Evidence of tuberculosis among children in medieval (13th–15th century) Wrocław: A case study of hip joint tuberculosis in a juvenile skeleton excavated from the crypt of the St. Elizabeth church

Agata Izabela Cieślik

Ludwik Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, Department of Anthropology in Wrocław, Poland

ABSTRACT: Paleopathological examinations of the skeletal remains of people who died centuries ago are material source of knowledge about health and diseases in the past. In this article, a case of skeletal tuberculosis from historical (13th–15th c.) Wrocław, Poland has been presented. The juvenile skeleton excavated from grave No 93, from the crypt located under the church of St. Elizabeth, displayed pathological lesions within the right hip joint resulting from a chronic inflammation, which might have been assigned to signs typical for skeletal tuberculosis. The results of macroscopic and radiological analyses appeared to be consistent, and allowed to determine a reliable diagnosis of this paleopathological case.

KEY WORDS: Mycobacterium tuberculosis, hip joint tuberculosis, juvenile tuberculosis, paleopathology

Introduction

Tuberculosis is a disease described in paleopathological literature by many authors in a variety of ways. Some researchers focus on the shared history of humans and Mycobacterium, proving that tuberculosis has accompanied the humans for thousands of years (e.g. Donoghue et al. 2004; Hershkovitz et al. 2008). There are also many works on the paleopathological and molecular methodology of research on tuberculosis, which enable us to have a better understanding of the origin, pathways and demographic effects of the disease (e.g. Donoghue 2011; Roberts and Buikstra 2003). There are also descriptions of individual cases, which provide us with more efficient ways of detecting different forms of skeletal tuberculosis manifestation in archeological material (e.g. Bianucci et al. 2012; Pálfi and Molnár 2009; Holloway et al. 2011).
The main goal of this paper is to present a probable case of the extrapulmonary skeletal tuberculosis which affected the right hip joint of a young individual, whose skeleton was excavated from a medieval grave located in the crypt under the St. Elizabeth church in Wrocław.

Currently, skeletal TB is seen in 1–2% of children (Cruz and Starke 2007). The development of the disease is caused by the movement of *Mycobacteria* in the blood stream from the initial focus, located usually in the lungs, lymph nodes or in the gastrointestinal tract to bones and joints. The result of the *Mycobacteria* spreading in bony tissue are small pathological lesions which tend to be located in the places characterized by the greatest blood flow and the greatest scarcity of phagocytic cells (Hopwell and Bloom 1994; Panek and Chyczewska 2001). A typical and most frequent in archaeological material form of the disease is spinal tuberculosis (Pott’s disease) of the thoracic and lumbar vertebrae. Usually, only between one and four vertebrae are involved and neural arches are spared. Vertebral bodies are destroyed, potentially leading to angular kyphosis and fusion of vertebrae (Holloway et al. 2011) joints, hands, feet, which leads to severe disability.

The bodies of the thoracic vertebrae are the most common site of skeletal tuberculosis, mainly due to good blood supply (Malawski 2003) and large mass of the red marrow in trabecular bone that can be invaded by the bacilli. For the same reason in children, as in adults, the most frequently affected parts of the skeleton are epiphyseal parts of the long bones and large joints, such as the hip and knee. In general, tuberculosis may affect every element of the skeleton but in some areas, for example the metacar-...
A rare paleopathological case of juvenile hip joint tuberculosis

surface of the cranial bones, which were given the name “serpentine engravings” (serpes endocrania symmetrica, SES). One of the diseases that these signs could be linked to is tuberculosis, although it is not a pathognomonic trait of the disease. However, it should be noted that there is an interaction between the incidence of SES with another pathological condition – the hypertrophic osteoarthropathy of long bones. (Lovejoy et al. 1977; Mensforth et al. 1978; Hershkovitz et al. 2002; Hershkovitz et al. 2008; Assis et al. 2011). All the factors that hinder the differentiation between the tuberculosis and other diseases may make the diagnosis of the skeletal TB based solely on the results of nonspecific macroscopic observations misleading. Thus it should be supported by other diagnostic methods, especially X-ray analysis and molecular techniques.

Material and methods

The archeological site at the St. Elizabeth church in Wroclaw

The subject of the research – a juvenile skeleton from burial No 93 with pathological lesions – was unearthed from one of the brick lined tombs in the crypt localized under the church of St. Elizabeth in Wroclaw. The temple was built in the 30s of the 13th century and served the residents of the western part of the city. It was a typical middle-class church, generously donated to by the rich patricians (Młynarska–Kaletynowa 1986; Wojcieszak 2012), so the residents of the city could count on burial within the walls of the parish church, which was previously reserved only for kings and priests. Within the walls of this late-Romanesque church, 61 inhumations were localized in the presbytery and in the eastern part of the nave. The location of the burials in the heart of the temple may indicate the high socio-economic status of the people who were buried here. Under the presbytery, four brick tombs were also found, including one double tomb, containing a total of 13 burials (Wojcieszak 2012).

The skeleton unearthed from grave No 93

The skeleton is partially complete: the only preserved part of the skull is the right temporal bone and the postcranial elements are incomplete. The vertebrae are also incomplete – only 5 cervical, 7 thoracic, 5 lumbar and 3 sacral are present but in a good state of preservation. Components of the chest, in particular the ribs are preserved in fragments. Shoulder girdle and upper limbs: only a fragment of the right clavicle, right humerus (with damaged distal epiphysis), right radius and left humerus, ulna and radius preserved. From the skeleton of the right hand, only the hamate and capitate bone are present and elements of the left hand skeleton are missing. Pelvic girdle and lower limbs: hip, pubic and sciatic bones are preserved on both sides. Both femora (right with damaged distal epiphysis and left – complete), tibiae (right – complete and left – damaged proximal epiphysis) are also present. The skeleton of the right and left tarsus is complete; also the bones of the right metatarsus are present while most of the phalanges and bones of the left metatarsus are fragmentary.

Skeletal material explored from burial No 93 was cleaned from soil and segregated. Due to the incompleteness of the skeleton and young age of the individual, it was impossible to determine the
biological sex with certainty. Estimation of the age at death was also difficult, because teeth of the individual were not preserved, therefore, age could be determined only by an assessment of the degree of morphological development of the skeleton, based on the diaphyseal length measurements of the well-preserved long bones (Gindhart 1973; Maresh 1970; Scheuer et al. 2009). According to the metric features, the age at death of this juvenile can be estimated at approximately 10–15 years (Table 1).

**Table 1. Diaphyseal measurements of the well preserved long bones and estimated age at death of the individual**

<table>
<thead>
<tr>
<th>Bone measured</th>
<th>Value of the metric feature (mm)</th>
<th>Estimated age at death (in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ulna</td>
<td>258</td>
<td>14-15 (Maresh 1970 after Scheuer and Black 2009)</td>
</tr>
<tr>
<td>Left radius</td>
<td>186</td>
<td>10 (Gindhart 1973 after Scheuer and Black 2009)</td>
</tr>
<tr>
<td>Right femur</td>
<td>377</td>
<td>11-12 (Maresh 1970 after Scheuer and Black 2009)</td>
</tr>
<tr>
<td>Right tibia</td>
<td>340</td>
<td>11 (Maresh 1970 after Scheuer and Black 2009)</td>
</tr>
</tbody>
</table>

Paleopathological evaluation

Pathological lesions were recorded during careful macroscopic examination and radiographic analysis. Attention was paid to the localization of the lesion in the skeleton and bony structures that were affected by the inflammatory process. Morphological features of the lesion were assessed according to the descriptions given by Aufderheide and Rodriguez-Martin (1998), Ortner (2003), Ortner (2008). In general, skeletal TB is characterized by the tendency to extensive destruction of bony structures composed primarily of trabecular bone, thus various types of bony defects and erosions that result from the accumulation of tuberculous granulomas are typical in the macroscopic picture. X-rays analysis gave an information regarding intensity of bone reactivity within the lesion, as well as the presence of sequestra and the type of bone remodeling resulting from the ongoing inflammatory process.

**Results**

**Macroscopic and radiological picture of the disease**

A single, large lesion was visible in the skeleton, in the proximal extremity of the right femur, which was distorted due to the pathological process (Fig. 1–2). The lesion in the form of an extensive erosion was located on the lower surface of the femoral neck (Fig. 3). As a result of ongoing inflammation, the size of the whole superior epiphysis was increased (it looks like it was “swollen”) relative to the proximal extremity of the left femur, in which there was no visible signs of pathological lesions. The outline of the head was enlarged and distorted, and in the trochanter minor region massive bone formation of hypertrophic tissue could be seen. Signs of the disease were also apparent inside the acetabulum, on the inner surface of the ischium (Fig. 4), which indicates that the inflammatory process was actively spreading to other structures of the hip joint. Pathological lesions were located within the joint capsule, which must have become stretched due to the inflammatory process and the whole joint was probably swollen and painful.

The radiological picture of the disease can be considered as a typical example of
A rare paleopathological case of juvenile hip joint tuberculosis

Fig. 1. Pathologically changed proximal metaphysis of the right femur in comparison to the left femur - without any visible signs of infection (anterior aspect)

Fig. 2. Comparison between pathologically changed proximal metaphysis of the right femur and free from lesions proximal epiphysis of the left femur (posterior aspect)
synovial tuberculosis with extensive erosions at the point of synovium attachment to the femoral neck (Fig. 5). During the individual’s life, the gap of the hip joint was probably narrowed and the femoral head could have been overgrown (coxa magna) (Borejko and Dziak 1979).

Inflammatory changes in the hip joint were clearly visible, but they were not the only skeletal signs of infection. In the thoracic vertebrae, evidence of hypervascularization, which is also connected to skeletal TB (Pálfi et al. 2012) could also be observed.

**Discussion**

Tuberculosis of bones and large joints (hip, knee) in paleopathological research is observed much less frequently than tuberculosis of the spine, moreover, this type of pathological changes are more often found in the skeletons of adults, for instance described by Jankauskas (1998), Molnár et al. (1998), Marcsik et al. (2006). In juvenile skeletons, this form of tuberculosis is observed very rarely due to the difficulties associated with the specificity of the immature skeleton, as well as diagnostic problems. Probably for these reasons, the common descriptions of juvenile skeletal TB refer to inflammation of the vertebrae, which is the most frequently occurring in archaeological material form of the disease (eg. Matos 2011; Lewis 2011).
Tuberculosis of the hip joint usually starts with the initial focus formation, which is situated in the roof of the acetabulum, femoral head or neck, or (less frequently) in the synovial membrane. In 10% of all cases, infection is restricted to the bone and takes the form of periarticular foci or breaks off the joint with periarticular abscesses and fistulae formation. In children’s periarticular tuberculosis, swelling of the infected epiphysis may also be observed (Malawski 2003). In the first stage of infection, the primary focus forms in the bony tissue beneath the surface of the cartilage, then it expands to the articular cartilage and synovial membrane covering the whole joint. The pathological process, which leads to bone and articular structure degradation, involves formation of granulation tissue with foci of necrosis and caseation. They become fluid and break off from the synovial cavity with the formation of periarticular abscesses (Borejko and Dziak 1979; Hopwell and Bloom 1994).

The signs of tuberculous arthritis of the hip joint seems to be clearly identifiable in skeleton No 93, described here. In this case, it is most probable that the bacteria reached the joint cavity directly from the initial focus located in the femoral neck. Tuberculous arthritis is the second most common manifestation of tuberculosis in children (after the tuberculous spondylitis (spondylitis), and before tuberculous osteomyelitis. In the course of the disease, significant damage of the skeletal structures is usually inevitable and visible even in the macerated bony material, but due to the ambiguous morphological appearance of inflammatory diseases in historical skeletal material, initial diagnosis should be compared to paleopathological pictures of the diseases that leave signs in bones similar to skeletal tuberculosis.

**Differential diagnosis**

Taking into consideration the form and radiological signs of the disease observed in juvenile skeleton excavated from grave No 93, skeletal tuberculosis seems to be possible cause of hip joint pathology, although differential diagnosis is pivotal in paleopathology and needs to be performed. In Table No 2 three common inflammatory diseases that may cause lesions similar to skeletal TB lesions in the hip joint have been compared in terms of lesion localizations, skeletal manifestations and radiological pictures.

From the data presented in the Table No 2 it can be concluded that mainly due to the good conditions of blood supply, localizations of all types of infectious inflammatory processes within the skeleton are similar, however, the course of infection is dependent on the etiological factor and its impact on bony tissue.

Sarkar and coauthors (2016) demonstrated that some strains of *M. tuberculosis* may have inhibitory effects on osteoblasts, so it can be concluded that reactive changes observed in tuberculous arthritis may be poorly expressed, while *T. pallidum* infections produce strong bony reactions. In the examined case, well demarcated focus of osteolysis, as well as intense bone remodeling within the entire proximal epiphysis can be observed, which can be taken as a typical sign of chronic infection. Taking into consideration this observation, it is possible to exclude *T. pallidum* infection as the most probable cause of pathology within the hip joint.

The specific disease that seems to be the most similar to skeletal TB in terms
of paleopathological and radiological observations is brucellosis, but in this case the localization of the pathological process would be rather unusual, as more advanced changes in the vertebrae should be expected, whereas in the examined case only traces of hypervascularization within the vertebral bodies were noted.

In paleopathological differential diagnosis, pyogenic arthritis of the hip joint should be also taken into consideration as a possible cause of the infection. It usually is monoarthritic and has radiological features simila to skeletal TB infection. However, in examined case any sequestra within pathologically changed superior epiphysis of the femur, which would be typical in chronic inflammatory process of the hip joint could be observed. Moreover, in late-stage TB of the large peripheral joints, besides periarticular osteopenia, Phemister’s triad signs (peripheral osseous erosions, articular destruction with narrowing of the joint and juxta-articular osteoporosis) can be found (Garcia-Arias et al. 2012), which seems to be consistent with the macroscopic picture of the lesions observed in skeleton No 93.

In the differential diagnosis of tuberculosis of the hip joint also other diseases, e.g. sarcoidosis, rheumatoid arthritis, Sudeck’s disease, some types of neoplasms (Hopwell and Bloom, 1994)
should be taken into consideration as a probable cause but due to the young age at death of the examined individual and quite clear macroscopic picture of the disease, they seem to be less probable.

**Risk factors and socio-economic background of tuberculosis**

As a separate issue, there remains the problem of the background of the TB spreading in the medieval Wrocław population. Young children (under 5th year of life) are very prone to pulmonary and other forms of tuberculosis (Maltezou et al. 2000; Marais et al. 2004; Cruz and Starke 2007; Newton et al. 2008) due to the immaturity of the immune system. As written above, the form of tuberculosis (intra or extrapulmonary and, in the case of skeletal TB, one or multifocal locations) is strongly related to the immune status. Jones et al. (1993) stated that extrapulmonary TB involvement tends to increase in frequency if immune function is lowered. Tuberculosis of the hip joint observed in the skeleton No 93 could suggest that immune status of this individual was low.

There are plenty of environmental conditions which strongly affect the immune system, and one of them is malnutrition, which is strongly linked to infectious diseases. Malnutrition can make a person more susceptible to infection, and infection also contributes to malnutrition, which causes a vicious cycle. An inadequate dietary intake leads to weight loss, lowered immunity, mucosal damage, invasion by pathogens, and impaired growth and development in children (Katona and Katona-Apte, 2008).

Malnutrition does not have to be severe—just a shortage of certain substances, especially protein can result in significant immunosuppression. Apart from deficiencies in single nutrients, such as vitamins, fatty acids, amino acids, iron, and trace elements, undernourishment based on PEM (protein energy malnutrition) greatly increases susceptibility to major human infectious diseases in low-income countries, particularly in children (Moret and Schmidt-Hempel 2000; Scrimshaw and SanGiovanni 1997; Ambrus and Ambrus 2004; Schaible and Kaufmann 2007). The main reason is that malnutrition causes impairment of both acquired immunity and innate host defense mechanisms.

In TB infection, the interaction between macrophage and *Mycobacterium tuberculosis* plays a main role. *Mycobacterium* is an intracellular microorganism, so it has to penetrate inside the macrophage through one of the numerous trans-membrane receptors which enable internalization of the bacteria (Mason and Ali 2004). Macrophage is, in fact, the first line of defense against intracellular microbial pathogens. It has been proved (Rivadeneira et al. 2001) on a cellular level that malnutrition can induce macrophage apoptosis, which is crucial in immuno-resistance to infectious diseases, particularly in the mechanism of TB infection.

Skeleton No 93 was unearthed in the crypt located under the St. Elizabeth Church in Wrocław and this burial site indicates that this individual could belong to a wealthy middle class. None of visible physiological stress markers (*cribra orbitalia, enamel hypoplasia*) could have been observed on preserved bones in the macroscopic examination, mainly due to the bad state of preservation of the skeletal material, but it does not mean that the child did not suffer from any nutritional deficiencies.
Another factor contributing to infection risk, could have been life in the crowded big city environment, which is inextricably linked to continuous exposure to infectious agents. A child living among adults suffering from active pulmonary tuberculosis, might have become infected, even though the overall health and nutrition were satisfactory.

A combination of different environmental conditions, especially poverty, overcrowding and malnutrition (Millet et al. 2013) that have a negative influence on human health is the perfect background for the development and spread of infectious diseases.

Conclusion

In a skeleton of a juvenile who died centuries ago, traces of the disease, which was (and still is a serious medical problem) were revealed. In a pre-antibiotic era, the only protection against the development of tuberculosis was an efficient immune system and its functioning was dependent on many factors affecting the immunological status of the individuals. In the past, tuberculosis was thought to be a disease of the poor and the highest morbidity was among children and young adults, which reflected the high prevalence of the disease in historical populations. This situation is similar to the pattern of the incidence of tuberculosis in the societies of developing countries, which indicates that there is significant association between socio-economic status and the risk of developing tuberculosis (Millet et al. 2013). However, in medieval times, the disease was not restricted only to the poor strata of the community and, as shown by the example of the young individual, who was buried in the crypt under the church of St. Elizabeth in Wroclaw, even wealthy patricians of Wroclaw were under the risk of infection caused by *Mycobacterium tuberculosis*.

Acknowledgments

I am grateful to Professor Maciej Henneberg from the University of Adelaide (Australia) for the text corrections and interesting discussion regarding TB occurrence in the past. I would also like to thank the anonymous Reviewers for their careful reading of the manuscript and insightful comments and suggestions.

Corresponding author

Agata Izabela Cieślik, Ludwik Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, Department of Anthropology in Wroclaw, 75 Podwale St, 50-445 Wroclaw, Poland e-mail address: atagace@gmail.com

References


Assis S, Santos AL, Roberts CA. 2011. Evidence of hypertrophic osteoarthropathy in individuals from the Coimbra Skele-


Jankauskas R. 1998. History of human tuberculosis in Lithuania: possibilities and


