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A Case of Extensive Inflammatory Changes (Osteomyelitis) in an Infant's Skeleton from the Medieval Burial Ground (11th–12th c) in Wawrzeńczyce (Near Krakow)

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ABSTRACT

The aim of this study was to diagnose and describe extensive inflammatory changes in a child's skeleton from Wawrzeńczyce, (the medieval period). The aim of the analysis was to determine the nature of the inflammatory changes and their etiology by means of macroscopic techniques as well as X-ray analysis. The tests revealed that the individual suffered from a hematogenous multifocal osteitis. This condition might have been a result of an acute or sub-acute osteitis, and the untreated form of osteomyelitis might have contributed to the infection of the entire developing organism, leading to death.

Key words: *bone infections, osteomyelitis, Polish medieval population, enamel hypoplasia*

Introduction

Inflammatory diseases, both specific and non-specific, are a category of conditions that can be observed in human bones[1,2]. The former occur as a result of the organism being infected with a pathogen. The latter occur when the organism is in contact with microorganisms such as bacteria, viruses, parasites, protozoa or fungi[3,4,5].

Osteomyelitis belongs to the category of specific inflammatory diseases[6,7]. The name derives from the combination of three Greek morphemes: »osteo-«, »myelo-«, »-itis«, which mean »bone«, »bone marrow« and »inflammation« respectively. The term coined by combining these words means an infection of the bone and the bone marrow. The inflammatory condition which occurs in the organism attacks mainly the periosteum, the compact tissue and the cancellous tissue as well as the bone marrow, tendons and cartilage. Untreated osteomyelitis may cause serious complications leading to limb necrosis or even death as a result of a systemic infection (sepsis).

Inflammation causes the bacteria of the species *Staphylococus aureus*[8]. The receptors located on their surface enable them to cling to and penetrate into the bone tissue and cartilage[5,9,10]. There are also other groups of bacteria which are responsible for causing osteomyelitis, but to a lesser extent, including *Streptococcus* (mainly *Haemophilus influenza*), *Pseudomonas* – which mainly causes of inflammation in foot injury, *Mycobacterium tuberculosis* – which lead to osteomyelitic changes within the spine – the so- called Pott's disease. Apart from these bacteria there are also two species of fungi such as *Blastomyces dermatitidis* and *Coccidioides immitis* which can be the cause of inflammation in the organism[11]. Irrespective of the type of pathogen, it attacks the organism in a twofold way[12]. One route of infection is open wounds, fractures or injuries which cause a disruption of tissue continuity. In this case we deal with a primary inflammation. The inflammation of this type is introduced into the organism exogenously. The other type of osteomyelitis is blood-derived. Pathogens permeate into the bone tissue through blood vessels from other infected areas (boils, emphysemas, skin lesions, pneumonia) or from encircling its soft

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tissues. This phenomenon is particularly observed in elderly people or patients after radiotherapy, in case of a neoplasm, a diabetic abscess or with people suffering from stricture of blood vessels which nourish the bone.

Material and Methods

A series of complex anthropological tests were performed on a child skeleton with noticeable inflammatory changes. The skeleton comes from a vast mediaeval burial ground (11–12th c.) located at the archaeological excavation site no. 32 in Wawrzeńczyce, in southern Poland near Cracow[13], Figure 1.

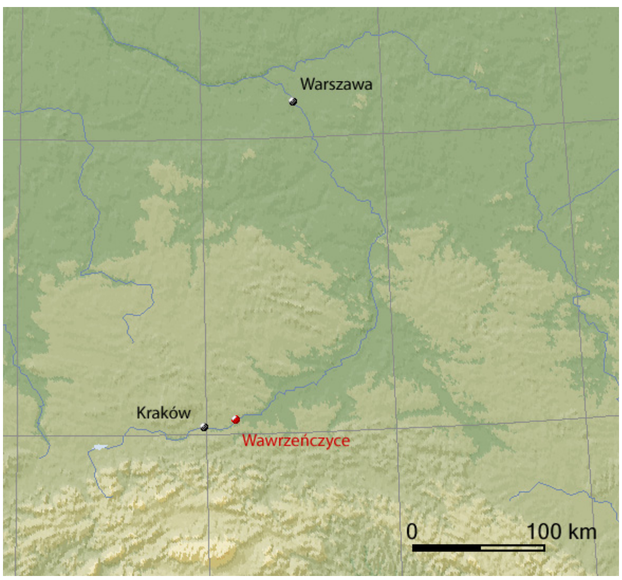

Fig. 1. Location of Wawrzeńczyce 32 site.

Medieval Wawrzeńczyce was a rural settlement. Farming, cattle- and horse-raising were the settler's basic activities. At this time, Wawrzeńczyce was partly under the ownership of Krakow bishops. In 1223 in Wawrzeńczyce, Iwo Odrowąż erected the brick church of St. Mary Magdalene, which has survived to this day. Wawrzeńczyce was connected with Krakow and Sandomierz by a public route, the remains of which were presumably uncovered during excavation works.

In spring 2004, a considerable number of human bones were unearthed during field work. The Institute of Archaeology and Ethnology of the Polish Academy of Sciences in Krakow was commissioned by the Regional Conservation Officer in Krakow to implement a rescue project, the outcome of which led to the discovery of Neolithic settlement pits and a medieval skeleton burial ground. The burial ground was dated based on unearthed artefacts in the form of Slavic female burial decorations and coins identical to those used between the 10th and 12th century[14]. An area of about 7 acres was explored between 2004 and 2010[15].

There are 134 skeletons in varied state of preservation including numerous single bones (not associated with any of them) which have been examined. 28.4% of all inhumations were child graves (0–15 years old), out of which 13.2% had died before the age of 3. Macroscopic analysis of the skeleton allowed the detection of the so-called physiological stress indicators in the form of *cribra orbitalia* and enamel hypoplasia in nine individuals, and carious defects on the occlusal surfaces of molars in two other individuals (Table 1).

TABLE 1
CHANGES REPORTED IN CHILDREN FROM THE MEDIEVAL BURIAL GROUND IN WAWRZEŃCZYCE.

Grave no.	Age of individuals	Pathological changes			
		Inflammatory changes	Enamel hypoplasia	*Cribra orbitalia*	Caries
111	2–3 y				M^1
305	3.5–4 y		+		
68	5 y			+	
329	7–8.5 y		+		
143	7–15 y		+		
57	8–9 y			+	
323	8.5–9 y		+		
21	9 y			+	
157	10–12 y				M_1
312*	11–14 y	+	+		
482	13–14 y		+	+	

* the individual being the subject of the present study

Grave 312, in which a child's skeleton subjected to this analysis was found, was located in the north-western section of the row-layout burial ground, with spatial arrangement typical of the medieval period and grave orientation along the northwest-southwest axis.

The remains in Grave 312 were laid in a straight supine position, with upper limbs along the torso and hands presumably resting on the pelvis. Under the pelvis a small iron knife was found. According to archaeological criteria of sex determination, this may suggest a male type of grave furnishing. Judging by the coins found in graves forming the arrangement in which the skeleton was found, it can be dated back to the early 11th century.

The skeleton of a child which is the subject of this analysis was well- and completely preserved. Epiphyseal unions were not present. The cranium sustained secondary mechanical damaged *post mortem*, but facial skeleton has survived; almost all teeth are also present in the alveoli of the complete maxilla and the mandible (Table 2).

The age at death of individual under examination was determined according to standard methods commonly ap-

TABLE 2
DENTITION OF THE INDIVIDUAL FROM GRAVE 312.

Right side								Left side							
M^3					C^*					C^*					M^3
	M^2	M^1	P^2	P^1							P1		M^1	M^2	
	M_2	M_1		M_1	C	I_2	I_1	I_1		C	M_1	M_2	M_1	M_2	
M_3^*			P_2	P_1^*							P_1^*	P_2^*			M_3^*

*tooth buds

plied in anthropology[16–19]. Dental age along with developmental age was taken into account. The former was determined based on the order of tooth eruption, whereas the latter with reference to the degree of ossification of particular parts of the skeleton. After individual measurements of the length of the diaphysis in the left side of the body, unaffected by pathological changes, the age at death was estimated in reference to standards developed for isochronous Carpathian populations and infant skeleton from Poland population[20–22]. An attempt was made to determine the sex of the individual by means of 3 complementary methods based on morphological characteristics of the mandible[23–25].

Results

Judging by the progress of the deciduous dentition replacement, the individual's age at death can be estimated at 11 to 14 years. The scope of age between 11 and 14 results from an altered (disrupted?) permanent tooth eruption sequence. In mandible, permanent molars M1 (A_c) and M2 (R3/4) are fully erupted, although at the same time deciduous teeth m_1 and m_2 on the left and m_1 on the right are present, with premolar buds still in the alveolar process. This category of teeth in contemporary humans erupts earlier than M2[26,27]. The P_2 crown of the right side of the mandible has reached the attrition line and is fully developed. Maxillary premolars have fully developed crowns, and their roots are in formation (R1/2).

Skeletal age determined on the basis of measurements of upper left and lower left limbs' long bone shafts unaffected by the pathological process (Table 3) is 13–13.5 years. This value approaches the upper limit of the age established according to the phase of dentition replacement process.

TABLE 3
LONG BONE SHAFT MEASUREMENTS WITH ESTIMATED SKELETAL AGE

Type of bone	Right side (r), [mm]	Left side (l), [mm]	Difference between r and l [mm]	Age
Humerus	249	235	14	13.5 y
Radius	–	170	–	13 y
Ulna	190	186	4	13 y
Femur	328	319	9	13 y
Tibia	279	259	20	13 y
Fibula	257	253	4	13.5 y

The comparison of the dimensions of long bones reveals augmented values for bones in which pathological changes were reported. Bone elongation in this case could be a result of metaphyseal plate stimulation[28]. The greatest differences are noticeable in the tibial shaft.

Sex determination for minors based on morphological characteristics of the skeleton is very problematic due to the lack of clear dimorphism indicators, since there are few characteristics (e.g. of the mandible) the development of which differs for either sex. Judging by the region of the individual's mentum, which is angular in outline, with a prominent area of the *gonion*, as well as the shape of the dental arch, we may expect that the buried individual was a boy[23–25].

Morphological changes on the surfaces of the right humerus, right ulna and particular intensification of changes on the right tibia were observed macroscopically. The lower part of the diaphysis of the humerus, the upper part of the diaphysis of the radius as well as the proximal epiphysis of and upper part of the diaphysis of the ulna (the area of the elbow joint) demonstrated an untypical development of cortical bone when compared to the left-hand side (Figure 2).

The diaphysis of the right tibia demonstrates a protuberance along its entire length (Figure 3). An arch-like lateral curve of the diaphysis is observed. There is a deep bone defect of the bone tissue on the front medial surface of the diaphysis along its long axis. On the rear surface of the diaphysis there is an irregularly developed area of the soleus attachment. Within the proximal epiphysis there is a fistula extending towards the inside of the diaphysis (Figure 4).

Macroscopic observations suggest that the lesions were caused by bone inflammation known as osteomyelitis. Radiological tests were performed to further analyze the reported lesions. Images of the area within the right ulna did not reveal any structural changes that could indicate a disease. On the right ulna there is a slight extension of the diaphyseal outer edges and a thickened cortical layer (Figure 5). The bone does not show any characteristics of osteolytic destruction.

The radiological image of the right tibia displays evident massive plaque-like reactions joined with the cortical layer[29]. Periosteal structure is rebuilt towards markedly intensified osteosclerosis with numerous radiolucent pseudo-cyst spots. The arch-like section of the diaphysis point-

Fig. 2. Pathological changes in the metaphyseal part of the right ulnar bone. Next to it, a left ulnar bone without lesions.

Fig. 3. Extensive inflammatory changes with an exposed fistula along the diaphysis of the right tibia. A sound left tibia next to it shown for reference.

ed towards the fibular side has extended outer edges with irregular outer contours (Figure 6). There are bone defects both on the outer edge of the bone and within the proximal section of the diaphyseal-metaphyseal area where they

Fig. 4. An exposed fistula within the proximal epiphysis of the right tibia (inferior view).

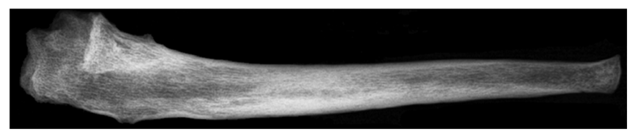

Fig. 5. A radiological image of an altered metaphyseal section of the right ulna.

Fig. 6. A radiological image of an altered diaphysis and metaphyseal part of the right tibia.

run parallel to the long axis of the diaphysis – the so-called involucra, which are the remains of the excreted cortical sequestra. Further down the diaphysis there are radiolucent spots – the results of a purulent fistula. The proximal epiphysis shows characteristics of sclerosis as well as of microfocal osteolysis with numerous lacunas located centrally within both the intercondylar outgrowth and the lateral condyle of the tibia. Within the two osseous lacunae in the medial section of the epiphysis there are sequestra with a different degree of sequence.

This individual has also been diagnosed with enamel hypoplasia in the form of strongly marked transversal grooves. These prove to be the result of disturbance of mineral balance in the moment of enamel formation. Hypoplastic lesions were exposed on C and M1 of the both sides of maxilla and mandible, and also on P^1 of the right and left side of maxilla (Figure 7). The age at which the first hypoplastic line C emerged was established a 6 months, and the last one (P^1) between 4.5 and 5 years acc. to Reid and Dean[30]. We may thus suppose that in this period the individual's body was exposed to stress-inducing factors which had an adverse effect on his biological condition.

Fig. 7. A deep hypoplastic line observable on front molars (mandible).

Discussion

The number of child inhumations at the burial ground in Wawrzeńczyce suggests that the population inhabiting this area in the Middle Ages was characterized by a high frequency of deaths of individuals in low-age categories. Yet this finding is in line with paleodemographic indicators for agricultural communities of the period.

No bone lesions were observed in the investigated series of child skeletons that would indicate the direct cause of death.

Hypoplastic defects reported in the dentition of five children, sieve-like perforations inorbital vaults (*cribra orbitalia*) (both types of lesions in one case) in three children, i.e. physiological stress indicators, are examples of the body's reaction to malnutrition-related stress-inducing factors or a result of disruptions in bodily functions due to pathological factors. Such situations may lead to a greater incidence of juvenile diseases[31,32], e.g. infections, which leave no trace on the bones, as well as being the effect of deficiency in micro- and macronutrients or periods of malnutrition[33].

Extensive inflammatory changes investigated in this study were found only in one individual.

Taking into consideration the severity of inflammatory bone infection we can distinguish the three following stages: acute, subacute and chronic blood-derived pyogenic bone infection[34–36]. The first of the mentioned stages usually develops secondarily for about 2 to 3 weeks from the onset of the infection in its primary focus. The development of infection starts in metaphyseal sinuses and then it spreads to the proximal end of the femur and to the tibial diaphysis as well as to the proximal section of the humerus and of the radius. Initially subperiosteal reaction appears as the result of the destruction of the cortical layer in the form of oval defects. In the subacute stage of the development of the disease, an intensification of productive processes occurs, contributing to the thickening of the cortical layer, and to the obliteration of the marrow cavity. The acute form of inframmation occurs more frequently in boys and the causes which might favour its development are malnutrition, chronic diseases, anemia and injuries which all lead to the debilitation of the immune system.

The subacute form usually develops secondarily from a month to several months after the organism becomes infected[37–39]. This form of infection occurs most frequently in the tibia and on the basis of the location of lesions we can distinguish four subtypes: I – within the metaphyseal section – Brodie's abscess, II – within the diaphysis, III – located on the epiphysis and IV – located in places other than long bones.

Chronic blood-derived pyogenic bone inflammation is a chronic condition which develops gradually without any violent initial symptoms. Most frequently it occurs as a result of previously untreated forms of disease which can lead to limb amputation or systemic infection (sepsis) as a consequence of the occurrence of inflammatory focus containing pus, inflammatory granulation tissue and sequestra.

After a detailed anthropological analysis and assessment of pathological changes by means of macroscopic and radiological methods it can be concluded that the examined individual suffered from blood-borne – probably a chronic form of osteomyelitis. Diagnostic features of osteomyelitis e.g. a drainage canal from the marrow cavity and sequestered bone associated with new periosteal formation are visible.

This form could have been a result of acute or subacute bone inflammation this individual suffered from in childhood. The first bone affected by the disease was the tibia.

Osteomyelitic lesions are most frequently located in such bones as the tibia, femur and humerus[40]. They can also occur in the vertebrae, maxilla and mandible. The location of the lesions is determined by the age of an individual. The focus of inflammation in newborns and infants aged 18 to 24 months can permeate into a joint. In older children where the presence of growth cartilage separates the metaphyseal vessels from the vessels of epiphysis an inflammation usually occurs within the diaphysis and fails to permeate into the epiphysis. As a result of the combination of epiphyseal and metaphyseal vascular systems in adolescents and adults the infection spreads towards the diaphysis and epiphysis.

There might be a time relation between the initial stage of infection which caused the structural changes of the bone and developmental disorders. A considerable development of gluteal protuberance of the left femur and of vastus muscle attachment of the left lower extremity as well as a strongly marked line of the soleus of the left tibia might suggest that, when walking, the individual used to put a greater strain on the healthy left lower extremity (for example, foot bending, lifting the foot off the ground). Walking would have been extremely difficult for this individual, so it was necessary to immobilize the leg.

It cannot be excluded that the form of osteomyelitis the examined individual suffered from developed into a chronic disease, which untreated led to an infection of the entire organism, presumably with sepsis, thus causing death at the age of 12 or 14. The hematogenous form most often afflicts children between ages 3 and 12, when bone growth and formation is most active[4,5].

Conclusions

Complex pathological changes allow us to conclude that the individual, whose age at death was estimated at ca. 13–14, suffered from a chronic hematogenous osteitis. Chronic inflammatory lesions in children are rare in paleopathology and we can treat this case as a »osteological paradox«. A relatively long life span, lesions reported in the muscle attachment regions of the limbs, indicating mobility problems, suggest that the individual had received caring attention. Moreover we can suppose he had a good immunity system, enabling him to survive with infection for long time. The fact that the individual had been buried in the part of the medieval cemetery where well-furnished graves were located proves that he had belonged to a more affluent family.

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SLUČAJ EKSTENZIVNIH UPALNIH PROMJENA KOSTURA DOJENČADI (OSTEOMIJELITIS) SA SREDNJOVJEKOVNOG GROBLJA (11.–12. st.) U WAWRZEŃCZYCAMA (BLIZU KRAKOWA).

SAŽETAK

Cilj ovog istraživanja bio je dijagnosticirati i opisati ekstenzivne upalne promjene u djetetovu kosturu iz Wawrzeńczyce, (period srednjega vijeka). Cilj analize bio je utvrditi prirodu upalnih promjena i njihovu etiologiju pomoću makroskopskih tehnika, kao i X-zraka. Testovi su pokazali da je pojedinac patio od hematogenog multifokalnog ostitisa. Takvo je stanje moglo biti posljedica akutnog ili subakutnog ostitisa, a ne tretirani oblik osteomijelitisa mogao je pridonijeti infekciji cijelog organizma u razvoju, što je dovelo do smrti.