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Anthropological and epidemiological characterization of Great-Moravian population in connection with the social and economic structure

Craniometric Analysis of the Great Moravian Population from Mikulčice – X-ray film study

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The study was focused on detailed craniometric analysis of lateral X-ray films of a highly-representative sample of 129 well-preserved skulls of Slavs from Mikulčice. Using special craniometric software, a total of 170 linear, angular, proportional and special dental chracteristics was evaluated. We focused on size and shape craniofacial sexual dimorphisms. Male skulls were significantly larger in all linear dimensions except for the height of the occipital bone. In the males an indentation between the nasal bones and os frontale, as well as more conspicuous anteriorotation of mandible was recorded. The females, on the other hand, had a more prominent proclination of both the dento-alveolar maxillar process and the medial upper incisors. The determined average metric data were compared with the norms of the recent population, which were developed specifically for the needs of bioachaeology. The skulls of recent population were characterized by two general morphological features: neurocranial globularity and retrusion of jaws. The length of the mandible is shortened, while the height of its ramus is extended. The overall height of the face, the intermandibular and interalveolar relationships has not changed from the Middle Ages to the present day. We also compared certain basic skull dimensions (e.g. length and height of the skull, the height of the whole face as well as the upper and lower face) with historical populations of the upper Palaeolithic, Neolithic, Eneolithic, Bronze, Middle and Modern Age. The relationship between recent, Early Middle Age and other historical populations that lived on the territory of our state was evaluated using cluster analysis. The results obtained are in concordance with both the morphological and the molecular genetic studies used for comparison.

Key words: Great Moravian population – craniometric analysis – X-ray film

1. Introduction

Despite the massive development of experimental and genetic techniques, craniometry remains an integral part of research into current and past populations. It is an important analytical method in the area of palaeoanthropology and forensic anthropology. It indirectly provides information which is also usefull for archaeology, history and other related sciences. It is commonly known that the size and shape of the skull are strongly controlled by genetic mechanisms (e.g. Manfredi et al. 1997; Johannsdottir et al. 2005). A study of skull morphology may thus answer questions pertaining to intra and inter-population variability.

The methodology of craniometry has undergone significant development from real measurement of skulls to 2D craniometric analysis of photographs or X-rays to classical or geometric morphometry of 3D skull models.

Classical craniometry is usually supplemented by 2D graphical analysis of lateral X-ray films or photographs. The metric evaluation of X-rays is still common, and indeed optimal for resolving many issues in the field of clinical anthropology.

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Analysis of lateral X-ray films is most frequently used in orthodontics or the study of congenital defects (Šmahel 1987). The importance of X-rays in skeletal anthropology lies not only in the documentation of pathological findings but also in the monitoring of mutual relations between endo- and ectocranial structures, their macro and microevolutionary changes in either the temporal and geographical horizon (Wescott/Jantz 2005).

Craniometric analysis is used for the detailed evaluation of variability and development of the craniofacial complex as a whole. It also facilitates the monitoring of intracranial relations between the individual structures (Keeling et al. 1989; Key/Jantz 1981, de la Rua 1992).

The method contributes towards the identification of growth patterns, the evaluation of mandibular rotation and the monitoring of saggital intermandibular relations. Many authors have monitored the mutual relationship between certain structures of the skull. Björk (1955) analysed the mechanism of growth of the base of the cranium during adolescence; Anderson and Popovich (1983) studied the relationship between the curvature of this important structure, the skull shape and the position of the mandible. As the maxilla and mandible are in contact with the base of the cranium, it can logically be presumed that the length and angle of the base affect the mutual relationship between the lower and upper jaw, thus also affecting occlusion. Understanding similar relationships and their mechanisms is highly significant in the field of evolutionary biology, for instance.

Vlček and Šmahel (1997, 1998) used metric evaluation of lateral X-ray films in research conducted on the remains of Czech monarchs. They compared the proportions of the skulls with norms valid for the present Czech population. They also determined certain selected proportions in upper Palaeolithic skulls from Dolní Věstonice (Vlček/Šmahel 2002) and in important personalities from the field of culture (e.g. Vlček et al. 2006). Macková (2004) created norms applicable in the craniometric analysis of photographs which were then used to verify the reliability of their measurement (Velemínská et al. 2003) and also for the study of macroevolutionary changes of skulls (Velemínská et al. 2005).

The variability of skull shapes is best characterised by methods of geometric morphometry. These 2D and 3D geometric morphometric methods are based on the analysis of using shape curves (e.g. Fourier's analysis), or of landmarks. Localisation of landmarks forms the basis for methods such as the FESA method (Richtsmeier/Cheverud 1986; Sameshima et al. 1996; Singh/Rivera-Robles/de Jesus-Vinas 2004), Bookstein and Procrustes transformation (Bookstein 1991) or the TPS method (Singh/McNamara/Lozanoff 1997; Dryden/Mardia 1998). The shape evaluation of skulls independently on their size, using methods of geometrical morphometry is our aim in a subsequent publication.

The goal of this study was the detailed craniometric analysis of X-ray films of a highly representative sample of well-preserved skulls of Slavs from Mikulčice. The main advantages of the methodology described in the text below include the measurement of classically inaccessible structures and the high precision of the measurement and estimation of morphological traits thanks to the enlargement of the digitized image, the alteration of brightness and contrast and the option of using various filters in the computer's memory.

We focused on sex-associated size and shape skull dimorphisms. Then we compared the linear, angular and special inter-maxillar and dental traits with the recent population. We also compared certain basic skull dimensions (e.g. length and height of the skull, the height of the whole face as well as the upper and lower face) with historical populations of the upper Palaeolithic, Neolithic, Eneolithic, Bronze, Middle and Modern Age.

2. Material

Craniometric analysis was performed on a sample of skulls from the Early Middle Ages from the Mikulčice power centre. A total of 129 adult skulls were analysed, of which 65 were male and 64 female. They came from burial areas near the first,

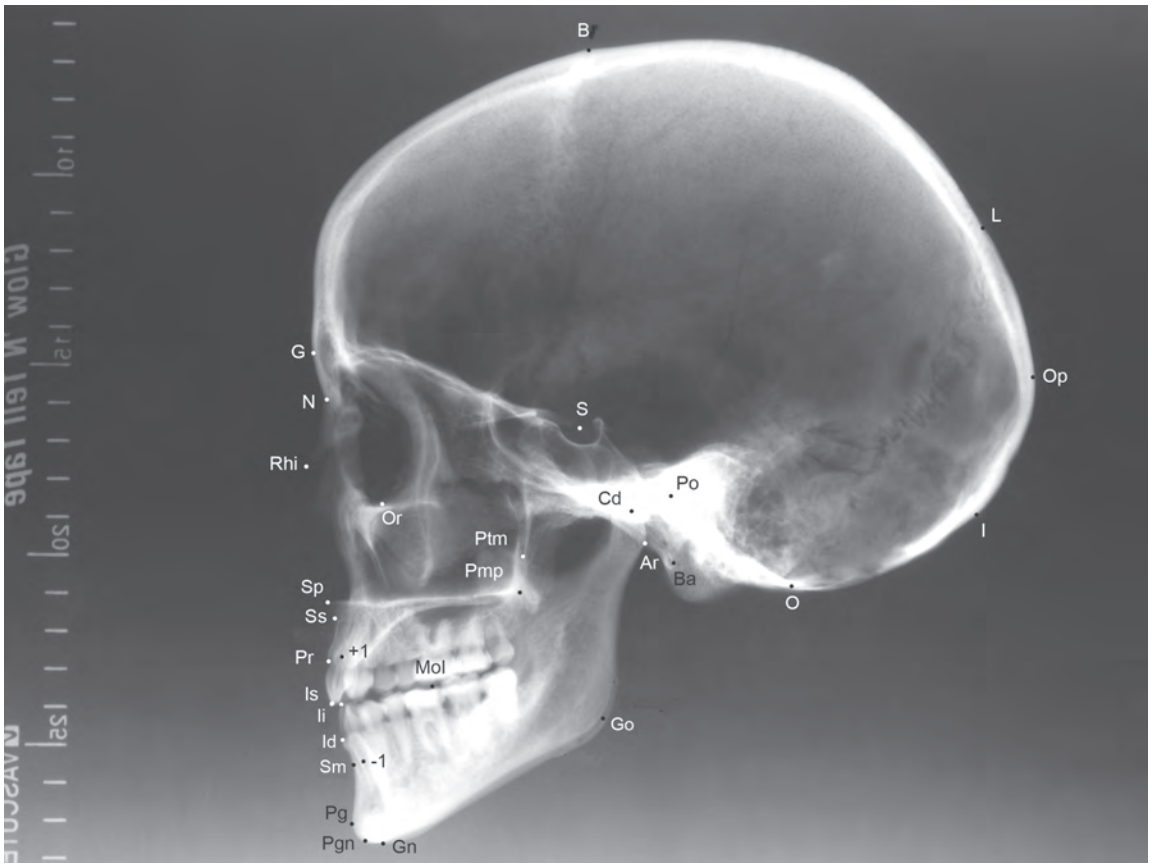


Fig. 1. Craniometric points (landmarks) used in this study: **Ar** (articulare) – intersection of inferior contour of the posterior cranial base and posterior contour of the ramus; **B** (bregma) – intersection of the coronal and sagittal sutures; **Ba** (basion) – most posteroinferior point on the clivus; **Cd** (condylion) – most superior point on the condylar head; **G** (glabella) – the most anterior point on the arcus superciliaris; **Gn** (gnathion) – the lowest point of the mandibular symphysis; **Go** (gonion) – point on the angle of the mandible determined by the axis of ML/RL angle; **I** (inion) – top of the protuberantia occipitalis externa; **Id** (infradentale) – point of the alveolar contact with the lower central incisor; **Ii** (incision inferius) – incisal tip of the lower central incisor; **Is** (incision superius) – incisal tip of the upper central incisor; **L** (lambda) – intersection of the sagittal and lambda sutures; **Mol** (molare) – tip of the posterior cuspid of the lower first molar; **N** (nasion) – the most anterior point on the frontonasal suture; **O** (opisthion) – point located at the midpoint of the posterior border of the foramen magnum; **Op** (opistocranion) point on the surface of the cranial vault farthest from the glabella point; **Or** (orbitale) the lowest point on the orbital margin; **Pg** (pogonion) – the most anterior point on the bony chin; **Pgn** (prognathion) – point on the mandibular symphysis farthest from Cd; **Pmp** (pterygomaxillare palatinum) – point of intersection of the palate plane and fissura pterygomaxillaris; **Po** (porion) the most superior point on the porus acusticus externus; **Pr** (prosthion) – point of alveolar contact with the upper central incisor**; Ptm** (pterygomaxillare) – most inferior point of the fossa pterygopalatina where fissura pterygomaxillaris begins; **Rhi** (rhinion) – the most anteroinferior point on the nasal bone; **S** (sella) – centre of sella turcica; **Sm** (supramentale) – the deepest point on the anterior contour of the mandibular symphysis**; Sp** (spinale) – tip of the anterior nasal spine; **Ss** (subspinale) – the deepest point of the subspinal concavity; **+1** – axis of the upper incisor; **-1** – axis of the lower incisor;

second, third, sixth and eleventh Mikulčice church and from the burial areas at Mikulčice-Kostelisko and Mikulčice-Klášteřisko. With the exception of two juveniles (one male and one female), all the individuals were adults. In the case of the males, we estimate that 18 individuals died in the adultus category, and 47 individuals were older than forty years. 31 females belonged to the adultus category, and 23 females probably reached maturity. The basic condition for selecting skeletal material from Mikulčice was a good state of preservation of the skulls with the lower jaw including intact dentition, so that articulation with the mandibular joint and occlusion of the upper and lower jaws was possible.

The lower jaw was fixed to the skull with the aid of adhesive gum, which was removed immediately after the images were checked, with no remnants or damage to the skulls.

The comparative recent sample entailed lateral X-ray films of 52 healthy males and 36 females from the archive of the Clinic of Plastic and Reconstructive Surgery, 3rd Faculty of Medicine, Charles University in Prague. Norms specially created for the needs of bioarchaeology were developed by Macková (2004).

Another goal of the study was to compare the skulls not only with recent but also with historical populations. We used the comparative data for the Upper Palaeolithic Age from Matiegka's (1934) and Vlček's (1997) publications; for the Neolithic Age from the publications of Černý/Velemínský (1998); for the Eneolithic and Bronze Age from the PhD thesis of Černý (1999). We also included other Great Moravian (Hanáková/Staňa/Stloukal 1986), Middle and Modern Age (Hanáková/Sekáčová/Stloukal 1984) burial grounds. The aforementioned authors conducted direct measurements of the skulls, and thus we could use only published dimensions, which were not distorted on the X-ray films, i.e. measured in the medial plane.

3. Method

The skulls were X-rayed using the COSMOS 2 skiagraphic apparatus at the Anthropological Department of the National Museum in Horní Počernice. They were scanned under standard conditions in lateral projection at a distance of 1 metre. The X-ray films were then digitized. The landmarks were localized using the SigmaScan program, Version 5. The craniometric analysis was based on a total of 30 landmarks that are schematically marked in Fig. 1. The caption of the figure contains exact definitions of all the used points. The following lines were used to mark the angular dimensions or the distance between the points and the planes: **NSL** – line passing through points N and S, **VL** – line perpendicular to line NSL at point S, **PL** – line passing through points Sp and Pmp, **OL** – occlusion line passing through the centre of the distance connecting the apices of the upper and lower incisors at the central occlusion and point Mol, **+1** – axis of the upper middle incisors, **-1** – axis of the lower middle incisors, **CL** – line passing through points Pg and Id, **ASL** – tangent to the alveolar process of the upper jaw passing through point Pr, **ML** – tangent of the body of the lower jaw passing through point Gn, **RL** – tangent of the ramus of the lower jaw passing through point Ar.

Duplicate contours may appear on the images, most often in the region of the angle and ramus of the mandible. In such cases, we used a point lying in the middle, between both sides. The most variable factor is the localisation of points on the contour concavities and convexities such as e.g. gonion, condylion, subspinale, supramentale and others.

The entered landmarks are the primary data for metric evaluation of the X-ray films using the application "Craniometrics", which was developed as a MS Excel application. It enables the single measurement of the required amount of selected metric variables of the neurocranium and facial skeleton on the calibrated images. These include linear dimensions (the distance between two points, the distance between a point and a straight line) and angular characteristics (angles determined by three points or two straight lines) that can be pre-defined according to specific needs. We thus programmed the required scale of traits, and by using one command we were able to measure numerous sets of digitalised lateral X-ray films. The output comprised the measured variables in a table editor which could be further manipulated and processed statistically.

Together with this variable component, which could also be used to measure, other parts of the skeleton or of photographs of a known scale, the program included special dental and mandibular dimensions (see below).

For the sake of clarity, we include the various types of designations of the dimensions used and the definitions of certain special dimensions. For example, the vertical distance from the point of the reference line (positional dimension) is

denoted as Ar-VL; angles are denoted as N-S-Ar or as a fraction of two reference lines forming the given angle (ML/RL). This study is also based on certain proportional characteristics such as S-Go%N-Gn designating the dimension of S-Go as a percentage of the N-Gn dimension. The slope of the axis formed by the upper incisors in relation to the palatal plane is designated +1/PL; that formed by the lower incisors in relation to the body of the mandible is designated –1/ML. Overjet (Is-Ii) is defined as the distance between the cusps of the upper and lower incisors measured parallel with the occlusion plane; overbite (Is+Ii) is the distance between the cusps of the upper and lower incisors assessed perpendicular to the occlusion plane. Pr+Id is the difference between point Pr and Id after their perpendicular projection to the modified occlusion plane that passes through the centre of the distances of the upper and lower incisors and the peak of angle PL/ML (if Pr is posterior to Id, the value is negative). Ss+Sm is the difference between points Ss and Sm after their perpendicular projection to the mentioned modified occlusion plane (if Ss is posterior to Sm, the value is negative).

Within the Craniometrics software we selected a total of 107 characteristics (50 linear, 43 angular, three indexes and 11 special dental variables). The designations of the dimensions, average values, SD and their numbers are cited in the tables in the Result section of the study. They are always divided into three tables: dimensions of the neurocranium, linear dimensions of the splanchnocranium and dimensions characterising the shape of the facial skeleton.

We used the Statistica 6.0 software for statistical analysis, with the aid of which we calculated the basic statistical indicators, of which tables 1-9 include number of measurement (N), the mean, standard deviation (SD), t-value, degree of freedom (df) and level of significance (p) for the individual variables. We evaluated sexual dimorphism (Tables 1-3) and the comparison with a recent (Tables 4-9), or Neolithic population (Tables 10-13) with the aid of a two-sample t-test. We used analysis of variance – Scheffe' test – for comparison with the Eneolithic and Únětice populations (Tables 14-15). We included a total of 10 populations living in the region of the Czech Republic from an aspect of sexual dimorphism into a cluster analysis (Euclidean distance, complete linkage). The relationship between the populations (Graph 1, 2) was assessed on the basis of four size dimensions (M1, M17, M47, M48).

4. Results

4.1 Sexual dimorphism

Estimation of the skeleton's sex was conducted depending on the state of preservation of the pelvic bones. In individuals with a preserved pelvis, sex was determined with the aid of so-called primary sexual diagnosis (Brůžek/Velemínský 2006). In the case of the other skeletons, sex was determined on the basis of the morphology of the whole skeleton (e.g. Stloukal 1963, 1967; Stloukal/Hanáková 1985; Velemínský et al. 2005). The sample of 129 skulls included 65 male and 64 female skulls. We tested sexual dimorphism using a two-sample t-test, the results of which are detailed in Tables 1-3. The most significant differences are illustrated in colour (Fig. 2). Important, significantly larger dimensions of the males are highlighted in red and those of females in green. Dimensions with similar size are in black. Linear (size) distances mostly show significantly larger cranial dimensions in male individuals. The exceptions in the case of the facial skeleton are the heights of the upper (Sp-PL) and lower (Id-Sm) alveolar process and the height of the nasal bones (N-Rhi). These are structures frequently very poorly preserved (Rhi, Sb, Id regions). Another explanation may be the reduction of the alveolar processes associated with age-related changes of these structures.

In the neurocranial region there are no significant differences in the region of the occipital bone (L-Op, L-O, L-NO, Op-NO, I-NO). The average length dimensions encompassing the area of the face until the occipital region are longer in males than in females (e.g. G-L, G-Op, G-I).

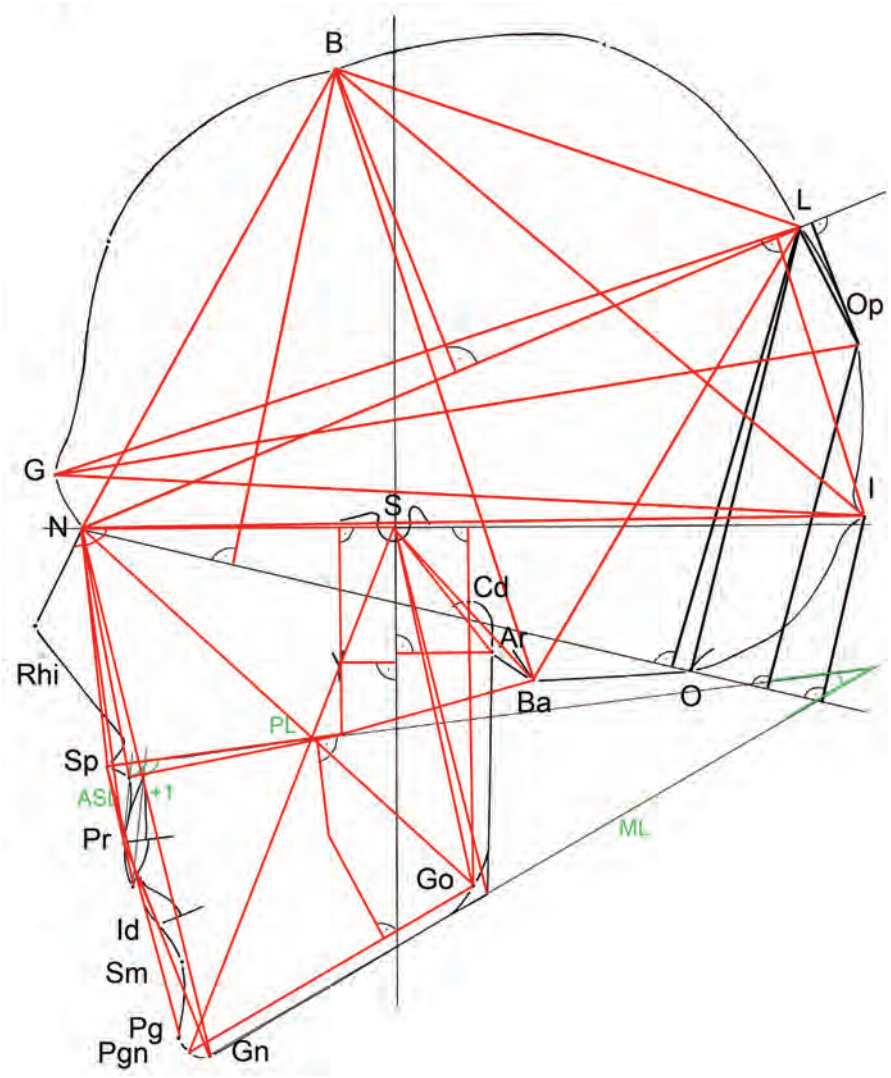


Fig. 2. Lateral craniogram with the most important sexual differences coloured (red – dimension significantly greater in males, green – dimension significantly greater in females, black – dimension without significant differences).

As for shape characteristics (angular dimensions), significant differences are – in contrast – less frequent. In males the indentation in the area of the nasal radix (S-N-Rhi) is more pronounced. The anteriorotation of their lower jaw is on average more pronounced by three degrees. In contrast, females have a more protruded upper alveolar process as well as upper incisors in relation to the plane of the palate (ASL/PL, +1/PL) and to the plane of mandible (ASL/ML). Significant differences in the characteristics of ML/NSL and S-Go%N-Gn show that the lower jaw of the male skulls assumes more significant anteriorotation compared to female skulls.

Similarly to most of the determined angular dimensions characterising the shape of the face and the braincase, the angle of the cranial base (N-S-Ba) does not show any sexual dimorphism. The N-I-L angle representing the prominence of the external protuberant occipital prominence is sharper (of greater prominence) in males. Females have a relatively more vaulted cranium (N-B-Ba, N-L-Ba). The sagittal inter-mandibular and dental relationships are the same in both sexes.

4.2 Comparison of male skulls from the Middle Ages and recent periods

We compared the male skulls from the Middle Ages and from recent periods using the two-sample t-test, the results of which are summarised in Tables 4-6. The most significant differences are highlighted in colour (Fig. 3). Significantly larger dimensions relating to males from recent periods

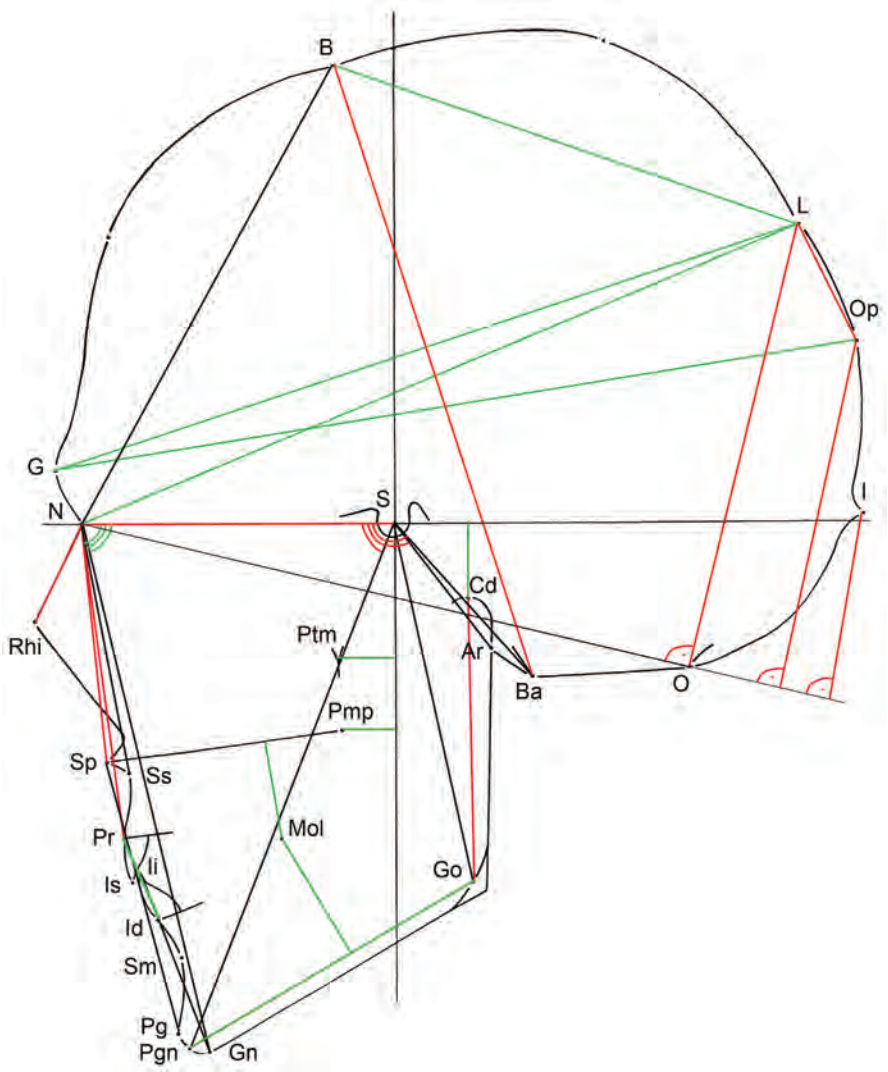


Fig. 3. Lateral craniogram with the most important differences between Medieval and recent skulls in males coloured (red – dimension significantly greater in recent skulls, green – dimension significantly greater in Early Medieval skulls, black – dimension without significant differences).

are highlighted in red, while those relating to males from Mikulčice are highlighted in green. Unchanged dimensions are in black.

The average cranium of males from Mikulčice is significantly longer (G-L, G-Op) and at the same time lower (Ba-B, L-NO, …). The values of the angular dimensions (e.g. N-B-O, N-L-O) correspond to this fact. It is interesting that in contrast the length of the anterior cranial base is longer in the recent population. The length of the posterior cranial base remains unchanged.

The overall height of the anterior (N-Gn) and posterior (S-Go) face does not differ in the two population samples studied. If we were to divide the anterior height of the face into an upper and lower region, males from Mikulčice have, on average, significantly lower height dimensions of the upper jaw (N-Rhi, N-Sp, N-Pr). The height dimensions of the lower face (Ii-Gn, Id-Gn, Sp-Pg) remain unchanged. The significantly reduced height dimensions of the maxilla in Slavs are also demonstrated by the index N-Sp %N-Gn. The depth of the maxilla (Ss-Pmp) is the same for both groups as a whole. A significant difference in favour of the recent group for the same dimension including the spina nasalis anterior (Sp-Pmp) may be due to the frequently incomplete preservation of the skeletal sample from Mikulčice. The ramus of the lower jaw is significantly shorter in the skulls from the Middle Ages, whilst the body of the lower jaw is significantly longer. The articular head (caput) of the lower jaw is at a significantly longer distance from the NS line (Cd-NSL). The molar point is more distant with respect to the

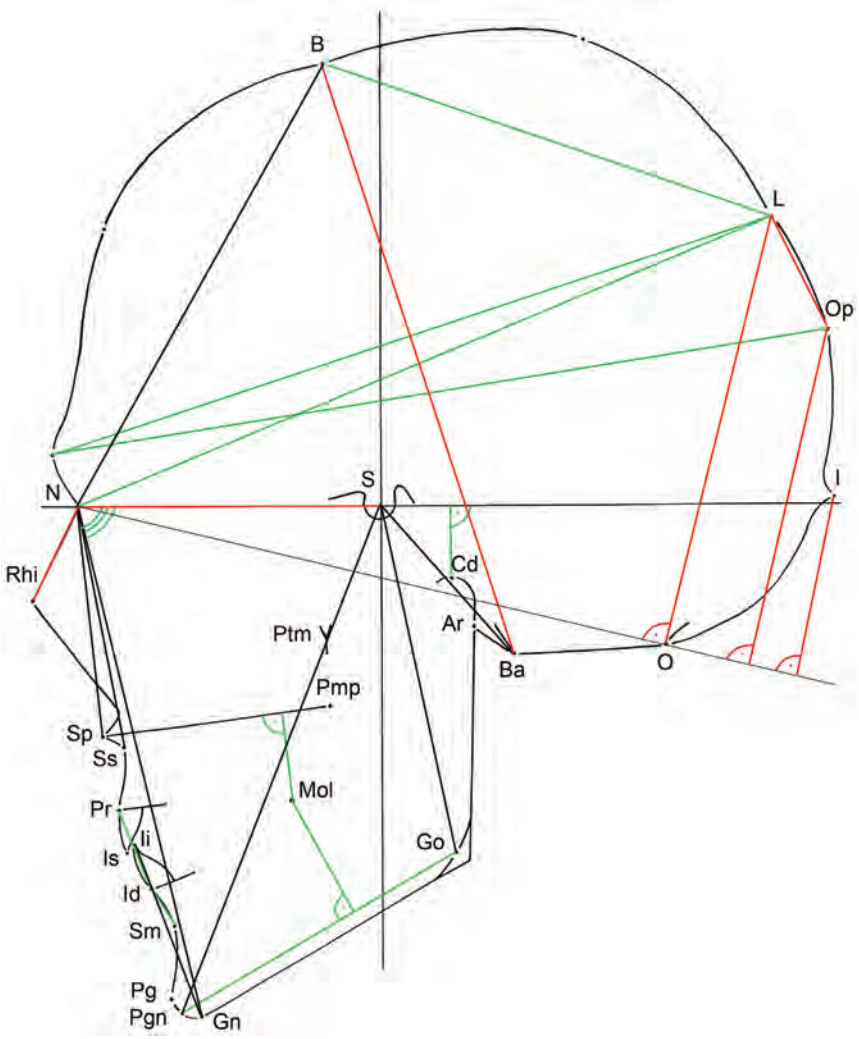


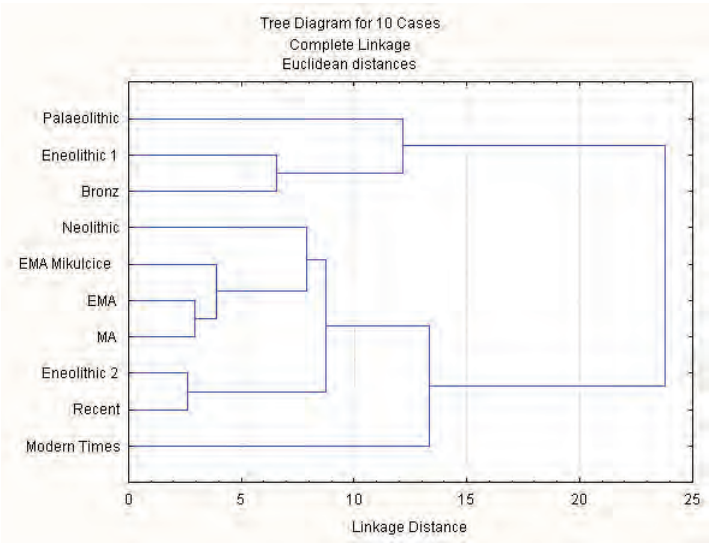
Fig. 4. Lateral craniogram with coloured the most important differences between Medieval and recent skulls in females (red – dimension significantly greater in recent skulls, green – dimension significantly greater in Early Medieval skulls, black – dimension without significant differences).

level of the palate plane (Mol-PL) as well as to the lower jaw plane (Mol-ML).

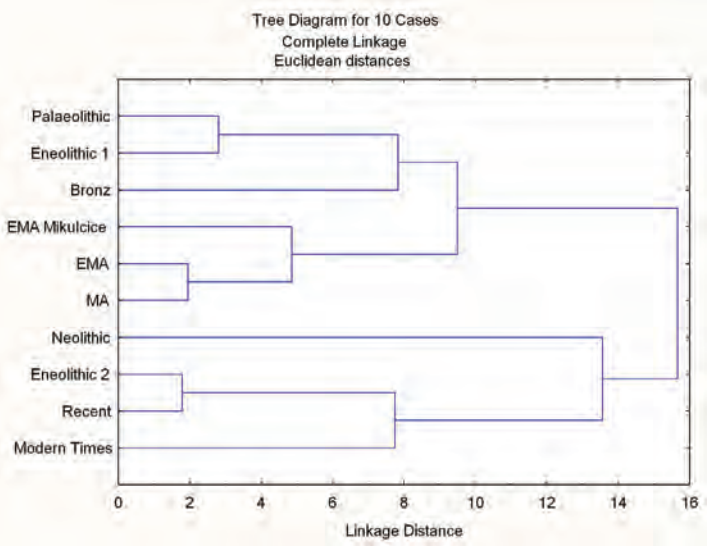
The angle of the cranial base in the Mikulčice Slavs is significantly smaller, as are the angles expressing the position of the mandibular joint or the antero-posterior position of the mandibular ramus (N-S-Cd, N-S-Ar). In contrast, the angular dimensions, which express the position of the skeletal profile in relation to the cranial base, are larger in the group from the Middle Ages, especially in the area of both alveolar processes and the whole lower jaw. Both jaws are thus in a position of slight protrusion. This subsequently leads to a non-significant accentuation of the convexity of the face, and the prominence of the chin is more emphasised. The angular dimensions characterising the shape of the lower jaw (ML/RL, CL/ML) or its position in relation to the other components of the skull (ML/NSL, RL/NSL, RL/PL, OL/ML) do not differ. The sagittal inter-mandibular and inter-alveolar relationships also remain stable in the two groups. Dimensions associated with rotation of the lower jaw (N-tGo-Gn, ML/NSL, S-Go%N-Gn) show similar average values in both groups. The first incisors do not show increased protrusion in relation to the corresponding structures (+1/NSL, -1/NSL, -1/ML). In contrast, +1/PL and ASL/PL dimensions show a retrusion of the upper incisors as well as the upper alveolar process in relation to the palate compared to the recent group.

4.3 Comparison of female skulls from the Middle Ages and recent periods

The skulls of females from the Middle Ages were compared with skulls from recent periods



Graph 1. Cluster analysis explaining the relationships between nine (pre)historical and one recent populations; Males (UP = Upper Palaeolithic, N=6; NEOL = Neolithic, N=15; CWC = Eneolithic Corded Ware culture, N=35; BBC = Eneolithic Bell Beaker culture, N=63; UC = Bronze Age Únětice culture, N=163; EMA = Early Middle Ages, N=175; MA = Middle Ages, N=394; MP = Early Modern period, N=68; REC = recent, N=52); Euclidean distances, complete linkage.



Graph 2. Cluster analysis explaining the relationships between nine (pre)historical and one recent populations; Females (UP = Upper Palaeolithic, N=5; NEOL = Neolithic, N=13; CWC = Eneolithic Corded Ware culture, N=20; BBC = Eneolithic Bell Beaker culture, N=37; UC = Bronze Age Únětice culture, N=97; EMA = Early Middle Ages, N=263; MA = Middle Ages, N=399, MP = Early Modern period, N=82; REC = recent, N=36); Euclidean distances, complete linkage.

using the two-sample t-test, the results of which are summarised in Tables 7-9. The most significant differences are highlighted in colour (Fig. 4). Significantly larger dimensions relating to females from recent periods are highlighted in red, while those relating to females from Mikulčice are highlighted in green. Unchanged dimensions are in black.

With a few exceptions, the differences in the cranial region are identical to those of the males; i.e. a longer and lower cranium in the Mikulčice females, a longer antrior cranial base in the recent population and an unchanged length of the posterior cranial base.

The overall height of the anterior (N-Gn) and posterior (S-Go) face does not differ in the two population samples studied and neither do most of the partial height dimensions of the anterior face. The significantly shorter height of the nasal bones may be due to the poorer preservation of the skulls from Mikulčice, compared to the evidence value of skull X-ray films of the recent population. In contrast, the greater height of the incisors on Pr-Id occlusion in Great Moravian females was probably due to incomplete occlusion (Is+Ii negative average values). The slightly reduced Sp-N dimension in combination with a slightly extended height of the face of Slav female led to a significantly lower N-Sp%N-Gn

index. The depth of the maxilla in the groups of females is the same (Ss-Pmp). The significant difference in favour of the recent population for this same dimension including the Spina nasalis anterior (Sp-Pmp) could be due to the frequent incomplete preservation of the skeletal sample from Mikulčice.

The ramus of the lower jaw is non-significantly shorter in the skulls from the Middle Ages, whilst the body of the lower jaw is significantly longer. The articular head (caput) of the lower jaw is at a significantly longer distance from the NS line (Cd-NSL). The molar point is more distant with respect to the level of the plane (Mol-PL) as well as the plane of mandible (Mol-ML) in the recent population.

In the case of female skulls, the angle of the cranial base as well as the angles expressing the position of the mandibular joint or the antero-posterior position of the mandibular ramus (N-S-Cd, N-S-Ar) remain unchanged from the Middle Ages until today. The angular dimensions expressing the position of the skeletal profile in relation to the cranial base are significantly greater (S-N-Rhi, S-N-Ss, S-N-Pr, S-N-Id, S-N-Sm, S-N-Pg, S-N-Gn) in the population from the Middle Ages, with the exception of the S-N-Sp angle (probably affected by the preservation of the Spina nasalis anterior). Both jaws are thus in mild protrusion, which leads to a significant increasing of the convexity of the face.

The dental angular dimensions expressing the inclination of the incisors in relation to other structures of the female skulls remain unchanged over the ages, as do the inter-alveolar and inter-mandibular relations.

4.4 Comparison of skulls from the Early Middle Ages with those from Prehistoric and historical populations.

In this chapter, we attempted to compare data relating to populations from the Early Middle Ages with that from Prehistoric and historic populations, taking into consideration data accessibility and measurement techniques.

In our comparison of the Slavs from Mikulčice with the Neolithic or more recent populations, we used the dimensions (G-Op, B-Ba, N-Gn, N-Pr). The exact figures are detailed in Tables 10-13. It must be emphasised that the results may be affected by the poor preservation of Neolithic skulls and also by the low number of measurements cited in the appropriate tables (Černý/Velemínský 1998). Compared to Neolithic skulls, those from Mikulčice have a significantly greater facial height. The height of the skulls themselves, though, is shorter (significantly so only in the case of males). As to the length of the cranium, there are no differences between the two populations.

Using analysis of variance, we compared the size of skull dimensions of Mikulčice, Eneolithic (Bell Beaker Culture, Corded Ware Culture), Bronze Age (Unětice Culture) and recent skulls (Tables 14-15) separately for each of the following dimensions G-Op, B-Ba, N-Gn, N-Pr, N-Sp, Id-Gn). The length of the cranium of Slavs from Mikulčice differs most from the population with a culture of Bell Beaker Culture (not significant in female) and the recent population, both of which have on average the shortest cranium. The Eneolithic populations mutually differ significantly only in the length of their skull, which is longer in the Corded Ware Culture population. On average and in comparison with all the others, this population is most dolicho-cephalic (193 cm in males, 184 in females). From the aspect of skull length, the Eneolithic Bell Beaker Culture population most resembles the recent population.

As to the height of the cranium, Slavs have the lowest among all the studied populations. The skulls of male from Mikulčice differ significantly only from the Únětice Culture. Female skulls differ from all those of the studied populations with the exception of the Eneolithic Corded Ware Culture population.

As to the facial skeleton, female from Mikulčice differ only in the height of the lower face, which is significantly shorter only compared to the Únětice

Culture. Compared to this culture, the males, moreover, have a significantly shorter upper face.

We included a total of 10 samples of skulls from various periods to the construction of comparison diagrams (Graph 1, 2). Dendrograms were calculated separately for male and female skulls. Apart from the aforementioned data of Slavs from Mikulčice, recent, Neolithic, Eneolithic and Bronze Age populations, we also used data from Upper Palaeolithic skulls published by Matiegka (1934) and Vlček (1997). These included male skulls P3, P9, DV13, DV14, DV16, Pavlov I and female skulls P4, P10, DV3, DV15, Brno III. We also included in the analysis the average dimensions of skulls from the Early Middle Ages from Rajhrad (Hanáková/Staňa/Stloukal 1986), skulls from the Middle Ages and modern period from Ducové (Hanáková/Sekáčová/Stloukal 1984). The historical populations were clustered on the basis of their G-Op, B-Ba, N-Gn, N-Pr dimensions. On the dendrograms it is possible to follow congruently three main branches. The first cluster includes all the three burial grounds from the Middle Ages, with the Great Moravian burial ground in Rajhrad and the burial ground from the Middle Ages in Ducové showing the closest resemblance. The other branch is represented by Palaeolithic and Eneolithic skulls (Corded Ware Culture) and Bronze Age skulls (Únětice Culture). The third and last cluster conveys the similarities between recent, Modern Age and Eneolithic (Bell Beaker Culture) populations.

5. Discussion and conclusions

The main goal of this study was to monitor the variability of the Mikulčice skulls from the Early Middle Ages and to look for evolutionary changes in relation to historical and recent populations on the territory of the Czech Republic. Our underlying premise was the fact that the skull, a dynamic structure, changes during phylogenesis and ontogenesis. The size, shape and position of the individual skull components affect each other to a certain extent. Deviation of one component may lead to a series of changes to both neighbouring and more distant structures which enable these to adapt to primary stimuli. These mutual relations are determined by adaptation mechanisms in the skull (Šmahel/Škvařilová 1988).

If we focus on the most distinctive evolutionary changes of the skull approximately in the past 26.000 years, several significant differences are observed with respect to the present day. The Upper Palaeolithic skulls are relatively longer and narrower. Anteriorotation of the face produces a strong protrusion of the upper and lower jaw. The eye sockets and piriform aperture are wider. The crania of anatomically modern humans are characterised by two general structural features: facial retrusion and neurocranial globularity. The facial skeleton of recent skulls is narrower, including eye socket and piriform aperture (Svoboda 2006; Velemínská et al. 2005).

Among the main factors that contribute to changes in the shape of skulls from an evolutionary aspect, we include climatic changes (Beals/Smith/Dood 1983), a sedentary lifestyle associated with changes in food habits, improvement of health (Angel 1982), urbanism and others. It has been described that individuals with rounded (globular) types of skulls are more adaptable to new social situations and social stress. There is an unsubstantiated relation between brachycephaly and greater resistance of humans. Reduction in the length of the cranium is usually associated with a reduction of massetter muscles and the retrusion of both jaws (Velemínská et al. 2008).

The questions regarding the origin of the population of Bohemia and Moravia in the Neolithic period are being answered mainly by molecular genetics. Based on the results of MSY as well as mtDNA analysis, it is presumed that 20-25% of the current European population originates from Neolithic farmers (e.g. Semino et al. 2000). According to Kračmarová's results (2005), more than 4/5 of the population can trace their origin to the colonisation of our lands during the Early or Late Palaeolithic Age.

The study of skull morphology has also brought forth data consistent with the conclusions of molecular genetic analysis. Chochol/Blajerová/

Hanáková (1960) and Chochol (1964) states that the Neolithic-Eneolithic autochtonic formation in Bohemia embodies the traditions of the Mesolithic substrate, enriched and transformed by the invasion of farmers of the Mediterranoid anthropological type. Two invasion waves may be recognised during the Eneolithic period. In their view, the first is represented by people of the Corded Ware Culture, physically similar to the local population (hyper-dolichocephalic skull). The second invasion is represented by people of the Bell Beaker Culture (brachycephalic skull). The Únětice culture then postulates a strengthening of the cromanoid influence. If we compare these 40-year-old results with the dendrograms in Graph 1 and 2, the results of our cluster analysis are not inconsistent. On average, the Palaeolithic skulls (according to the parameters used) resemble most the Eneolithic (Corded Ware Culture) skulls and the skulls from Únětice. Neither Neolithic nor Eneolithic (Bell Beaker Culture) skulls, which could represent the newly arrived population in our lands, have a closer relationship with the others.

The missing link between the compared populations is found between the Únětice Culture and the Early Middle Ages. Fragmentation, low incidence of findings from the Latene period and the period of population migration are so great that we did not find any suitable published comparative group of craniometric data.

Comparative data relating to the Middle Ages, on the other hand, are plentiful. Preservation of Great Moravian burial grounds, for example, is very good. Proof of this are the 129 complete skulls in our study which could be subjected to detailed craniometric analysis. Slavic burial grounds from early settlements and the Middle Ages were investigated by Blajerová (1974, 1975), who also conducted a comparison of the populations from the Early Middle Ages until the Modern Age in Bohemia (Blajerová 1980). In this work she describes the gradual shortening and widening of the cranium, with the height of the skull and face remaining unchanged. In our results we have also noted a shortening of the cranium, in the Slavs from Mikulčice compared to the recent population, but the cranium also increased in height among both sexes. The overall height of the face has remained unchanged, in concordance with the results of Blajerová (1980). Neither has the height ratio of the anterior and posterior face (S-Go%N-Gn) changed, despite the change in the relationship between the upper and lower height of the face (N-Sp%N-Gn). This supported the findings of Manfredi et al. (1997) that the vertical parameters have a higher genetic control than the horizontal ones. Heritability, according to them, seems to have more influence on anterior vertical parameters than posterior ones.

Hanáková/Sekáčová/Stloukal (1984) described the burial ground in Ducové in Slovakia, where tombs from the Great Moravian period through the Middle Ages to the modern period were uncovered. Significant brachy-cephalization has been noted here, along with a widening of the face and a decline of the fronto-mandibular index in males. In the Great Moravian burial grounds in Rajhrad the average metric skull indicators that we were able to compare with ours (M1, 17, 47, 48, 69) were very similar (Hanáková/Staňa/Stloukal 1986). We included the data of Hanáková/Sekáčová/Stloukal (1984) and Hanáková/Staňa/Stloukal (1986) in our cluster analysis. Both burial grounds, Great Moravian and other Medieval, became closely associated in the case of male and female skulls, forming a common branch in our dendrogram. Dohnalíková//Dušek/Novotný (1997) used cluster analysis to study the mutual relationship between several Slavic burial grounds. Chronological and geographical differences between populations were described on the basis of neuro-cranial linear dimensions.

As expected, in the Slavs from Mikulčice we found significant sexual dimorphism of linear dimensions with the exception of the vertical dimensions of the occipital bone. Conversely, sexual dimorphism in the shape of skulls characterised by angular dimensions and proportions was very rare. Males have more prominent nasal bones in relation to the anterior cranial base. Females

show a typically more significant proclination of the upper alveolar processes and upper incisors.

Detailed craniometric comparison with the recent population was conducted separately for both sexes. For both of them equally, the most typical evolutionary changes were the development of neuro-cranial globularity, decreased facial convexity and stable height of the face. We observed all these micro-evolutionary changes taking place over a period of roughly 1000 years, also in comparison with Upper Palaeolithic skulls. Our results correspond to the micro-evolutionary secular changes described by Jantz/Meadows Jantz (2000) and Wescott/Jantz (2005). This process assumes increasingly stronger expression among the Upper Palaeolithic and recent reference samples which were the subject of our previous study (Velemínská et al. 2008).

The lower jaw changes its basic dimensions from the Early Middle Ages until today. The length of its body is shortened, while the height of the mandibular ramus is extended (not significantly in females). In male skulls, height dimensions of the anterior and posterior face have extended over the ages. The angle of the cranial base has increased. The lower jaw is in retrusion, compared to the Middle Ages. Recent metric data from skulls included in the cluster analysis correlated most with the Eneolithic culture (Bell Beaker Culture) and also with Neolithic skulls in females. All the aforementioned groups had a short cranium in common.

The selected method of evaluating X-ray skull images provided data complementing classical craniometry. Structures inside the skull were evaluated (dimensions related to the Sella craniometric point), and inter-mandibular and inter-alveolar relations were also studied. Analysis of lateral X-ray images loaned by the Clinic of Plastic Surgery facilitated a detailed comparison and thus the monitoring of micro-evolutionary trends until modern times. On the other hand, comparison with historical populations was limited due to different methods of measurement or the preservation of the skeletal material. We plan to conduct a detailed study of the variability of skull shapes in the next stage of our research into the Great Moravian population using 2D and 3D methods of geometric morphometrics.

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Table 1. Sexual dimorphism of facial linear dimensions at the Mikulčice's population.

	N		Mean		SD				
Dimension	Male	Female	Male	Female	Male	Female	t-value	df	p
N-Rhi	55	52	18.356	17.452	3.180	3.489	1.402	105	0.164
N-Sp	62	61	50.588	48.430	3.367	3.248	3.618	121	0.000
N-Ss	64	60	55.480	52.657	3.686	3.340	4.460	122	0.000
N-Pr	63	62	67.364	64.681	4.244	4.717	3.344	123	0.001
N-Gn	65	63	119.678	112.646	7.745	7.491	5.218	126	0.000
N-Go	64	62	116.461	108.280	7.628	5.915	6.713	124	0.000
Sp-Is	36	35	28.699	26.947	2.468	3.084	2.646	69	0.010
Pr-Id	62	62	21.485	20.041	3.303	2.603	2.703	122	0.008
Ii-Gn	52	51	42.444	39.302	3.411	3.460	4.640	101	0.000
Id-Gn	64	63	32.154	29.629	3.198	3.198	4.448	125	0.000
Id-Sm	64	64	8.422	8.153	2.383	1.946	0.699	126	0.486
Sp-Pg	62	61	61.551	57.139	5.462	6.540	4.063	121	0.000
Sp-Pmp	61	61	49.925	47.424	2.924	2.930	4.719	120	0.000
Ss-Pmp	63	60	48.287	45.952	2.817	2.557	4.805	121	0.000
Pmp-Ba	63	59	44.704	42.623	3.089	3.409	3.537	120	0.001
S-Go	56	54	82.506	74.117	7.182	5.796	6.726	108	0.000
S-tGo	56	55	86.212	77.503	7.325	5.958	6.865	109	0.000
S-Pgn	57	56	126.983	118.456	6.673	6.393	6.934	111	0.000
Cd-Go	64	61	58.959	53.858	6.154	4.710	5.186	123	0.000
Pgn-Go	64	62	75.542	72.032	4.825	4.200	4.349	124	0.000
S-Ar	57	55	36.379	32.937	2.947	5.217	4.319	110	0.000
Pmp-NSL	58	57	45.050	42.063	3.455	3.897	4.353	113	0.000
Cd-NSL	60	59	22.415	19.272	4.422	4.508	3.839	117	0.000
Pr-PL	61	59	17.352	16.204	4.454	2.749	1.691	118	0.093
Mol-PL	51	48	25.649	23.297	2.891	3.355	3.743	97	0.000
Mol-ML	51	48	31.596	29.283	3.382	3.116	3.533	97	0.001
Pmp-VL	57	56	14.976	14.025	3.678	2.848	1.535	111	0.128
Ptm-VL	56	49	15.453	14.033	3.273	2.397	2.505	103	0.014
Ar-VL	57	55	20.256	18.102	3.644	2.953	3.430	110	0.001

Table 2. Sexual dimorphism of shape and dental characteristics of the face at the Mikulčice's population.

	N		Mean		SD				
Dimension	Male	Female	Male	Female	Male	Female	t-value	df	p
N-S-Ba	55	54	129.330	130.494	5.115	4.618	-1.246	107	0.215
N-S-Cd	56	55	125.691	127.160	7.034	7.019	-1.101	109	0.273
N-S-Ar	56	55	123.877	123.829	5.506	5.554	0.046	109	0.963
N-S-Go	55	54	100.981	101.983	4.713	4.217	-1.169	107	0.245
N-S-Pgn	57	56	66.422	66.593	3.968	3.842	-0.233	111	0.816
S-N-Rhi	52	51	115.705	111.534	7.470	8.153	2.708	101	0.008
S-N-Sp	55	54	85.722	85.495	4.006	4.389	0.281	107	0.779
S-N-Ss	56	53	83.753	83.541	3.507	3.596	0.310	107	0.757

	N		Mean		SD				
Dimension	Male	Female	Male	Female	Male	Female	t-value	df	p
S-N-Pr	55	54	85.673	85.966	3.587	3.383	-0.439	107	0.661
S-N-Id	56	56	82.291	82.336	3.396	3.238	-0.072	110	0.942
S-N-Sm	57	56	80.600	80.399	3.302	3.202	0.328	111	0.743
S-N-Pg	57	56	82.369	81.704	3.590	3.125	1.049	111	0.297
S-N-Gn	57	55	79.370	78.457	3.446	3.161	1.459	110	0.147
PL/NSL	54	54	5.978	6.973	3.376	3.512	-1.501	106	0.136
ML/NSL	56	54	27.701	30.349	5.964	5.684	-2.382	108	0.019
ML/RL	64	61	120.626	122.082	7.626	5.857	-1.193	123	0.235
CL/ML	63	62	69.693	70.392	5.452	5.208	-0.732	123	0.466
RL/NSL	56	59	87.297	85.724	6.058	9.611	1.044	113	0.299
RL/PL	60	61	98.454	97.712	5.845	12.422	0.419	119	0.676
PL/ML	60	60	21.931	24.308	5.900	5.267	-2.328	118	0.022
ASL/PL	59	56	103.598	107.176	6.552	6.806	-2.872	113	0.005
ASL/NSL	56	58	98.828	101.015	8.372	7.695	-1.453	112	0.149
S-Ar-tGo	57	55	142.853	145.312	8.243	7.623	-1.637	110	0.104
OL/NSL	25	28	12.024	15.004	5.300	6.541	-1.808	51	0.076
Ar-tGo-N	64	60	48.489	48.613	4.710	4.291	-0.153	122	0.879
N-tGo-Gn	64	60	72.138	73.317	4.991	5.051	-1.306	122	0.194
N-Ar/OL	28	32	30.823	31.505	4.756	4.366	-0.579	58	0.565
N-Ss-Pg	64	60	177.234	176.549	5.642	5.821	0.665	122	0.507
Ss-N-Sm	64	60	3.130	3.023	2.326	2.538	0.245	122	0.807
Pr-N-Id	62	62	3.466	3.545	1.928	1.971	-0.228	122	0.820
S-Go%N-Gn	56	53	0.690	0.659	0.047	0.044	3.435	107	0.001
S-tGo%N-Gn	56	54	0.721	0.690	0.050	0.047	3.298	108	0.001
N-Sp%N-Gn	63	60	0.430	0.431	0.057	0.024	-0.198	121	0.843
+1/PL	38	33	104.779	108.810	7.593	6.930	-2.323	69	0.023
-1/ML	52	50	95.762	94.514	6.900	7.080	0.901	100	0.370
+1/-1	35	34	134.759	131.243	10.915	10.608	1.356	67	0.179
+1/NSL	34	32	99.083	101.350	8.578	8.051	-1.105	64	0.273
-1/NSL	46	43	55.793	53.474	7.507	6.949	1.509	87	0.135
Is-Ii	29	35	2.361	2.573	2.072	2.384	-0.375	62	0.709
Is+Ii	29	34	-0.249	-0.216	1.883	1.869	-0.068	61	0.946
Ss+Sm	28	31	0.950	0.330	2.294	2.684	0.949	57	0.347
Pr+Id	27	32	2.849	2.485	2.410	2.680	0.545	57	0.588
Ss+Sm(modif.OL)	33	34	-0.588	-0.890	3.351	3.434	0.364	65	0.717
Pr+Id(modif.OL)	32	35	1.845	2.014	3.090	2.894	-0.230	65	0.818

Table 3. Sexual dimorphism of linear and shape characteristics of the neurocranium the Mikulčice's population.

	N		Mean		SD				
Dimension	Male	Female	Male	Female	Male	Female	t-value	df	p
N-S	57	56	68.267	64.793	3.221	3.327	5.640	111	0.000
S-Ba	56	54	45.007	41.144	3.542	2.639	6.468	108	0.000
G-Op	65	62	187.536	179.793	7.840	6.407	6.077	125	0.000
Ba-B	64	58	136.537	130.948	6.477	5.337	5.171	120	0.000
N-B	65	63	112.638	108.841	5.138	4.237	4.554	126	0.000
B-L	65	63	118.793	115.839	6.850	6.088	2.576	126	0.011
L-Op	65	62	28.652	27.361	7.238	7.315	1.000	125	0.319
L-Ba	64	58	116.469	112.713	5.896	5.203	3.715	120	0.000
N-L	65	63	178.718	172.741	7.100	6.154	5.082	126	0.000
N-I	65	60	174.417	166.204	8.318	6.785	6.020	123	0.000
G-L	65	63	181.014	174.049	7.405	6.049	5.817	126	0.000
G-I	65	60	180.507	171.036	8.666	6.961	6.702	123	0.000
B-I	65	60	155.336	149.278	6.363	6.658	5.200	123	0.000
L-O	65	60	96.537	95.027	5.227	5.338	1.597	123	0.113
B-NO	65	58	149.287	143.935	6.014	5.828	4.999	121	0.000
L-NO	65	60	95.392	93.587	5.394	5.580	1.839	123	0.068
Op-NO	65	59	72.678	71.362	5.717	6.878	1.163	122	0.247
I-NO	65	58	35.904	35.446	5.797	5.441	0.450	121	0.653
B-NL	65	63	73.330	71.654	4.767	4.257	2.095	126	0.038
Op-NL	64	62	28.803	27.243	6.874	7.340	1.232	124	0.220
I-NL	65	60	60.717	57.646	5.988	6.285	2.797	123	0.006
N-B-O	65	61	61.091	59.488	2.848	2.751	3.211	124	0.002
N-L-O	65	60	49.421	47.823	2.528	2.897	3.293	123	0.001
N-Op-O	65	59	43.340	41.969	2.609	2.768	2.838	122	0.005
N-I-O	65	58	35.041	35.034	3.421	4.067	0.011	121	0.991
N-B-L	65	63	101.149	100.519	3.552	3.372	1.028	126	0.306
N-Op-L	65	62	75.830	76.821	3.246	3.376	-1.688	125	0.094
N-I-L	65	60	83.485	85.867	4.113	3.867	-3.329	123	0.001
N-S-B	57	55	84.354	83.938	3.133	3.841	0.629	110	0.531
N-S-L	57	55	151.431	151.118	3.677	4.984	0.378	110	0.706
N-S-I	57	53	175.063	175.361	3.791	3.228	-0.442	108	0.660
N-S-Op	57	54	165.467	165.106	3.816	4.897	0.434	109	0.665
N-S-O	57	54	152.497	152.182	4.551	4.614	0.362	109	0.718
Ba-O/NSL	56	51	5.008	4.898	3.227	3.357	0.173	105	0.863

Table 4. Craniofacial comparison between Early Medieval and recent males (linear dimensions of the face).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Rec.	Mikulčice	Recent	t-value	df	p
N-Rhi	18.356	23.078	55	52	3.180	3.634	-7.162	105	0.000
N-Sp	50.588	52.936	62	52	3.367	3.395	-3.694	112	0.000
N-Ss	55.480	56.128	64	52	3.686	3.347	-0.981	114	0.329
N-Pr	67.364	69.855	63	52	4.244	4.030	-3.204	113	0.002
N-Gn	119.678	120.281	65	52	7.745	6.769	-0.443	115	0.659
N-Go	116.461	117.681	64	52	7.628	4.786	-1.004	114	0.318
Sp-Is	28.699	28.808	36	52	2.468	3.178	-0.174	86	0.863
Pr-Id	21.485	19.485	62	52	3.303	2.049	3.795	112	0.000
Ii-Gn	42.444	42.485	52	52	3.411	3.285	-0.062	102	0.951
Id-Gn	32.154	32.193	64	52	3.198	2.911	-0.069	114	0.945
Id-Sm	8.422	8.401	64	52	2.383	2.463	0.047	114	0.963
Sp-Pg	61.551	62.351	62	52	5.462	6.018	-0.744	112	0.459
Sp-Pmp	49.925	53.377	61	52	2.924	3.192	-5.995	111	0.000
Ss-Pmp	48.287	48.935	63	52	2.817	2.957	-1.201	113	0.232
Pmp-Ba	44.704	44.102	63	52	3.089	2.924	1.066	113	0.289
S-Go	82.506	81.999	56	52	7.182	5.233	0.417	106	0.678
S-Pgn	126.983	125.826	57	52	6.673	5.974	0.950	107	0.344
Cd-Go	58.959	61.619	64	52	6.154	4.158	-2.661	114	0.009
Pgn-Go	75.542	73.311	64	52	4.825	3.839	2.708	114	0.008
S-Ar	36.379	35.819	57	52	2.947	3.332	0.932	107	0.353
Pmp-NSL	45.050	45.431	58	52	3.455	3.007	-0.612	108	0.542
Cd-NSL	22.415	18.688	60	52	4.422	3.922	4.685	110	0.000
Pr-PL	17.352	16.981	61	52	4.454	2.904	0.514	111	0.608
Mol-PL	25.649	24.583	51	52	2.891	2.237	2.095	101	0.039
Mol-ML	31.596	30.259	51	52	3.382	2.656	2.234	101	0.028
Pmp-VL	14.976	12.479	57	52	3.678	2.835	3.942	107	0.000
Ptm-VL	15.453	12.798	56	52	3.273	2.418	4.764	106	0.000
Ar-VL	20.256	20.978	57	52	3.644	2.904	-1.136	107	0.258

Table 5. Craniofacial comparison between Early Medieval and recent males (shape and dental characteristics of the face).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
N-S-Ba	129.330	131.627	55	52	5.115	5.516	-2.235	105	0.028
N-S-Cd	125.691	128.847	56	52	7.034	8.402	-2.122	106	0.036
N-S-Ar	123.877	126.128	56	52	5.506	5.123	-2.195	106	0.030
N-S-Go	100.981	101.709	55	52	4.713	4.199	-0.841	105	0.402
N-S-Pgn	66.422	68.198	57	52	3.968	4.102	-2.297	107	0.024
S-N-Rhi	115.705	115.850	52	52	7.470	6.867	-0.104	102	0.918
S-N-Sp	85.722	85.491	55	52	4.006	4.292	0.287	105	0.775
S-N-Ss	83.753	80.634	56	52	3.507	3.989	4.321	106	0.000
S-N-Pr	85.673	83.087	55	52	3.587	4.179	3.440	105	0.001
S-N-Id	82.291	80.301	56	52	3.396	4.092	2.758	106	0.007
S-N-Sm	80.600	78.346	57	52	3.302	3.923	3.254	107	0.002
S-N-Pg	82.369	80.017	57	52	3.590	3.932	3.264	107	0.001
S-N-Gn	79.370	76.841	57	52	3.446	3.923	3.583	107	0.001
PL/NSL	5.978	7.990	54	52	3.376	3.634	-2.954	104	0.004
ML/NSL	27.701	29.819	56	52	5.964	6.798	-1.724	106	0.088
ML/RL	120.626	121.772	64	52	7.626	7.069	-0.831	114	0.407
CL/ML	69.693	70.943	63	52	5.452	5.984	-1.171	113	0.244
RL/NSL	87.297	88.056	56	52	6.058	4.796	-0.718	106	0.474
RL/PL	98.454	99.746	60	52	5.845	4.497	-1.296	110	0.198
PL/ML	21.931	22.015	60	52	5.900	6.884	-0.070	110	0.945
ASL/PL	103.598	108.355	59	52	6.552	7.197	-3.645	109	0.000
ASL/NSL	98.828	100.653	56	52	8.372	7.294	-1.204	106	0.231
S-Ar-tGo	142.853	141.879	57	52	8.243	5.652	0.713	107	0.477
OL/NSL	12.024	12.460	25	52	5.300	4.367	-0.383	75	0.703
Ar-tGo-N	48.489	49.160	64	52	4.710	3.553	-0.849	114	0.398
N-tGo-Gn	72.138	72.603	64	52	4.991	5.850	-0.462	114	0.645
N-Ar/OL	30.823	30.163	28	52	4.756	4.023	0.657	78	0.513
N-Ss-Pg	177.234	178.587	64	52	5.642	5.055	-1.345	114	0.181
Ss-N-Sm	3.130	2.353	64	52	2.326	2.182	1.840	114	0.068
Pr-N-Id	3.466	2.741	62	52	1.928	1.422	2.246	112	0.027
S-Go%N-Gn	0.690	0.683	56	52	0.047	0.050	0.711	106	0.478
S-tGo%N-Gn	0.721	0.704	56	52	0.050	0.054	1.717	106	0.089
N-Sp%N-Gn	0.423	0.440	62	52	0.020	0.025	-4.046	112	0.000
+1/PL	104.779	108.964	38	52	7.593	7.060	-2.690	88	0.009
-1/ML	95.762	94.705	52	52	6.900	7.491	0.749	102	0.456
+1/-1	134.759	134.213	35	52	10.915	9.042	0.254	85	0.800
+1/NSL	99.083	101.261	34	52	8.578	7.233	-1.268	84	0.208
-1/NSL	55.793	55.517	46	52	7.507	6.883	0.190	96	0.850
Is-Ii	2.361	2.693	29	52	2.072	1.018	-0.968	79	0.336
Is+Ii	-0.249	2.487	29	52	1.883	1.757	-6.547	79	0.000

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
Ss+Sm	0.950	1.630	28	52	2.294	2.989	-1.047	78	0.298
Pr+Id	2.849	2.453	27	52	2.410	1.818	0.819	77	0.415
Ss+Sm(modif.OL)	-0.588	-1.261	33	52	3.351	3.007	0.961	83	0.339
Pr+Id(modif.OL)	1.845	1.068	32	52	3.090	2.091	1.376	82	0.173

Table 6. Craniofacial comparison between Early Medieval and recent males (linear and shape characteristics of the neurocranium).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
N-S	68.267	69.481	57	52	3.221	2.950	-2.045	107	0.043
S-Ba	45.007	45.484	56	52	3.542	3.137	-0.737	106	0.463
G-Op	187.536	180.624	65	52	7.840	4.994	5.522	115	0.000
Ba-B	136.537	140.293	64	52	6.477	5.029	-3.426	114	0.001
N-B	112.638	114.500	65	52	5.138	5.202	-1.937	115	0.055
B-L	118.793	109.774	65	52	6.850	5.847	7.545	115	0.000
L-Op	28.679	41.658	52	52	7.174	6.648	10.135	118	0.000
L-Ba	116.469	115.286	64	52	5.896	4.964	1.152	114	0.252
N-L	178.718	172.194	65	52	7.100	4.600	5.731	115	0.000
N-I	174.417	174.176	65	52	8.318	5.649	0.179	115	0.859
G-L	181.014	173.846	65	52	7.405	4.769	6.046	115	0.000
G-I	180.507	180.588	65	52	8.666	5.716	-0.058	115	0.954
B-I	155.336	154.498	65	52	6.363	6.845	0.684	115	0.495
L-O	96.537	100.453	65	52	5.227	5.672	-3.877	115	0.000
L-NO	95.392	100.260	65	52	5.394	5.781	-4.698	115	0.000
Op-NO	72.678	78.895	65	52	5.717	7.399	-5.128	115	0.000
I-NO	35.904	41.658	65	52	5.797	6.648	-4.998	115	0.000
B-NL	73.330	71.663	65	52	4.767	4.943	1.849	115	0.067
Op-NL	28.803	28.051	64	52	6.874	7.858	0.549	114	0.584
I-NL	60.717	64.616	65	52	5.988	7.191	-3.200	115	0.002
N-B-O	61.091	59.857	65	52	2.848	2.119	2.600	115	0.011
N-L-O	49.421	53.385	65	52	2.528	2.313	-8.749	115	0.000
N-Op-O	43.340	49.162	65	52	2.609	2.782	-11.646	115	0.000
N-I-O	35.041	39.501	65	52	3.421	4.411	-6.161	115	0.000
N-B-L	101.149	100.396	65	52	3.552	3.703	1.117	115	0.266
N-Op-L	75.830	75.886	65	52	3.246	3.355	-0.092	115	0.927
N-I-L	83.485	77.286	65	52	4.113	3.876	8.310	115	0.000

Table 7. Craniofacial comparison between Early Medieval and recent females (linear dimensions of the face).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Rec.	Mikulčice	Recent	t-value	df	p
N-Rhi	17.452	23.025	52	36	3.489	4.132	-6.829	86	0.000
N-Sp	48.430	49.155	61	36	3.248	3.282	-1.058	95	0.293
N-Ss	52.657	53.178	60	36	3.340	3.628	-0.716	94	0.476
N-Pr	64.681	64.794	62	36	4.717	4.741	-0.114	96	0.909
N-Gn	112.646	109.785	63	36	7.491	7.735	1.807	97	0.074
N-Go	108.280	109.590	62	36	5.915	6.542	-1.017	96	0.312
Sp-Is	26.947	27.067	35	36	3.084	3.343	-0.157	69	0.875
Pr-Id	20.041	18.047	62	36	2.603	1.950	3.988	96	0.000
Ii-Gn	39.302	38.167	51	36	3.460	3.224	1.551	85	0.125
Id-Gn	29.629	28.476	63	36	3.198	2.901	1.783	97	0.078
Id-Sm	8.153	7.098	64	36	1.946	1.878	2.634	98	0.010
Sp-Pg	57.139	55.233	61	36	6.540	6.538	1.386	95	0.169
Sp-Pmp	47.424	51.025	61	36	2.930	2.901	-5.869	95	0.000
Ss-Pmp	45.952	45.473	60	36	2.557	2.256	0.928	94	0.356
Pmp-Ba	42.623	42.629	59	36	3.409	3.328	-0.008	93	0.994
S-Go	74.117	74.369	54	36	5.796	5.904	-0.200	88	0.842
S-Pgn	118.456	115.979	56	36	6.393	5.692	1.892	90	0.062
Cd-Go	53.858	55.240	61	36	4.710	4.855	-1.381	95	0.171
Pgn-Go	72.032	70.034	62	36	4.200	3.670	2.375	96	0.020
S-Ar	32.937	33.289	55	36	5.217	2.922	-0.368	89	0.714
Pmp-NSL	42.063	43.103	57	36	3.897	2.968	-1.369	91	0.174
Cd-NSL	19.272	17.582	59	36	4.508	2.819	2.019	93	0.046
Pr-PL	16.204	15.723	59	36	2.749	2.962	0.804	93	0.424
Mol-PL	23.297	21.641	48	36	3.355	2.062	2.612	82	0.011
Mol-ML	29.283	27.029	48	36	3.116	2.664	3.487	82	0.001
Pmp-VL	14.025	13.727	56	36	2.848	3.066	0.476	90	0.636
Ptm-VL	14.033	13.558	49	36	2.397	2.628	0.866	83	0.389
Ar-VL	18.102	18.373	55	36	2.953	3.094	-0.420	89	0.676

Table 8. Craniofacial comparison between Early Medieval and recent females (shape and dental characteristics of the face).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
N-S-Ba	130.494	130.937	54	36	4.618	5.624	-0.408	88	0.684
N-S-Cd	127.160	128.483	55	36	7.019	6.676	-0.896	89	0.373
N-S-Ar	123.829	123.659	55	36	5.554	5.577	0.143	89	0.887
N-S-Go	101.983	101.655	54	36	4.217	3.943	0.371	88	0.711
N-S-Pgn	66.593	66.511	56	36	3.842	4.570	0.092	90	0.927
S-N-Rhi	111.534	115.199	51	36	8.153	6.116	-2.281	85	0.025
S-N-Sp	85.495	87.195	54	36	4.389	4.647	-1.758	88	0.082
S-N-Ss	83.541	80.683	53	36	3.596	3.860	3.572	87	0.001

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
S-N-Pr	85.966	83.772	54	36	3.383	3.888	2.839	88	0.006
S-N-Id	82.336	80.345	56	36	3.238	3.671	2.731	90	0.008
S-N-Sm	80.399	78.577	56	36	3.202	3.742	2.492	90	0.015
S-N-Pg	81.704	80.164	56	36	3.125	3.961	2.076	90	0.041
S-N-Gn	78.457	76.759	55	36	3.161	3.855	2.295	89	0.024
PL/NSL	6.973	6.676	54	36	3.512	3.127	0.410	88	0.683
ML/NSL	30.349	28.989	54	36	5.684	7.145	1.002	88	0.319
ML/RL	122.082	120.134	61	36	5.857	7.037	1.467	95	0.146
CL/ML	70.392	71.238	62	36	5.208	6.571	-0.703	96	0.484
RL/NSL	85.724	88.856	59	36	9.611	4.166	-1.849	93	0.068
RL/PL	97.712	97.914	61	36	12.422	4.568	-0.094	95	0.926
PL/ML	24.308	22.344	60	36	5.267	6.930	1.568	94	0.120
ASL/PL	107.176	112.333	56	36	6.806	7.431	-3.421	90	0.001
ASL/NSL	101.015	105.601	58	36	7.695	6.744	-2.941	92	0.004
S-Ar-tGo	145.312	145.176	55	36	7.623	5.569	0.092	89	0.927
OL/NSL	15.004	12.946	28	36	6.541	4.487	1.491	62	0.141
Ar-tGo-N	48.613	49.841	60	36	4.291	3.362	-1.467	94	0.146
N-tGo-Gn	73.317	70.291	60	36	5.051	6.179	2.611	94	0.011
N-Ar/OL	31.505	30.899	32	36	4.366	4.425	0.567	66	0.572
N-Ss-Pg	176.549	179.077	60	36	5.821	5.902	-2.050	94	0.043
Ss-N-Sm	3.023	2.106	60	36	2.538	2.213	1.796	94	0.076
Pr-N-Id	3.545	3.426	62	36	1.971	1.770	0.299	96	0.766
S-Go%N-Gn	0.659	0.679	53	36	0.044	0.054	-1.916	87	0.059
S-tGo%N-Gn	0.690	0.697	54	36	0.047	0.059	-0.631	88	0.529
N-Sp%N-Gn	0.431	0.449	60	36	0.024	0.025	-3.311	94	0.001
+1/PL	108.810	108.606	33	36	6.930	6.332	0.128	67	0.898
-1/ML	94.514	94.433	50	36	7.080	8.908	0.047	84	0.963
+1/-1	131.243	134.558	34	36	10.608	10.730	-1.299	68	0.198
+1/NSL	101.350	101.874	32	36	8.051	6.420	-0.299	66	0.766
-1/NSL	53.474	56.598	43	36	6.949	9.923	-1.640	77	0.105
Is-Ii	2.573	3.425	35	36	2.384	1.219	-1.905	69	0.061
Is+Ii	-0.216	2.958	34	36	1.869	1.561	-7.729	68	0.000
Ss+Sm	0.330	0.858	31	36	2.684	2.599	-0.816	65	0.417
Pr+Id	2.485	2.813	32	36	2.680	2.240	-0.550	66	0.584
Ss+Sm(modif.OL)	-0.890	-0.786	34	36	3.434	3.163	-0.132	68	0.895
Pr+Id(modif.OL)	2.014	1.962	35	36	2.894	2.539	0.080	69	0.937

Table 9. Craniofacial comparison between Early Medieval and recent females (linear and shape characteristics of the neurocranium).

	Mean		N		SD				
Dimension	Mikulčice	Recent	Mik.	Recent	Mikulčice	Recent	t-value	df	p
N-S	64.793	66.868	56	36	3.327	3.297	-2.931	90	0.004
S-Ba	41.144	41.486	54	36	2.639	2.758	-0.591	88	0.556
G-Op	179.793	173.982	62	36	6.407	8.345	3.865	96	0.000
Ba-B	130.948	134.924	58	36	5.337	5.201	-3.546	92	0.001
N-B	108.841	108.685	63	36	4.237	4.893	0.166	97	0.868
B-L	115.839	111.906	63	36	6.088	7.764	2.792	97	0.006
L-Op	27.361	44.489	62	36	7.315	6.710	11.512	96	0.000
L-Ba	112.713	112.357	58	36	5.203	6.374	0.296	92	0.768
N-L	172.741	168.133	63	36	6.154	8.307	3.148	97	0.002
N-I	166.204	166.650	60	36	6.785	7.260	-0.304	94	0.762
G-L	174.049	168.829	63	36	6.049	8.580	3.536	97	0.001
G-I	171.036	171.666	60	36	6.961	7.404	-0.419	94	0.676
B-I	149.278	148.663	60	36	6.658	7.107	0.427	94	0.670
L-O	95.027	97.900	60	36	5.338	5.212	-2.576	94	0.012
L-NO	93.587	97.855	60	36	5.580	5.193	-3.722	94	0.000
Op-NO	71.362	75.739	59	36	6.878	11.341	-2.345	93	0.021
I-NO	35.446	44.489	58	36	5.441	6.710	-7.156	92	0.000
B-NL	71.654	71.277	63	36	4.257	4.962	0.399	97	0.691
Op-NL	27.243	27.262	62	36	7.340	10.582	-0.011	96	0.991
I-NL	57.646	57.351	60	36	6.285	5.664	0.232	94	0.817
N-B-O	59.488	59.101	61	36	2.751	2.231	0.715	95	0.476
N-L-O	47.823	52.704	60	36	2.897	3.088	-7.798	94	0.000
N-Op-O	41.969	48.947	59	36	2.768	3.883	-10.205	93	0.000
N-I-O	35.034	43.300	58	36	4.067	4.572	-9.132	92	0.000
N-B-L	100.519	99.201	63	36	3.372	4.253	1.698	97	0.093
N-Op-L	76.821	79.019	62	36	3.376	3.224	-3.158	96	0.002
N-I-L	85.867	81.253	60	36	3.867	3.587	5.813	94	0.000

Table 10. The craniofacial comparison between Early Medieval and Neolithic populations (males).

	EMA Mikulčice (Male)			Neolithic (Male)				
	N	Mean	SD	N	Mean	SD	t	p
G-Op	65	187.536	7.840	9	184.100	6.210	1.258	
Ba-B	64	136.537	6.477	5	139.400	3.650	-0.972	
N-Pr	63	67.364	4.244	6	68.200	2.990	-0.470	
N-Gn	65	119.678	7.745	6	113.000	4.100	2.075	*

Table 11. The craniofacial comparison between Recent and Neolithic populations (males).

	Recent (Male)			Neolithic (Male)				
	N	Mean	SD	N	Mean	SD	t	p
G-Op	52	180.624	4.994	9	184.100	6.210	-1.861	
Ba-B	52	140.293	5.029	5	139.400	3.650	0.386	
N-Pr	52	69.855	4.030	6	68.200	2.990	0.972	
N-Gn	52	120.281	6.769	6	113.000	4.100	2.568	*

Table 12. The craniofacial comparison between Early Medieval and Neolithic populations (females).

	EMA Mikulčice (Female)			Neolithic (Female)				
	N	Mean	SD	N	Mean	SD	t	p
G-Op	62	179.793	6.407	8	178.300	6.960	0.615	
Ba-B	58	130.948	5.337	6	138.800	4.120	-3.488	***
N-Pr	62	64.681	4.717	4	59.500	4.200	2.140	*
N-Gn	63	112.646	7.491	2	100.500	0.710	2.276	*

Table 13. The craniofacial comparison between Recent and Neolithic populations (females).

	Recent (Female)			Neolithic (Female)				
	N	Mean	SD	N	Mean	SD	t	p
G-Op	36	173.982	8.345	8	178.300	6.960	-1.359	
Ba-B	36	134.924	5.201	6	138.800	4.120	-1.731	
N-Pr	36	64.794	4.741	4	59.500	4.200	2.137	*
N-Gn	36	109.785	7.735	2	100.500	0.710	1.675	

Table 14. The evaluation of differences between populations using linear dimensions of the skull (males). Explanatory notes: * 5% level of statistical significance; ** 1% level of statistical significance; *** 0,1% level of statistical significance.

Dimension	Anal. of Variance			Eneolithic		Bronz	Earl.M.Age	Recent
	F-test	p		Cord.W.C.	Bell Beak.C.	Unětice C.		
M1 (G-Op)	24.387	***	Mean	193.433	181.843	190.422	187.536	180.624
			N	30	51	154	65	52
			SD	7.740	9.186	8.790	7.840	4.994
			Scheffe Test					
			Cord.W.C.		***		*	***
			Bell Beak.C.	***		***	**	
			Unětice C.		***			***
			Earl.M.Age	*	**			***
			Recent	***		***	***	
M17 (B-Ba)	3.603	**	Mean	141.556	140.071	141.484	137.187	140.293
			N	9	28	93	65	52
			SD	6.766	7.039	7.452	8.293	5.029
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.				**	
			Earl.M.Age			**		
			Recent					
M47 (N-Gn)	3.501	**	Mean	112.813	118.000	117.949	119.678	120.281
			N	16	23	59	65	52
			SD	8.368	6.564	7.973	7.745	6.769
			Scheffe T					
			Cord.W.C.				*	*
			Bell Beak.C.					
			Unětice C.					
			Earl.M.Age	*				
			Recent	*				
M48 (N-Pr)	4.163	**	Mean	67.267	70.210	70.074	67.364	69.855
			N	15	31	81	63	52
			SD	5.7379	4.5639	5.5154	4.244	4.0303
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.				*	
			Earl.M.Age			*		
			Recent					
M55 (N-Sp)	4.455	**	Mean	49.563	50.563	51.326	50.588	52.936
			N	16	32	86	62	52
			SD	3.723	3.501	3.987	3.367	3.395

Dimension	Anal. of Variance			Eneolithic		Bronz	Earl.M.Age	Recent
	F-test	p		Cord.W.C.	Bell Beak.C.	Unětice C.		
			Scheffe T					
			Cord.W.C.					*
			Bell Beak.C.					
			Unětice C.					
			Earl.M.Age					*
			Recent	*			*	
M69 (Id-Gn)	4.155	**	Mean	31.563	33.200	34.489	32.154	32.193
			N	16	30	45	64	52
			SD	4.472	3.305	4.208	3.198	2.911
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.				*	*
			Earl.M.Age			*		
			Recent			*		

Table 15. The evaluation of differences between populations using linear dimensions of the skull (females). Explanatory notes: * 5% level of statistical significance; ** 1% level of statistical significance; *** 0,1% level of statistical significance.

Dimension	Anal. of Variance			Eneolithic		Bronz	Earl.M.Age	Recent
	F-test	p		Cord.W.C.	Bell Beak.C.	Unětice C.		
M1 (G-Op)	9.932	***	Mean	183.867	174.429	181.533	179.793	173.982
			N	15	28	90	62	36
			SD	8.314	8.570	8.264	6.407	8.345
			Scheffe Test					
			Cord.W.C.		**			**
			Bell Beak.C.	**		**		
			Unětice C.		**			***
			Earl.M.Age					*
			Recent	**		***	*	
M17 (B-Ba)	7.459	***	Mean	135.800	136.412	136.519	130.948	134.924
			N	5	17	54	58	36
			SD	6.181	5.906	6.658	5.337	5.201
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.				*	
			Unětice C.				***	
			Earl.M.Age		*	***		*
			Recent				*	
M47 (N-Gn)	1.708		Mean	107.200	110.667	112.793	112.646	109.785
			N	5	12	29	63	36
			SD	6.301	4.228	5.846	7.491	7.735

Dimension	Anal. of Variance			Eneolithic		Bronz	Earl.M.Age	Recent
	F-test	p		Cord.W.C.	Bell Beak.C.	Unětice C.		
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.					
			Earl.M.Age					
			Recent					
M48 (N-Pr)	0.743		Mean	66.800	64.882	65.958	64.681	64.794
			N	5	17	48	62	36
			SD	6.301	4.961	4.212	4.717	4.741
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.					
			Earl.M.Age					
			Recent					
M55 (N-Sp)	1.305		Mean	46.833	47.188	48.551	48.430	49.155
			N	6	16	49	61	36
			SD	4.875	3.311	3.440	3.248	3.282
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					
			Unětice C.					
			Earl.M.Age					
			Recent					
M69 (Id-Gn)	6.760	***	Mean	30.455	31.800	31.684	29.629	28.476
			N	11	20	38	63	36
			SD	3.532	3.622	2.762	3.198	2.901
			Scheffe T					
			Cord.W.C.					
			Bell Beak.C.					**
			Unětice C.				*	***
			Earl.M.Age			*		
			Recent		**	***		