ANTHROPOLOGICAL EVALUATION OF EARLY SKELETAL TUBERCULOSIS IN THE MEDIEVAL POPULATION OF DEVÍN-CASTLE (11TH–12TH CENTURY AD., SLOVAKIA)

Antropologická analýza počiatočných štádií tuberkulózy kostí v stredovekom súbore z pohrebiska Devín-Hrad (11.–12. storočie n. l., Slovensko)

Klaudia Kyselicová[1], Lukáš Šebest[2], Radoslav Beňuš[1], Csaba Bognár[2], Michaela Dörnhöferová[1]

[1]Department of Anthropology, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia

[2]Department of Molecular Biology, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia

Abstract

This paper presents the results of a macroscopic analysis of early-stage tuberculosis in the medieval population of Devín-Castle (11th–12th century AD) and it summarizes the first data on possible occurrence of tuberculosis in a historical population from the territory of Slovakia. A total of 210 individuals (129 adults and 81 subadults) was analysed for the presence of lesions attributable to tuberculosis. First this skeletal collection was analysed only macroscopically, where special attention was given to the presence of lesions typical for a tuberculosis infection with it´s typical predilection sites (tubercle formation, ankylosis of the spine, or severe inflammation of hip joints). After typical cases of a tuberculosis infection were excluded, the study was aimed on finding early stage TB (tuberculosis) or atypical lesions possibly linked with TB (most of them referred to as "MOLAT"). Based on our findings, we assume that in this population were 6 adult individuals suffering from early stage TB (4 females and 2 males) and an unexpectedly high number of subadult individuals with lesions attributable to an early skeletal form of TB. As many as 23 out of 81 (28.40%) individuals younger than 18 years at death had skeletal changes like hypervascularisation of vertebral bodies (with or without resorptive lesions) and periosteal depositions on the ventral rib surface. As these alterations are not always tuberculosis specific and the here presented results are derived from a macroscopic observation only, they can only indicate an infectious disease, but the presence of a mycobacterial infection and its pathogen *(Mycobacterium tuberculosis)* causing TB can only be confirmed by a DNA analysis. Therefore the here presented data will be verified molecularly and by shot gun sequencing in a later stage of the research.

Keywords: *paleopathology, infectious diseases, periostitis, MOLAT, vertebral bodies*

Introduction

Tuberculosis is principally caused by two members (*M. bovis* and *M. tuberculosis*) of the pathogenic *Mycobacterium tuberculosis* complex (MTB). It is primarily a soft tissue infection, according to Roberts and Buikstra (2003) only 3–5% of untreated people develop bone damage in the skeleton. The pathogen (most frequently *Mycobacterium tuberculosis*) is spread via haematogenous and lymphatic route from a primary focus in the lungs or gastrointestinal tract, most often it is the spine that is involved. Osseous tuberculosis is a chronic destructive inflammatory process with tubercle formation in bone comparable to affection of other organs/tissues (Nerlich & Lösch, 2009). The predilection site of osseous tuberculosis is not only the spine, but also the epiphyses of large joints, the skull and various small and flat bones. In general, every bone may be affected (Ortner & Putschar, 1985).

The here presented research is based on the analysis of human skeletal remains from the medieval settlement at the Castle Devín, which is dated to the 11th to 12th century AD (Plachá & Hlavicová, 1987). The skeletal collection from this settlement represents one of the most elaborate bone sets from the territory of Slovakia. Due to its good preservation, it was the subject of several anthropological studies aimed on mainly paleopathological lesions such as traumatic and growth lesions, manifestation of physical stress, metabolic diseases, diseases of teeth and periodontium, neoplastic lesions and manifestations of unspecific stress (Beňuš & Masnicová, 2012).

The here presented study derives from the macroscopic analysis of lesions referred to as MOLAT (Minor Osseous Lesions Attributable to Tuberculosis; Maczel, 2003). These minor lesions are often used as diagnostic criteria for early skeletal tuberculosis and are represented by rather atypical location or manifestation like periosteal depositions on the ventral surface of ribs, hypervascularisation or collapsed vertebral bodies and abnormal blood vessel impressions or possible lesions on the endocranial surface of the skull (due to tuberculous meningitis; Hershkovitz et al., 2002). Other unspecific changes possibly related to tuberculosis such as periostitis of long bones and osteomyelitis were observed as well.

The analysed skeletal collection consisted of 129 adult individuals (54 males, 62 females and 13 individuals of not determined sex) and 81 subadult individuals and it is the first medieval skeletal collection from the territory of Slovakia which was examined for the presence of specific infectious diseases. Paying special attention to the above described minor lesions might be a helpful tool in avoiding the underestimation of the frequency of TB in any skeletal collection.

Aim

The aim of this study was to detect the presence of atypical or early TB changes in skeletal remains and characterize them by location and frequency, in order to better understand the etiology and spread of this infectious disease in medieval populations.

Methodology

All examinations were carried out macroscopically at the Department of Anthropology at the Comenius University in Bratislava, where the collection is currently deposited. Age and sex of the studied population were determined previously by Beňuš and Masnicová (2012), for age estimation the methodologies of Ubelaker (1978), Lovejoy (1985), Meindl and Lovejoy (1985), Hanihara and Suzuki (1987) and Lovejoy, Meindl and Przybeck (1985) were followed. For sex estimation Beňuš and Masnicová (2012) followed the methodologies of Acsádi and Nemeskéri (1970), Černý and Komenda (1980), Ferembach,

Schwidetzky and Stloukal (1979), Iscan and Derrick (1984), Loth and Hennenberg (1996) and Phenice (1969).

At first, the study was aimed on finding lesions typical for a tuberculosis infection, but after the presence of lesions such as ventral collapse of vertebral bodies leading to angulation of the vertebral column ("gibbus"; Ortner & Putschar, 1985) or inflammation of hip joints was excluded, the material was studied for the presence of lesions likely to be linked with an early stage of TB (known as "MOLAT"; Maczel 2003):

- rib lesions: periosteal depositions on the ventral surface of ribs (but also on the whole surface of the rib), or lytic lesions, indicative of pulmonary TB (Matos & Santos, 2006; Raff, Cook, & Kaestle, 2006).
- lesions on vertebral bodies: irregular pitting, hypervascularisation, resorptive lesions, minor cavitation (Zink et al., 2007; Nerlich & Lösch, 2009).
- other lesions linked with TB, but not TB specific: endocranial lesions – small granular impressions, abnormal blood vessel impressions (Hershkovitz et al., 2002) indicative of tuberculous meningitis, or other unspecific changes like osteomyelitis of different bones, and morphological alterations attributed to environmental and nutritional stress (due to malnutrition, bad hygiene, infectious disease) – cribrotic *cribra orbitalia* and anemic conditions.

The observed skeletal changes were compared with findings in literature (Aufderheide & Rodríguez-Martin, 1998; Nerlich & Lösch, 2009; Ortner 2003) and recent publications (Blondiaux, de Broucker, Colard, Haque, & Naji, 2015; Coqueugniot et al., 2015; Pálfi et al., 2015; Molnár et al., 2015). Samples were collected from the affected bones and will be tested molecularly for the presence of the tuberculosis pathogen (*Mycobacterium tuberculosis*) to confirm and attest the results of the morphological examination. This part of the research is still in progress.

Results

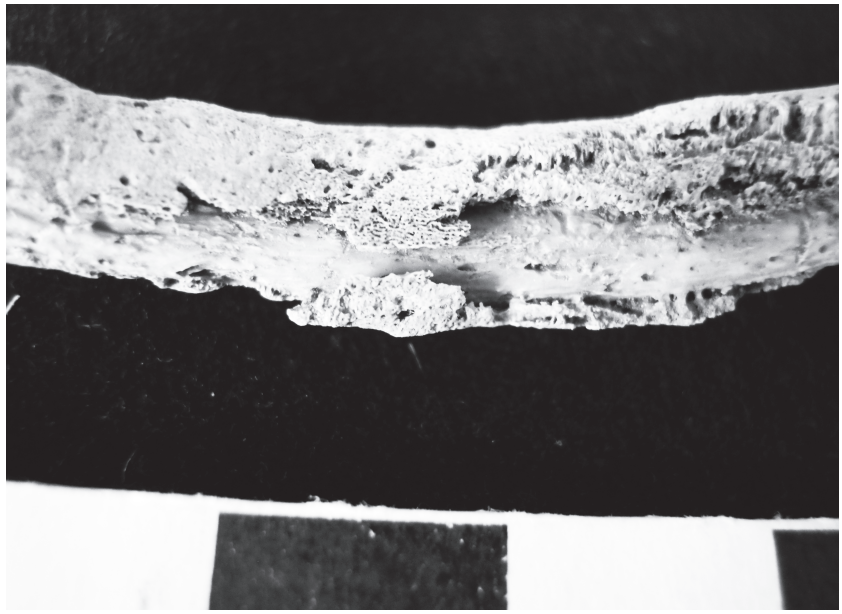
Skeletal lesions attributable to early tuberculosis were present in 6 out of 129 examined adult individuals (4 females and 2 males), which means that 4.65% of adults were probably suffering from TB. All of the 6 cases occurred in one of the age categories classified as adults (2 females and 1 male aged 20 to 29 years, 1 female and 1 male aged 30 to 39 and one female classified as adult without precise determination) (Table 1). The localization of lesions on the adult skeletons was as following – hypervascularization of vertebral bodies was present in 2 of the affected individuals (1 female and 1 male), 2 individuals had periosteal depositions on the ventral surface of ribs (1 female and 1 male) and 2 female skeletons had a different localization of the lesions (periostitis of the left femur and periostitis of the left scapula) (Table 3).

The occurrence of minor osseous lesions attributable to tuberculosis was unexpectedly high in subadult individuals. As many as 23 (28.40%) out of 81 analyzed individuals younger than 18 years were suffering from skeletal changes indicative of TB. One half of the affected individuals were juveniles (14–18 years at death), surprisingly more than 60% of the whole group of juvenile individuals of this population had lesions attributable to this disease. Tuberculosis affected also children under 14 years, 6 were from the age category of younger infants (6 months – 6.9 years at death), 4 were aged between 7 and 13.9 years, and 2 were of undetermined subadult age. Based on an anthropological analysis only, no lesions indicative of tuberculosis were found in the 11 inspected circumnates from this population (Table 2). In the group of subadults the macroscopic diagnosis revealed a high frequency of TB affected vertebrae and ribs (Table 4): 14 cases of hypervascularisation of vertebral bodies (60.9% of all cases; Picture 2), 5 cases of affected vertebral bodies and periostitis of ribs (21.7% of all cases; Picture 1), 2 cases of affected ribs and periostitis of other bone than vertebrae (8.7%), 1 case of periostitis of ribs (4.3%) and 1 case of affected vertebrae, ribs and some other bone (4.3%).

Out of the 29 TB cases, in as many as 22 there was an involvement of the vertebral column (which is characteristic of osseous tuberculosis (Cotran, Kumar, & Robbins, 1994; Ortner & Putschar, 1985). All of the 22 individuals without exception, had lesions affecting thoracic vertebrae, two had also lesions on cervical vertebrae and two on lumbar vertebrae as well. The most frequently affected thoracic vertebrae were these: Th_7 (in 13 out of 22 cases of spine involvement), Th_5 and Th_8 (in 11 out of 22 cases).

To minimize the mistake rate when evaluating subadult vertebral bodies that normally occur open/displaying the inner spongiosa and not confuse this condition with pathological hy-

Picture 1. *Periosteal deposition on ventral rib surface*



Picture 2. *Abnormal vascularisation and pitting of the vertebral body of a subadult individual*

pervascularisation, additional TB indicating lesions were observed as well. These TB unspecific but probably related changes were observed in 5 out of the 14 subadults who had only vascularized vertebrae as only TB specific lesion. The majority of these changes were potentially related to physical and nutritional stress, most often it was a cribrotic *cribra orbitalia*, *cribra cranii*, or hyperostosis of *lamina interna* of the skull, which may also be associated with tuberculosis as these are generally attributed to iron-deficiency anemia developing from the interaction of factors such as diet, hygiene, parasites and infectious disease. Other observed osseous changes in subadult individuals with affected vertebrae and ribs were osteomyelitis of different bones and minor periosteal depositions on different bones of the skeleton. All together there were 8 out of the 23 TB affected subadult skeletons which had lesions that could be indirectly correlated with an infectious disease as a respond to weakened immunity.

Discussion

Regarding the results of this macroscopic investigation aimed on paleopathological lesions attributable to skeletal tuberculosis, we can state that in the skeletal collection from Devín-Castle only alterations indicative of early skeletal tuberculosis were present. Atypical changes and early stage TB changes (reported in literature under the term "MOLAT"; Maczel 2003), which are considered to be closely linked with pulmonary TB (Masson et al., 2015; Haas et al., 2000; Baker, 1999; Maczel, 2003; Pálfi, Bereczki, Ortner, & Dutour, 2012) like periostitis of the ventral rib surface, or hypervascularisation and resorptive lesions on vertebral bodies, were present.

Table 1. *Adult individuals with tuberculous (TB) lesions*

Sex	Age			Total
	Adultus I (20–29 years)	Adultus II (30–39 years)	Adultus (age not determined)	
Females with TB	2	1	1	4
Analyzed females in the categories of adults	40	8	4	52
TB (%)	5	12.50	25	7.69
Total of analyzed females				62
TB (%)				6.45
Males with TB	1	1	–	2
Analyzed males in the categories of adults	28	13	3	44
TB (%)	3.57	7.69	–	4.55
Total of analyzed males				54
TB (%)				3.70
Females + males with TB	3	2	1	6
Analyzed individuals in the categories of adults	73	23	9	105
TB (%)	4.11	8.70	11.11	5.71
Total of analyzed individuals other than subadults				129
TB (%)				4.65

The number of ribs affected by periostitis or periosteal deposits was unexpectedly high (in 11 out of 29 affected individuals), which might reflect the fact, that the pulmonary form of TB was quite common in this population. We suppose that there was a primary infection of the lungs with a locus either at the ventral or dorsal surface of the lung lobes and the pathogen might have proceeded onto the rib surface. Even today, the respiratory tract is the most common organ affected by a TB infection, from this initial site of infection, the pathogen is spread into the circulatory system (by hematogenous route) and can potentially affect any organ (Ortner & Putschar, 1985).

A typical pattern of spine involvement was present in 22 out of 29 tuberculosis cases. These lesions had the form of hypervascularised skeletal tissue, with or without minor resorptive lesions and without collapsed vertebral bodies, so they can be considered an early stage of tuberculosis of the vertebral column. The most frequently affected vertebrae were vertebrae of the thoracic spine (Th_7, Th_5, Th_8), which is according to literature (Aufderheide & Rodríguez-Martin, 1998; Nerlich & Lösch, 2009; Ortner, 2003) besides the lumbar spine, the most common place of infection.

Despite the presence of a tuberculosis infection in the medieval population of Devín-Castle, there were no cases with typical late skeletal TB changes significant for a developed infection, that is usually described in literature as Pott's disease (tuberculosis of the spine, with collapsed vertebral bodies and

Table 2. *Subadults with tuberculous (TB) lesions*

Sex	Age					Total
	circumnatale (5month intreuterine – 6 month postnatal)	Infans I (6 months – 6,9 years)	Infans II (7 years – 13,9 years)	Juvenis (14 years – 18 years)	Subadultus (not specified)	
Subadult females with TB	–	–	–	3	–	3
Analyzed subadult females	–	–	–	4	–	4
(%)	–	–	–	75	–	75
Total of subadult individuals with TB	–	6	4	11	2	23
(%)	–	0	0	27.27	0	13.04
Subadult males with TB	–	–	–	5	–	5
Analyzed subadult males	–	–	–	6	–	6
(%)	–	–	–	83.33	–	83.33
Total of subadult individuals with TB	–	6	4	11	2	23
(%)	–	0	0	45.45	0	21.74
Subadult individuals with TB (sex not determined)	–	6	4	3	2	15
Analyzed subadult individuals with not determined sex	11	36	12	8	4	71
(%)	0	16.67	33.33	37.50	50	21.13
Total of subadult individuals with TB	–	6	4	11	2	23
(%)	–	100	100	27.27	100	65.22
Total of subadult individuals with TB	–	6	4	11	2	23
Total of analysed subadult individuals	11	36	12	18	4	81
(%)	0	16.67	33.33	61.11	50	28.40

Table 3. *Localization of tuberculous (TB) lesions on the skeleton of adult individuals*

Sex	Bone			
	vertebrae	vertebrae and ribs	ribs	other
Females with TB	1	–	1	2
Males with TB	1	–	1	–
Total	2	–	2	2

Table 4. *Localization of tuberculous (TB) lesions on the skeleton of subadult individuals*

Age group	Bone				
	vertebrae	ribs	vertebrae + ribs	vertebrae + ribs + other	ribs + other
Infans I (6 months – 6,9 years)	3	1	1	1	–
Infans II (7 years – 13,9 years)	3	–	1	–	–
Juvenis (14 years – 18 years)	7	–	2	–	2
Subadultus (age not determined)	1	–	1	–	–
Total	14	1	5	1	2

a serious malformation of the spine), nor tuberculosis of the hip joint or other severe skeletal changes (Ortner & Putschar, 1985). This might be due to the fact that individuals affected by TB simply didn't survive long enough to reach a developed stage of skeletal tuberculosis – a study by Blondiaux, de Broucker, colard, Haque and Naji (2015) assumes that individuals who may have died from TB are also part of the sample of individuals who were in their study free of paleopathological tuberculosis and didn´t develop skeletal lesions. Paleopathological skeletal series typically exhibit frequencies of tuberculosis carriers between 1% and 5% (Roberts & Buikstra 2003). In case of a primary infection during childhood or adolescence where the disease maintained in the latent phase (dormant tuberculosis), some of these individuals may have died from active tuberculosis in a later stage of their life, without leaving traces of the disease (Blondiaux et al., 2015).

Regarding the most frequently affected age groups, it was obvious that the skeletal changes wouldn't appear in newborns or very old (senile) individuals after 60 years, which was confirmed by this analysis. Tuberculosis is a chronic condition with onset usually occurring in childhood, therefore individuals dying by young adulthood or who experienced a later onset may not have survived long enough and the infection might not have reached its skeletal form. Referring to this - in the skeletal collection from Devín-Castle (11th–12th century AD), the most frequently affected individuals were in their teens and early adulthood. In general, younger individuals are more susceptible also because of the greater degree of vascularity in juvenile bone, which has a large amount of hematopoietic marrow and associated vascularity. According to Ortner and Putschar (1985) ribs and vertebrae are especially susceptible at all ages.

During the last years several studies aimed on analyzing TBC in affected skeletal samples were published. Some of these studies were also dealing with nontypical osseous changes, like periostitis and hypervascularisation on thoracic and lumbar vertebrae or osteolytic changes of ribs – found in individuals from 17th century Hungary (Haas et al., 2000). Another study confirmed TBC in a 7th–8th century Avar individual from Hungary with macroscopically affected vertebrae and abnormal blood vessel impressions on the endocranium (Pálfi et al.,

2015). Rib changes, abnormal blood vessel impressions and hypervascularization of vertebrae were further reported to be found in a Late Neolithic population from Hungary (Masson et al., 2015). In most of the above described cases with early TB skeletal changes a molecular analysis confirmed the diagnosis of tuberculosis.

Although there is a lot of literature (Kelley & Micozzi, 1984; Matos & Santos, 2006; Molnár et al., 2005; Pálfi & Molnár, 2009; Roberts, Lucy, & Manchester, 1994; Santos & Roberts, 2006) reporting the connection of the above described skeletal lesions and a tuberculosis infection, it is important to note that these alterations are not always TB specific, therefore in all of the cases (especially in the group of subadult individuals) the diagnosis of tuberculosis is only presumed and has to be confirmed by a biomolecular analysis. The presence of mycobacterial DNA can be proved only by amplification and sequencing. For this purpose samples have been taken from all of the affected bones and are currently being sequenced, only then we can collect and establish exact paleoepidemiological data from this medieval population and compare them with other medieval populations.

Conclusion

A macroscopic analysis of the skeletal collection from the medieval site Devín-Castle revealed the presence of skeletal alterations highly suggestive of tuberculosis:

1. In this skeletal collection only lesions attributable to an early stage of skeletal tuberculosis were present, such as hypervascularization and circumferential pitting of vertebral bodies, periosteal depositions on the ventral rib surface and unspecific lesions likely to be linked with TB, such as periostitis of different bones.
2. The most frequently affected adults belonged to the age category Adultus I (3 individuals) and Adultus II (2 individuals). Regarding subadult individuals – there was a very high prevalence of TB affected juveniles (11 individuals) and children up to 7 years (6 cases). The high rate of infected children and juveniles in this population might be explained by the fact that young individuals are more susceptible to infection because of a greater degree of vascularity and more haematopoetic marrow in bone.
3. The most frequently affected bones were the vertebral column (in 2 out of 6 adults) and in 20 out of 23 affected subadults, with a typical location of the thoracic spine. There was also a high frequency of affected ribs – 2 out of 6 adults, 9 out of 23 affected subadults.

Súhrn

Príspevok približuje výsledky makroskopickej analýzy ranných štádií tuberkulózy kostí v stredovekej populácií z pohrebiska Devín-Hrad (11.–12. storočie n. l.). Tento súbor je prvým stredovekým súborom z územia Slovenska, ktorý bol cielene vyšetrený na prítomnosť paleopatologických lézií súvisiacich s tuberkulózou kostí, a tak poskytuje prvé dáta o výskyte tohto ochorenia na území Slovenska. Celkovo bolo zhodnotených 210 jedincov (129 dospelých a 81 nedospelých), u ktorých bola sledovaná prítomnosť lézií spôsobených tuberkulózou. Primárne bol sledovaný výskyt lézií typických pre skeletálnu tuberkulózu a ich lokalizáciu v miestach ktoré bývajú najčastejšie postihnuté (prítomnosť tuberkulov, ankylóza chrbtice, postihnutie bedrových kĺbov výrazným zápalovým procesom). Po tom, čo boli tieto typické prejavy vylúčené, bola pozornosť upriamená na počiatočné štádiá a s nimi spojené nešpecifické prejavy (často označované aj ako „MOLAT“). Paleopatologické lézie pravdepodobne súvisiace s tuberkulózou boli zistené u šiestich dospelých jedincov (štyroch žien a dvoch mužov) a u 23 nedospelých jedincov (28,40 %), čiže u jedincov do 18 rokov. Spomedzi lézií súvisiacich s TBC, boli najčastejšie zastúpené – hypervaskularizácia tiel stavcov (s alebo bez známok kostnej resorpcie) a periostitída ventrálneho povrchu tiel rebier, buď osamotené drobné periosteálne ložiská alebo rozsiahla periostitída obaľujúca celý povrch tela rebra. Prítomnosť týchto lézií sa dáva do súvislosti s pretrvávajúcou tuberkulóznou infekciu, ale nemožno ich považovať za TBC špecifické. Prítomnosť patogénu spôsobujúceho toto infekčné ochorenie *(Mycobacterium tuberculosis)* možno dokázať iba molekulárnou analýzou zo vzoriek postihnutého tkaniva jedincov. Preto budú tu prezentované výsledky makroskopickej analýzy verifikované a doplnené prostredníctvom sekvenácie v druhej fáze tohto výskumu.

Kľúčové slová: *infekčné ochorenia, periostitída, MOLAT, telá stavcov*

References

Acsádi, G., & Nemeskéri, J. (1970). *History of Human Life Span and Mortality.* Budapest: Akadémia Kiadó.

Aufderheide, A. C., & Rodríguez-Martin, C. (1998). *The Cambridge Encyclopedia of Human Paleopathology.* Cambridge University Press, Cambridge.

Baker, B. J. (1999). Early manifestation of tuberculosis in the skeleton. In Pálfy, G., Dutour, O., Deák, J., Hutás, I. (Eds.). *Tuberculosis* (pp. 301–307). Szeged and Budapest: TB Foundation and Golden Book Publisher.

Beňuš, R., & Masnicová, S. (2012). Antropologická, paleodemografická a paleopatologická analýza historickej populácie z Hradu Devín. *Slovenská archeológia, 60,* 1–38.

Blondiaux, J., de Broucker, A., Colard, T., Haque, A., & Naji, S. (2015). Tuberculosis and survival in past populations: A paleoepidemiological appraisal. *Tuberculosis, 95,* 93–100.

Cotran, R. S., Kumar, V., & Robbins, S. L. (1994). *Pathologic Basis of Disease.* Philadelphia. W. B. Saunders.

Coqueugniot, H., Dutailly, B., Desbarats, P., Boulestin, B., Pap, I., Szikossy, … Dutour, O. (2015). Three-dimensional imaging of past skeletal TB: From lesion to process. *Tuberculosis, 95,* 73–79.

Černý, M., & Komenda, S. (1980). Sexual Diagnosis by the Measurement of Humerus and Femur. Sbor. Prací Ped. Fak.Univ. Olomouc. *Biol. 2,* 147–167.

Ferembach, D., Schwidetzky, I., & Stloukal, M. (1979). Empfehlungen für die Alters- und Geschlechtsdiagnose am Skelett. *Homo, 30,* 1–32.

Haas, Ch., Zink, A., Molnár, E., Szeimies, U., Reischl, U., & Marcsik, A., … Nerlich, A. G. (2000). Molecular Evidence for Different Stages of Tuberculosis in Ancient Bone Samples from Hungary. *American Journal of Physical Anthropology, 113,* 293–304.

Hanihara, K., & Suzuki, T. (1978). Estimation of Age from the Pubic Symphysis by Means of Multiple Regression Analysis. A*merican Journal of Physical Anthropology, 48,* 233–240.

Hershkovitz, I., Greenwald, C. M., Latimer, B., Jellema, L. M., Wish-Baratz, S., & Eshed, V., … Rothschild, B. M. (2002). Serpens Endocrania Symmetrica (SES): A new term and a possible clue for identifying intrathoracic disease in skeletal populations. *American Journal of Physical Anthropology, 118,* 201– 216.

Iscan, M. Y., & Derrick, K. (1984). Determination of Sex from the Sacroiliac. A Visual Assessment Technique. *Florida Scien, 47,* 94–98.

Kelley, M. A., & Micozzi, M. S. (1984). Rib lesions in chronic pulmonary tuberculosis. *American Journal of Physical Anthropology, 56,* 381–386.

Loth, S. R., & Hennenberg, M. (1996). Mandibular Ramus Flexure. A New Morphologic Indicator of Sexual Dimorphism in the Human Skeleton. *American Journal of Physical Anthropology, 99,* 473–485.

Lovejoy, C. O. (1985). Dental Wear in the Libben Population. Its Pattern and Role in the Determination of Adult Skeletal Age at Death. *American Journal of Physical Anthropology, 68,* 47–56.

Lovejoy, C. O., Meindl, R. S., & Przybeck, T. R. (1985). Chronological Metamorphosis of the Auricular Surface of Illium. A New Method for the Determination of Adult Skeletal Age at Death. *American Journal of Physical Anthropology, 68,* 15–28.

Maczel, M. (2003). On the Traces of Tuberculosis. *Diagnostic criteria of tuberculosis affection of the human skeleton and their application in Hungarian and French anthropological series.* PhD Thesis. University of Szeged – University of La Méditerranée.

Masson, M., Bereczki, Z., Molnár, E., Donoghue, H., Minnikin, D. E., & Lee, O., … Pálfi, G. (2015). 7000 year-old tuberculosis cases from Hungary – Osteological and biomolecular evidence. *Tuberculosis, 95,* 13–17.

Matos, V. & Santos, A. L. (2006). On the trail of pulmonary tuberculosis based on rib lesions: results from the Human Identified Skeletal Collection from the Museum Bocage (Lisbon, Portugal). *American Journal of Physical Anthropology, 130,* 190–200.

Meindl, R. S., & Lovejoy, C. O. (1985). Ectocranial Suture Closure: A Revised Method for the Determination of Skeletal Age at Death and Blind Tests of ist Accuracy. *American Journal of Physical Anthropology, 58,* 57–66.

Nerlich, A. G., & Lösch, S. (2009). Paleopathology of Human Tuberculosis and the Potential Role of Climate. *Interdisciplinary Perspectives on Infectious Diseases 2009,* Article ID 437187, 9 pages, 2009. doi: 10.1155/2009/437187.

Molnár, E., Donoghue, H. D., Lee, O., Wu, H., Besra, G., & Minnikin, D., … Pálfi, G. (2015). Morphological and biomolecular evidence for tuberculosis in 8th century AD skeletons from Bélmegyer-Csömöki domb, Hungary. *Tuberculosis, 95,* 35–41.

Ortner, D. J. (2003). *Identification of pathological conditions in human skeletal remains.* Academic Press, San Diego.

Ortner, D. J., & Putschar, W. G. J. (1985). *Identification of Pathological Conditions in Human Skeletal Remains.* Washington and London: Smithsonian Institution Press.

Pálfi, G., Bereczki, Z., Ortner, D. J. & Dutour, O. (2012). Juvenile cases of skeletal tuberculosis from the Terry anatomical collection (Smithsonian Institution. Washington DC, USA). *Acta Biol Szeged, 56,* 1–12.

Pálfi, G., Maixner, F., Maczel, M., Molnár, E., Pósa, A., Kristóf, L. A., … Zink, A. (2015). Unusual spinal tuberculosis in an Avar Age skeleton (Csóngrád-Felgyö, Ürmöstanya, Hungary): A morphological and biomolecular study. *Tuberculosis, 95,* 29–34.

Pálfi, G. & Molnár, E. (2009). The paleopathology of specific infectious diseases from Southeast Hungary: a brief overview. *Acta Biologica Szegediensis, 53,* 111–116.

Phenice, T. W. (1969). A Newly Developed Visual of Sexing the Os Pubis. *American Journal of Physical Anthropology, 30,* 297–301.

Plachá, V., & Hlavicová, J. (1987). *Nálezová správa za roky 1980–1987. Sektor 15* (Mestské múzeum v Bratislave). Bratislava 1987. Unpublished.

Raff, J., Cook, D. C., & Kaestle, F. (2006). Tuberculosis in the New World: a study of ribs from the Schild Mississippian population, West-Central Illinois. *Memórias do Instituto Oswaldo Cruz, 101,* 25–27.

Roberts, Ch., Lucy, D. & Manchester, K. (1994). Inflammatory lesions of ribs: an analysis of the Terry Collection. American *Journal of Physical Anthropology, 95,* 169–182.

Roberts, C. A. & Buikstra, J. E. (2003). *The bioarchaeology of tuberculosis. A global view on a reemerging disease.* Florida: University Press of Florida.

Santos, A. L., & Roberts, Ch. (2006). Anatomy of a serial killer: differential diagnosis of tuberculosis based on rib lesions of adult individuals from the Coimbra Identified Skeletal Collection, Portugal. A*merican Journal of Physical Anthropology, 130,* 38-49.

Ubelaker, D. H. (1978). *Human skeletal remains. Excavation, analysis, interpretation.* Washington.

Zink, A. R., Molnár, E., Motamedi, N., Pálfy, G., Marcsik, A., & Nerlich, A. G. (2007). Molecular history of tuberculosis from ancient mummies and skeletons. *International Journal of Osteoarchaeology, 17,* 380-391.

Kyselicová, K., Šebest, L., Beňuš, R., Bognár, C. & Dörnhöferová, M. (2016). Anhtropological evaluation of early skeletal tuberculosis in the medieval population of Devín-Castle (11th–12th century ad, Slovakia). *Česká antropologie, 66*(2), 20–25.