P. Velemínský/L. Poláček (Hrsg.), Studien zum Burgwall von Mikulčice VIII. Brno 2008, 177-208
Anthropological and epidemiological characterization of Great-Moravian population in connection with the social and economic structure

Skeletal Asymmetry of Locomotor Apparatus at Great Moravian Population

MARTINA KUJANOVÁ[1] – LUCIE BIGONI[1] – JANA VELEMÍNSKÁ[1] – PETR VELEMÍNSKÝ[2]

Monitoring the asymmetry rate of different parts of human body can contribute to population studies. It may be connected with the social structure of society and the quality of living conditions. Asymmetry can be the result of non-specific stress affecting the organism or preference for the right or the left side of body during specific activities. In this paper, directional (DA), fluctuating (FA) asymmetry, the antisymmetry (AS) and possibly cross-asymmetry of the dimensions of the upper and lower limb bones was assessed and these indicators were used to compare the differences within and among the medieval, and the recent population. A sample of medieval population came from two Great-Moravian cemeteries Mikulčice-Kostelisko (78 males, 132 females) and Prušánky (66 male, 69 female). A collection from Bohemia from the first half of the 20th century (143 males, and 157 females) was used as a comparative sample of recent population. Only adult individuals were selected. Males and females were evaluated separately. DA was recorded in most dimensions of the studied bones. In the upper limb it was mostly expressed on the humerus, and except for the clavicle it was always in favour of the right side. On the lower limb bones, DA was less frequent than in the upper limb bones and in most cases it was in favour of the left side. In addition, on the lower limb bones, it was more expressed on the transversal, sagittal and circumferential dimensions of the diaphyses and epiphyses than on the length dimensions. The FA values were very low and almost negligible in relation to the size, nevertheless FA was markedly more frequent on the lower than on the upper limb. In contrast to the Great Moravian population, the recent population had higher FA values and also DA was found more often there. All the long bones of the right upper limb as well as the left femur of most individuals in both populations are statistically significantly longer. However, in most individuals cross-asymmetry was not confirmed. AS was not observed.

Key words: Directional asymmetry – fluctuating asymmetry – antisymmetry – cross-asymmetry – bones of the upper and lower limb – Great Moravian population – recent population

1. Introduction

Asymmetry is a feature commonly found in nature, it is one of the fundamental characteristics of living organisms. Of course, the human body is also asymmetric – apart from striking variations, very slight deviations (in the range of 1%, or less from a trait size) are encountered which cannot be noticeable at first sight. These deviations may provide many clues about the person's living conditions, or about health (PALMER 1996). But if the deviations are too marked, they may be evidence of pathologic asymmetry (BURIAN 1939). Knowledge of asymmetry may be used for the cognition of the ontogenetic principals and their disturbances. Asymmetry indicates fitness assessment of organisms, their evolutional stability, health, etc. (PALMER 1996). From this perspective, it is considered a useful source of information about behaviour differences within

---

[1] Department of Anthropology and Human Genetic, Faculty of Science, Charles University, Prague, CZ, martina.kujanova@gmail.com

[2] Department of Anthropology, National Museum, Prague, CZ, petr_veleminsky@nm.cz

populations and among them (Ruff/Jones 1981; Fresia/Ruff/Larson 1990)

At this time we distinguish several asymmetry types which may manifest in a similar manner but arise from different causes (Palmer 1994); they may develop in the prenatal (Schultz 1937; Pande/Singh 1971), or postnatal period (Steele/Mays 1995), in childhood (Van Dusen 1939), during adolescence (Schell et al. 1985), or during adult life (Laubach/McConville 1967; Malina/Buschang 1984).

Origination and development of asymmetry is affected by specific factors. Their intensity may be *inter alia* assessed by the measure of asymmetry. In summary, these factors have been described: genetic, hormonal, environmental, biomechanical, age, sex and body weight of individual. We focused on the following of them: *environmental factors* involve stress of a different origin, e.g. malnutrition, excessive noise, cold, heat, etc., which increase asymmetry (Kieser/Groenveld/Preston 1986; Schell et al. 1985; Čuk/Leben-Seljak/Štefančič 2001). The degree of asymmetry reflects also the *biomechanical impacts* (Graham/Freeman/Emlen 1993) – the force which affected the right or left side. Then, the localization of asymmetry on particular bones indicates the type of the used force. The greater the load affecting long bones, the more asymmetrical their morphology results (Čuk/Leben-Seljak/Štefančič 2001; Schell et al. 1985; Ruff/Jones 1981). The *age of the individual* may be another factor. The dependence of the asymmetry rate on age has been confirmed by B. Škvařilová (1999), Helmkamp/Falk (1990), Ruff/Jones (1981) but not confirmed by Roy/Ruff/Plato (1994) and J.H. Plochocki (2002). The *sex of the individual* is also taken into account. Here again, the conclusions are contradictory about the role of this factor in asymmetry development. A list of authors who did not find sex differences in the degree of asymmetry include B. Škvařilová (1999), Steel/Mays (1995), Schell et al. (1985), Roy/Ruff/Plato (1994). In some studies the samples were not divided according to sex (Čuk/Leben-Seljak/Štefančič 2001; Roy/Ruff/Plato 1994). Other studies demonstrate that this factor also contributes to asymmetry (Feik/Thomas/Clement 1996; Mays/Steele/Ford 1999; Lazenby 2002). Seemingly, *body weight* has no impact on asymmetry considering that the lower limbs are under a higher load but exhibit a less degree of asymmetry than the upper limbs (Schell et al. 1985).

The basic asymmetry types are directional asymmetry, fluctuating asymmetry, antisymmetry, and cross-asymmetry. *Directional asymmetry (DA)* is a type of bilateral asymmetry where in the whole sample a statistically significant difference exists between sides and the side that is larger is generally the same. The mean of values [right side (R) – left side (L)] differs from zero (see Figure 1b) (Van Valen 1962; Palmer 1994). *Fluctuating asymmetry (FA)* is a type of bilateral asymmetry where the mean value (R - L) is zero all variations are normally distributed about the mean (see Figure 1a). It may be assessed only if DA or antisymmetry are absent (Palmer 1994). *Antisymmetry (AS)* is the presence of bilateral variation where a statistically significant difference exists between sides, but the side that is larger varies among individulas. The mean (R - L) is zero, and the distribution of variations around this mean is platykurtic or bimodal (see Figure 1c) (Van Valen 1962).

Cross-asymmetry has been described as the phenomenon when in one individual the right upper limb is more developed together with the left lower limb, or *vice versa.* In general, the right-handers have a better developed right upper limb and left lower limb (Ruff/Jones 1981). According to Čuk/Leben-Seljak/Štefančič (2001), about 90% of people have a more developed right upper limb, and about 55-75% people have a more robust left lower limb. The dominant lower limb has a more robust structure of the tibia, and it is on the opposite side to the dominant upper limb. According to B.E. Ingelmark (1946) 85% of right-handers have a longer left lower limb while 85% of left-handers have a longer right lower limb. Disregarding handedness (see below), the left lower limb may be more robust because its

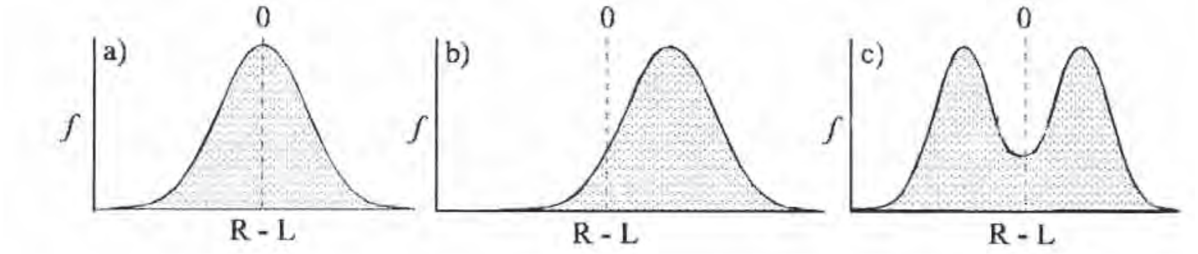


Figure 1. Three common distributions of the R - L difference in bilateral organisms: a) fluctuating asymmetry; b) directional asymmetry; c) antisymmetry (Palmer 1994).

function is to support while the right lower limb is used for other functions (e.g. kicking) (Singh 1970; Plato/Fox/Garruto 1985; Macho 1991; Čuk/Leben-Seljak/Štefančič 2001). In conjunction with asymmetry of the limbs we encounter the term *'handedness'*, which means a preference for one (right or left) hand for certain manipulations. Handedness exerts an impact on the asymmetry of the long bones of the limbs: they are longer and larger on the dominant side. The general trend is a preference for the right hand (Steele/Mays 1995; Čuk/Leben-Seljak/Štefančič 2001).

Investigations have been carried out both on skeletal collections (Čuk/Leben-Seljak/Štefančič 2001; Albert/Greene 1999; Mays/Steele/Ford 1999; Plochocki 2002; Steele/Mays 1995; Stock/Pfeiffer 2001; Stirland 1993) and on clinical material (most frequently body dimensions, dermatoglyphs, X-ray prints) (Schell et al. 1985; Škvařilová 1999; Plato/Wood/Norris 1980; Laubach/McConville 1967; Fields et al. 1995; Roy/Ruff/Plato 1994; Macho 1991; Little/Buschang/Malina 2002). As a rule, the results show that bilateral asymmetry is more expressed in the upper limbs. On average, the long bones of the right upper limb are 1-3% longer, and 2-4% heavier than the long bones of the left side. The most asymmetric bone is the humerus by which we can probably assess the preference, and therefore also the dominance of one or the other upper limb (Čuk/Leben-Seljak/Štefančič 2001). As a rule, the left lower limb is more robust (the results vary with regard to the length dimensions) (Latimer/Lowrance 1965; Ruff 1992; Macho 1991). According to Čuk/Leben-Seljak/Štefančič (2001), the lower limb bones, especially the femur, are longer and heavier on average.

The diaphyseal widths and circumferences are more asymmetric than the longest lengths of the long bones. The proximal humeral epiphyses are more asymmetric than the distal ones, and this relation is reversed in the forearm bones; therefore, the wrist and shoulder joints are evidently more 'stressed' than the elbow (Čuk/Leben-Seljak/Štefančič 2001).

The upper and lower limb length as a whole is less asymmetric than the length of particular segments of the relevant limbs (Jurowska 1972; Škvařilová 1999).

According to Mays/Steele/Ford (1999), the right clavicle is shorter and more robust in most individuals, especially in adults. They did not find any deviations in its curvature or in its vascularization. As a rule, the muscle and ligament insertion sites were larger on the right side.

2. Material

Two osteological collections were used to represent medieval and recent population.

A sample of medieval population dated to the Great Moravia came from two archaeological sites Mikulčice-Kostelisko (sub-castle of the centre) and Prušánky (hinterland). Only adult individuals with ascertained sex, estimated age at the time of death and in good conditions of preservation and completness were considered (Dobisíková 1999). On this basis, 78 males and 132 females skeletons from the Mikulčice-Kostelisko necropolis and 66 males with 69 females skeletons from the Prušánky necropolis were selected.

We used the so called 'Pachner's collection' as a comparative sample of recent population. The uniqueness of this collection is that it consists of more than 300 postcranial skeletons with following documentation: name, sex, age, height, and autopsy year of individuals. The collection came from the1930's and involves Czech inhabitants from socially less situated ranks. The sex distribution is equal (Pachner 1937). From this collection 143 males and 157 females were selected.

The bones of the lower limb (femur, tibia, fibula), and the bones of the upper limb (humerus, radius, ulna, scapula, clavicula) were used for the analysis. Bones with pathologic findings were not processed.

3. Methods

All age categories of the adult individuals were assessed together. Both sexes were evaluated separately.

In asymmetry assessment it is desirable to have dimensions of both left and right bones and so only cases where the individual's paired bones remained preserved were included. For assessment of the difference between sexes or populations we also included cases where only one of the individual's paired bone remained preserved.

The defined metric dimensions (Martin/Saller 1957; Velemínský 2000) were measured – 21 linear dimensions on the upper limb, and 27 linear and circumferential measures on the lower limb (for list of dimension see Table 1).

Apart from basic statistical characteristics, the testing of repeatability was done. Both left and right bones of 16 individuals were remeasured (Steele/Mays 1995; Mays/Steele/Ford 1999) and the interobserver error was calculated using the reliability coefficient of the particular measurements and of asymmetry scores (Fields et al. 1995). The systematic error was assessed using the paired t-test. The ANOVA test was used to rule out the FA being caused by measurement error (Little/Buschang/Malina 2002; Roy/Ruff/Plato 1994).

The comparison of recent versus medieval population and assessment of sexual dimorphism was analysed using the t-test for independent samples (confidence values: p-value ≤ 0, 05).

Normal distribution of the difference between the right and left side was expressed graphically and also presence of antisymmetry (bimodal, or platykurtic curve) was excluded.

The presence and degree of DA was determined using the paired t-test. Dimensions with significant differences (p-value ≤ 0, 05) between the right, and the left side were considered to be directionally asymmetric. On the remaining dimensions where neither DA, nor AS was manifested we tested for the presence of FA. We used the formulas according to Palmer/Strobeck (1986), specifically the values FA1, FA2, FA4, and FA6. The values FA1 and FA2 yield the information about unsigned (absolute) asymmetry – if and by how much on average the magnitudes R and L differ. The values FA4 and FA6 provide information about signed asymmetry – the direction of the asymmetry. FA2 and FA6 are not biased by size-dependence of the right-left difference (for the formulas see Table 5).

In order to assess cross-asymmetry the sample of individuals was divided into four groups (according to the longest humerus length): hypothetical 'right-handers' (longer right humerus), 'left-handers' (longer left humerus), and ambidextrous (both bones equally long) (Čuk/Leben-Seljak/Štefančič 2001; Steele/Mays 1995). In subsequent processing, the percentage of hypothetic right-handers with longer left lower limb bones, or left-handers with longer right lower limb bones were compared. For this analysis the maximum humerus length, the maximum length of femur as well as the physiological length of the femur, the overall and medial tibia length, and the maximum fibula length were used.

The software STATISTICA for Windows version 5.0 and Microsoft Excel 1997 was used to carry out the calculations.

4. Results

No statistically significant differences between repeated measurements were shown in the measurement accuracy test by reliability calculation (reliability coefficient), systematic error testing, and the ANOVA test. The reliability coefficient did not drop below 0.8, thus, all measurements were meaningful and the variability between traits was not caused by a measurement error. But the repeatability of particular measurements is not an adequate guide to the repeatability of asymmetry scores derived from it – because it depends both on measurement error and on the size of the difference between sides (Fields et al. 1995; Mays 2002). In particular, in FA assessment differences between sides are generally small, so the contribution made by measurement errors in asymmetry scores is larger than is the case for raw measurements. Measurement error tends to have a randomizing effect on the data. Hence in our study FA (the greater the measurement error, the greater the impact on the estimate of the subtle asymmetries; Palmer 1994) was assessed only on dimensions, where no measurement error was noted in asymmetry scores.

Within the scope of sexual dimorphism monitoring males from recent population had all dimensions statistically significantly greater than females. In the Great Moravian population it was the same, except for the left humeral head and the length of the right ulna.

Tables 1 and 2 give the data of a population comparison using the metric characteristics of the upper and lower limb bones. When considering the upper limb bones, it was found out that males from both populations differed in 25% of monitored traits. Males from the Great Moravian population exhibited greater length dimensions of the upper limb long bones whereas males from the recent population had a significantly greater vertical diameter of the left humerus head, and sagittal diameter of the radius diaphysis. The size differences between females of these populations were more frequent than between males (45% of monitored traits). For medieval females greater

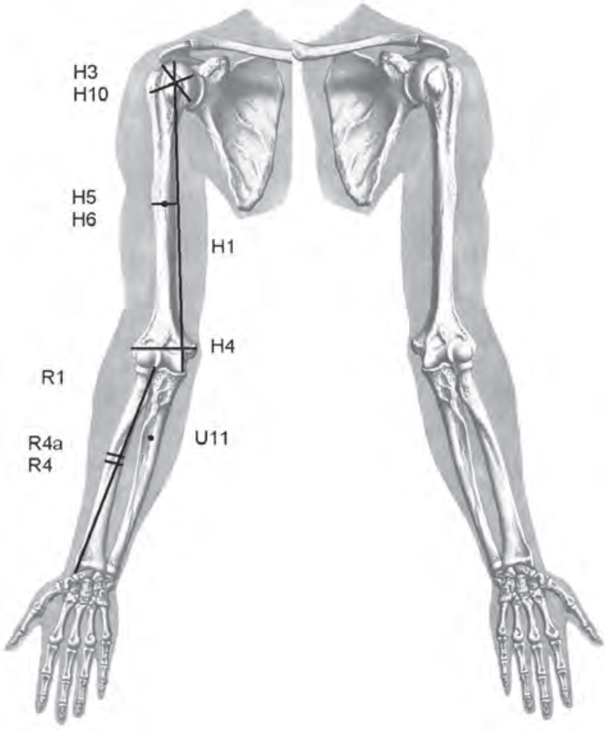


Figure 2. Depiction of the dimensions of upper limb bones in which DA was observed. Great Moravian Males.

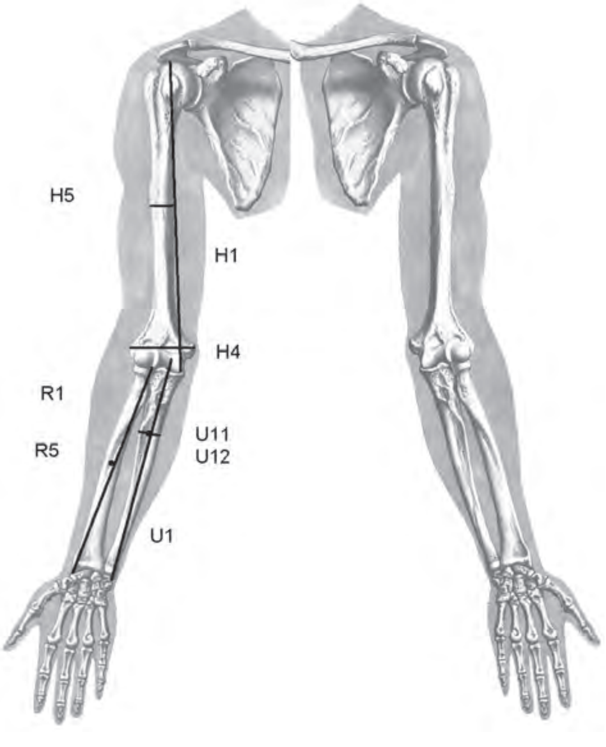
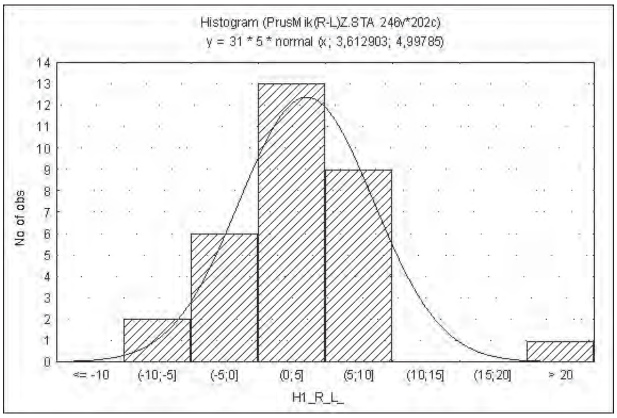
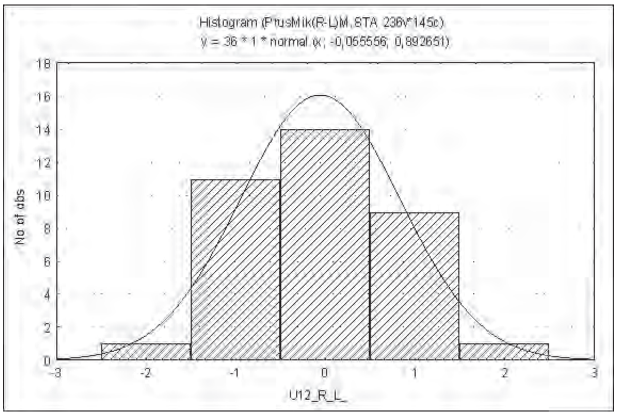


Figure 3. Depiction of the dimensions of upper limb bones in which DA was observed. Great Moravian Females.



Graph 1. Histogram of R - L difference distribution (females, Great Moravian population, maximum length of the humerus).



Graph 2. Histogram of R - L difference distribution (males, Great Moravian population, width of the diaphysis of the ulna).

length dimension values of forearm bones were characteristic. Females from the recent population had higher values of most humeral, and clavicular diameters, and of forearm bones width parameters.

The situation is similar with lower limb dimensions. Females from both populations differed more than males (in 43% compared to males in 27% of measured traits). All statistically significant as well as insignificant differences of the lower limb bones were greater in recent than in medieval females. In males, significant differences became evident on the lower limb bones especially on the femoral diaphysis and tibial length but it varied according to the population. Comparison of the average femoral and tibial dimension values in males indicated, that medieval males were greater in length dimensions; recent males mostly in the dimensions of diaphyses and epiphyses.

The graphical analysis showed that the R - L difference was normal distributed and therefore antisymmetry did not manifest itself in any trait (for example see Graph 1 and 2).

DA was more frequent in both populations on bones of the upper limb than on bones of the lower limb. Figures 2-5 illustrate the dimension in which DA was observed in the both population.

In the recent population (Tables 3 and 4) DA was present in almost all upper limb bones studied (in 81% of metric traits in females and 67% in males) and with the exception of the clavicular length it was always in favour of the right side. It was most expressed on the humerus (in all dimensions) and on the maximum lengths of forearm bones, and least on the dimensions of the scapula. The clavicle was shorter and more robust on the right side in most individuals. The differences between sexes were not very expressive; however, greater differences between average dimension values were noted in females.

DA in the lower limb bones of recent population was recorded only in the size characteristics of the femur; it was not manifested in the tibia and fibula. DA was pronounced on 47% of the dimensions in females, and on 33% of the dimensions in males. The DA of the length dimensions and the diaphyseal dimensions was directed to the left in both sexes, in epiphyseal dimensions it was directed to the right side. In males and females, left side DA on the femur was recorded in the physiological length and in most sagittal diaphyseal diameters, in females moreover in the diaphyseal circumference, and in some transversal diaphyseal diameters. Right side DA on the femur was manifested on the lower epicondylar width in males, on the upper width of the epiphysis in females.

In the Great Moravian population (Tables 5 and 6) DA of the upper limb bones was recorded less (in 38% of metric traits in females and 48% in males), especially in the length dimensions of all the long bones, except for the clavicle. With regard to sexual dimorphism there were some differences. On the humerus and radius asymmetry was manifested in males almost in all dimensions, in females only in the maximum lengths and also on certain diaphyseal diameters of these bones. On the contrary, the ulna was more asymmetric in females (DA was seen in all dimensions); in males it only involved the sagittal diaphyseal dimension.

In the lower limb dimensions the presence DA was recorded more frequently than in the recent population, and it was always directed to the left. It was manifested on the femur in 53% of traits in males, in 33% in females; on the tibia in both sexes in 18% of traits. On the femur, in males DA was recorded in the length dimensions, in most diaphyseal diameters, and also in the diaphyseal circumference. In females it was less frequent; it was observed in the physiological length, in certain transversal diameters, and in the lower sagittal diaphyseal diameter. The most statistically significant deviations were in the transversal epiphyseal diameter. On the tibia, DA was manifested in both sexes in the overall tibia length, in males in the diaphyseal circumference, and in females in the medial tibia length.

Neither population, with regard to the upper limb, had more asymmetric widths of the long bone diaphysis in comparison with their length dimensions; this also applies to the comparison of proximal and distal humeral epiphyses

The presence of FA (Table 7 and 8) on the bones of the upper limb was very low; on the lower limb FA was manifested much more frequently in both sexes, but even there its values were very low. FA attained the highest values in the length dimensions (FA1, FA4) but if the FA values were related to the size of the measured trait it was almost negligible (FA2, FA6). Recent population, where FA could be seen especially in the scapula dimensions, reached higher FA values in both upper and lower limb bones than the medieval population. Higher FA values of

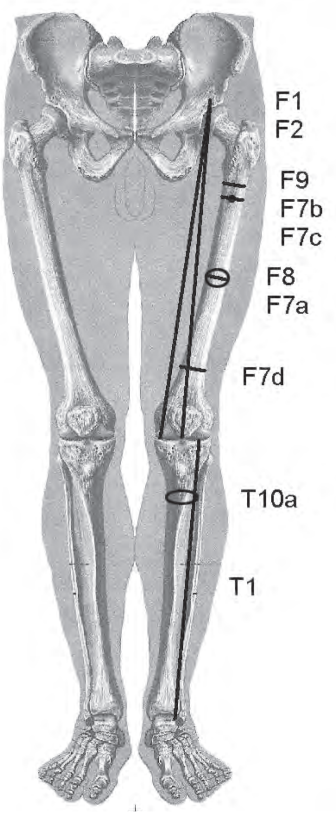


Figure 4. Depiction of the dimensions of lower limb bones in which DA was observed. Great Moravian Males.

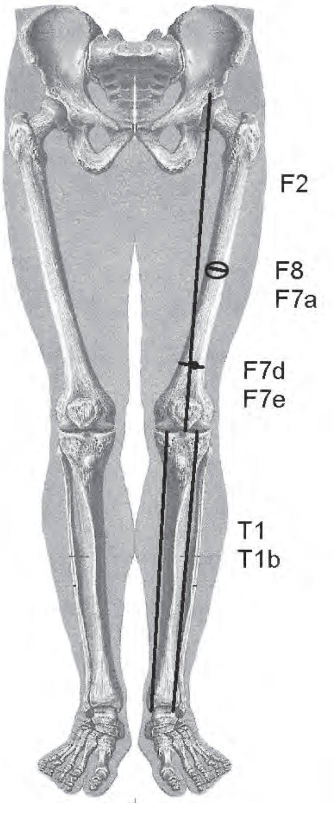


Figure 5. Depiction of the dimensions of lower limb bones in which DA was observed. Great Moravian Females.

the upper limb had the Great Moravian population in the clavicle, and in the maximal length of the ulna. In both populations lower limb FA reached the highest values in lengths and in circumferential dimensions in tibia and on upper epiphysis of femur.

All the long bones of the right upper limb (with the exception of ulna in Great Moravian males) were significantly longer in most individuals from both populations. The same result was in the case of left femora but these findings cannot be interpreted as cross-asymmetry because they do not tell us whether individuals with longer long bones of the right upper limb had longer long bones of the left lower limb at the same time. In the Great Moravian population, subsequent analysis did not confirm cross-asymmetry either in males or females who had a longer right humerus. Individuals with a longer left humerus could not be assessed because of the low number of preserved bones. In the recent population, only tibia and fibula lengths in males indicated cross-asymmetry.

In both populations, the percentage of individuals with a longer right/left humerus, or with both humeri equally long, corresponds to the distribution of right-handers and left-handers, and ambidextrous individuals in the recent European population.

5. Discussion

If asymmetry is considered – *inter alia* – indicative of non specific stress affecting the organism, it could be indirectly connected also with the social structure of the society, the quality of the living conditions (nutrition, individual health, degree of stress of different origin, etc. (e.g. Graham/Freeman/Emlen 1993; Livshits et al. 1998), and also with influences from biomechanical stress (Roy/Ruff/Plato 1994), or with the activities carried out as well as with a preference for the right or left side of the body (Steele/Mays 1995).

With regard to sexual dimorphism, males and females from both populations differed markedly in most assessed dimensions. It was noticeable that in the Mikulčice-Kostelisko necropolis no sexual differences were found in several dimensions. This involves the maximum length of the right ulna, and the maximum transversal, and vertical dimensions on the head of the left humerus. P. Velemínský (2000) came to the same conclusion about this necropolis. Similar results were also available from other Great Moravian burial-grounds – Josefov (Stránská et al. 2002), and Bulhary (Dobisíková et al. 2003). According to the publication of Černý/Komenda (1982), quite reliable sex identification can be done from the humeral head, which contradicts our results. It is possible that this method cannot be applied to the Mikulce's Great Moravian population. Our findings on the recent population comply with the work of M. Černý (1971). The most significant sexual differences were recorded in head diameters, the circumferences and diameters of the middle of the diaphysis, and in the maximum femur length. On the tibia, in agreement with the work of Leopold/Minuth/Krüger (1986) and G. Singh/S. Singh/S.P. Singh (1975), the most expressed sexual dimorphism was manifested on the epiphyses, in bone length, and in all circumferential dimensions. The differences in the average dimension values of females and males proved that sexual dimorphism was more expressed in the Great Moravian population. A high degree of sexual dimorphism is considered to be a sign of good health, and low stress (Lazenby 2002). If so, it can be presumed that the medieval population was submitted to lower environmental stress than the sample of the recent population.

Comparing the size characteristics of single dimensions using the t-test for independent samples, certain differences between the two populations were found**.** Size differences were encountered more frequently in females than in males. The upper limb long bones of males from the Great Moravian population had greater length dimensions. This could be affected by the fact that individuals from the recent population had in general a gracile figure (they came from a lower social status, Pachner 1937). In comparison with the medieval males, recent males had a shorter but more robust femur and tibia; on the upper limb they had only a greater vertical diameter of the left humeral head. According to our investigations, medieval females had higher length dimensions of the forearm bones. Females from the recent population had significantly higher values of most dimensions of the humerus and clavicle, and they also had greater values of the forearm bones width parameters. In the lower limb they exibited greater dimensions of the diaphyses of the studied bones. This was a surprising result regarding the supposed gracility as a consequence of the lower life standard of 'Pachner's collection' individuals. Conversely, this might relate to the secular trend for increased stature through time.

The scapula, clavicle, and fibula of the populations do not show any statistically significant differences. However, in the case of the Great Moravian population group the result for the scapula and fibula may be affected by the low number of observations.

For the comparison of the cemeteries Mikulčice-Kostelisko and Prušánky with other Great Moravian cemeteries, Josefov (Stránská et al. 2002), Břeclav-Pohansko (Drozdová 1997), and Bulhary (Dobisíková et al. 2003) were chosen. We could make a general conclusion about the *upper limb bones* that the greatest metric characteristics were seen in Pohansko, and in the Prušánky burial-place (above all in males), whereas they were least in the Mikulčice-Kostelisko cemetery, which could be partially explained by the shortage of males in this burial-ground. In the case of *lower limb bones,* Prušánky and Bulhary were about average but when females femur robustness was concerned they were among the greatest. Individuals from the Mikulčice-Kostelisko cemetery had the most gracile and shortest lower limb bones; their dimensions most resemble those of Josefov.

We can confirm the assumption based on prior investigations (e.g. Čuk/Leben-Seljak/Štefančič 2001; Škvařilová 1999; Steele/Mays 1995), that DA should be present in most bones of the upper limb, and that it is most expressed in the humerus, namely in favour of the right side. Velemínký (2000) also recorded asymmetry of the upper limb bones in favour of the right side in the Great Moravian population.

In most of the studied upper limb bones DA was shown especially on their maximum lengths, and irregularly on the diaphyseal diameters. In the medieval population, DA appeared less than in the recent population (Pearson Chi-square value=7.4; p=0.006). As the recent sample was of a lower socially class, a certain non-specific stress could be assumed because asymmetry could also be caused by such an overload (long-lasting unsuitable living conditions, insufficient nutrition, or other stresses from the environment; *inter alia:* Livshits/Kobyliansky 1987; Graham/Freeman/Emlen 1993). Again, Steele/Mays (1995) presumed that the DA of limb bones develops as a consequence of greater mechanical stress affecting the dominant limb, and that it increases with age (prolonged stress). It is possible that in individuals from the recent population, one (the dominant) upper limb was submitted to greater stress.

Earlier studies (e.g. Mays/Steele/Ford 1999; Huggare/Houghton 1995) showed that the right clavicle is shorter and more robust in most individuals. Our study agreed with these results in the case of recent males and females but in the medieval population we did not confirm this assumption. This phenomenon is explained by the assumption that clavicle growth of the dominant limb is inhibited due to the greater muscle development in this area (Mays/Steele/Ford 1999).

Compared to earlier investigations (Steele/Mays 1995; Mays/Steele/Ford 1999; Čuk/Leben-Seljak/Štefančič 2001) on the handedness, it was found that in the recent population, there were about 81% of right-handers. Therefore, the majority of right-handers had a shorter and more robust right clavicle, and primarily longer and slightly more robust long bones of their right upper limb. The differences were most expressed on the humerus.

In accordance with the results of most studies (*inter alia:* Škvařilová 1999; Čuk/Leben-Seljak/Štefančič 2001) DA in the lower limb appeared much less than in the upper limb, and this applied to both populations. In the majority of cases, it was directed to the left, and thus confirmed the greater robustness of the left lower limb in connection with stress affecting it during life (Čuk/Leben-Seljak/Štefančič 2001). In the recent sample DA was shown only in the femur, in the medieval sample it appeared also in certain dimensions of the tibia. DA was not registered on the fibula.

In earlier studies (Ruff 1992; Latimer/Lowrance 1965; Singh 1970) asymmetry was usually not found in the bone lengths but only in their robustness. To a certain extent, this agrees with our results: DA was found rather in the dimensions on the diaphyses than on their lengths. According to Čuk/Leben-Seljak/Štefančič (2001), this might be due to the fact that the longitudinal bone growth is completed between the 18th and 25th year of age, but the width growth of the bones continues during the rest of life.

Individuals from the Great Moravian population exhibited little more DA in the lengths of lower limb bones (namely the tibia and femur), but there was no significant difference (Pearson Chi-square value=1.20; p=0.274). The left femur had a more robust diaphysis in both populations (similar to Čuk/Leben-Seljak/Štefančič 2001; Ruff/Hayes 1983; Macho 1991; Velemínský 2000). According to many authors (e.g. Ruff/Hayes 1983), the reason consisted mainly of the stress resulting from the supporting function of the lower limb. It is interesting, however, that femur of recent females was little more asymmetric than medieval females population (47% of traits in recent compared to 33% of traits of medieval females), whereas lower limb of medieval males was little more asymmetric than in recent males (38% of traits in medieval compared to 19% of traits of recent males). In addition, recent males – in contrast to the medieval males – had less sagittal flattening of left femoral diaphyses than of the right. Conversely, Great Moravian males had left femur wider in the transversal direction. The epiphyseal femoral dimensions showed DA in favour of the right side only in the recent population, although the right side was non-significantly greater in medieval population as well. According to Čuk/Leben-Seljak/Štefančič (2001) this might be the result of stress affecting the knee (and the hip) of the right lower limb which has not any supporting function.

The more robust diaphysis of the left tibia in medieval males might be connected with the dominance expression of the left lower limb (on the opposite side to that of the dominant upper limb; Čuk/Leben-Seljak/Štefančič 2001).

If the sexual dimorphism was considered, different conclusions were recorded as in earlier studies. Some investigators did not find differences between the degree of asymmetry and the sexes (e.g. Škvařilová 1999; Steel/Mays 1995). According to other studies, this factor contributes to asymmetry (Feik/Thomas/Clement 1996; Mays/Steele/Ford 1999; Schultz 1937). Our investigations suggested that the differences were not so substantial.

In the recent population DA occurred more often in females in accordance with the study of Schultz (1937; in 41% of traits in males, in 52.3% in females). Conversely, in the Great Moravian population DA occurred more often in males as was confirmed by the investigations of Schell et al. (1985), or Lazenby (2002) who suggested that females are better able to buffer detrimental effects of environmental stress. In recent females, DA occurred in most dimensions of the upper limb (in 81% of traits). In the Great Moravian population DA was manifested in 48% of traits in males (mostly on the humerus); in females it occurred in 38% of traits (mostly on the ulna). P. Velemínský (2000) similarly confirms greater asymmetry of femur in males from the Mikulčice-Kostelisko necropolis while Ruff/Hayes (1983) found more asymmetric femora in females. Like our study, C.B. Ruff (1992) did not register sexual differences in femur length asymmetry.

Based on these observations, it could not be unequivocally established if males or females were in general 'more asymmetric', neither could the impact rate of this factor regarding DA on the upper limb be defined.

For the assessment of **fluctuating asymmetry (FA)** it was chosen the procedure published by Palmer/Strobeck (1986). FA evaluation is often criticised if it was present prior to exclusion of antisymmetry or DA. Unfortunately, a comparison with other studies is not possible because FA has not been monitored so far in the bones of analogous populations. When studying FA, it is very important to remove or qualify the measurement error. In this study the measurement of the bones of 16 individuals was repeated (Steele/Mays 1995, Mays/Steele/Ford 1999). FA was assessed only in dimensions where no measurement error of raw measurement and also in asymmetry scores was recorded (Fields et al. 1995; Mays 2002). Yet, our results agreed with a study of the upper limb performed on clinical material (Škvařilová 1999) which showed that DA occurred above all on the bones of the upper limb. In our study FA values were very low, and if related to the size of the measured trait it was almost negligible. In spite of the low values, in the recent population higher values of FA were noted, particularly in the scapula. In the medieval population, relatively higher FA values appeared in the clavicle. Possible explanation was that DA appears often in this dimension (Mays/Steele/Ford 1999), but this was not confirmed in our sample. Higher values were also observed on the ulna length but also in this case, this is a dimension where DA occurs very often, according to our results. On the other hand, in clinical material, Škvařilová (1999) assessed the presence of FA on the forearm length. She registered FA of the width of the distal epiphysis of the humerus. We did not find similar results in either population.

With regard to the lower limb, the highest variance values (FA4), and absolute FA deviations (FA1) were registered in the length dimensions, lower values were registered in the diaphyseal and epiphyseal metric characteristics. But as soon as the FA size was related to the trait size (FA2 and FA6) the result was negligible, as in the upper limb.

The FA of limb bones reached higher values in the recent population than in the medieval sample. Some studies connect higher FA with increased environmental stress (Van Valen 1962; Palmer 1994; Zakharov/Graham 1992). This might also confirm the results of sexual dimorphism where more expressed differences were found between sexes in the medieval population – and a high degree of sexual dimorphism is considered to be a sign of good health, and low environmental stress (Lazenby 2002). Accordingly, the recent sample (lower social class) was subject to higher environmental stress than the group from Great Moravian period.

The length dimensions of the long bones of the upper limb (humerus + radius) as well as the lower limb (femur + tibia) were summarized to compare the maximum lengths of limbs and their asymmetry. The limb lengths asymmetry was similarly assessed inter alia by Ingelmark (1946). The relevant number of observations was so low, however, that we could not proceed to any assessment.

In general, right-handers have a better developed right upper limb, together with a better developed left lower limb (Ruff/Jones 1981; Siniarska/Sarna 1980). Therefore, all groups were divided according to their maximum humeral length into hypothetical 'right-handers' (longer right humerus), 'left-handers' (longer left humerus), and into ambidextrous individuals (both humeri of equal length) (*inter alia* according to Čuk/Leben-Seljak/Štefančič 2001; Steele/Mays 1995). The results for the Great Moravian population were: 95.8% of males had a longer right humerus, 4.2% had a longer left humerus, and any case of equally long humeri was found. In females from Great Moravia, 73.3% had a longer right humerus, 20% a longer left humerus, and 6.7% had both bones equally long.

In the recent population results indicated that 81.2% of males had a longer right humerus, 12% had a longer left humerus, and 6.8% of males had both humeri equally long. In recent females, the results were similar: 81.6% of females had a longer right humerus and 13.6% of females had a longer left humerus while 4.8% of females had both humeri equally long. Our findings correspond with the following investigations: Annet/Kilshaw (1983) (82% right-handers, 15% left-handers, and 3% of ambidextrous individuals), Steele/Mays (1995) (81% right-handers, 16% left-handers, and 3 % of ambidextrous individuals), Čuk/Leben-Seljak/Štefančič (2001) (87% longer right humerus, 10% longer left humerus, and 3% both bones equally long).

In subsequent analyses, the percentage of hypothetic 'right-handers' and 'left-handers' with longer left/right lower limb bones [e.g. according to Ingelmark (1946) 85% of right-handed individuals had a longer left lower limb while 85% left-handers had a longer right lower limb]. Among males and females from the Great Moravian population who had longer humeri on their right upper limb a greater percentage of individuals with a longer right femur, tibia, and fibula was found. Here, cross-asymmetry also was not statisticaly confirmed. The results on hypothetic left-handed individuals from the Great Moravian population cannot be interpreted because of the low number of preserved bones.

We are grateful to Stephany Leach from Archaeology Dept, Medecroft, University College Winchester, United Kingdom, who helped us to improve this article and Prof. Václav Seichert from Institute of Anatomy, First Faculty of Medicine, Charles University, Czech Republic, for provision of skeletal material. This project was supported by the Grant Agency of the Czech Republic under grant GAČR 206/03/0725 and by the Research plan MSM 0021620843.

Literature

Albert/Greene 1999 – A.M. Albert/D.L. Greene, Bilateral Asymmetry in Skeletal Growth and Maturation as an Indicator of Environmental Stress. Am. J. Phys. Anthropol. 110, 1999, 341–349.

Annett/Kilshaw 1983 – M. Annett/D. Kilshaw, Right and left-hand skill II: estimating the parameters of the distribution of L-R differences in males and females. Br. J. Psychol. 74, 1983, 269–283.

Burian 1939 – F. Burian, Asymetrie chirurgická. Encyklopedie Praktického lékaře díl II., seš. 43-44.

Černý 1971 – M. Černý, Určování pohlaví podle postkraniálního skeletu In: E. Vlček (ed.), Symposium o určování stáří a pohlaví jedince na základě studia kostry. Národní muzeum v Praze (Praha 1971) 46–42.

Černý/Komenda 1982 – M. Černý/S. Komenda, Reconstruction of body height based on humerus and femur lengths (material from Czech lands). In: V. Novotný (ed.), IInd Anthropological Congress of A. Hrdlička (Universitas Carolina Pragensis 1982) 475–480.

Čuk/Leben-Seljak/Štefančič 2001 – T. Čuk/P. Leben-Seljak/M. Štefančič, Lateral Asymmetry of Human Long Bones. Variability and Evolution 9, 2001, 19–32.

Dobisíková 1999 – M. Dobisíková, Určování pohlaví. In: M. Stloukal et al., Antropologie. Příručka pro studium kostry (Národní muzeum, Praha 1999) 168–234.

Dobisíková et al. 2003 – M. Dobisíková/P. Velemínský/J. Velemínská/M. Stloukal, Anthropologische Bearbeitung der Skelettüberreste aus Bulhary. Čas. Nár. muz., ř. přírodovědná 172 (1-4), 2003, 21–44.

Drozdová 1997 – E. Drozdová, Antropologická studie staroslovanského obyvatelstva sídelního komplexu Břeclav-Pohansko (antropometrická studie). PhD thesis, Faculty of Science, Masaryk University Brno (Brno 1997).

Feik/Thomas/Clement 1996 – S.A. Feik/C.D. Thomas/J.G. Clement, Age trends in remodelling of the femoral midshaft digger between the sexes. J. Orthop. Res. 14, 1996, 590–597.

Fields et al. 1995 – S.J. Fields/M. Spiers/I. Herschkovitz/G. Livshits, Reliability of coefficients in the estimation of asymmetry. Am. J. Phys. Anthropol. 96, 1995, 83–87.

Fresia/Ruff/Larson 1990 – A.E. Fresia/C.B. Ruff/C.S. Larson, Temporal decline in bilateral asymmetry of the upper limb on the Georgia coast. In: C.S. Larson (ed.), Biocultural Interpretation of a Population in Transition. Papers of the American Museum of Natural History 68, 1990, 121–132.

Graham/Freeman/Emlen 1993 – J.H. Graham/D.C. Freeman/J.M. Emlen, Antisymmetry, directional asymmetry, and dynamic morphogenesis. Genetica 89, 1993, 121–137.

Helmkamp/Falk 1990 – R.C. Helmkamp/D. Falk, Age- and Sex-Associated Variations in the Directional Asymmetry of Rhesus Macaque Forelimb Bones. Am. J. Phys. Anthropol. 83, 1990, 211–218.

Huggare/Houghton 1995 – J. Huggare/P. Houghton, Asymmetry in the human skeleton, a study on prehistoric Polynesians and Thais. Eur. J. Morphol. 33, 1995, 3–14.

Ingelmark 1946 – B.E. Ingelmark, Über die Längenasymmetrien der Fxtremitäten und ihren Zusammenhang mit der Rechts-Linkshändigkeit. Upsala Läkareförenings Förhandlingar N.F. 52, 1946, 17–82.

Jurowska 1972 – W.Z. Jurowska, Wozrastnyje izmienienia asimetri i wariabilnosti niekatorych rozmierow czielawieczoskowo tiela. Voprosy Antropologie 45, 1972, 104–111.

Kieser/Groenveld/Preston 1986 – J.A. Kieser/H.T. Groenveld/C.B. Preston, Fluctuating dental asymmetry as measure of odontogenic canalization in man. Am. J. Phys. Anthropol. 71, 1986, 437–444.

Latimer/Lowrance 1965 – H.B. Latimer,/E.W. Lowrance, Bilateral Asymmetry in Weight and in Length of Human Bones. Anat. Rec. 152, 1965, 217–224.

Laubach/McConville 1967 – L.L. Laubach/J.T. McConville, Notes on Anthropometric Technique: Anthropometric measurements – right and left sides. Am. J. Phys. Anthropol. 26, 1967, 367–370.

Lazenby 2002 – R.A. Lazenby, Sex dimorphism and bilateral asymmetry: modelling developmental instability and functional adaptation. Am. J. Phys. Anthropol. 96, suppl. 32, 2002.

Leopold/Minuth/Krüger 1986 – D. Leopold/ I. Minuth/G. Krüger, Zum Sexualdimorphism der Unterschenkelknochen – ein Beitrag zur Identification. Kriminalistik u. forens. Wiss. 63, 64, 1986, 62–66. In: M. Stloukal et al. 1999, Antropologie. Příručka pro studium kostry (Národní muzeum, Praha 1986) 40–111.

Little/Buschang/Malina 2002 – B.B. Little/P.H. Buschang/R.M. Malina, Anthropometric asymmetry in chronically undernourished children from Southern Mexico. Ann. Hum. Biol. 29, 2002, 526–537.

Livshits/Kobyliansky 1987 – G. Livshits/E. Kobyliansky, Dermatoglyphic traits as possible markers of developmental processes in humans. Am. J. Med. Genet. 26, 1987, 111–122.

Livshits et al. 1998 – G. Livshits/K. Yakovenko/ L. Kletselman/D. Karasik/E. Kobyliansky, Fluctuating Asymmetry and Morphometric Variation of Hand Bones. Am. J. Phys. Anthropol. 107, 1998, 125–136.

Macho 1991 – G.A. Macho, Anthropological evaluation of left-right differences in the femur of southern African populations. Anthropol. Anz. 49 (3), 1991, 207–216.

Malina/Buschang 1984 – R.M. Malina/P.H. Buschang, Anthropometric asymmetry in normal and mentally retarded males. Ann. Hum. Biol. 11, 1984, 515–532.

Martin/Saller 1957 – R. MartinK. Saller, Lehrbuch der Anthropologie (Stuttgart 1957).

Mays 2002 – S.A. Mays, Asymmetry in Metacarpal Cortical Bone in a Collection of British Post-Mediaeval Human Skeletons. J. Archaeol. Sci. 29, 2002, 435–441.

Mays/Steele/Ford 1999 – S. Mays/J. Steele/M. Ford, Directional Asymmetry in the Human Clavicle. Int. J. Osteoarchaeol. 9, 1999, 18–28.

Pachner 1937 – P. Pachner, Pohlavní rozdíly na lidské pánvi (Česká Akademie Věd a Umění, Praha 1937).

Palmer 1994 – A.R. Palmer, Fluctuating asymmetry analyses: A primer. In: T.A. Markow (ed.), Developmental Instability: its Origins and Evolutionary Implications (Kluver, Dordrecht 1994) 335–364.

Palmer 1996 – A.R. Palmer, Waltzing with Asymmetry. Bioscience 46, 1996, 518–532.

Palmer/Strobeck 1986 – A.R. Palmer/C. Strobeck, Fluctuating asymmetry: measurement, analysis, pattern. Annu. Rev. Ecol. Syst. 17, 1986, 391–421.

Pande/Singh 1971 – B.S. Pande/I. Singh, One sides dominance in the upper limbs of human fetuses as evidenced by asymmetry in muscle and bone weight. J. Anat. 109, 1971, 457–459.

Plato/Fox/Garruto 1985 – C.C. Plato/K.M. Fox/ R.M. Garruto, Measures of Lateral Functional Dominance: Foot Preference, Eye Preference, Digital Interlocking, Arm Folding and Food Overlapping. Hum. Biol. 57, 1985, 327–334.

Plato/Wood/Norris 1980 – C.C. Plato/J.L. Wood/ A.H. Norris, Bilateral asymmetry in bone measurements of the hand and lateral hand dominance. Am. J. Phys. Anthropol. 52, 1980, 27–31.

Plochocki 2002 – J.H. Plochocki, Directional Bilateral Asymmetry in Human Sacral Morphology. Int. J. Osteoarchaeol. 12, 2002, 349–355.

Roy/Ruff/Plato 1994 – T.A. Roy/C.B. Ruff/C.C.Plato, Hand Dominance and Bilateral Asymmetry in the Structure of the Second Metacarpal. Am. J. Phys. Anthropol. 94, 1994, 203–211.

Ruff 1992 – C.B. Ruff, Age changes in endosteal and periosteal sensitivity to increased mechanical loading. Transactions of the 38th Annual Meeting of the Orthopaedic Research Society 17, 1992, 532.

Ruff/Hayes 1983 – C.B. Ruff/W.C. Hayes, Cross-sectional Geometry of Pecos Pueblo Femora and Tibiae – A Biomechanical Investigation: II. Sex, Age and Side Differrences. Am. J. Phys. Anthropol. 60, 1983, 383–400.

Ruff/Jones 1981 – C.B. Ruff/H.H. Jones, Bilateral asymmetry in cortical bone of the humerus and tibia-sex and age factors. Hum. Biol. 53, 1981, 69–86.

Schell et al. 1985 – L.M. Schell/E.E. Johnston/D.R. Smith/A.M. Paolone, Directional asymmetry of body dimensions among white adolescents. Am. J. Phys. Anthropol. 67, 1985, 317–322.

Schultz 1937 – A.H. Schultz, Proportions, Variability and Asymmetries of the Long Bones of the Limbs and the Clavicles in Man and Apes. Hum. Biol. 9 (3), 1937, 97–101.

G. Singh/S. Singh/S.P. Singh 1975 – G. Singh/S. Singh/S.P. Singh, Identification of sex from tibia. J. Anat. Soc. India 24, 1975, 20–24 (In: M. Stloukal et al. 1999, Antropologie. Příručka pro studium kostry (Národní muzeum, Praha 1975) 40–111.

Singh 1970 – I. Singh, Functional asymmetry in the lower limbs. Acta Anat. 77, 1970, 131–138.

Siniarska/ Sarna 1980 – A. SiniarskaJ. Sarna, Asymmetry of human body – a synthetic approach. Studies in Human Ecology 4, 1980, 217–241.

Steele/Mays 1995 – J. Steele/S. Mays, Handedness and Directional Asymmetry in the Long Bones of the Human Upper Limb. Int. J. Osteoarchaeol. 5, 1995, 39–49.

Stirland 1993 – A.J. Stirland, Asymmetry and Activity-related Change in the Male Humerus. Int. J. Osteoarchaeol. 3, 1993, 105–113.

Stock/Pfeiffer 2001 – J. Stock/S. Pfeiffer, Linking Structural Variability in Long Bone Diaphyses to Habitual Behaviors: Foragers From the Southern African Later Stone Age and the Andaman Islands. Am. J. Phys. Anthropol. 115, 2001, 337–348.

Stránská et al. 2002 – P. Stránská/P. Velemínský/ J. Likovský/J. Velemínská, The Great Moravian Cemetery at Josefov. Basic Anthropological Characteristic, Possible Expressions of Physiological and Physical Loads, State of Health. Čas. Nár. muz., ř. přírodovědná 171 (1-4), 2002, 131–175.

Škvařilová 1999 – B. Škvařilová, Asymmetry of the Upper Extremity in Contemporary Czech Children. Anthropologie 37/2, 1999, 195–204.

Van Dusen 1939 – C.R. Van Dusen, An anthropometric study of the upper extremities of children. Hum. Biol. 11, 1939, 227–284.

Van Valen 1962 – L. Van Valen, A study of fluctuating asymmetry. Evolution 16, 1962, 125–142.

Velemínský 2000 – P. Velemínský, Mikulčice-Kostelisko. Projevy nespecifické zátěže a možnosti stanovení pokrevní příbuznosti na základě morfologických znaků. PhD thesis (Faculty of Science, Charles University, Praha 2000).

Zakharov/Graham 1992 – V.M. Zakharov/H.J. Graham, Developmental stability in natural populations. Acta Zoologica Fennica 191, 1992, 1–200.

Table 1. Results obtained by comparing males from a medieval, and a recent population – independent t-test .

Expanatory notes: averages are specified in mm; t-value – value of the t-test; df – degrees of freedom; N –number of dimensions; Std.Dev. – standard deviation; p – test level attained; significance levels: * = 5%, ** = 1%, *** = 0.1%

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
SCAPULA	anatomical width	Sc1	sin	95	1	162.2	149.0	94	9.2	0.0	1.425	0.158		
			dx	92	0	161.4		90	8.9					
	anatomical length	Sc2	sin	121	3	105.0	111.0	122	6.4	1.0	-1.595	0.113		
			dx	116	4	103.9	109.3	118	5.7	3.4	-1.841	0.068		
	length of the margo materalis	Sc3	sin	119	1	138.6	139.0	118	8.1	0.0	-0.049	0.961		
			dx	117	7	137.6	142.1	122	8.6	12.3	-1.321	0.189		
CLAVICULA	maximum clavicle length	Cl1	sin	106	23	151.0	150.0	127	7.8	11.2	0.530	0.597		
			dx	110	17	149.0	148.8	125	8.2	11.4	0.074	0.941		
	vertical diameter	Cl4	sin	116	47	11.1	11.1	161	1.3	1.3	0.291	0.771		
			dx	121	48	11.3	11.5	167	1.5	1.5	-0.764	0.446		
	sagittal diameter	Cl5	sin	116	47	12.6	12.7	161	1.4	1.2	-0.393	0.695		
			dx	121	48	12.9	12.8	167	1.4	1.5	0.453	0.651		
HUMERUS	maximum length of the humerus	H1	sin	128	39	322.6	326.2	165	17.4	17.5	-1.133	0.259		
			dx	121	37	326.0	334.1	156	17.0	14.8	-2.620	0.010	*	med
	width of the upper epiphysis	H3	sin	128	21	50.5	50.0	147	2.4	2.5	0.810	0.419		
			dx	121	19	51.5	51.5	138	2.4	2.9	0.105	0.917		
	width of the lower epiphysis	H4	sin	127	29	61.7	62.2	154	3.8	5.1	-0.600	0.550		
			dx	123	35	62.3	63.3	156	3.9	3.8	-1.314	0.191		
	maximum diameter of the middle of the diaphysis	H5	sin	129	78	23.3	22.8	205	2.0	1.8	1.716	0.088		
			dx	123	75	23.8	23.6	196	2.1	2.0	0.793	0.429		
	minimum diameter of the middle of the diaphysis	H6	sin	129	79	18.6	18.5	206	1.7	1.5	0.684	0.495		
			dx	123	76	19.0	18.7	197	1.7	1.7	1.088	0.278		
	maximum transverse diameter of the head	H9	sin	127	13	44.3	43.2	138	2.1	3.9	1.622	0.107		
			dx	116	5	44.8	44.2	119	2.3	2.6	0.529	0.598		
	maximum vertical diameter of the head	H10	sin	128	24	48.0	45.4	150	2.5	6.3	3.422	0.001	**	rec
			dx	121	19	48.6	47.9	138	2.3	6.0	0.807	0.421		

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
ULNA	maximum length of the ulna	U1	sin	109	18	256.1	269.3	125	13.1	20.5	-3.616	0.000	***	med
			dx	107	28	257.3	267.9	133	13.0	25.2	-3.094	0.002	**	med
	sagittal diameter of the diaphysis	U11	sin	112	48	14.3	14.3	158	1.3	1.6	0.225	0.822		
			dx	107	55	14.4	14.4	160	1.4	1.6	-0.067	0.947		
	width of the diaphysis	U12	sin	112	48	17.6	17.6	158	1.4	1.8	-0.203	0.840		
			dx	107	54	17.6	17.4	159	1.5	1.8	0.896	0.371		
RADIUS	maximum length of the radius	R1	sin	103	24	237.3	246.5	125	12.0	16.8	-3.092	0.002	**	med
			dx	105	25	239.2	248.1	128	12.3	17.3	-2.977	0.003	**	med
	maximum width of the diaphysis	R4	sin	103	47	17.8	17.3	148	1.7	1.7	1.617	0.108		
			dx	107	48	18.1	17.8	153	1.8	1.4	1.178	0.241		
	width of the middle of the diaphysis	R4a	sin	104	42	16.7	16.4	144	1.5	1.6	1.146	0.254		
			dx	107	48	17.2	16.8	153	1.7	1.6	1.419	0.158		
	sagittal diameter of the diaphysis	R5	sin	103	46	12.4	12.2	147	1.1	1.2	1.091	0.277		
			dx	107	48	12.6	12.5	153	1.1	1.4	0.457	0.648		
	sagittal diameter of the middle of the diaphysis	R5a	sin	104	41	12.7	12.2	143	1.1	0.9	2.371	0.019	*	rec
			dx	107	48	12.8	12.5	153	1.0	0.9	1.994	0.048	*	rec
FEMUR	maximum length of the femur	F1	sin	76	48	450.6	456.2	122	26.2	29.9	-1.104	0.272		
			dx	72	43	449.5	450.3	113	24.4	29.4	-0.154	0.878		
	physiological length	F2	sin	76	61	448.4	453.2	135	25.8	24.9	-1.108	0.270		
			dx	72	56	446.6	452.3	126	24.3	24.9	-1.295	0.198		
	sagittal diameter of the middle of the diaphysis	F6a	sin	78	86	28.3	28.5	162	2.5	2.8	-0.467	0.641		
			dx	72	88	28.6	28.5	158	2.5	2.8	0.440	0.661		
	transverse diameter of the middle of the diaphysis	F7a	sin	78	87	28.4	28.9	163	2.6	2.5	-1.173	0.243		
			dx	72	86	28.5	28.0	156	2.4	2.4	1.499	0.136		
	upper transverse diameter of the diaphysis	F7b	sin	78	80	30.6	32.3	156	2.8	2.7	-3.918	0.000	***	med
			dx	72	81	30.6	31.1	151	2.7	3.0	-1.258	0.210		
	upper sagittal diameter of the diaphysis	F7c	sin	78	81	28.5	27.4	157	2.4	2.7	2.649	0.009	**	rec
			dx	72	81	28.0	26.7	151	2.3	2.9	3.132	0.002	**	rec

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
FEMUR	lower transverse diameter of the diaphysis	F7d	sin	78	72	35.6	35.5	148	4.0	4.2	0.192	0.848		
			dx	72	71	35.7	34.6	141	4.1	3.9	1.544	0.125		
	lower sagittal diameter of the diaphysis	F7e	sin	78	73	31.5	30.7	149	3.2	2.8	1.767	0.079		
			dx	72	71	31.0	30.7	141	2.9	2.5	0.595	0.553		
	circumference of the middle of the diaphysis	F8	sin	78	67	86.8	89.6	143	6.3	5.9	-2.793	0.006	**	med
			dx	72	67	87.1	88.7	137	5.7	5.7	-1.616	0.108		
	subtrochanteric transverse diameter of the diaph.	F9	sin	78	90	33.3	34.5	166	2.7	2.8	-2.753	0.007	**	med
			dx	72	88	33.7	33.5	158	2.6	2.7	0.412	0.681		
	subtrochanteric sagittal diameter of the diaphysis	F10	sin	78	89	28.7	27.8	165	2.5	2.9	2.083	0.039	*	rec
			dx	72	88	28.6	27.4	158	2.2	2.2	3.395	0.001	**	rec
	upper widht of the epiphysis	F13	sin	77	55	101.3	100.2	130	6.9	7.3	0.925	0.357		
			dx	72	43	101.8	100.1	113	5.8	7.9	1.308	0.194		
	vertical diameter of the head	F18	sin	76	44	48.5	48.8	118	2.8	2.3	-0.716	0.476		
			dx	72	43	48.8	48.1	113	2.6	2.9	1.240	0.217		
	transverse diameter of the head	F19	sin	76	39	48.2	48.3	113	2.7	2.4	-0.188	0.852		
			dx	72	37	48.4	48.3	107	2.6	3.0	0.191	0.849		
	epicondylar width	F21	sin	76	18	82.1	82.8	92	4.4	5.0	-0.548	0.585		
			dx	72	18	82.9	82.3	88	4.5	5.8	0.487	0.628		
FIBULA	maximum length of the fibula	Fi1	sin	106	13	359.9	367.8	117	24.2	23.3	-1.111	0.269		
			dx	112	6	358.0	360.3	116	24.8	16.5	-0.227	0.820		
	overal length tibie	T1	sin	63	38	367.7	377.5	99	21.1	22.3	-2.216	0.029	*	med
			dx	67	35	371.1	374.3	100	20.6	30.4	-0.620	0.536		
	medial length	T1b	sin	61	30	358.3	372.3	89	21.3	22.3	-2.889	0.005	**	med
			dx	65	22	361.1	373.6	85	20.6	23.7	-2.367	0.020	*	med
TIBIA	maximum width of the upper epiphysis	T3	sin	61	6	75.0	76.8	65	3.1	0.8	-1.396	0.167		
			dx	65	8	75.1	75.8	71	3.4	3.7	-0.503	0.617		
	width of the lower epiphysis	T6	sin	62	20	48.8	47.8	80	3.1	3.8	1.206	0.231		
			dx	68	21	49.0	48.4	87	3.0	4.8	0.660	0.511		

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
TIBIA	minimum diameter of the middle of the diaphysis	T8	sin	67	61	29.5	29.5	126	3.0	2.5	0.035	0.972		
			dx	71	65	29.9	29.2	134	2.3	2.4	1.732	0.086		
	width of the middle of the diaphysis	T9	sin	67	61	23.0	22.3	126	2.1	2.0	1.922	0.057		
			dx	71	66	22.8	22.2	135	2.0	2.0	1.785	0.076		
	sagittal diameter in the upper foramen nutricium	T8a	sin	66	79	34.1	33.3	143	3.2	3.3	1.512	0.133		
			dx	70	77	34.2	33.4	145	2.9	3.1	1.616	0.108		
	width of the diaphysis in the upper for.nutric.	T9a	sin	66	78	25.1	23.7	142	2.2	2.3	3.637	0.000	***	rec
			dx	70	79	25.3	24.0	147	2.4	2.2	3.576	0.000	***	rec
	circumference of the middle of the diaphysis	T10	sin	67	55	80.6	80.4	120	6.0	5.3	0.197	0.844		
			dx	71	60	81.0	79.8	129	5.8	5.1	1.193	0.235		
	circumference of the diaphysis on the for.nutric.	T10a	sin	66	68	91.7	90.7	132	7.4	6.8	0.809	0.420		
			dx	70	63	92.2	90.3	131	6.7	6.7	1.695	0.093		
	minimum circumference of the diaphysis	T10b	sin	67	63	72.1	73.4	128	5.0	5.5	-1.374	0.172		
			dx	71	60	72.6	72.9	129	4.9	4.5	-0.311	0.756		

Table 2. Results obtained by comparing females from a medieval and a recent population – independent t-test (for legend see Table 1).

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
SCAPULA	anatomical width	Sc1	sin	97	1	144,8	148,0	96	9,0	0,0	-0,360	0,720		
			dx	90	3	144,8	140,0	91	9,1	1,0	0,907	0,367		
	anatomical length	Sc2	sin	122	7	96,4	93,1	127	5,4	3,1	1,597	0,113		
			dx	122	3	96,6	92,0	123	5,6	3,0	1,409	0,161		
	length of the margo materalis	Sc3	sin	118	3	125,3	130,3	119	8,5	1,5	-1,033	0,304		
			dx	122	4	126,3	127,3	124	8,6	5,3	-0,217	0,828		
CLAVICULA	maximum clavicle length	Cl1	sin	93	29	136,1	133,0	120	7,0	7,9	2,026	0,045	*	rec
			dx	92	35	135,1	130,3	125	7,0	7,8	3,359	0,001	**	rec
	vertical diameter	Cl4	sin	120	45	9,1	9,6	163	1,3	1,2	-2,208	0,029	*	med
			dx	120	44	9,2	9,5	162	1,2	1,2	-1,709	0,089		
	sagittal diameter	Cl5	sin	120	46	10,9	10,6	164	1,2	1,3	1,480	0,141		
			dx	120	44	11,4	10,7	162	1,3	1,2	3,083	0,002	**	rec
HUMERUS	maximum length of the humerus	H1	sin	133	52	297,4	291,5	183	14,9	16,9	2,323	0,021	*	rec
			dx	136	50	300,3	296,6	184	15,2	15,0	1,496	0,136		
	width of the upper epiphysis	H3	sin	133	33	44,8	43,5	164	2,5	2,3	2,697	0,008	**	rec
			dx	136	32	45,4	44,4	166	2,6	2,7	2,022	0,045	*	rec
	width of the lower epiphysis	H4	sin	133	41	54,0	54,3	172	3,1	3,0	-0,470	0,639		
			dx	137	40	54,6	54,9	175	3,3	3,1	-0,458	0,648		
	maximum diameter of the middle of the diaphysis	H5	sin	134	94	20,6	20,2	226	1,7	1,5	2,046	0,042	*	rec
			dx	137	94	21,1	20,4	229	1,7	1,8	3,191	0,002	**	rec
	minimum diameter of the middle of the diaphysis	H6	sin	134	94	16,2	15,8	226	1,3	1,3	2,240	0,026	*	rec
			dx	137	95	16,4	15,8	230	1,5	1,3	3,300	0,001	**	rec
	maximum transverse diameter of the head	H9	sin	126	20	39,1	39,1	144	2,0	2,3	-0,010	0,992		
			dx	126	18	39,3	39,0	142	2,2	1,5	0,633	0,528		
	maximum vertical diameter of the head	H10	sin	131	32	42,2	41,6	161	2,3	2,3	1,305	0,194		
			dx	131	30	42,4	41,3	159	2,5	2,6	2,114	0,036	*	rec

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
ULNA	maximum length of the ulna	U1	sin	129	32	230,8	241,3	159	11,3	10,7	-4,790	0,000	***	med
			dx	133	21	234,2	241,8	152	12,2	13,6	-2,581	0,011	*	med
	sagittal diameter of the diaphysis	U11	sin	136	59	11,8	11,6	193	1,1	1,3	1,322	0,188		
			dx	137	60	12,2	11,9	195	1,1	1,4	1,836	0,068		
	width of the diaphysis	U12	sin	136	60	14,9	14,7	194	1,3	1,6	0,871	0,385		
			dx	137	60	15,3	14,8	195	1,2	1,7	2,502	0,013	*	rec
RADIUS	maximum length of the radius	R1	sin	135	32	212,9	216,7	165	11,4	11,7	-1,678	0,095		
			dx	131	31	216,0	222,0	160	12,0	13,8	-2,449	0,015	*	med
	maximum width of the diaphysis	R4	sin	136	49	15,7	15,0	183	1,6	1,2	2,519	0,013	*	rec
			dx	135	48	15,9	15,4	181	1,5	1,6	1,970	0,050		
	width of the middle of the diaphysis	R4a	sin	136	56	14,7	14,2	190	1,4	1,4	2,264	0,025	*	rec
			dx	135	59	15,1	14,6	192	1,4	1,5	2,401	0,017	*	rec
	sagittal diameter of the diaphysis	R5	sin	136	50	10,6	10,6	184	0,8	1,1	-0,077	0,939		
			dx	135	51	10,6	10,8	184	0,8	1,3	-1,150	0,252		
	sagittal diameter of the middle of the diaphysis	R5a	sin	136	55	10,6	10,5	189	0,8	1,0	0,403	0,687		
			dx	135	57	10,7	10,6	190	1,0	1,0	0,974	0,331		
FEMUR	maximum length of the femur	F1	sin	74	74	414,1	406,5	146	22,4	27,4	1,845	0,067		
			dx	72	65	414,7	411,4	135	20,7	20,5	0,939	0,349		
	physiological length	F2	sin	74	81	410,6	408,8	153	22,4	16,7	0,577	0,565		
			dx	72	71	410,7	408,3	141	20,6	17,7	0,737	0,462		
	sagittal diameter of the middle of the diaphysis	F6a	sin	80	128	25,8	24,4	206	2,0	2,5	4,239	0,000	***	rec
			dx	77	114	26,0	24,4	189	2,1	2,3	4,614	0,000	***	rec
	transverse diameter of the middle of the diaphysis	F7a	sin	80	127	26,7	25,7	205	2,4	2,2	3,072	0,002	**	rec
			dx	77	114	26,4	25,3	189	2,2	2,1	3,251	0,001		
	upper transverse diameter of the diaphysis	F7b	sin	80	107	29,2	29,2	185	2,5	2,2	-0,159	0,874		
			dx	77	100	28,5	29,1	175	2,6	2,7	-1,471	0,143		
	upper sagittal diameter of the diaphysis	F7c	sin	80	105	25,8	23,5	183	2,2	2,5	6,387	0,000	***	rec
			dx	77	97	25,3	23,3	172	2,0	2,5	5,663	0,000	***	rec

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
FEMUR	lower transverse diameter of the diaphysis	F7d	sin	80	101	33,0	31,3	179	3,5	3,7	3,071	0,002	**	rec
			dx	77	91	32,9	30,9	166	3,7	3,4	3,788	0,000	***	rec
	lower sagittal diameter of the diaphysis	F7e	sin	80	98	28,6	26,7	176	2,2	2,5	5,471	0,000	***	rec
			dx	77	89	27,9	26,3	164	2,3	2,3	4,509	0,000	***	rec
	circumference of the middle of the diaphysis	F8	sin	81	83	80,0	78,9	162	5,9	5,4	1,252	0,212		
			dx	77	78	79,6	78,7	153	5,5	5,6	1,013	0,312		
	subtrochanteric transverse diameter of the diaph.	F9	sin	80	127	31,3	31,0	205	2,3	2,3	1,078	0,282		
			dx	75	120	31,1	30,9	193	2,5	2,5	0,539	0,591		
	subtrochanteric sagittal diameter of the diaphysis	F10	sin	80	128	26,0	23,9	206	1,9	2,2	6,918	0,000	***	rec
			dx	75	122	26,0	24,1	195	2,1	2,5	5,474	0,000	***	rec
	upper widht of the epiphysis	F13	sin	76	66	87,9	88,4	140	5,2	5,5	-0,557	0,578		
			dx	72	60	88,5	89,0	130	5,6	6,1	-0,514	0,608		
	vertical diameter of the head	F18	sin	74	56	42,8	42,5	128	2,7	2,2	0,584	0,561		
			dx	72	55	43,0	42,9	125	2,7	2,3	0,249	0,804		
	transverse diameter of the head	F19	sin	74	46	42,4	42,0	118	2,3	2,1	1,086	0,280		
			dx	70	50	42,8	42,3	118	2,4	2,1	1,195	0,234		
	epicondylar width	F21	sin	74	32	73,5	71,5	104	3,8	2,8	2,647	0,009	**	rec
			dx	72	28	74,0	72,1	98	3,7	3,1	2,486	0,015	*	rec
FIBULA	maximum length of the fibula	Fi1	sin	93	18	326,8	328,6	109	18,4	15,8	-0,396	0,693		
			dx	104	22	327,8	329,0	124	17,5	13,4	-0,328	0,744		
TIBIA	overal length tibie	T1	sin	80	47	337,9	337,2	125	17,2	18,3	0,229	0,819		
			dx	77	51	337,6	335,7	126	16,8	19,2	0,582	0,562		
	medial length	T1b	sin	78	34	327,8	333,3	110	20,6	16,8	-1,365	0,175		
			dx	74	37	328,8	329,6	109	17,0	19,1	-0,212	0,832		
	maximum width of the upper epiphysis	T3	sin	73	16	66,5	65,4	87	4,0	3,3	0,974	0,333		
			dx	69	13	67,0	66,7	80	3,6	3,0	0,248	0,805		
	width of the lower epiphysis	T6	sin	74	35	43,6	42,5	107	2,9	2,9	1,957	0,053	*	rec
			dx	69	27	44,1	41,5	94	2,7	3,6	3,800	0,000	*	rec

	Measurements	Abbr.		Recent	Medieval	Recent	Medieval		Recent	Medieval				
				N	N	Mean		df	Std.Dev.	Std.Dev.	t-value	p	Signf.	Larger
TIBIA	minimum diameter of the middle of the diaphysis	T8	sin	86	75	26,6	26,7	159	2,3	2,2	-0,038	0,969		
			dx	83	81	26,5	26,2	162	2,4	2,4	0,694	0,489		
	width of the middle of the diaphysis	T9	sin	86	75	20,6	19,8	159	1,9	2,1	2,533	0,012	*	rec
			dx	83	82	20,9	19,9	163	2,3	2,2	2,880	0,005	**	rec
	sagittal diameter in the upper foramen nutricium	T8a	sin	86	93	30,0	29,8	177	2,5	2,4	0,520	0,603		
			dx	83	98	29,9	29,6	179	2,4	2,6	0,652	0,515		
	width of the diaphysis in the upper for.nutric.	T9a	sin	86	94	22,2	21,0	178	2,0	2,2	3,750	0,000	***	rec
			dx	83	99	22,3	21,3	180	2,2	1,9	3,458	0,001	**	rec
	circumference of the middle of the diaphysis	T10	sin	86	66	72,4	71,7	150	5,2	4,6	0,819	0,414		
			dx	84	64	72,3	72,0	146	5,8	4,9	0,288	0,774		
	circumference of the diaphysis on the for.nutric.	T10a	sin	86	80	81,2	80,5	164	5,9	5,8	0,820	0,413		
			dx	84	74	81,1	80,2	156	5,8	6,1	0,920	0,359		
	minimum circumference of the diaphysis	T10b	sin	86	75	65,6	66,0	159	4,5	3,9	-0,575	0,566		
			dx	85	67	65,7	66,2	150	4,8	3,7	-0,739	0,461		

Table 3. Studied DA. Results of paired t-tests of males from the recent population.

Expanatory notes: diameters specified in mm; t-value - value of the t-test; df – degrees of freedom; N – number of dimensions; Std.Dev. – standard deviation; p – test level attained; significance levels: * = 5%, ** = 1%, *** = 0.1%

	Measurements	Abbr.	N	Mean $_{\mathrm{sin}}$	Std.Dv.	Mean $_{\mathrm{dx}}$	Std. Dv.	t-test	p	Signf.	Larger
SCAPULA	anatomical width	Sc1	80	161,9	9,1	161,3	8,6	1,334	0,186		
	anatomical length	Sc2	112	104,6	6,3	104,0	5,8	3,104	0,002	**	sin
	length of the margo lateralis	Sc3	112	138,3	8,1	138,0	8,5	1,000	0,319		
CLAVICLE	maximum clavicle length	Cl1	97	150,8	8,0	149,2	7,8	3,334	0,001	**	sin
	vertical diameter	Cl4	112	11,1	1,3	11,3	1,5	-1,815	0,072		
	sagittal diameter	Cl5	112	12,6	1,4	13,0	1,4	-3,040	0,003	**	dx
HUMERUS	maximum length of the humerus	H1	117	322,4	17,3	325,7	16,7	-9,933	0,000	***	dx
	width of the upper epiphysis	H3	118	50,5	2,3	51,4	2,3	-8,274	0,000	***	dx
	width of the lower epiphysis	H4	118	61,7	3,8	62,2	3,9	-3,544	0,001	***	dx
	maximum diameter of the middle of the diaphysis	H5	120	23,2	1,9	23,8	2,1	-5,344	0,000	***	dx
	minimum diameter of the middle of the diaphysis	H6	120	18,6	1,7	18,9	1,7	-4,698	0,000	***	dx
	maximum transverse diameter of the head	H9	112	44,3	2,0	44,7	2,3	-3,145	0,002	**	dx
	maximum vertical diameter of the head	H10	118	48,0	2,4	48,5	2,2	-4,148	0,000	***	dx
ULNA	maximum length of the ulna	U1	100	255,4	13,2	257,5	13,1	-6,387	0,000	***	dx
	sagittal diameter of the diaphysis	U11	103	14,3	1,3	14,4	1,4	-0,904	0,368		
	width of the diaphysis	U12	103	17,5	1,4	17,7	1,5	-1,618	0,109		
RADIUS	maximum length of the radius	R1	96	237,0	11,9	239,7	12,0	-8,445	0,000	***	dx
	maximum width of the diaphysis	R4	97	17,8	1,6	18,2	1,7	-3,523	0,001	***	dx
	sagittal diameter of the diaphysis	R5	97	12,4	1,1	12,5	1,1	-1,026	0,308		
	width of the middle of the diaphysis	R4a	98	16,7	1,6	17,3	1,6	-4,570	0,000	***	dx
	sagittal diameter of the middle of the diaphysis	R5a	98	12,7	1,1	12,8	1,0	-1,440	0,153		
FEMUR	maximum length of the femur	F1	66	451,8	23,5	450,9	22,8	1,457	0,150		
	physiological length	F2	66	449,7	23,2	448,0	22,6	2,761	0,007	**	sin
	sagittal diameter of the middle of the diaphysis	F6a	67	28,5	2,4	28,7	2,5	-1,130	0,262		
	transverse diameter of the middle of the diaphysis	F7a	67	28,6	2,4	28,5	2,3	0,639	0,525		
	upper transverse diameter of the diaphysis	F7b	67	30,8	2,7	30,6	2,7	1,390	0,169		
	upper sagittal diameter of the diaphysis	F7c	67	28,7	2,2	28,0	2,3	5,457	0,000	***	sin

	Measurements	Abbr.	N	Mean $_{sin}$	Std.Dv.	Mean $_{dx}$	Std. Dv.	t-test	p	Signf.	Larger
FEMUR	lower transverse diameter of the diaphysis	F7d	67	35,9	4,0	35,7	4,1	0,878	0,383		
	lower sagittal diameter of the diaphysis	F7e	67	31,7	3,1	31,1	2,9	4,243	0,000	***	sin
	subtrochanteric transverse diameter of the diaph.	F9	67	33,7	2,6	33,7	2,6	-0,168	0,867		
	subtrochanteric sagittal diameter of the diaphysis	F10	67	28,9	2,2	28,5	2,2	2,690	0,009	**	sin
	circumference of the middle of the diaphysis	F8	67	87,3	5,7	87,2	5,7	0,521	0,604		
	upper widht of the epiphysis	F13	66	101,8	6,3	102,0	5,9	-0,327	0,745		
	epicondylar width	F21	67	82,1	4,5	82,8	4,5	-3,339	0,001	**	dx
	vertical diameter of the head	F18	66	48,6	2,6	48,8	2,7	-0,976	0,333		
	transverse diameter of the head	F19	66	48,3	2,4	48,4	2,7	-0,757	0,452		
FIBULA	maximum length of the fibula	Fi1	93	359,2	24,6	359,3	23,8	-0,170	0,865		
TIBIA	overal length tibie	T1	47	367,2	21,4	367,7	20,8	-0,622	0,537		
	medial length	T1b	46	356,8	20,3	357,5	20,5	-0,811	0,422		
	maximum width of the upper epiphysis	T3	46	74,6	2,9	74,2	3,0	2,008	0,051		
	width of the lower epiphysis	T6	47	48,5	3,0	48,1	2,9	1,449	0,154		
	minimum diameter of the middle of the diaphysis	T8	53	29,4	2,7	29,5	2,3	-0,855	0,396		
	width of the middle of the diaphysis	T9	53	22,7	2,0	22,6	2,1	0,484	0,630		
	sagittal diameter in the upper foramen nutricium	T8a	51	33,8	3,3	33,7	3,0	0,409	0,684		
	width of the diaphysis in the upper for.nutric.	T9a	51	25,0	2,1	25,1	2,4	-0,461	0,647		
	circumference of the middle of the diaphysis	T10	53	80,4	5,9	79,8	5,6	1,965	0,055		
	circumference of the diaphysis on the for.nutric.	T10a	51	91,2	7,3	91,0	6,8	0,446	0,657		
	minimum circumference of the diaphysis	T10b	53	71,8	5,1	71,7	4,9	0,778	0,440		

Table 4. Studied DA. Results of paired t-tests of females from the recent population (for legend see Table 3).

	Measurements	Abbr.	N	Mean $_{\text{sin}}$	Std.Dv.	Mean $_{\text{dx}}$	Std. Dv.	t-test	p	Signf.	Larger
SCAPULA	anatomical width	Sc1	78	144,3	9,0	144,4	8,9	-0,076	0,939		
	anatomical length	Sc2	112	96,6	5,5	96,7	5,6	-0,343	0,733		
	length of the margo lateralis	Sc3	106	125,2	8,9	126,3	8,8	-4,003	0,000	***	dx
CLAVICLE	maximum clavicle length	Cl1	75	136,1	7,1	134,4	7,1	4,548	0,000	***	sin
	vertical diameter	Cl4	108	9,1	1,3	9,2	1,2	-0,465	0,643		
	sagittal diameter	Cl5	108	10,9	1,2	11,4	1,3	-4,696	0,000	***	dx
HUMERUS	maximum length of the humerus	H1	125	297,7	15,2	301,2	15,2	-10,003	0,000	***	dx
	width of the upper epiphysis	H3	125	44,8	2,5	45,5	2,6	-7,016	0,000	***	dx
	width of the lower epiphysis	H4	126	54,0	3,2	54,8	3,3	-5,608	0,000	***	dx
	maximum diameter of the middle of the diaph.	H5	127	20,6	1,6	21,2	1,6	-6,655	0,000	***	dx
	minimum diameter of the middle of the diaph.	H6	127	16,2	1,4	16,4	1,5	-3,675	0,000	***	dx
	maximum transverse diameter of the head	H9	112	39,0	2,0	39,5	2,2	-4,578	0,000	***	dx
	maximum vertical diameter of the head	H10	119	42,1	2,2	42,5	2,5	-3,214	0,002	**	dx
ULNA	maximum length of the ulna	U1	118	230,8	11,6	234,0	12,2	-10,806	0,000	***	dx
	sagittal diameter of the diaphysis	U11	126	11,9	1,1	12,2	1,1	-4,024	0,000	***	dx
	width of the diaphysis	U12	126	15,0	1,2	15,3	1,3	-4,887	0,000	***	dx
RADIUS	maximum length of the radius	R1	123	212,8	11,7	216,3	12,2	-9,617	0,000	***	dx
	maximum width of the diaphysis	R4	128	15,6	1,6	15,9	1,5	-4,078	0,000	***	dx
	sagittal diameter of the diaphysis	R5	128	10,6	0,8	10,6	0,8	-0,961	0,338		
	width of the middle of the diaphysis	R4a	128	14,7	1,4	15,1	1,4	-6,121	0,000	***	dx
	sagittal diameter of the middle of the diaphysis	R5a	128	10,6	0,8	10,7	0,8	-2,350	0,020	*	dx
FEMUR	maximum length of the femur	F1	58	415,0	19,2	414,6	19,6	0,681	0,499		
	physiological length	F2	58	411,6	19,3	410,5	19,8	2,106	0,040	*	sin
	sagittal diameter of the middle of the diaphysis	F6a	64	25,9	2,0	25,9	2,2	-0,244	0,808		
	transverse diameter of the middle of the diaphysis	F7a	64	26,8	2,5	26,5	2,2	2,116	0,038	*	sin
	upper transverse diameter of the diaphysis	F7b	64	29,3	2,6	28,6	2,8	3,550	0,001	***	sin
	upper sagittal diameter of the diaphysis	F7c	64	25,7	2,3	25,2	2,1	2,657	0,010	**	sin

	Measurements	Abbr.	N	Mean $_{sin}$	Std.Dv.	Mean $_{dx}$	Std. Dv.	t-test	p	Signf.	Larger
FEMUR	lower transverse diameter of the diaphysis	F7d	64	33,0	3,7	33,0	3,8	0,000	1,000		
	lower sagittal diameter of the diaphysis	F7e	64	28,7	2,2	28,0	2,4	3,832	0,000	***	sin
	subtrochanteric transverse diameter of the diaph.	F9	63	31,5	2,3	31,2	2,5	1,474	0,146		
	subtrochanteric sagittal diameter of the diaphysis	F10	63	25,9	1,9	25,9	2,2	0,000	1,000		
	circumference of the middle of the diaphysis	F8	65	80,2	5,9	79,6	5,6	2,100	0,040	*	sin
	upper width of the epiphysis	F13	59	88,1	5,6	88,6	5,8	-2,151	0,036	*	dx
	epicondylar width	F21	59	73,8	3,9	73,9	3,8	-0,769	0,445		
	vertical diameter of the head	F18	58	43,1	2,8	43,1	2,9	-0,136	0,892		
	transverse diameter of the head	F19	58	42,5	2,2	42,7	2,3	-1,763	0,083		
FIBULA	maximum length of the fibula	Fi1	81	328,6	16,4	328,3	16,6	0,762	0,449		
TIBIA	overal length tibie	T1	63	338,5	17,5	337,9	17,2	1,257	0,214		
	medial length	T1b	59	329,4	17,6	328,9	17,4	1,137	0,260		
	maximum width of the upper epiphysis	T3	55	66,7	3,4	66,6	3,7	0,457	0,649		
	width of the lower epiphysis	T6	54	44,0	2,6	44,1	2,7	-0,339	0,736		
	minimum diameter of the middle of the diaphysis	T8	69	26,6	2,4	26,7	2,5	-0,173	0,863		
	width of the middle of the diaphysis	T9	69	20,6	1,9	20,8	2,3	-1,396	0,167		
	sagittal diameter in the upper foramen nutricium	T8a	69	29,9	2,6	29,9	2,5	0,346	0,730		
	width of the diaphysis in the upper for.nutric.	T9a	69	22,2	2,0	22,3	2,3	-0,956	0,343		
	circumference of the middle of the diaphysis	T10	70	72,1	4,9	72,1	6,0	-0,082	0,935		
	circumference of the diaphysis on the for.nutric.	T10a	70	80,8	5,4	80,9	6,1	-0,271	0,788		
	minimum circumference of the diaphysis	T10b	71	65,5	4,4	65,6	4,8	-0,518	0,606		

Table 5. Studied DA. Results of paired t-tests of males from the Great Moravian population (for legend see Table 3).

	Measurements	Abbr.	N	Mean $_{sin}$	Std.Dv.	Mean $_{dx}$	Std. Dv.	t-test	p	Signf.	Larger
CLAVICLE	maximum clavicle length	Cl1	8	151,8	13,0	149,9	13,7	0,535	0,609		
	vertical diameter	Cl4	39	11,1	1,4	11,5	1,5	-1,833	0,075		
	sagittal diameter	Cl5	39	12,7	1,2	12,9	1,5	-1,062	0,295		
HUMERUS	maximum length of the humerus	H1	24	328,3	17,2	333,6	16,1	-6,226	0,000	***	dx
	width of the upper epiphysis	H3	11	49,4	2,6	50,5	2,8	-3,357	0,007	**	dx
	width of the lower epiphysis	H4	20	62,8	4,2	63,9	3,7	-3,399	0,003	**	dx
	maximum diameter of the middle of the diaphysis	H5	58	22,8	1,7	23,8	1,9	-7,856	0,000	***	dx
	minimum diameter of the middle of the diaphysis	H6	60	18,5	1,5	18,9	1,6	-2,572	0,013	*	dx
	maximum transverse diameter of the head	H9	3	42,3	2,5	44,0	2,6	-2,500	0,130		
	maximum vertical diameter of the head	H10	10	45,9	7,4	47,1	8,1	-3,343	0,009	**	dx
ULNA	maximum length of the ulna	U1	12	273,8	14,4	275,1	14,3	-1,470	0,170		
	sagittal diameter of the diaphysis	U11	37	14,4	1,7	14,9	1,5	-3,074	0,004	**	dx
	width of the diaphysis	U12	36	17,7	2,0	17,6	1,7	0,373	0,711		
RADIUS	maximum length of the radius	R1	13	245,0	20,2	246,2	19,7	-2,259	0,043	*	dx
	maximum width of the diaphysis	R4	26	17,5	1,5	18,2	1,2	-3,241	0,003	**	dx
	sagittal diameter of the diaphysis	R5	27	12,3	1,2	12,5	1,2	-1,412	0,170		
	width of the middle of the diaphysis	R4a	27	16,5	1,6	16,9	1,5	-2,294	0,030	*	dx
	sagittal diameter of the middle of the diaphysis	R5a	26	12,2	0,8	12,4	0,8	-1,413	0,170		
FEMUR	maximum length of the femur	F1	28	451,5	26,8	449,7	27,3	2,120	0,043	*	
	physiological length	F2	42	450,8	26,1	449,4	26,3	2,117	0,040	*	
	sagittal diameter of the middle of the diaphysis	F6a	67	28,8	2,6	28,7	2,8	0,394	0,695		
	transverse diameter of the middle of the diaphysis	F7a	65	29,0	2,5	28,1	2,3	7,913	0,000	***	
	upper transverse diameter of the diaphysis	F7b	60	32,3	2,4	31,0	3,0	4,347	0,000	***	
	upper sagittal diameter of the diaphysis	F7c	62	27,4	2,5	27,1	2,8	2,537	0,014	*	
	lower transverse diameter of the diaphysis	F7d	53	35,5	4,1	34,9	3,9	3,951	0,000	***	sin
	lower sagittal diameter of the diaphysis	F7e	53	31,0	2,6	30,9	2,5	0,513	0,610		
	subtrochanteric transverse diameter of the diaph.	F9	69	34,7	2,6	33,8	2,5	4,626	0,000	***	sin
	subtrochanteric sagittal diameter of the diaphysis	F10	69	27,9	2,5	27,7	2,1	1,656	0,102		

	Measurements	Abbr.	N	Mean $_{\text{sin}}$	Std.Dv.	Mean $_{\text{dx}}$	Std. Dv.	t-test	p	Signf.	Larger
FEMUR	circumference of the middle of the diaphysis	F8	55	89,7	5,8	89,0	5,7	2,390	0,020	*	sin
	upper widht of the epiphysis	F13	35	100,5	7,8	100,6	7,7	-0,193	0,848		
	epicondylar width	F21	14	81,9	5,3	81,9	5,2	-0,234	0,818		
	vertical diameter of the head	F18	33	48,6	2,3	48,6	2,4	0,000	1,000		
	transverse diameter of the head	F19	24	48,0	2,3	48,4	2,9	-1,895	0,071		
TIBIA	overal length tibie	T1	25	378,3	25,2	376,4	24,8	3,201	0,004	**	sin
	medial length	T1b	17	375,2	26,3	373,6	26,0	1,765	0,097		
	maximum width of the upper epiphysis	T3	4	77,0	0,8	74,8	1,5	2,029	0,135		
	width of the lower epiphysis	T6	12	47,9	4,2	47,8	4,2	0,432	0,674		
	minimum diameter of the middle of the diaphysis	T8	49	29,1	2,6	29,3	2,3	-1,070	0,290		
	width of the middle of the diaphysis	T9	50	22,2	2,1	22,2	2,0	-0,330	0,743		
	sagittal diameter in the upper foramen nutricium	T8a	58	33,3	3,3	33,3	2,9	-0,275	0,784		
	width of the diaphysis in the upper for.nutric.	T9a	59	23,9	2,4	23,9	2,2	-0,219	0,827		
	circumference of the middle of the diaphysis	T10	47	79,9	5,3	79,6	5,2	0,975	0,335		
	circumference of the diaphysis on the for.nutric.	T10a	56	90,3	6,6	89,5	6,2	2,064	0,044	*	sin
	minimum circumference of the diaphysis	T10b	54	72,8	5,6	72,5	4,5	0,664	0,510		

Table 6. Studied DA. Results of paired t-tests of females from the Great Moravian population (for legend see Table 3).

	Measurements	Abbr.	N	Mean $_{\text{sin}}$	Std.Dv.	Mean $_{\text{dx}}$	Std. Dv.	t-test	p	Signf.	Larger
CLAVICLE	maximum clavicle length	Cl1	17	132,2	8,9	131,0	8,6	1,605	0,128		
	vertical diameter	Cl4	39	9,6	0,9	9,6	1,1	0,198	0,844		
	sagittal diameter	Cl5	40	10,6	1,2	10,7	1,1	-0,781	0,440		
HUMERUS	maximum length of the humerus	H1	30	290,6	15,8	293,6	15,1	-4,280	0,000	***	dx
	width of the upper epiphysis	H3	23	43,6	2,5	44,2	2,8	-1,845	0,079		
	width of the lower epiphysis	H4	23	54,5	2,8	55,2	3,0	-2,626	0,015	*	dx
	maximum diameter of the middle of the diaph.	H5	64	20,1	1,5	20,5	1,5	-3,291	0,002	**	dx
	minimum diameter of the middle of the diaph.	H6	66	15,5	1,3	15,8	1,4	-1,626	0,109		
	maximum transverse diameter of the head	H9	10	38,6	2,0	39,4	1,3	-2,228	0,053		
	maximum vertical diameter of the head	H10	20	41,5	2,4	41,3	2,4	1,045	0,309		
ULNA	maximum length of the ulna	U1	15	239,8	7,7	242,3	8,4	-3,510	0,003	**	dx
	sagittal diameter of the diaphysis	U11	42	11,6	1,3	12,1	1,5	-3,490	0,001	**	dx
	width of the diaphysis	U12	42	14,5	1,6	14,9	1,6	-2,638	0,012	*	dx
RADIUS	maximum length of the radius	R1	17	214,6	13,6	217,8	13,9	-6,246	0,000	***	dx
	maximum width of the diaphysis	R4	33	15,1	1,2	15,4	1,4	-2,101	0,044		
	sagittal diameter of the diaphysis	R5	36	10,6	1,1	10,9	1,2	-2,142	0,039	*	dx
	width of the middle of the diaphysis	R4a	35	14,0	1,3	14,3	1,6	-1,819	0,078		
	sagittal diameter of the middle of the diaphysis	R5a	33	10,5	0,8	10,4	0,9	0,571	0,572		
FEMUR	maximum length of the femur	F1	47	410,3	17,6	409,4	18,0	1,872	0,068		
	physiological length	F2	57	406,4	14,5	405,0	14,7	2,909	0,005	**	sin
	sagittal diameter of the middle of the diaphysis	F6a	96	24,5	2,4	24,3	2,3	1,520	0,132		
	transverse diameter of the middle of the diaphysis	F7a	95	25,7	2,0	25,3	2,0	3,956	0,000	***	sin
	upper transverse diameter of the diaphysis	F7b	78	29,2	2,4	28,9	2,6	1,828	0,071		
	upper sagittal diameter of the diaphysis	F7c	76	23,4	2,4	23,3	2,6	0,681	0,498		
	lower transverse diameter of the diaphysis	F7d	74	31,4	3,6	30,9	3,4	3,158	0,002	**	sin
	lower sagittal diameter of the diaphysis	F7e	73	26,5	2,5	26,2	2,3	2,021	0,047	*	sin
	subtrochanteric transverse diameter of the diaph.	F9	89	31,0	2,4	30,9	2,5	0,600	0,550		

	Measurements	Abbr.	N	Mean $_{sin}$	Std.Dv.	Mean $_{dx}$	Std. Dv.	t-test	p	Signf.	Larger
FEMUR	subtrochanteric sagittal diameter of the diaphysis	F10	89	23,9	2,3	23,9	2,5	-0,478	0,634		
	circumference of the middle of the diaphysis	F8	70	79,1	5,4	78,7	5,4	2,159	0,034	*	sin
	upper widht of the epiphysis	F13	45	88,5	5,4	88,6	6,1	-0,380	0,705		
	epicondylar width	F21	21	71,9	2,8	72,0	3,4	-0,149	0,883		
	vertical diameter of the head	F18	40	42,4	2,2	42,5	2,2	-0,552	0,584		
	transverse diameter of the head	F19	34	41,7	2,1	41,9	2,1	-1,643	0,110		
TIBIA	overal length tibie	T1	31	336,7	15,1	335,4	15,5	2,599	0,014	*	sin
	medial length	T1b	23	329,7	15,7	328,0	15,7	3,169	0,004	**	sin
	maximum width of the upper epiphysis	T3	7	65,6	1,7	66,1	2,4	-0,934	0,386		
	width of the lower epiphysis	T6	18	42,0	2,5	41,9	2,3	0,270	0,790		
	minimum diameter of the middle of the diaphysis	T8	56	26,6	2,1	26,6	2,1	0,000	1,000		
	width of the middle of the diaphysis	T9	57	19,9	2,1	20,1	2,0	-0,714	0,478		
	sagittal diameter in the upper foramen nutricium	T8a	66	30,2	2,3	30,0	2,4	0,745	0,459		
	width of the diaphysis in the upper for.nutric.	T9a	69	21,3	2,2	21,4	1,9	-0,860	0,393		
	circumference of the middle of the diaphysis	T10	56	71,6	4,7	71,9	5,0	-1,166	0,249		
	circumference of the diaphysis on the for.nutric.	T10a	70	80,2	5,6	80,2	6,2	-0,276	0,784		
	minimum circumference of the diaphysis	T10b	63	66,1	3,9	66,1	3,7	-0,278	0,782		

Table 7. Results of evaluation of the FA from the recent population (FA1, FA2, FA4, FA6: indices of the calculation of FA values. FA1: mean /R-L/; FA2: mean {/R-L/ / [(R+L) /2]}; FA4: var (R-L); FA6: var {(R-L) / [(R+L) /2]}; DA – dimension for which DA presence was found; for the nomenclature of measures see Table 3).

Males

Abbr. of Measur.	FA1	FA2	FA4	FA6
Sc1	2,925	0,018	13,423	0,001
Sc3	2,304	0,017	8,917	0,000
Cl4	0,821	0,073	1,301	0,010
U12	0,602	0,034	0,719	0,002
F1	3,500	0,008	22,845	0,000
F6a	0,985	0,034	2,255	0,003
F7a	0,970	0,034	1,765	0,002
F8	1,567	0,018	4,385	0,001
F13	2,364	0,023	8,955	0,001
F19	0,864	0,018	1,277	0,001
Fi1	2,559	0,007	13,243	0,000
T1	3,574	0,010	30,973	0,000
T1b	3,957	0,011	37,410	0,000
T3	1,217	0,016	2,554	0,000
T6	1,167	0,024	2,608	0,001
T8	1,132	0,040	2,530	0,003
T9	1,000	0,044	1,972	0,004
T8a	1,235	0,037	2,873	0,003
T9a	0,863	0,034	1,445	0,002
T10	1,358	0,017	3,759	0,001
T10a	2,157	0,024	9,648	0,001
T10b	1,170	0,016	3,059	0,001

Table 8. Results of evaluation of the FA from the medieval population (for legend see Table 7).

Males

Abbr. of Measur.	FA1	FA2	FA4	FA6
Cl1	6,875	0,046	85,859	0,004
Cl4	0,949	0,084	1,673	0,012
U1	2,500	0,009	9,056	0,000
F6a	0,866	0,030	1,519	0,002
F13	1,200	0,012	2,968	0,000
F19	0,458	0,012	0,901	0,000
T1b	2,941	0,008	12,014	0,000
T6	0,417	0,009	0,410	0,000
T8	0,878	0,031	1,415	0,002
T9	0,560	0,025	0,718	0,001
T8a	1,483	0,045	3,581	0,003
T9a	0,847	0,035	1,389	0,002
T10	1,617	0,020	4,294	0,001
T10b	1,259	0,018	2,497	0,000

Females

Abbr. of Measur.	FA1	FA2	FA4	FA6
Cl1	2,529	0,019	9,474	0,001
Cl4	0,590	0,061	0,640	0,007
H3	1,261	0,029	2,749	0,001
H9	1,200	0,031	1,160	0,001
H10	0,750	0,018	1,088	0,001
R4a	0,714	0,051	1,016	0,006

	Females			
Abbr. of Measur.	FA1	FA2	FA4	FA6
Sc1	2,981	0,015	19,230	0,001
Sc2	1,723	0,018	6,110	0,001
Cl4	0,713	0,078	1,063	0,013
F1	3,517	0,008	21,070	0,000
F6a	0,813	0,031	1,030	0,002
F19	0,397	0,009	0,441	0,000
Fi1	2,296	0,007	8,408	0,000
T1	2,794	0,008	12,816	0,000
T1b	2,966	0,009	13,420	0,000
T3	1,364	0,020	4,184	0,001
T6	0,796	0,018	1,423	0,001
T8	0,928	0,035	1,912	0,003
T9	0,765	0,035	1,458	0,003
T8a	0,957	0,032	1,910	0,002
T9a	0,629	0,028	1,001	0,002
T10	1,543	0,020	8,342	0,001
T10a	1,300	0,016	4,809	0,001
T10b	1,099	0,016	3,311	0,001

	Males			
Abbr. of Measur.	FA1	FA2	FA4	FA6
F1	3,021	0,007	12,574	0,000
F6a	0,667	0,027	0,875	0,001
F13	1,556	0,017	5,404	0,001
F19	0,412	0,015	0,381	0,000
T6	0,611	0,014	0,719	0,000
T8	0,600	0,022	0,927	0,001
T9	0,772	0,039	1,217	0,003
T8a	1,076	0,036	2,178	0,002
T9a	0,826	0,039	1,563	0,003
T10	1,536	0,021	4,182	0,001
T10a	1,886	0,024	6,678	0,001
T10b	0,937	0,014	1,823	0,000