.554
Wolpoff 1983	Pygmies	stature	BM = 0.00011*Stat^2.592
	Pygmies	stature	BM = 0.00062*Stat^2.241
McHenry 1988	Homo sapiens	subtrochanteric product	logBM = 0.624*log*Subtroch - 0.0562
	African apes, and Homo sapiens	subtrochanteric product	logBM = 1.189*log*Subtroch - 1.663
McHenry 1991d	Human	femoral head	logBM = 1.7125*logHead - 1.048
	Ape	femoral head	logBM = 2.9844*logHead - 2.8903
	Human	subtrochanteric product	logBM = 0.7316*logSubtroch - 0.4527
	Ape	subtrochanteric product	logBM = 1.1782*logSubtroch - 1.5679
	Human	distal femoral product	logBM = 0.960*logDistFem - 1.5678
	Ape	distal femoral product	logBM = 1.2066*logDistFem - 2.1745
	Human	proximal tibial product	logBM = 1.0583*logProxTib - 1.9537
	Ape	proximal tibial product	logBM = 1.3848*logProxTib - 2.8941
	Human	distal tibial product	logBM = 0.9005*logSubtroch - 0.8790
	Ape	distal tibial product	logBM = 1.3202*logDistTib - 1.8449
McHenry 1992 a	Intra Homo - least squares	femoral head	logBM = 1.7125*logHead - 1.0480
	Intra Homo - major axis		logBM = 1.7754*logHead - 1.1481
	Intra Homo - reduced major axis		logBM = 1.7538*logHead - 1.1137
	Hominoidea - least squares	femoral head	logBM = 2.6465*logHead - 2.4093
	Hominoidea - major axis		logBM = 2.7930*logHead - 2.6269
	Hominoidea - reduced major axis		logBM = 2.7284*logHead - 2.5310
	Intra Homo - least squares	subtrochanteric product	logBM = 0.7927*logSubtroch - 0.5233
	Intra Homo - major axis		logBM = 0.8069*logSubtroch - 0.5628
	Intra Homo - reduced major axis		logBM = 0.8107*logSubtroch - 0.5&33
	Hominoidea - least squares	subtrochanteric product	logBM = 1.1823*logSubtroch - 1.5745
	Hominoidea - major axis		logBM = 1.2217*logSubtroch - 1.6775
	Hominoidea - reduced major axis		logBM = 1.2152*logSubtroch - 1.6605
	Intra Homo - least squares	distal femoral product	logBM = 0.9600*logDistFem - 1.5678
	Intra Homo - major axis		logBM = 0.9919*logDistFem - 1.6754
	Intra Homo - reduced major axis		logBM = 0.9921*logDistFem - 1.6762
	Hominoidea - least squares	distal femoral product	logBM = 1.0829*logDistFem - 1.8467
	Hominoidea - major axis		logBM = 1.1326*logDistFem - 2.0011
	Hominoidea - reduced major axis		logBM = 1.1271*logDistFem - 2.7066
	Intra Homo - least squares	proximal tibial product	logBM = 1.0583*logProxTib - 1.9537
	Intra Homo - major axis		logBM = 1.0689*logProxTib - 1.9903
	Intra Homo - reduced major axis		logBM = 1.0683*logProxTib - 1.9880
	Hominoidea - least squares	proximal tibial product	logBM = 1.2770*logProxTib - 2.5918
	Hominoidea - major axis		logBM = 1.3224*logProxTib - 2.7380
	Hominoidea - reduced major axis		logBM = 1.3127*logProxTib - 2.7066
	Intra Homo - least squares	distal tibial product	logBM = 0.9005*logDistTib - 0.8790
	Intra Homo - major axis		logBM = 0.9227*logDistTib - 0.9418
	Intra Homo - reduced major axis		logBM = 0.9246*logDistTib - 0.9473
	Hominoidea - least squares	distal tibial product	logBM = 1.1806*logDistTib - 1.5390
	Hominoidea - major axis		LogBM = 1.2319*logDistTib - 1.6721
	Hominoidea - reduced major axis		LogBM = 1.2232*logDistTib - 1.6493
Jungers 1987	Higher primates	femoral head	LnBM = 2.9084*lnHead - 6.3369
Jungers 1988a	All hominoids	femoral head	lnBM = 2.6142*lnHead - 5.4282
	Nonhuman hominoids	femoral head	lnBM = 2.9047*lnHead - 6.3233
	All hominoids	medial condyle width	lnBM = 2.1224*lnMCW - 2.6824
	Nonhuman hominoids	medial condyle width	lnBM = 2.1743*lnMCW - 2.8023

	All hominoids	lateral condyle width	**lnBM = 1.9335*lnLCW - 1.7269**
	Nonhuman hominoids	lateral condyle width	**lnBM = 2.1865*lnLCW - 2.3033**
	All hominoids	AP distal tibial articulation	**lnBM = 2.5037*lnDTB - 3.9397**
	Nonhuman hominoids	AP distal tibial articulation	**lnBM = 2.8561*lnDTB - 4.8747**