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Enthesopathies and Activity Patterns in the Early Medieval Great Moravian Population: Evidence of Division of Labour

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Key words: enthesopathies; occupational stress markers; Great Moravia; sexual division of labour; Early Middle Ages; MSM

Introduction

The socio-economic character of ancient populations and their daily lives have been of interest to both archaeologists and physical anthropologists for many years (Kennedy, 1989). The study of human skeletal material supported by archaeological finds can provide information not only about the appearance, health and lifestyle of our ancestors, but also about their habitual activities. The physical stress accompanying such activities may give rise to various skeletal changes, and these manifestations of stress may include a whole range of markers: degenerative changes involving the joints (e.g. Beňuš, 2002; Lieverse *et al.*, 2007), stress fractures (e.g. Bláha, 1963; Merbs, 1989), the flattening of long bones/platymeria and platycnemia (e.g. Buxton, 1938; Marchi *et al.*, 2006) and in particular changes at the attachment sites of muscles, ligaments and tendons, i.e. the entheses.

Although change in the entheseal surface is frequently associated with advanced age or considered an accompanying marker to diffuse idiopathic skeletal hyperostosis (DISH) or seronegative spondyloarthropathies (SpA), it also occurs in association with physical activity (Resnick & Niwayama, 1983; Benjamin *et al.*, 2002; Benjamin *et al.*, 2006). The terminology that describes these changes is not unified. The two terms used most frequently have been 'musculoskeletal stress markers' or MSM (e.g. Hawkey & Merbs, 1995; Steen & Lane, 1998; Wilczak, 1998) and 'enthesopathies' (e.g. Dutour, 1986; Crubézy *et al.*, 2002; Mariotti *et al.*, 2004; Villotte, 2006; Villotte *et al.*, in press). The term 'enthesopathies' denotes a pathological modification at the site of insertion, regardless of aetiology (inflammatory disease, mechanical action, trauma, etc.) or appearance. 'Entheseal changes', is another term which could be used for both pathological and non-pathological cases. We will use here both 'enthesopathies' and 'entheseal changes'. When evaluating the entheseal changes associated with physical activity, other possible causes of their development (age, diseases) should be excluded where possible (e.g. Dutour, 1992; Hawkey & Merbs, 1995; Mariotti *et al.*, 2004; Villotte *et al.*, in press).

The study of entheseal changes incurred by physical stress in ancient populations is particularly interesting for the possibility it offers for reconstructing human behaviour and patterns of living (e.g. Larsen, 1999;

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Crubézy *et al.*, 2002; Capasso *et al.*, 2004). The study of such changes allows the acquisition of information of various kinds. A number of works have focussed on the study of the differences in physical activities between populations with different subsistence strategies (e.g. Eshed *et al.*, 2004), populations living in different terrains (al-Oumaoui *et al.*, 2004) or the sexual division of labour (e.g. Chapman, 1997).

Many authors have attempted to reconstruct habitual activities on the basis of archaeological finds and the prevalence of entheseal changes (Dutour, 1986; Hawkey, 1988; Beňuš, 2002; Capasso *et al.*, 2004). This approach may, however, be associated with several problems. First of all, it is not possible to distinguish fully between entheseal changes which have different aetiologies. Although we may exclude individuals on the basis of advanced age or on suspicion of DISH or SpA, other entheseal changes need not to be linked to physical stresses either (e.g. Zumwalt, 2005; Zumwalt *et al.*, 2006). Other problems are associated with the methodology itself: (1) the evaluation of entheseal changes by visual scoring is more or less subjective; (2) different methods distinguish various numbers of stages, and it is thus near impossible to compare the data acquired by these methods; (3) methods for studying entheseal changes were, at least until recently, not based on a medical understanding of entheses. These methodological limitations may therefore raise some doubts about the results obtained (Mariotti *et al.*, 2004, 2007; Villotte *et al.*, in press).

Our research focuses on studying two Early Medieval population groups from Mikulčice (Czech Republic); i.e. individuals from Mikulčice castle and from its hinterland. We suppose that the inhabitants of Mikulčice castle itself lived in different conditions than did the people of the hinterland. It may thus be assumed that the types of physical activities undertaken differed between these two groups. The underlying hypothesis is that different socio-economic conditions will be reflected in changes at muscle attachment sites. We have attempted to reveal different socio-economic characters among and within the groups, and reconstruct those habitual activities that could have formed part of the day-to-day lives of males and females in the 9th century.

Archaeological background

During the 9th century, the first historically documented Slavic proto-state, Great Moravia, appeared in central Europe, in the area north of the Middle Danube. In the latter third[Q4] of that century, at the time of its zenith, this represented a serious political partner and rival for the European 'powers' of the time—the West Frankish, East Frankish, Byzantine and Bulgarian empires. At the time of its greatest political conquests, this 'empire' encompassed an area that today includes Bohemia, Moravia, Slovakia, northern Austria, Pannonia, part of the land of the Avars (in the Tisza valley), Lusatia and Malopolsko (see Figure 1). Archaeological research indicates that nucleus of Great

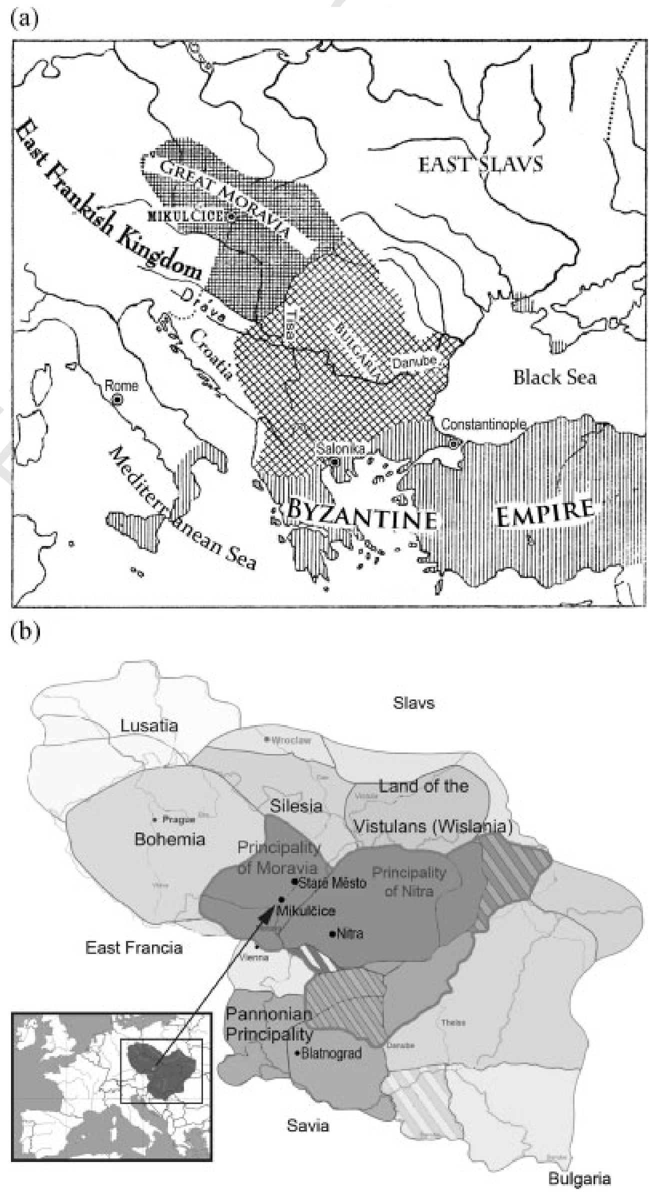

Figure 1. (a) Map of Europe[Q5] showing the location of Great Moravia and Mikulčice (modified illustration in Poulik, 1975). (b) Map showing the location of Great Moravia and locality Mikulčice in Europe (modified illustration according to http://commons.wikimedia.org/wiki/File:Great_Moravia-eng.png).

Moravia was located in the middle of the Morava basin (or Pomoraví). This was also the site of the two most important centres of this state-like formation—the settlement agglomerations at Staré Město-Uherské Hradiště and Mikulčice-Valy. The highest concentration of political power is documented by the results of archaeological research at Mikulčice.

Mikulčice-Valy was the centre of an extensive settlement agglomeration, which in part occupied the flood plain of the Morava (Poláček, 1996; Poláček *et al.*, 2006). The fortified nucleus of the Mikulčice settlement had an area of approximately 10 hectares. It consisted of the fortified enclosure itself—the 'castle' ('acropolis' and bailey) and the suburbium. During 55 years of archaeological research, almost 2500 graves were uncovered at this site (Poláček & Marek, 2005). The human skeletal remains are housed in the depository of the National Museum in Prague. The foundations of at least 10 churches were found in this locality. As this represents the largest accumulation of church structures at a single site in the whole Slavic world of the 9th century, it is likely that Mikulčice was the spiritual centre of the Great Moravia (Poulík, 1975; Klanica, 1985; Poláček, 2008a).

A three-aisled basilica was the largest of these churches, its foundations being discovered within the acropolis. Apart from almost 550 graves that were excavated around the basilica, several tombs were found inside this church, and these are considered to be the graves of the most prominent individuals from the Mojmírid ruling dynasty (Schulze-Dörrlamm, 1995; Poláček, 2008b). The basilica is also one of the places where the tomb of Archbishop Methodius has been sought (see Měřínský, 2006). The grave goods of the individuals buried in the castle itself generally point to the higher social status of its inhabitants. Nonetheless, it is like that as well as the nobles, clergy and military retinue, the castle was also inhabited by craftsmen, servants and others whose work was closely related to the functioning of the stronghold. The workshops of iron-founders, blacksmiths, jewellers etc. have also been found in the castle.

The immediate surroundings of Mikulčice (a radius of approximately 10 km) are considered to form its hinterland. This was predominantly inhabited by a farming population. It is inferred that this region mainly served as the agricultural base for the castle itself (Klanica, 2006; Klíma, 2007), although the existence of independent courts of the lesser aristocracy cannot be ruled out either (Poláček, 2008b).

Materials

We chose for our research three burial sites within the Mikulčice settlement agglomeration with different socio-economic structures. The first of these is located within the castle, around the three-aisled basilica. It may be presumed that individuals from the highest echelons of society were buried here. This burial site includes around 550 graves, and 117 individuals could be used for the purposes of our research. The other processed burial sites—Josefov and Prušánky—are located in the hinterland, which had an agricultural character. Representatives of the middle and lower social classes were probably buried here. Given the good state of preservation of this material, we were able to evaluate the skeletal remains of 23 individuals from Josefov and 57 individuals from Prušánky.

Only adult individuals were included in the sample. These were subsequently divided into three age groups: 20–40 years, 40–50 years and individuals over 50 years of age. We excluded individuals showing manifestations of diffuse idiopathic skeletal hyperostosis (DISH) or spondyloarthropathy (SpA). Individuals with healed trauma and severe degenerative-productive diseases were also not included. The preservation of the skeletal remains was itself a limiting factor. Table 1 lists the number of individuals processed according to sex and biological age at death. The influence of age on the manifestation of bone remodelling around entheses has been well documented by studies of cadavers (Durigon & Paolaggi, 1991) and of skeletons with known age at death (e.g. Cunha & Umbelino, 1995; Villotte, 2009). Enthesopathies seem not to be good markers of activity after 50 years (Dutour, 1992; Villotte, 2009); for this reason, only

Table 1. Individuals from the castle and hinterland by age and sex (*N*: number of individuals, M: males, F: females)

Locality	All			20–40			40–50			50+		
	N	M	F	*N*	M	F	*N*	M	F	*N*	M	F
All	197	103	94	60	22	38	77	42	35	60	39	21
Castle	117	68	49	33	17	16	51	27	24	33	24	9
Hinterland	80	35	45	27	5	22	26	15	11	27	15	12

those individuals who died before this age were considered in the attempt to reconstruct past activities.

Methods

Enthesopathies were evaluated according to a method previously proposed by one of the authors (Villotte, 2006). This method is based on current anatomical and histological studies of muscle attachment sites. It has been developed on the basis of the study of the differences between the normal and pathological appearances of individual entheses. In keeping with the findings relating to the structure of individual entheses, fibro-cartilaginous and fibrous entheses are evaluated separately (e.g. Benjamin *et al.*, 1986). The evaluated attachment sites were divided into four groups (Villotte, 2006; Villotte *et al.*, in press).

The first three groups include fibrocartilaginous insertion sites. These are typical of epiphyses and apophyses of the long bones, but they also occur on the short bones of the hands and feet and certain ligaments on the vertebral column (Benjamin *et al.*, 1986; Benjamin & McGonagle, 2001). Enthesopathies do not affect the surface of the insertion uniformly. They are more marked at the edges of the insertions, were the layer of cartilage is thin. The fourth group consists of fibrous enthesis. These occur in areas of the post-cranial skeleton with a thick layer of cortical bone, especially in the area of the diaphyses of long bones. They are connected to the strongest muscles of the body (such as pectoralis major, deltoid, muscles attached to the linea aspera (rough line) of the femur, Benjamin *et al.*, 1986). Fibrous insertions are generally extensive and poorly demarcated.

In this study only nine enthesis on each side of group 1 were used (Table 2; L: enthesis of the left side, R: enthesis of the right side). This is because the application of this method to a large sample of individuals of known sex, age and occupation has shown that physical activity affects only the enthesopathies for this group of entheses (Villotte, 2009; Villotte *et al.*, in press). This group includes only fibrocartilaginous entheses (Benjamin *et al.*, 1986; Benjamin & McGonagle, 2001). The structure of these entheses is well known: there is no periosteum at the site of these entheses and a layer of cartilage is located on the surface, but need not extend throughout whole surface of the enthesis. Fibrocartilaginous entheses in adult individuals have a characteristic structure, which forms the basis of their mechanical properties. Such entheses consist of four layers: tendon, non-calcified cartilage, calcified cartilage and bone (Cooper & Misol, 1970; Benjamin *et al.*, 1986). The so-called 'tidemark' at the boundary between the calcified and non-calcified cartilage provides healthy entheses with their characteristic appearance: they are smooth, with no vascularisation and apertures and their surface resembles that of joints. Enthesopathies do not affect the surface of the entheses uniformly: they are more marked at the edges of the attachment, where the layer of cartilage is thin.

The evaluation itself is conducted with the aid of a three-grade scale (stages A, B, C). The surface and contour are evaluated separately (often both are involved). A stage of 0, 1 or 2 is assigned to each of these evaluations. All types of re-modelling may occur on the surface of the entheses (enthesophytes, foramina, cysts...). The contour is most often re-modelled in the form of enthesophytes. The resulting stage (A, B, C) is based on the sum of the partial evaluations (A = 0, B = 1–2, C = 3–4).

In addition to the scoring system itself (ABC), we also evaluated taphonomy, i.e. the possibility or lack thereof of evaluating the attachment due to its degree

Table 2. Attachment sites evaluated on the appendicular skeleton

Enthesis	Location	Code
Insertion of the *M. subscapularis*	Lesser tubercle of the humerus	HSC
Common insertion of the *MM. supraspinatus* and *infraspinatus*	Greater tubercle of the humerus	HSI
Common origin of wrist extensors (*MM. extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, extensor carpi ulnaris* and *M. supinator)*	Lateral epicondyle of the humerus	HEL
Common origin of wrist flexors (*MM. flexor carpi radialis, flexor carpi ulnaris, flexor digitorum superficialis* and *flexor palmaris longus*)	Medial epicondyle of the humerus	HEM
Insertion of the *M. biceps brachii*	Radial tuberosity	RBB
Common origin of the *MM. biceps femoris, semitendinosus* and *semimembranosus*	Ischial tuberosity of the coxal bone	CSB
Insertion of the *M. gluteus minimus*	Greater trochanter of the femur	FPF
Insertion of the *M. gluteus medius*	Greater trochanter of the femur	FMF
Insertion of the *M. iliopsoas*	Lesser trochanter of the femur	FIP

of damage. Following Mariotti *et al*. (2004), attachments with more than one half of the contour and/or surface damaged were not included in the study. Entheses that could not be evaluated were marked NR (non-recordable); those which were completely missing were marked ABS (absent) (Havelková & Villotte, 2007). STATISTICA 7.0 and Microsoft Office Excel 2003 software were used for the statistical evaluation. Intra-observer and inter-observer errors of trait evaluation were expressed using two types of calculations. The degree of agreement was expressed as a percentage value as well as with the aid of the κ coefficient that also assesses the quality of agreement between the observers (Landis & Koch, 1977).

The methodology used in this work results in categorical data on an ordinal scale. For this type of data, it is most appropriate to use non-parametric tests based on a median or range (Robb, 1998). The mean score is being used ever more frequently for basic evaluation as well (e.g. Hawkey, 1988; Hawkey & Merbs, 1995; Churchill[Q6] & Morris, 1998; Molnar, 2006). Another option is to plot the percentage values of the stages representing the presence of enthesopathies onto a graph. We have applied all these statistical tools to obtain a picture of the distribution of entheseal changes in the population groups evaluated. Nevertheless, the use of a median, mean score or percentage value may have certain limitations.

The median would seem applicable given the character of the data (Robb, 1998; Stirland,[Q7] 1998; Molnar, 2006), but in view of the limited number of stages (usually 3–5, here 3) and the fact 'that their distribution tends to be bunched around the centre of the distribution, the median tends to obscure rather than reveal differences between individuals and groups' (Robb, 1998: p. 368). The problem of using the mean score lies in the fact that it works with categorical data in the same way as with numerical data, and thus presumes a certain numerical value of the given score and also a numerical value between the individual stages. The percentage value of stages B and C records the presence of any defect, but does not take into consideration the degree of involvement of the entheses.

Because of the data acquired are categorical and ordinal, non-parametric tests were predominantly used for the statistical calculations. Spearman's coefficient R was used to determine the correlation of age and enthesopathies. Two types of tests were used to calculate the degree of sexual dimorphism and to study the different prevalence of enthesopathies in individuals from the castle and hinterland. The parametric T-test was used for the overall evaluation of differences between the population groups on the basis of the mean score for each individual (where $A=0$, $B=1$, $C=2$). Comparison of the prevalence of enthesopathies in individual entheses within and among the evaluated populations was conducted using the non-parametric Mann–Whitney test.

The null hypothesis was rejected at the level $\alpha=0.05$.

Results

The first step was the calculation of intra- and inter-observer error in the evaluation of prevalence of enthesopathies. Intra-observer error was evaluated for 126 individuals buried in the castle itself, and its value was 11% (the κ coefficient was 0.81). Inter-observer error was evaluated in 20 individuals from the castle and amounted to 12% (κ 0.81) (Havelková & Villotte, 2007).

Age

The influence of age on the prevalence of the enthesopathies was studied on the sample of 197 individuals from both the castle and the hinterland. As expected, the prevalence of enthesopathies was higher in individuals of more advanced age. Based on Spearman's R test, the overall correlation in all individuals was 0.458 ($p=0.000$)—Table 3. In the case of individual entheses, a demonstrable correlation was found in 16 entheses out of 18. A similar situation was recorded among individuals buried in the castle

Table 3. Correlation between age and the enthesopathy prevalence on the basis of Spearman's R coefficients (*: significant differences; X: number of entheses which show statistically significant correlations between the prevalence of enthesopathies and age)

Locality	All				Males				Females			
	Valid N	Spearman	p-level	X	Valid N	Spearman	p-level	X	Valid N	Spearman	p-level	X
All	197	0.458	0.000*	16	103	0.493	0.000*	13	94	0.411	0.000*	10
Castle	80	0.386	0.000*	16	68	0.659	0.000*	15	49	0.356	0.012*	3
Hinterland	117	0.508	0.000*	9	35	0.114	0.514	1	45	0.454	0.002*	6

although Spearman's coefficient was considerably lower (Spearman $R = 0.386$; $p = 0.000$). The highest correlation (Spearman $R = 0.508$) was recorded in the population group from the hinterland, though a relationship between enthesopathy prevalence and age was demonstrated in the case of only nine entheses.

The age-dependence of the enthesopathies is also clearly illustrated by Figure 2, which depicts the prevalence of traits within the individual age categories for the population groups from Mikulčice castle, both females and males, and for the groups of females and males from the hinterland. The highest Spearman's coefficient overall was recorded among the males from the castle (Spearman $R = 0.659$; $p = 0.000$; Figure 2), in whom a relationship was demonstrated in the case of 15 entheses. Females from the castle demonstrated a statistically significant correlation only in the case of three entheses. Nonetheless, the correlation between the average score and age for all the evaluated entheses was statistically significant even within this group (Spearman $R = 0.356$; $p = 0.012$).

The situation differs in the individuals from the hinterland. If we were to study both sexes separately, then in females only six entheses correlate with age, although the overall correlation has been demonstrated at a level of $p = 0.002$ (Spearman $R = 0.454$; Table 4)[Q8]. In males, though, the correlation between the prevalence of enthesopathies and age was statistically demonstrated only in the case of a single enthesis (CSB-R), and the value of the overall correlation was 0.114. Figure 2 shows that in males living in the hinterland, the greatest prevalence of enthesopathies is in individuals aged 40–50 years. In individuals aged over 50 years, the prevalence of enthesopathies declines for both stages, B and C.

Prevalence of enthesopathies

Enthesopathies occurred in at least one fibrocartilaginous enthesis on a long bone of a limb in 76% of individuals younger than 50 years. The greatest signs of stress were exhibited by attachment sites in the upper extremities of males buried in the Mikulčice hinterland (Figure 3), which show the highest prevalence of both stages B and C. A high prevalence of stages B and C was also recorded on the bones of the upper and lower extremities in females from the castle. The situation did not differ significantly in the upper limbs in females from the hinterland. A lower prevalence of enthesopathies on both extremities was found in males buried in the castle. The fewest signs of stress could be

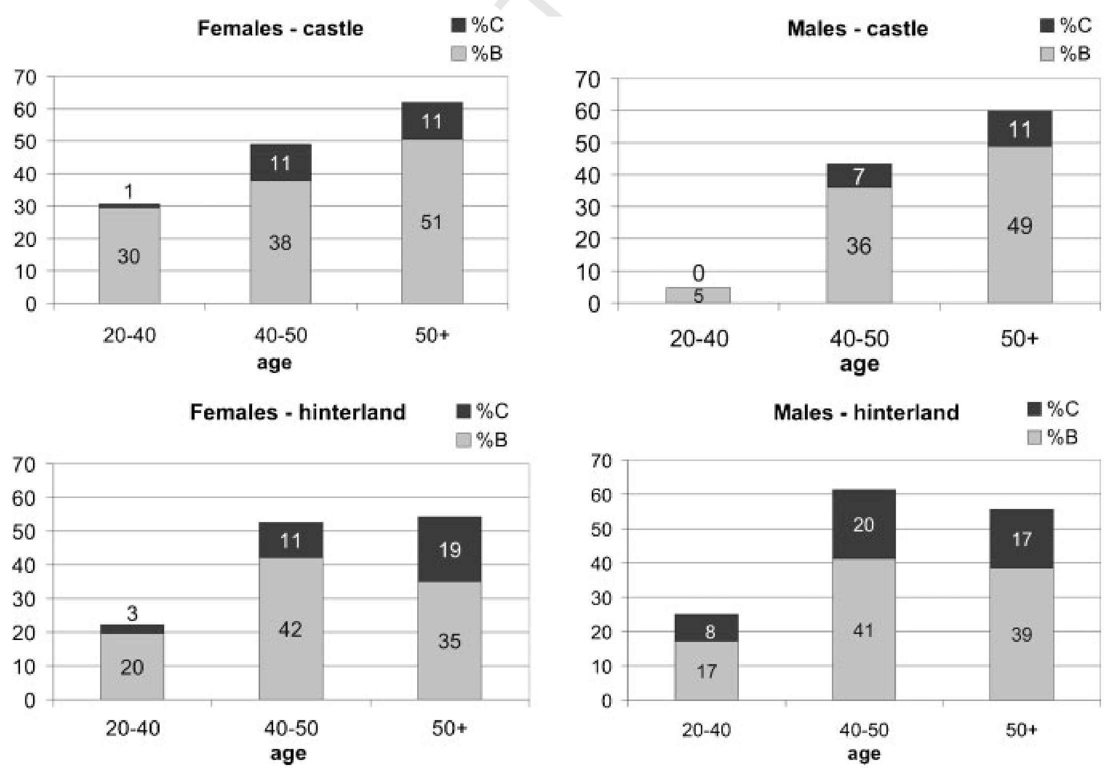

Figure 2. The prevalence of enthesopathies (percentage of stage B and C) in the individual age categories in females and males from the castle and the hinterland.

Table 4. Basic evaluation of enthesopathies for the individual entheses in males and females from the castle and hinterland (Enthesis: code for enthesis, see Table 2; R: right side, L: left side; %B + C: percentage value of the stage B plus stage C; %C: percentage value of the stage C)

Enthesis	Total				Castle								Hinterland							
	All				Males				Females				Males				Females			
	Mean	Rank	%B + C	%C	Mean	Rank	%B + C	%C	Mean	Rank	%B + C	%C	Mean	Rank	%B + C	%C	Mean	Rank	%B + C	%C
HSC-L	0.6	6	48.7	8.8	0.5	3	39.5	7.9	0.6	6	50.0	8.8	0.9	6	64.7	23.5	0.5	6	50.0	0.0
HSC-R	0.6	4	47.1	14.4	0.4	6	33.3	7.7	0.7	3	54.5	12.1	1.2	1	75.0	41.7	0.6	3	45.0	15.0
HSI-L	0.3	12	25.3	2.4	0.1	16	9.1	0.0	0.4	12	35.5	6.5	0.3	15	33.3	0.0	0.2	11	22.2	0.0
HSI-R	0.4	10	32.9	4.9	0.4	8	35.5	0.0	0.5	8	42.9	10.7	0.8	9	60.0	20.0	0.1	16	5.6	0.0
HEL-L	0.6	5	49.2	12.3	0.3	9	27.8	5.6	0.7	2	52.6	15.8	1.0	2	63.6	36.4	0.6	5	58.8	0.0
HEL-R	0.7	1	47.5	18.0	0.5	4	35.3	11.8	0.8	1	55.0	25.0	0.9	5	63.6	27.3	0.5	8	38.5	7.7
HEM-L	0.2	18	14.8	4.9	0.0	18	0.0	0.0	0.4	13	27.8	11.1	0.4	14	25.0	12.5	0.1	14	11.8	0.0
HEM-R	0.5	8	37.7	7.5	0.1	15	13.6	0.0	0.6	5	55.6	5.6	1.0	3	66.7	33.3	0.7	2	50.0	20.0
RBB-L	0.6	3	52.6	9.3	0.6	1	52.8	11.1	0.5	9	46.4	3.6	0.9	4	72.7	18.2	0.6	4	50.0	9.1
RBB-R	0.6	2	56.3	7.3	0.5	2	44.4	5.6	0.6	4	57.7	3.8	0.8	8	72.7	9.1	0.8	1	65.2	13.0
CSB-L	0.5	7	41.4	8.1	0.4	7	36.1	2.8	0.5	7	45.5	9.1	0.9	7	50.0	37.5	0.5	9	40.9	4.5
CSB-R	0.4	9	34.7	9.5	0.4	5	35.3	8.8	0.5	10	43.8	6.3	0.1	17	11.1	0.0	0.5	7	30.0	20.0
FPF-L	0.3	13	25.0	1.3	0.2	13	21.9	0.0	0.4	14	33.3	3.7	0.5	10	50.0	0.0	0.1	15	6.7	0.0
FPF-R	0.2	17	20.3	1.3	0.1	17	9.1	0.0	0.5	11	42.3	3.8	0.3	16	25.0	0.0	0.0	18	0.0	0.0
FMF-L	0.3	11	27.6	3.9	0.3	11	25.0	4.2	0.3	15	29.2	4.2	0.4	13	25.0	12.5	0.3	10	30.0	0.0
FMF-R	0.3	14	23.3	2.7	0.3	10	28.6	3.6	0.3	16	28.6	4.8	0.1	18	10.0	0.0	0.1	12	14.3	0.0
FIP-L	0.2	16	21.0	1.0	0.2	14	16.7	2.8	0.3	17	30.0	0.0	0.4	12	41.7	0.0	0.0	17	4.5	0.0
FIP-R	0.2	15	21.4	3.1	0.3	12	23.7	5.3	0.2	18	17.9	0.0	0.5	11	36.4	9.1	0.1	13	14.3	0.0

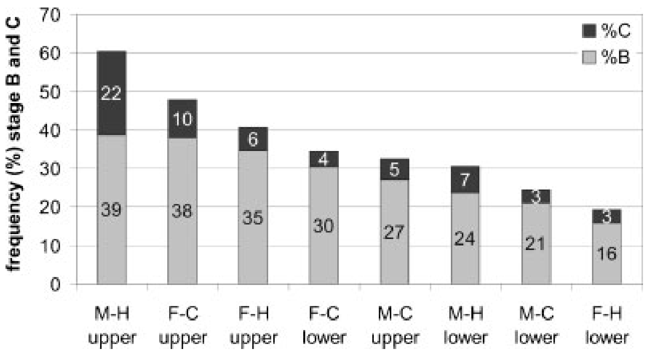

Figure 3. The frequency of stages B and C in different population groups for both the upper and lower extremities (M–H: males hinterland; M–C: males castle; F–H: females hinterland; F–C: females castle).

observed on the attachments of the lower limbs in females buried in the hinterland.

As can be seen from Figure 3, the upper limbs are more affected by enthesopathies than the lower limbs in all of the population groups. Table 4 summarises the prevalence of enthesopathies in all of the evaluated entheses. It includes the mean score, rank and frequency of enthesopathies for each enthesis (% stage B + C) and the frequency of the most severe stage (C).

The highest occurrence of entheseal changes in the lower limbs is represented by the area of the ischial tuberosity (CSB) on the pelvis in all population groups, and by the gluteus medius insertion (FMF) on the greater trochanter of the femur as well. The most important differences in the manifestation of a marker across the population groups are shown by the wrist flexors attached to the area of the medial epicondyle on the right humerus (HEM-R). While these muscles seem to be frequently used in the males and females from the hinterland, their entheses are ranked among the least involved attachment sites in males from the castle.

Sexual dimorphism

The differences in enthesopathy prevalence between the sexes were studied both in all individuals and in the population groups from the castle and the hinterland separately. In all individuals, regardless of the distinction between the upper and lower limbs, sexual dimorphism is not statistically significant ($p = 0.992$; see Table 5). Although the overall sexual dimorphism of enthesopathies on the upper limbs was not proved, differences between males and females in the individual entheses do exist (Figure 4—all individuals). In females, attachment sites that demonstrate the greatest signs of stress are located in the area of the elbow joint. In the case of the medial epicondyle of the humerus on the right side (HEM-R), the differences are even statistically significant. Males, on the other hand, demonstrate a higher prevalence of enthesopathies on the bones of the forearm, especially the insertion of the biceps brachii on the left side (RBB-L).

Sexual dimorphism is more accentuated in the hinterland sample and reaches statistical significance for the upper extremities (Table 5). In both limbs, there is a higher prevalence of enthesopathies in males. Evaluating the individual entheses, this difference is statistically significant for three markers (Figure 4—hinterland). Only the area of the right ischial tuberosity (CSB-R) and the gluteus medius insertion on the right side (FMF-R) demonstrate greater signs of stress in females. This difference is not statistically significant.

Most of the entheses in the castle sample show greater markers of stress in females (Figure 4—castle). Only two attachment sites, the biceps brachii insertion on the left side (RBB-L) and the iliopsoas insertion on the right side (FIP-R) are more affected in males. The difference in the prevalence of enthesopathies on the medial epicondyle of the humerus (HEM) between the sexes is statistically significant on both limbs and is also higher in females, as well as the area of the greater tubercle of the humerus on the left side (HSI-L) and the right insertion of gluteus minimus (FPF-R).

Castle versus hinterland

In the comparison of individuals (pooled sexes) from the castle and the hinterland we did not find any

Table 5. Differences in the prevalence of enthesopathies between males and females in the castle and hinterland, for the upper and lower limbs (*T*-test of the average score, rejected at the level of $\alpha = 0.05$, *: significant differences)

Limb	All			Castle			Hinterland		
	Mean F	Mean M	*p*	Mean F	Mean M	*p*	Mean F	Mean M	*p*
Upper	0.52	0.53	0.952	0.57	0.38	0.063	0.48	0.87	0.010*
Lower	0.30	0.35	0.490	0.41	0.25	0.070	0.28	0.43	0.279
Total	0.44	0.44	0.992	0.49	0.31	0.041*	0.38	0.73	0.016*

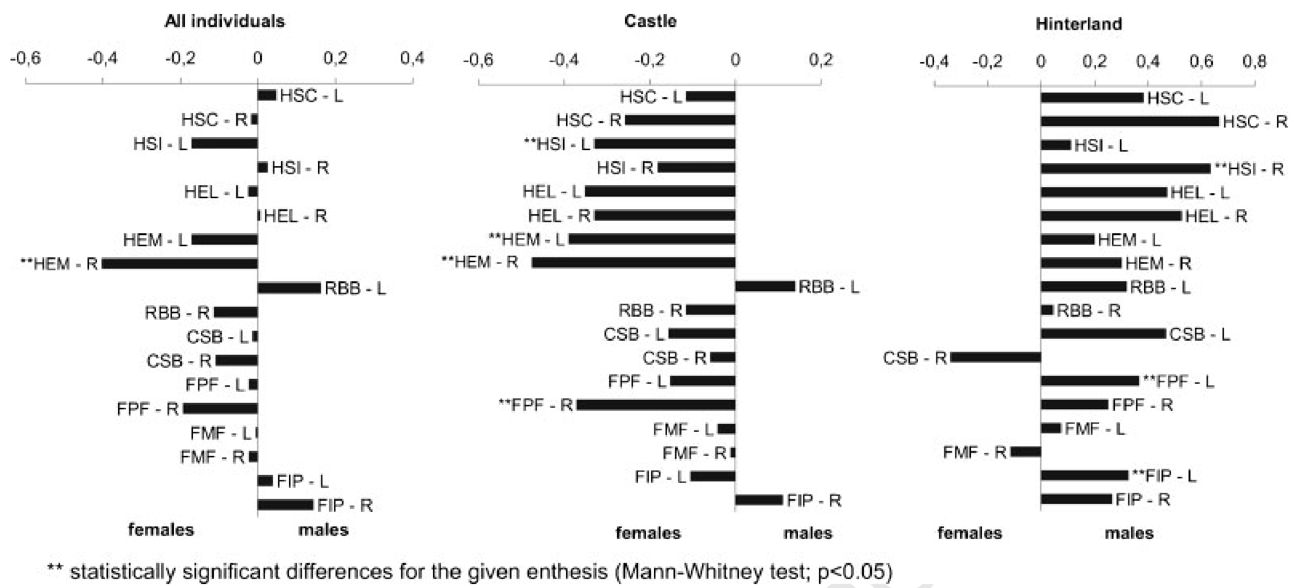

Figure 4. Differences in the prevalence of enthesopathies between males and females, expressed as the absolute difference between the average values for each enthesis, in all individuals, in the population group from the castle and from the hinterland.

statistically significant differences, although we recorded a higher prevalence of enthesopathies among individuals buried in the hinterland, especially on the upper extremities (Table 6). Generally, no statistically significant differences between the population groups from the castle and hinterland were observed even in an evaluation of the individual entheses (see Figure 5—all individuals), but there is a clear distribution of enthesopathies on the upper and lower extremities. Most of the attachment sites on the bones of the upper limbs show a higher prevalence of enthesopathies among individuals from the hinterland, while the prevalence of enthesopathies on the lower limbs indicate greater exposure to stress among the population group from the castle.

More information regarding the differences in enthesopathy prevalence between the selected sites is forthcoming if the sexes are evaluated separately. Among females, comparison of the mean scores shows no statistically significant differences for either the upper or lower limbs. Nevertheless, a higher prevalence of enthesopathies can be seen among females from the castle, especially on the lower limbs. This is also confirmed by evaluation of the individual attachment sites. A statistically significant difference between the castle and hinterland groups was recorded in the cases of three entheses (Figure 5—females). Two of these are located on the lower limbs (FPF-R, FIP-L) and one on the upper (HSI-R). All the attachment sites on the lower limbs, except for those of the ischial tuberosity (CSB-R) and iliopsoas insertion (FIP-R), were more affected in the females from Mikulčice castle. In comparison to the lower extremities, the attachment sites of the upper extremities do not show a higher prevalence of markers in either the castle or the hinterland. It may thus be concluded that females buried in the castle and the hinterland demonstrate similar exposures to stress of the muscle groups of the upper limbs, whereas the females from the castle demonstrate a greater manifestation of physical stress on the lower limbs.

Table 6. Differences in the prevalence of enthesopathies between individuals from the castle and the hinterland, for the upper and lower limbs (*T*-test of the average score, rejected at the level of $\alpha = 0.05$, *: significant differences)

Limb	All			Males			Females		
	Mean castle	Mean hinterland	*p*	Mean castle	Mean hinterland	*p*	Mean castle	Mean hinterland	*p*
Upper	0.47	0.63	0.071	0.38	0.87	0.000*	0.57	0.48	0.461
Lower	0.33	0.33	0.989	0.25	0.43	0.144	0.41	0.28	0.186
Total	0.40	0.51	0.143	0.31	0.73	0.001*	0.49	0.38	0.282

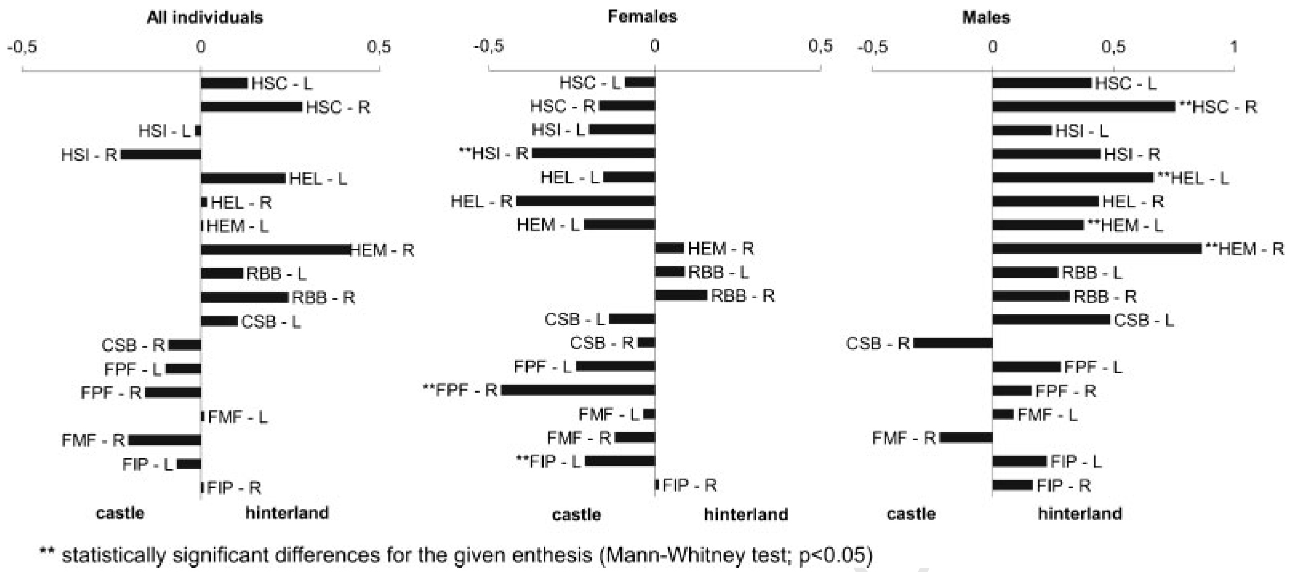

Figure 5. Distribution of the prevalence of enthesopathies in the population group from the castle and hinterland, expressed as the absolute difference between the average values for each enthesis, in all individuals, in females and in males.

In males, on the other hand, we observe an overall greater prevalence of enthesopathies in those buried in the hinterland for both upper and lower limbs (Table 6). Statistically, this difference is significant in the case of four entheses (Figure 5—males). All these entheses are associated with the upper limbs, and all show greater signs of stress in males from the hinterland. The lower limbs demonstrate a similar trend, but two attachment sites (CSB-R, FMF-R) are more affected by enthesopathies among males from the castle (although the difference is not statistically significant). The other entheses demonstrated greater signs of stress in males from the hinterland.

In summary in females, there is a higher prevalence of enthesopathies among those buried in the castle, predominantly involving entheses of the lower limbs. In males, on the other hand, the group from the hinterland demonstrates greater signs of stress, and the entheses of the upper limbs are more affected.

Discussion

Although skeletal changes associated with different lifestyles in past populations are considered to be an important source of knowledge about daily life, there are several limitations to studies of enthesopathies as occupational stress markers (Dutour, 1992; Jurmain & Roberts, 2008; Villotte, 2008, 2009). Methodology is one of them. In this paper, we have applied a method for studying the bony aspects of fibrocartilaginous entheses based on the current state of medical knowledge, which has been validated on a large sample of individuals of known sex, age and occupation (Villotte, 2009; Villotte *et al.*, in press). Mechanically induced enthesopathies are known from sports and/or occupational medicine to occur for each of the entheses studied here (references in Villotte, 2009). Even though the exclusion of pathological case and consideration of the influence of age make it possible to formulate, with caution, some hypotheses on physical activities for this sample, two further problems must be considered when approaching this kind of studies.

The first is the statistical evaluation of stress manifestations on attachment sites of the skeleton itself. The methodology used in this work results in categorical data on an ordinal scale. We have used different statistical tools to present our data and look for differences among the subgroups. We have plotted the percentage values of stages B and C onto graphs to study the correlation between enthesopathies and age. We have chosen to work with mean scores, especially when graphically depicting the differences between individuals of different sexes or buried at different sites. Comparison of the mean scores for individuals using parametric tests also yielded general information regarding the significance of the differences within a population, as well as between the population groups of the castle and the hinterland. Finally, non-parametric tests, most suitable for ordinal data, have been used to compare differences in the prevalence of enthesopathies in individual insertions.

Another problem lies in the interpretation of significant differences among the subgroups. In this paper, we have focussed on population differences, rather than trying to assign specific occupations to individual skeleton. We have approached this in two ways, trying to identify general patterns of activity, and to reconstruct daily activities. For general activity patterns our hypothesis, based on the results for identified skeletons (Villotte, 2009; Villotte *et al.*, in press), is that the prevalence of overall enthesopathies is higher in groups including subjects involved in forceful tasks. Our attempt to reconstruct daily activities is based on the approaches of Crubézy[Q9] (1988) and Hawkey & Merbs (1995): we have tried to identify the repetition of motions for specific entheses with a high frequency of lesions, and interpret these body movements according to the archaeological and iconographic context.

Age

The correlation between the prevalence of entheseal changes and biological age has been demonstrated by studies based on the evaluation of documented skeletal collections with known ages (e.g. Cunha & Umbelino, 1995; Mariotti *et al.*, 2004, 2007; Villotte, 2009; Villotte *et al.*, in press). This correlation has also been observed in historical material (Hawkey, 1988; Robb, 1998; Wilczak, 1998; al-Oumaoui *et al.*, 2004; Molnar, 2006). We may thus suppose that in older individuals, the development of enthesopathies is affected not only by mechanical stress but also by the degenerative changes associated with age.

This study has also recorded a statistically significant correlation between enthesopathy prevalence and age, this correlation differing in the various population groups as well as between the sexes. Differences in age correlation between males and females have also been described by al-Oumaoui *et al.* (2004), where a statistically significant correlation of age and enthesopathies was found in far more entheses among males than females. These differences may derive from the different types of physical activity among males and females, where during their lifetimes males usually undertake physically more strenuous activities (al-Oumaoui *et al.*, 2004). Similar results can be seen in the work of Wilczak (1998), which also proposes that those differences may be due to a delay of the adolescent growth spurt in males. These results show that the higher correlation of entheseal changes and age is associated with more intense physical activity, often meaning that it is higher in males.

Our results agree only partially with those of previous research. Males in the pooled sample (castle and hinterland) show higher correlation between enthesopathies and age than females. However, in the comparison for separated localities we see a different picture. The strongest correlations were found in males buried in the castle and females in the hinterland. We assume that these groups were exposed during their lifetimes to less intensive physical stresses. The correlation of age and enthesopathies was low in females from the castle and non-significant in males from the hinterland, who display the highest prevalence of entheseal changes of all the groups evaluated (the non-significant correlation in the case of the males from the hinterland might also result from the small number of individuals in this group).

On the basis of the results, we can see that, in contrast to the studies mentioned above, a higher correlation between age and enthesopathies was observed in the groups probably afflicted by less demanding physical activities, regardless of sex (males/castle, females/hinterland). Another interesting fact results from the age distribution of the entheseal changes: while the occurrence of enthesopathies differs among the population groups in the younger age categories (20–40 and 40–50), their prevalence in individuals older than 50 years is nearly equal (50–60%) in all population groups.

This is in accordance with the study of Niinimäki (2009), which revealed that 'MSM scores are high in early life in heavy labour group when muscle markers start to develop after longitudinal growth has ended, but with advancing age the differences in MSM sites between different labour intensities seem to level off' (Niinimäki, 2009). We can see a similar picture, especially in males, from the hinterland, where the occurrence of enthesopathies decreases in the older age category (>50 years). This is why the evaluation of entheseal changes in older individuals may be misleading, and is more likely to attest not to physical activity but to the influence of age.

General activity patterns

From the average scores (Tables 5 and 6) we can formulate some hypotheses about the general pattern of activities and sexual division of labour at the castle and in the hinterland.

For males in the castle, we observed almost the lowest prevalence of enthesopathies in the castle in comparison to other groups. Given the archaeological finds (e.g.Poláček, 2008b) we may suppose this population group to be ranked among the most privileged inhabitants, but we do not have an exact idea about their specific activities. The population group from the castle predominantly consisted of individuals of a higher social status—nobles, clergy and warriors but also servants and naturally their wives (Poláček, 2008b). It is likely that each of these population groups performed different work. The only thing that can be excluded for this group is agricultural activity. Males from the hinterland were probably exposed to physical stress frequently: their average scores are higher in comparison to other groups, both on the upper and lower limbs, but differences are statistically significant only for the upper limbs. Judging from the archaeological finds, these high levels of stress are probably related to two predominant activity types: building operations and activities relating to farming. The degree of physical stress appears to be similar between females, regardless of their site of burial. It is possible that the predominant activities of the females in the castle were nearly identical to those of females in the hinterland.

Within the study population, rates of sexual dimorphism differ in the castle and the hinterland. In previous studies, this rate was sometimes considered to be related to the dietary strategy and predominant economy of a given population. Agricultural populations usually demonstrate the least degree of sexual dimorphism in the lower limbs (Wilczak, 1998; al-Oumaoui *et al.*, 2004) while populations involved mainly in breeding livestock and those living in hilly terrain demonstrate the greatest sexual dimorphism of the lower limbs (al-Oumaoui *et al.*, 2004). These finds may be generalised as follows: significant sexual dimorphism in the muscles of the upper limbs and weak sexual dimorphism in the attachments of the lower limbs correspond to agriculturally based economies in flat terrain.

In the case of individuals from the hinterland, the prevalence of enthesopathies at individual entheses is almost exclusively higher in males. We presume that farming was the main activity in the population groups from Josefov and Prušánky, which are situated on the floodplain, even if many other tasks were undertaken by dwellers in the hinterland as well. Our results appear to confirm the hypothesis formulated above. Sexual dimorphism in this group is present for the upper and lower limbs but significant only for the upper limbs.

The situation in the castle is completely different. We did not record a significant sexual dimorphism on either the upper or the lower limbs; however, both were more affected in females while males show almost the lowest prevalence of the marker. In contrast to the predominantly agricultural population of the hinterland, the main activities and living patterns of the individuals living in the castle are not completely clear. The only fact that can be used as a basis is the importance of the Mikulčice castle with regards to the presence of the princely palace and three-aisled basilica. The interpretation of the results is thus problematic. We may, however, assume that, in contrast to males, females living in the 9th century in the Mikulčice castle did not represent a privileged social class, and were thus not kept from physically strenuous tasks. Although it is not impossible that females also conducted certain more arduous types of work, it seems likely that most of the entheseal changes result from repetitive tasks, i.e. the most common activities not demanding heavy force, but based on the same movements practised frequently (such as carrying water, grinding of grain, preparation of skins, weaving or spinning). It is also necessary to be aware of the environmental conditions. The castle was situated in the middle of an island, and the landscape around it is thought to be largely deforested; therefore, the supply of basic materials (such as kindling for heating and cooking) may also be included among notably strenuous activities undertaken by females.

Loading of the individual attachment sites of the upper limbs and possible associated activities

Evaluation of the entheseal changes at the fibrocartilaginous entheses of the upper limbs can tell us much about physical activity of past populations. Most of the muscles of the shoulder, elbow and forearm work in the functional groups, either as synergists or antagonists, and it is thus necessary to see the occurrence of enthesopathies in individual entheses in relation to each other. We can see the best example of this kind of relationship in the Mikulčice females.

The highest prevalences of enthesopathies in females, both in the castle and hinterland, are associated with the flexion and extension of the elbow and wrist. The females from the hinterland probably made more use of the flexors of the elbow (RBB) and the wrist (HEM) on both sides, and of the wrist extensors (HEL) more commonly on the left side. The situation in the females from the castle is similar. The most utilised muscles were the wrist extensors on both sides (HEL-R, HEL-L) and the flexors on the right side (RBB-R, HEM-R). Muscles attached to the area of the shoulder were probably frequently used as well, especially the subscapularis on the right side (HSC-R). The other attachment site of the shoulder, the common insertion of the supraspinatus and infraspinatus (HSI), shows far fewer enthesopathies.

The biceps brachii insertion (RBB) is rarely affected by enthesopathies in recent populations, but where it does is related in particular to the carrying of heavy loads with the arms bent (Commandré, 1977: p. 105). A high frequency of this marker has also been found in activity groups using their arms for strenuous activities (Cunha & Umbelino, 1995; Villotte, 2009: pp. 170–176). Enthesopathies of the attachment sites of the subscapularis (HSC), the flexors and the extensors of the elbow and wrist occur today in several sports and occupations involving repetitive and/or forceful tasks (e.g. Commandré, 1977; Rodineau, 1991; Johnstone & Maffulli, 2005).

The stress incurred by the muscles of the elbow, forearm and shoulder may correspond to certain activities, which according to the archaeological finds, may be supposed to have been part of the day-to-day life of Mikulčice females. One of these possible activities is the preparation of skins—tanning. This kind of activity and its possible impact on the muscle attachments has been described in detail by Hawkey & Merbs (1995): the flexors and extensors of the wrist (HEM, HEL) are needed especially when cutting skin, while repeated flexion (RBB, HEM) and extension (HEL) are required when scraping it. This technique was common in the Eskimo population and is not only well known from archaeological finds, but has also been documented in recent populations. Unfortunately we have no information about tanning techniques among the Slavs, and it is thus hard to tell whether this activity was carried out in the same way.

Other common tasks probably undertaken by females included weaving (in the 9th century involving the use of looms), spinning and the grinding of grain (Beranová, 2000), see Figure 6. These activities have been archeologically corroborated at Mikulčice by numerous series of whorls and spindles (Marek & Kostelníková, 1998) and quern-stones (Marek & Skopal, 2003). Last but not least, we must also mention a ceramic production as a common task probably undertaken by both females and males. The number of ceramic finds from Mikulčice (Poláček, 1995; Mazuch, 2009) indicates that pottery making was a day-to-day activity. The ceramic wares of the 9th century were made with the aid of a potter's wheel powered by the hands. All of these activities require the force of both limbs associated with different distributions of stress on the extensors and flexors of the right and left limbs.

The attachment sites on the upper limbs in males from the hinterland show the highest prevalence of enthesopathies of all of the evaluated groups. On the right side, entheseal changes seem to be concentrated in the insertion of the subscapularis (HSC) located on the proximal humerus, and the origin of wrist flexors attached on the medial epicondyle of the humerus (HEM). The biceps brachii (RBB), which ensures flexion and supination of the forearm, and the extensors of the wrist (HEL), were the most used muscles on the left side. As mentioned previously, enthesopathies in the area of these attachment sites occur today in several sports and occupations. It thus appears difficult to identify specific motions according to the ethiopathogenesis of the lesions, but several hypotheses regarding male activities may be formulated.

As mentioned above, we may presume two main categories of predominant activity among males: the procurement of subsistence including agricultural work, and building operations (Figure 6; Váňa, 1983).

The former ranked as a habitual activity exclusively in the hinterland. Apart from tillage (ploughing), which required the participation of almost all the evaluated muscles, one of the rather more male activities was harvesting—for which sickles, several types of which have been discovered in Mikulčice, were used. Some of these were serrated, and rather than for cutting and hewing were used for chopping and whittling. A handful of the cereal was grasped in the left hand and the right hand was used to cut the stalk about midway (Beranová, 2000). This activity mainly required the participation of the flexors and extensors of the elbow and wrist.

Another common and physically highly stressful activity was probably fishing. The whole region of the Mikulčice agglomeration was formed by a group of small islands between branches of the Morava River. In addition to canoes (logboat/monoxylon type vessels), fish-baskets (fish-pots), the primary means of catching fish, have also been discovered at Mikulčice (Mazuch, 2003; Poláček & Marek, 2005). This work required great physical strength in both the upper limbs, involving both the arms and forearms.

The activities associated with building operations are assumed to have been undertaken by males from the hinterland as well as those from the castle. In the Mikulčice settlement agglomeration, there were many wooden houses, stone churches and fortifications around the stronghold. Construction of these structures had to be associated with such genuine hard work as carrying stones and wood, hammering the stocks for a stockade, transporting of stone by logboat down the river from Slovakia and especially with carpentry. We may suppose that carpentry using an axe was one of the main activities of males. Such axes were likely to have been the most common tools used by Mikulčice males, as well as having been used in battle, something supported by many archaeological finds (Poláček *et al.*,

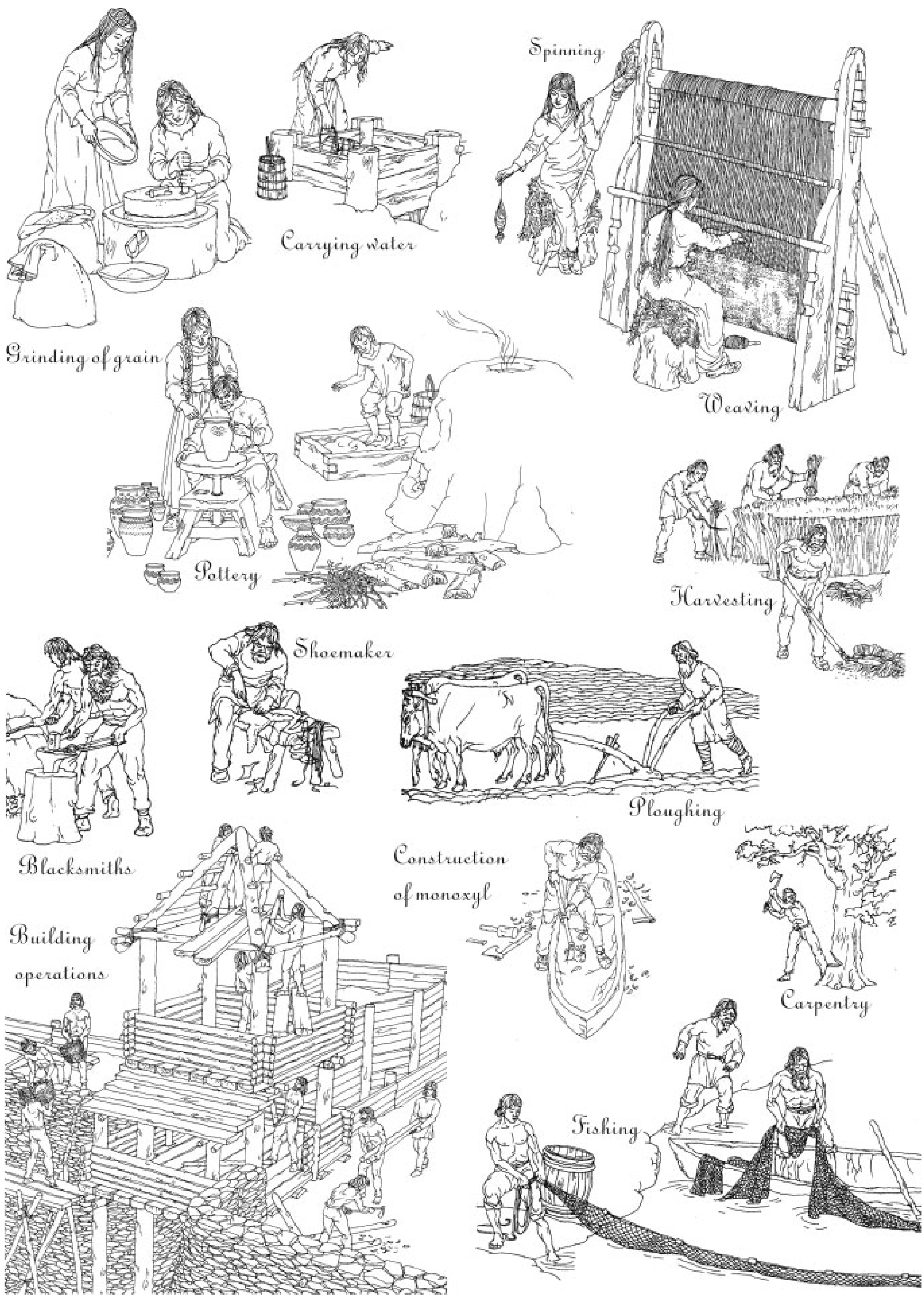

Figure 6. Reconstruction of the possible habitual activities of Slavic females and males (modified illustration according to Pavel Major in Váňa, 1983).

2000). In addition to the aforementioned attachment sites of the shoulder and elbow, changes affecting the triceps brachii on the ulna (olecranon process) are also seen to be associated with this activity by physical anthropologists (Dutour, 1986; Galera & Garralda, 1993). Although the prevalence of enthesopathies in the triceps insertion was not included in the present study, it is interesting to note that changes involving this insertion on the right side were exhibited by 33% of males in the hinterland.

The specific activities characteristic of males buried in the castle are near impossible to recognise, due to (1) the inaccuracy of archaeological hypotheses about possible activities in the castle, (2) the different social statuses of individuals within castle society (nobles, clergy, warriors and servants) and (3) the quite monotonous and low mean scores for all the entheses under study.

Loading of the individual attachment sites of the lower limbs

The reconstruction of activities associated with the lower limbs is much more complicated. All the fibrocartilaginous attachment sites on the lower limbs presented in this study are located on the proximal femur and pelvis, and they participate in movements of the hip and knee. In the living population, involvement of the entheses is uncommon. It may be associated with mid- or long-distance running and hurdling (Roger, 2001; Koulouris & Connell, 2006; Labareyre & Roger, 2006) in the case of common origin with the biceps femoris, semitendinosus and semimembranosus (CSB), and with several sporting activities such as soccer, rugby, canoeing, swimming or tennis (Krejci & Koch, 1985: pp. 71–74; Parier *et al.*, 2006) for the attachments located on the greater (FMF, FPF) and the lesser trochanter (FIP).

In physical anthropology, the lesions of these attachment sites have been linked to such activities as horseback riding, cart driving, and jogging with heavy loads in rough terrain or balancing the body's weight over the stance leg during walking (Lai & Lovell, 1992; Pálfi, 1992; Molleson & Hodgson, 1993; Reinhard *et al.*, 1994; Steen & Lane, 1998).

With regards to the locality of this study, we may exclude activities associated with walking in rough terrain, since Mikulčice is situated in the flood plain of the Morava and there were no hills or mountains in the neighbourhood. The presence of another activity, horse-riding, is corroborated by the archaeological recovery of horse bones and the horse trappings, especially in the castle (Chrzanowska & Krupska, 2003). As far as we are aware, however, enthesopathies of these attachment sites have not been related to riding in sporting medical studies (e.g. Auvinet, 1980; Pugh & Bolin, 2004). We may suppose that most changes in the entheses of the lower limbs are associated with such common and daily activities as walking, lifting from a seated position and preparation of potter's clay by treading. The carrying of heavy loads may also facilitate the apparition of lesions on the lower limbs (Villotte, 2009).

More information about physical activity associated with lower limbs is possible to acquire by studies of cross-sectional geometry. This method could help in clarifying the results obtained using enthesopathies and tell us more about mobility patterns of past populations (Holt, 2003; Sládek *et al.*, 2006; Marchi, 2008).

Conclusions

Entheseal changes in the area of the fibrocartilaginous entheses were evaluated in the Great Moravian population from the Mikulčice castle and its hinterland. Our results confirm most of the assumptions based on previous studies and the archaeological finds from the area.

The prevalence of enthesopathies correlates significantly with age in all of the evaluated groups except the males from the hinterland, where the highest level of physical stress is assumed. Entheseal changes thus seem to correlate significantly with age if the level of physical stress is low, while if the level of physical stress is high the correlation is less clear. The differences in the prevalence of enthesopathies recorded among the populations of younger individuals (20–50 years) disappeared in individuals older than 50 years.

The rate of sexual dimorphism was higher in the hinterland, especially for the upper limbs. Sexual dimorphism of the lower limbs was not proved in either the castle or the hinterland.

The males from the agricultural hinterland show the highest prevalence of enthesopathies of all the population groups, while the lowest prevalence of markers was recorded in the males from the castle. The situation was different in females; surprisingly, the females in the castle were more affected by entheseal changes than were females from the hinterland.

Reconstruction of habitual activities was possible, to a certain extent, only for females from the castle, and for those individuals from the hinterland where results may be supported by a number of archaeological finds and prior knowledge. The males from the hinterland were probably engaged in activities associated with farming and building. Habitual activities among females might include tanning skins, weaving, spinning and the grinding of grain and preparation of food. These activities were probably similar in both the castle and the hinterland. Entheseal changes in females were mainly concentrated in the area of the elbow, while in males the shoulder was strongly affected as well.

When attempting to reconstruct habitual activities we have to keep in mind that any given case of entheseal changes need not be associated with specific activities at all, and some may not even be the consequence of mechanical stress. Nevertheless, the differences in the enthesopathy prevalence in the sample of individuals younger than 50 years may indicate some trends in distribution of physical stress and allow us to reasonably explain the results obtained from the archaeological finds.

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