Growth and health status of children and adolescents in medieval Central Europe

Marta Krenz-Niedbała

Department of Human Evolutionary Biology, Institute of Anthropology, Faculty of Biology, Adam Mickiewicz University in Poznań

ABSTRACT: Subadult growth and health have been analyzed in three cemetery samples from medieval Poland, including two early-urban sites: Cedynia dated to the 10th–14th centuries AD, and Ostrów Lednicki dated to the 13th–15th centuries AD, and a rural site Słaboszewo dated to the 14th–17th centuries AD. The nutritional status was not expected to have substantially differed among the settlements, due to the culturally induced undiversified diet of children, and predominant share of medium-to-low status individuals. However, city life and village life were supposed to differ in factors correlated with the spread of infections, and as such it was expected to find significant differences in respiratory health among early-urban and rural dwellers.The prevalences of diet-dependent diseases, scurvy and rickets, were found to be statistically indistinguishable among the three studied populations, while higher frequency of skeletal signs of poor respiratory health was observed in early-urban Cedynia than rural Słaboszewo. Slightly lower prevalences of skeletal stress indicators were found for the rural than the early-urban site. Skeletal growth profiles and the dynamics of long bone growth were found to be remarkably similar for the early-urban samples (Cedynia and Ostrów Lednicki), with the rural subadults having the shortest diaphyseal lengths, and lower growth dynamics.It can be concluded that adverse factors associated with the urban settlement were more detrimental to respiratory health than those in the village. A variety of factors are potentially responsible for this pattern, including population density, building structure, quality of air and water, sanitation, and occupation. Perhaps, the key factor in response to environmental and socio-cultural constraints was the stability of living conditions in the village, which allowed the inhabitants to develop sufficient adaptive mechanisms. In contrast, the history of strongholds such as Cedynia was changeable due to political situation, military threats and migrations of people.

KEY WORDS: children, Middle Ages, paleopathology, growth profile, respiratory infections, stress markers

Bioarchaeological investigations of children – methodological perspective

The usefulness of subadult studies

In a cemetery sample infants and children are the most represented age groups. Their high mortality rates result from their belonging to the most vulnerable members of a population (http://www.who.int/environmental_health_emergencies/vulnerable_groups/en/). In relation to body weight children drink more water, eat more food, and breathe more air than adults. Thus they have higher exposures than adults to any harmful substances contained in water, food, or air (Pronczuk-Garbino 2005). Moreover, the development of the human immune system is a continuous process through childhood. Still developing immune defense makes children of different ages more susceptible to both viral, and bacterial, infections (Ygberg and Nilsson 2012). Due to the high rate of growth and development, their developmental processes can be easily disturbed. Environmental and socio-cultural risks, such as contaminated water, poor sanitation, indoor air pollution, poor food hygiene, poor quality housing, inadequate waste disposal, vector-borne diseases and hazards that cause accidents and injuries, have always endangered children's health (Pronczuk-Garbino 2005). Importantly, in prehistoric and historical societies practically no effective disease treatment could have been offered, especially in the absence of infection control with antibiotics (Halcrow and Tayles 2008). Since vulnerability is the degree to which an individual is unable to cope with, resist and recover from the impacts of adverse factors, subadult health and survival have been accepted as a general measure of the level to which the population has adapted to its environment (Eveleth and Tanner 1990; Lewis 2007). However, even when an individual survived childhood, the stresses they experienced during that period might have seriously affected their adult life. This phenomenon is known as DOHaD – developmental origins of health and disease (Meloni and Testa 2014). Early life stressors and adult morbidity and mortality are linked through epigenetic mechanisms, such as DNA methylation, which alters patterns of gene expression and results in phenotypic change (Gowland 2015). A variety of social and environmental exposures have been proved to impact epigenetic processes, such as parental diet, infant care and social status. A particularly significant factor in the DOHaD hypothesis is malnutrition (Gowland 2015).

Recently, it has been shown how to track longitudinal dietary changes during early childhood in past populations through advances in high-resolution isotopic analysis (Beaumont et al. 2015). This will allow to compare poor health experience between survivors and non-survivors from skeletal samples, and to address the osteological paradox, an idea raised by Wood and colleagues (1992). They described fundamental problems inherent to paleodemographic and paleopathological analyses of past human populations based on the skeletal remains. These problems include hidden heterogeneity in frailty (individuals differ between one another with respect to their susceptibility to diseases, stressors and the risk of death), and selective mortality (skeletal samples are biased representatives of the once-living populations). It is recommended to

focus on subadults as non-survivors and age-structured comparisons of health data, the more so that their age at death is more accurately and precisely assessed than in adults (DeWitte and Stojanowski 2015). Infants and children seem then to be the crucial age subgroups in a population to reconstruct past health and disease (Goodman and Armelagos 1989; Buikstra and Ubelaker 1994; Halcrow and Tayles 2008; Halcrow and Ward 2017), and, more generally, to show the degree to which a population had successfully adapted to its environment, which have been repeatedly demonstrated in bioarchaeological studies (such as Goodman and Armelagos 1989; Ribot and Roberts 1996; Mays 1999; Buckley 2000; Humphrey 2000; Saunders 2000; Lewis 2002; 2010). Two groups of stressors that are most often discussed in relation to growth and health status in past populations are infection and nutrition. They act synergistically, and their interrelationships are direct and causal, because malnutrition decreases resistance of the host to infection and infectious disease exaggerates existing malnutrition (King and Ulijaszek 1999; Pinhasi 2008).

Skeletal markers of growth and health

Human growth is characterized by high developmental plasticity driven by the environment (natural environmental and socio-cultural factors) and individual experience and as such it is a sensitive indicator of stress defined as compromised physiological status (Johnston 2002). Growth for a cemetery sample is commonly assessed through skeletal growth profiles. In order to construct the profiles diaphyseal lengths of the femoral and tibial bones are plotted against mean dental calcification ages (Armelagos et al. 1972; Ribot and Roberts 1996). Lower limb bones are usually chosen on account of their high growth rate and, in consequence, sensitivity to environmental stress (Eveleth and Tanner 1999). Bone growth patterns from past populations can be compared to modern growth data from various world regions in order to examine the impacts of diet, disease, and other factors (Pinhasi et al. 2014). According to the biocultural model, health is perceived as an adaptation to a combination of environmental stressors, including diseases, nutritional deficiencies, and adverse climatic factors (Halcrow and Ward 2017). In past populations the health status is examined through skeletal indicators. However, it should be borne in mind that health is a complex phenomenon that involves skeletal indicators of stress, but also the impact of processes underlying stress episodes on human life history and individual perception of well-being, physiological well-being, and mortality (Temple and Goodman 2014). There are many pathological conditions that can be identified on subadult remains, such as dental disease, specific and non-specific infections, rheumatoid arthritis, neoplasms, and congenital conditions (Lewis 2007; Gładykowska-Rzeczycka 1989; 2009), although subadult health status in bioarchaeological studies is usually evaluated through non-specific stress indicators, such as cribra orbitalia, porotic hyperostosis, dental enamel hypoplasia, and Harris lines, and indicators of non-specific infection: periostitis, endocranial new bone formation, maxillary sinusitis and otitis media. Moreover, direct information on diet can be obtained through an analysis of bony traces of diseases resulting from nutritional deficiencies, such as scurvy and rickets (Or-

tner 2003). Skeletal stress markers can be analyzed in relation to growth and development in order to assess the effects of exposure to different levels of stress on growth disruptions (Piontek 1992; Pinhasi et al. 2014) or to show how developmental instability predisposes to the development of stress markers (Gawlikowska-Sroka et al. 2013). The use of multiple lines of evidence may also help to at least partly avoid the "non-survivor" problem in skeletal studies. Long bone lengths are general and cumulative measures of nutritional status, but are non-specific in terms of chronology, unlike enamel hypoplasias, which reflect developmental disturbances from a definite childhood period (Goodman 1993). Extensive information about a range of

Fig. 1. Linear enamel hypoplasia on maxillary incisors in a 10-year-old child from Ostrów Lednicki (photo by Krenz-Niedbała)

health indicators for medieval Poland are enclosed in the monographs authored by Kozłowski (2012) and Piontek (2014).

Dental enamel hypoplasia

Dental enamel hypoplasia is a developmental disturbance of teeth characterized by deficient enamel matrix formation, and visible as areas of decreased enamel thickness (Fig. 1). Because tooth enamel is formed in a regular manner and does not remodel later in life, developmental defects of dental enamel provide chronological records of physiological stress episodes during fetal life (deciduous teeth), and childhood (permanent teeth). The enamel defects can be measured for reconstruction of age at formation (Krenz-Niedbała and Kozłowski 2013; Łukasik and Krenz-Niedbała 2014). Cutress and Suckling (1982) have listed nearly 100 factors as possible causes of enamel defects. They include nutritional imbalances, infections, vitamin deficiencies, low birth weight, maternal health, immunodeficiency diseases, drug toxicities, and almost any disease which severely stresses metabolism. This makes enamel defects a nonspecific and highly sensitive indicator of physiological and metabolic changes (Goodman and Rose 1990; Goodman and Martin 2002; Krenz-Niedbała and Kozłowski 2013; Hillson 2014).

Cribra orbitalia and porotic hyperostosis

These conditions develop in childhood and refer to porous lesions on the orbital roof (Fig. 2) and the cranial vault (Fig. 3), which result from an overactivity of the marrow, and a thinning of the outer table of the skull in response to the need of the

Fig. 2. Cribra orbitalia in a 15-year-old adolescent from Ostrów Lednicki (photo by Krenz-Niedbała)

Fig. 3. Porotic hyperostosis on the cranial vault of a 14-year-old child from Ostrów Lednicki (photo by Krenz-Niedbała)

organism to produce and store more red blood cells (Stuart-Macadam 1985). This is not a diagnostic term, but describes a particular morphological feature (Lewis 2007). The importance of healed and active lesions in determining the precise age at which children were most at risk has been demonstrated by Mensforth et al. (1978). Paleopathologists commonly attribute these lesions to anemia, and particularly iron-deficiency anemia (Jerszyńska and Piontek 2005; Kozłowski 2012; Nowak et al. 2013). However, other causes, such as inflammation, osteoporosis, and rickets have been shown to play a role in their etiology (Wapler et al. 2004). Walker et al. (2009) stated that hemolytic and megaloblastic anemias rather than iron-deficiency anemia are likely causes of the lesions, while the etiology of cribra orbitalia seems to be more complex than of porotic hyperostosis and includes a combination of several nutritional deficiencies (such as vitamin C and B_{12}). Their effect in past populations was undoubtedly enhanced by iron loss from diarrheal diseases in poor hygiene environments. However, Oxenham and Cavill (2010) claimed that iron-deficiency hypothesis was still a valid explanation of high frequencies of porotic hyperostosis and cribra orbitalia in skeletal samples.

Harris lines

Transverse lines of increased radio-opacity (Harris lines) occur in the growing bones of subadults in result of catch-up growth after an episode of deceleration of bone development. There are many conditions which can result in Harris lines formation, thus the exact etiology has never been established. Etiologies are similar to those implicated in enamel hypoplasias, and include malnutrition, starvation, septicemia, pneumonia, lead poisoning, rickets, congenital syphilis, birth trauma and poor maternal health (Piontek and Jerszyńska 1993; Jerszyńska and Nowak 1996; Piontek et al. 2001; Lewis 2007; Nowak and Piontek 2012). Scoring of Harris lines is subject to inter- and intraobserver error, thus some methodological improvements have been proposed for semiautomated Harris lines detection (Suter et al. 2008).

Periostitis

Periostitis can affect any bone in the skeleton, but is most often encountered on the long bones (Fig. 4). Pathological stimuli cause the periosteum to create woven bone, which remodels over time into lamellar bone. It displays as shaft thickening, rough striated exterior surface, and/or new bone deposition. Few archaeological studies, which have examined subadult periostitis, described the skeletal changes as unilateral, isolated patches of bone raised above the original cortex. Periostitis has been commonly regarded as an inflammatory response to nonspecific infection or trauma, although clinical literature points to multiple etiologies, including those that are noninfectious, such as nutritional deficiencies, neoplastic, metabolic, congenital, and genetic diseases (Geber and Murphy 2012; Weston 2012).

Endocranial new bone formation

Reactive new bone formation, observed on the endocranial surface appears as diffuse or isolated layers of new bone on the original cortical surface (Fig. 5), expanding around meningeal vessels. The lesions are commonly found on the occip-

Fig. 4. Severe periostitis on the right tibia of a 3-year-old child from Cedynia (photo by Krenz-Niedbała)

ital bone, but have also been recorded on the parietal and frontal bones. Its precise etiology is unknown, although various causes have been proposed for these lesions, including chronic meningitis, trauma, anemia, neoplastic diseases, scurvy, rickets, and tuberculosis (Lewis 2007).

Maxillary sinusitis

Chronic maxillary sinusitis manifests itself as resorptive lesions and new bone

Fig. 5. Endocranial new bone – isolated layers of new bone on the original cortical surface of the occipital bone in a 1-year-old child from Ostrów Lednicki (photo by Krenz-Niedbała)

formation within the floor and walls of the maxillary sinuses (Fig. 6) (Boocock et al. 1995a; Merrett and Pfeiffer 2000; Roberts and Manchester 2005, p. 174; Sundman and Kjellstrom 2013a, b). Sinusitis is an inflammation of the mucosa of the paranasal sinuses, involving both infectious and noninfectious mechanisms. There are three categories of etiological factors leading to sinusitis: systemic (for example genetic), local host factors (anatomic abnormalities, local pathologies) and environmental factors (viral, bacterial and fungal infections, allergies, and pollutants). This is a complex inflammatory process that can result from single or multiple independent (or interdependent) etiologies (Leung

Fig. 6. New bone on the floor of a maxillary sinus, caused by sinusitis in a an adolescent from Cedynia (photo by Łukasik)

and Katial 2008; Benninger 2010). In children, the most common predisposing factor is upper respiratory infection (File 2006; Hertler et al. 2006; Benninger 2010).

Otitis media

The skeletal manifestations of chronic otitis media include erosive lesions and new bone formation observed on the auditory ossicles (Fig. 7) (Roberts and Manchester 2005; Lewis 2007). Otitis media (OM) is a group of complex infective and inflammatory conditions, with a variety of subtypes differing in signs and symptoms, complications and treatment (Qureishi et al. 2014). The etiology of OM is complex and includes multiple interacting factors, which are, among others, host factors, anatomic/

Fig. 7. Erosion of an incus, caused by otitis media in a 1-year-old child from Cedynia (photo by Chowański)

physiologic features, infections (viral and bacterial) and environmental factors (tobacco smoke exposure, air pollution and socio-economic status) (Casselbrant and Mandel 2010; Ilechukwu et al. 2014; Qureishi et al. 2014; Zhang et al. 2014). In the majority of children, viral infection of the upper respiratory tract initiates the cascade of events that finally leads to the development of OM. Otitis media may be complicated by potentially life-threatening infectious intratemporal (among others, mastoiditis) or intracranial (such as meningitis) conditions (Casselbrant and Mandel 2010; Chole and Sudhoff 2010).

Scurvy

The most pathognomonic features of scurvy in archaeological skeletal remains are bilateral porosity and new bone formation found on the external surface of the skull vault, the orbital roof, the greater wing of the sphenoid (Fig. 8), the posterior surface of the maxilla, the inferior surface of the hard palate, the infraspinous and supraspinous fossae of the scapula and the metaphyses of long bones (Ortner and Ericksen 1997; Ortner et al. 1999; 2001; Ortner 2003). Insufficient dietary intake of vitamin C appears as the most common cause of scurvy, although other variables can contribute to the development of this disease. These variables can be categorized into four groups: reduced intake of vitamin C (e.g. resulting from socio-economic factors), increased requirement for vitamin C (e.g. during infections), malabsorption of vitamin C (e.g. in some gastrointestinal diseases) and genetic predisposition to lowered vitamin C levels (Delanghe et al. 2013; Halcrow et al. 2014).

Rickets

Rickets usually results from a deficiency or impaired metabolism of vitamin D, phosphorus or calcium. Small amounts of vitamin D are present in some foodstuffs such as fish oil and egg yolks, nonetheless, vitamin D status is primarily maintained by exposure to sunlight (Ortner 2003). The skeletal manifestations of rickets include deformation of the cranium (craniotabes), deposition of osteoid on the external table of the skull which mimics porotic hyperostosis, splaying and cupping of the long bone metaphyses and bowing of limb bones, expansion of the sternal ends of the ribs (Fig. 9), and deformities of the rib cage ("rachitic rosary"). In severe cases, the vertebral bodies may collapse (Ortner 2003; Lewis 2007). As both rickets and scurvy are associated with anemia, it is likely that all three conditions and their associated

Fig. 8. Porosity of the sphenoid bone caused by scurvy in a 7-year-old child from Cedynia (photo by Krenz-Niedbała)

Fig. 9. Expansion of the sternal end of a rib indicative of rickets in a 10-year-old child from Ostrów Lednicki (photo by Krenz-Niedbała)

bony lesions will be present in one individual (Kozłowski and Witas 2011).

Subadult growth and health in medieval and postmedieval Polish lands

Cemetery samples

The present overview of growth and health status of the medieval children and adolescents from the Polish territories was primarily based on the skeletal remains from the osteological collections of the Department of Human Evolutionary Biology, Institute of Anthropology, Adam Mickiewicz University in Poznań, and from the Museum of the First Piasts at Lednica, Ostrów Lednicki Island, Dziekanowice. Three cemetery samples were taken into account, including two early-urban sites: Cedynia (52°52′45.30″ N, 14°12′07.99″ E) dated to the 10th–14th centuries AD, and Ostrów Lednicki (52°31′37.00″ N, 17°22′40.00″ E) dated to the 13th–15th centuries AD, and a rural site Słaboszewo (52°47′21.82″ N,17°57′59.06″ E) dated to the 14th–17th centuries AD. Those three sites are located in Poland, lowland lake areas, at the distance below 250 km. In total, 257, 194, and 178 subadult skeletons have been examined from Cedynia, Ostrów Lednicki, and Słaboszewo, respectively (Table 1) and the results were published by Krenz-Niedbała (2009; 2016), and Krenz-Niedbała and Łukasik (2016; Early View). The samples of Cedynia, Ostrów Lednicki nad Słaboszewo represent rather homogenous populations in terms of ethnicity and religion (Latin Christianity). The nutritional status is not expected to have substantially differed among the settlements, due to the investigated specific age subsample, consisting only of subadults. The culturally-driven diet structure of infants and small children in medieval Poland was generally undiversified, based on cereals, and rather poor in vitamins, irrespective of the socio-economic position. In older childhood and adolescence the food composition mainly depended on the social status, while the studied cemetery samples consist predominantly of medium-to-low status people. Isotopic analyses of foods consumed by inhabitants of Polish early-medieval strongholds indicate high content of animal proteins, together with significant share of millet (Reitsema and Kozłowski 2013; Reitsema et al. 2010), which may speak for an adequate diet, at least in the examined sites (Piontek 2014).The principal aim of the research of subadult growth and health in medieval and postmedieval Poland was to examine the effects of environmental and cultural factors on developmental processes to provide information about the adaptation of past human populations to their environments. Health status was evaluated through the prevalences of the

Table 1. Age-at-death distributions in the medieval and postmedieval samples from Polish lands

Age categories (years)	Ostrów Lednicki 13th–15th AD		Cedynia 10th–14th AD		Słaboszewo 14th–17th AD		Total	
	N	%	N	%	N	%	N	%
0–3.9	63	32.5	86	33.5	69	38.8	218	34.7
4.0–11.9	94	48.4	127	49.4	73	41.0	294	46.7
12.0–19.9	37	19.1	44	17.1	36	20.2	117	18.6
Total (0–19.9)	194	30.8	257	40.9	178	28.3	629	100.0

skeletal indicators of physiological stress (enamel hypoplasia, cribra orbitalia, porotic hyperostosis, Harris lines), nonspecific infections (periostitis, endocranial lesions, maxillary sinusitis, and otitis media), and diet-dependent diseases (scurvy, and rickets). Growth status was examined through skeletal growth profiles of the femur and tibia. Furthermore, index of growth rate was calculated, as the difference between the diaphyseal measurements in the neighboring age groups with regard to the time unit. The specific methodologies have been described in above mentioned papers of Krenz-Niedbała, and Krenz-Niedbała and Łukasik.

Results

Skeletal growth profiles

The general patterns of femoral growth profiles in Polish medieval children are very much alike for the three compared samples (Krenz-Niedbała 2009), particularly until the 8th year of age (Fig. 10). Later on, and, more clearly, after the age of 12 years, the bone lengths start to differentiate between the sites. Nevertheless, both early-urban samples (Cedynia and Ostrów Lednicki) show remarkable similarity, while the rural subadults (Słaboszewo) have the shortest femoral diaphyses. The femoral lengths of the examined children fall well below those of their modern peers of European origin. This difference is the lowest in the youngest children, and successively increases with age. For example, 3-year-old modern children have similar femoral measurements to 5-year-old skeletal children, and the bone size of modern 9-year-olds is comparable to 14-year-old skeletal adolescents. In all three examined samples there is a growth retardation after the 2nd year of age, while such slowdown did not occur in the modern
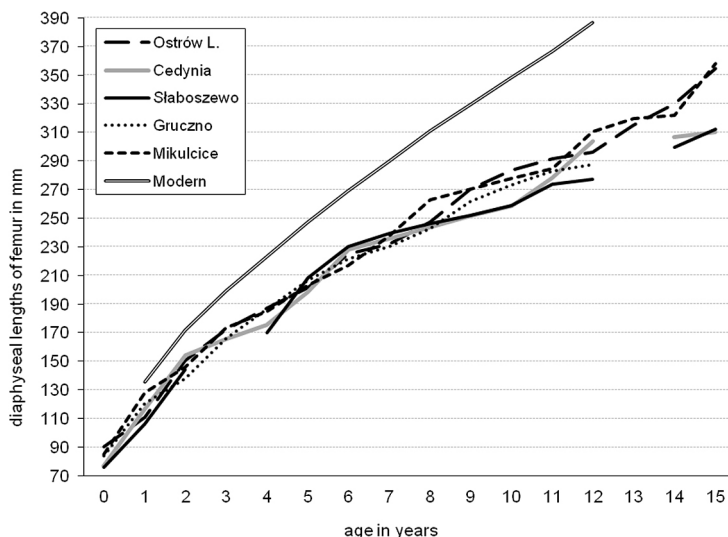

Fig. 10. Femoral growth profiles for medieval and postmedieval samples from Polish territories. Cedynia, Słaboszewo, and Gruczno – data cited from Jerszyńska (2004); Mikulcice – data from Stloukal and Hanáková (1978); modern data from Maresh (1970), cited after Schaefer et al. (2009)
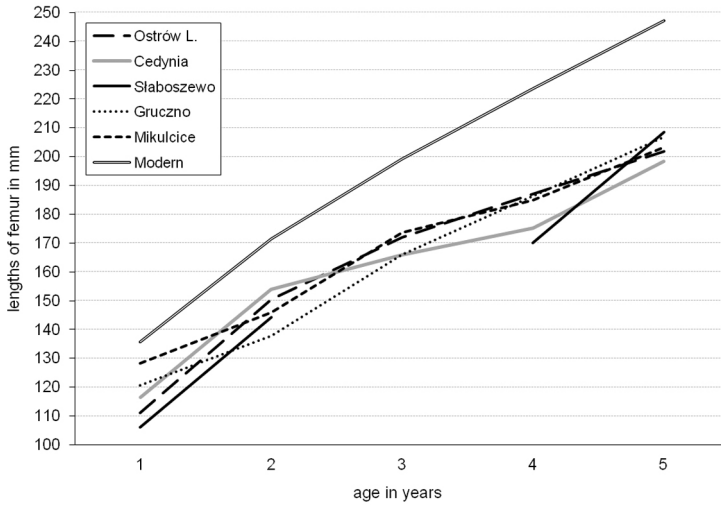
Fig. 11. Femoral growth profiles for subadults aged 1–5 years. Cedynia, Słaboszewo and Gruczno – data cited from Jerszyńska (2004); Mikulcice – data from Stloukal and Hanáková (1978); modern data from Maresh (1970), cited after Schaefer et al. (2009)

sample (Fig. 11). The dynamics of femoral growth was also found to be markedly similar in the subadults from early-urban sites – Ostrów Lednicki, Cedynia,

and Gruczno (Fig. 12). In these samples a gradual decrease in growth rate is apparent until about 5 years of age, then growth slightly accelerates, and speeds
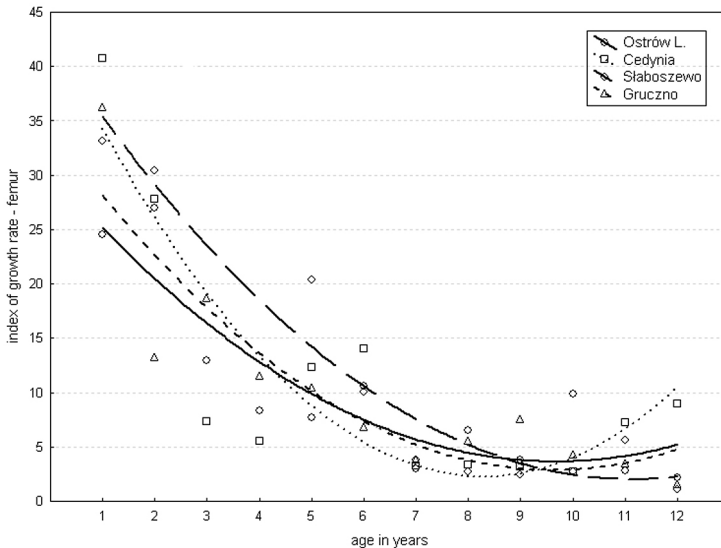

Fig. 12. Index of growth rate for medieval and postmedieval samples from Polish territories. Cedynia, Słaboszewo, and Gruczno – author's calculations for the data from Jerszyńska (2004)

up after 8th year of age. In the Słaboszewo subadults the decrease of growth rate shows no signs of recovery.

Health indicators

The prevalences of skeletal health indicators in medieval and postmedieval European populations and the comparative data on early-urban and rural samples from Kozłowski (2012) are presented in Table 2 and Table 3, respectively. Except for Harris lines, all skeletal stress markers occur with medium-to-low prevalence, as compared with other medieval European populations (Krenz-Niedbała, 2009). The comparison among the Pol-

ish skeletal data does not show a regular pattern of stress experience in the early-urban and rural samples, with Słaboszewo rural subadults being the least exposed to harmful environmental and cultural factors. The prevalences of indicators of diet-dependent diseases, scurvy and rickets, proved to be statistically indistinguishable among the three studied populations (Krenz-Niedbała 2016). However, both conditions commonly occur at low frequencies in the presented skeletal samples. The skeletal signs of maxillary sinusitis and otitis media (recorded as erosion of ear ossicles) were found to be more frequent in early urban Cedynia than in rural Słaboszewo (18.0%

Table 2. Prevalence (%) of skeletal health indicators in medieval European samples

Site	Cribra orbitalia	Porotic hyperostosis	Enamel hypoplasia	Harris lines	Periostitis	Rickets	Endocranial new bone
Central and Southern Europe							
Ostrów Lednicki, Poland	44.8	6.8	50.0	77.3	25.7	3.1	7.3
Cedynia, Poland	77.6	5.6	19.7	88.1	17.1	2.1	19.3
Słaboszewo, Poland	35.0	3.7	27.3	95.1	10.4	1.3	10.3
Mikulčice, Czech Rep.	44.0		71.2	72.9			
Borovce, Slovakia	76.9		24.0				
Stara Torina, Serbia	46.1	2.9					
Nova Rača, Croatia	58.6		64.4		55.2		31.0
Nin, Croatia	43.8		44.2		20.0		
Composite series, Croatia	53.7		74.8		26.7		
Northern Europe							
Chichester, UK	67.0	15.0	38.0	42.0	55.0		
Wharram, UK	56.0		30.0		13.0	1.2	15.2
Raunds, UK	55.0	17.0	32.0	32.0	18.0		13.7
St. Helen, UK	56.0		34.0		20.0		12.0
Næstved, Denmark	57.8		42.1		25.0		6.2
Æbelholt, Denmark	52.4		16.4		8.5		8.6

Data sources: Cedynia and Słaboszewo, Harris lines – Jerszyńska (2004); Ostrów Lednicki, Harris lines – Łubocka (2003); Mikulčice – Havelková et al. (2008), Trefný, Velemínský (2008), Velemínský et al. (2009); Borovce – Obertová, Thurzo (2004), Obertová (2005); Stara Torina – Djuric et al. (2008); Nova Rača – Šlaus (2000); Nin – Novak et al. (2012); composite series – Šlaus (2008); Chichester – Ribot and Roberts (1996); Wharram Percy, Raunds Furnells, Saint Helen – Lewis (2002); Æbelholt, Næstved – Bennike et al. (2005).

Table 3. Prevalence (%) of skeletal health indicators in early-urban and rural subadult samples from Polish territories

Sample	Cribra orbitalia	Porotic hyperostosis	Enamel hypoplasia	Harris lines	Scurvy	Rickets	Periostitis
Cedynia, early-urban 10th–14th AD	77.6[1]	5.6[1]	19.7[1]	88.1[2]	1.6[1]	1.1[1]	17.1[5]
Słaboszewo, rural 14th–17th AD	35.0[1]	3.7[1]	27.3[1]	95.1[2]	1.7[1]	1.3[1]	10.4[5]
Ostrów Lednicki, early-urban 13th–15th AD	44.8[1]	6.8[1]	50.0[1]	77.3[3]	3.0[1]	3.1[1]	25.7[1]
Kałdus, early-urban 10th–13th AD	45.6[4]	7.2[4]	38.1[4]	–	7.4[4]	0.5[4]	7.1[4]
Kamionki Duże, rural 16th–18th AD	37.5[4]	10.8[4]	66.1[4]	–	2.9[4]	1.4[4]	33.3[4]
Płonkowo, lesser gentry 19th–20th AD	46.1[4]	10.6[4]	44.2[4]	–	6.9[4]	3.4[4]	48.1[4]

[1] – Krenz-Niedbała (2009); [2] – Jerszyńska (2004); [3] – Łubocka (2003); [4] – Kozłowski (2012); [5] – Krenz-Niedbała, unpublished data

vs 7.1%, and 53.4% vs 39.0%, respectively), although these differences are statistically non-significant (Krenz-Niedbała and Łukasik 2016; Early View). However, the frequency of eroded ossicles was significantly higher in Cedynia than in Słaboszewo (42.2% vs 25.9%, respectively; FET, p=0.0339). Our study on otitis media showed a significantly higher frequency of eroded incudes in the age category 0–3 years old than in the category 4–11 years old.

Discussion

Growth status

Long bone lengths are general and cumulative measures of nutritional status secondary to factors such as poor dietary intake and high disease loads (Goodman and Martin, 2002). Therefore, child growth standards are used to assess the general health status of the population, where poor growth indicates adverse conditions (Johnston and Zimmer 1989; Kaczmarek 1995). For example, Pinha-si et al. (2006) showed, that low socio-economic status had a major impact on growth retardation in 17th century London. Not surprisingly, the majority of growth studies in archaeological samples have demonstrated that the diaphyseal lengths of children fell below those of their modern peers. Each child has a genetic potential for increasing their body height, but this process depends upon different conditions related to stress, mostly to nutrition. Therefore, the deficit in long bone lengths in archaeological populations has been commonly attributed to greater disease load and poorer nutrition in the past (Ribot and Roberts 1996; Mays 1999, 2002; Lewis 2007). We found a similar pattern in our research on Polish medieval children – an increasing difference in femoral measurements between modern children and skeletal subadults, amounting to several years in adolescence, when the femoral lengths for a 14-year old from the skeletal sample approximates to that of a modern 9-year-old, similarly to the findings of Mays (1999). Growth patterns similar to the ones obtained by us have been

found in other studies of skeletal growth profiles in Polish medieval children (Jerszyńska 2004; Kozłowski 2012). The rural children from Słaboszewo proved to be the shortest subadults among all Polish medieval and postmedieval samples. We revealed a characteristic decrease of growth rate after the 2nd year of age, absent in modern children, which was also found by other authors (Šereikiene and Jankauskas 2004). It likely represents nutrition-infection interactions (King and Ulijaszek 1999), and has been commonly attributed to weaning and post-weaning experiences (Wall 1991). We haven't examined the effect of stress episodes on longitudinal bone growth, however Ribot and Roberts (1996) failed to show a relationship between the stress indicators and the long bone lengths, and concluded that skeletal and dental growth disturbances did not last long enough to retard catch-up-growth in their populations. Indeed, it seems from the study of Mays (1999), that the appositional rather than the longitudinal growth is a more sensitive indicator of stress (see also Jerszyńska 2004). Notably, aging methods used for younger and older subadults should be taken into account. While dental development was preferentially used, older individuals were aged also through bone fusion or bone size. Other problems related to age assessments of juveniles result from unknown proportion of boys and girls in a given skeletal sample and differential age they enter the pubertal spurt (Hoppa 1992; Lewis 2007).

Nonspecific stress

In order to examine the influence of cultural contexts of skeletal lesions and the biological processes leading to their development, multiple lines of research are recommended. Various skeletal indicators reflect conditions at death and conditions during life, and provide slightly different and complementary information about health status of past populations, which can help to distinguish among otherwise seemingly paradoxical interpretations. As already mentioned, long bone lengths are general and cumulative measures of the well-being of a population, but they do not clearly reflect nutritional status at a specific time, in contrast to growth disruption markers, such as linear enamel hypoplasia, which is a time-specific record of past physiological disturbances (Goodman and Martin 2002; Łukasik and Krenz-Niedbała 2014). Most indicators, such as cribra orbitalia, enamel hypoplasia, and periostitis signify survival for some time after the morbidity event, and such chronic and typically nonlethal conditions may illustrate, among others, everyday experience of nutritional adequacy, the level of infectious diseases, hygiene levels, and sanitation (Goodman 1993). For example, either active or healed cribra orbitalia does not indicate that the individual died from iron-deficiency anemia, but rather that iron deficiency, in combination with other factors, may have contributed to poor health (Goodman and Martin 2002).

Linear enamel hypoplasias are one of the most frequently studied skeletal stress markers. In comparison to growth measures, developmental enamel defects are time specific and may indicate more acute and short-term periods of stress. They develop in response to general poor living conditions, low socio-economic status, and malnutrition (Goodman and Martin 2002; Miszkiewicz 2015). Cook and Buikstra (1979) evidenced low probability that those who were exposed to

severe stress would die before forming a defect. The reported association between the occurrence of dental enamel defects and decreased mean age at death is likely due to lower social status throughout life, causing early stress and high mortality (Goodman and Martin 2002; Żądzińska et al. 2015).

The prevalences of enamel hypoplasia in medieval European populations (Ribot and Roberts 1996; Lewis 2002; Šlaus et al. 2002; Obertová 2005; Bennike et al. 2005; Novak et al. 2012) as well as Polish medieval and post-medieval samples typically oscillate around 30–50% (Dąbrowski and Gronkiewicz 1996; Krenz and Piontek 1996; Kwiatkowska and Gronkiewicz 2003; Staniowski et al. 2004; Łukasik 2011; Dąbrowski et al. 2014), and similar results were found for Cedynia, Ostrów Lednicki, and Słaboszewo. Occasionally, higher rates of this condition were found (Šlaus 2000; Palubeckaitė et al. 2002; Šlaus 2008; Trefný and Velemínský 2008). Harris lines tend to occur in great numbers in medieval subadults, commonly exceeding 80% (Gronkiewicz et al. 2001; Łubocka 2003; Havelková et al. 2008; Piontek 2014), which was also true for our samples, in contrast to lower rates found in some other European studies (Lewis 2002). Cribra orbitalia in child remains commonly ranges from 40% to 60% (Šlaus 2000; Piontek and Kozłowski 2002; Bennike et al. 2005; Kwiatkowska 2005; Djuric et al. 2008; Velemínský et al. 2009; Kozłowski 2012; Novak et al. 2012; Piontek 2014), although the subadults from Cedynia showed an elevated rate of this condition, similar to a sample from Slovakia (Obertová and Thurzo 2004). The high cribra orbitalia frequencies in children are not surprising. Children are particularly prone to develop

anemia, because of a combination of factors, such as high iron requirements, low iron content in breast milk, and weaning diets rich in organic compounds which inhibit intestinal absorption of iron, and compromise immunity (Mensforth et al. 1978; Šlaus 2008). Factors associated with low values of vitamin B12 predisposing to anemia are also gastrointestinal parasite infections and poor sanitation (Walker et al. 2009). The inhabitants of medieval Polish strongholds likely suffered from parasitic infections, because in an individual from Ostrów Lednicki a cyst of *Echinococcus granulosus* has been found (Gładykowska–Rzeczycka et al. 2003). Humans who do not follow basic hygiene practices become infected by this tapeworm through the alimentary tract. Low sanitary conditions in the Ostrów Lednicki site were suggested by archaeological data. Much lower frequencies (range of 3–20%) are usually found for porotic hyperostosis (Ribot and Roberts 1996; Lewis 2002; Djuric et al. 2008; Kozłowski 2012), and our samples from Polish territories demonstrate rather low occurrence of this condition. Periostitis was found to shift radically from group to group, and there is little comparability across studies (Goodman and Martin 2002). European medieval data on periostitis range from about 6% to 50% (Šlaus 2000; Lewis 2002; Šlaus et al. 2002; Bennike et al. 2005; Šlaus 2008; Kozłowski 2012; Novak et al. 2012), thus the examined subadults from Cedynia, Ostrów Lednicki and Słaboszewo exhibit rather moderate rates of this condition.

The studies of medieval subadult remains from Polish territories (Krenz-Niedbała 2009) have shown relatively lower prevalences of stress indicators in the rural sites than in early-urban settlements (Table 3). The picture

contrasted with other studies is not entirely clear, likely due to the non-specific character of the indicators with often idiopathic and only partially overlapping etiologies, different methods of data collecting and analyzing applied by various authors, and small sizes of some cemetery samples (Ribot and Roberts 1996). Garcin et al. (2010) failed to demonstrate a difference in the overall prevalence of enamel hypoplasias between early medieval urban and rural samples from different geographical locations, and concluded that dental stress presumably depended more on the environment than on lifestyle.

Respiratory infections

It is presumed that in pre-antibiotic times high morbidity and mortality rates were caused by pathogenic bacteria, driven by the lack of effective treatment. Bioarchaeological studies of medieval Europe have repeatedly addressed the differences between city life and village life resulting in differential morbidity, for example, respiratory infections were generally found to be more prevalent in urban sites (Lewis et al. 1995; Roberts and Lewis 2002; Roberts 2007). In medieval Europe by the 14th century city dwellers were fully engaged in non-agricultural production, and obtained food through market exchange. People lived where they worked, thus the population density was related to the intensity of social interactions. Growing population size in an area restricted by city walls caused spatial limitations, and increased density. Generally, there were spatial, political, economic, and social differences between the city and the countryside, which reflected in different stresses in the environment experienced by rural and urban families (Mitchell

2007; Cesaretti et al. 2016). It appears from archaeological and historical data on medieval Poland, that the population of the stronghold was dense and lived in a network of narrow streets lined with tightly packed wooden buildings (houses, shops, and workshops). The workshops, including metal smelting spots, tanneries, laundries, butcheries, malt houses, and steam houses, together with charcoal markets, produced smoke and dust. Hygiene levels were low, with regard to both personal hygiene and practices employed in domestic and everyday life settings. Water was contaminated by waste and feces, because the contents of rubbish bins and chamber pots were thrown into the open sewer running down the street, and latrines were often dug near the main water supply. Polluted water was likely a vector for the transmission of human adenoviruses, which belong to the most common human pathogens and the most abundant human viral pathogens in sewage, causing, among other things, upper respiratory tract infections (Okoh et al. 2010; Bibby and Peccia 2013). Furthermore, higher population mobility in urban compared to rural centers contributed to increased exposure to pathogens leading to respiratory infections. More condensed population groups gave rise to "crowd diseases". Contaminated food or water or direct acquisition of pathogens through defects in the skin were the most likely means of infectious disease spread. Diseases were also transmitted by rats living in the streets in large numbers. They carried fleas that were vectors of infections, such as bubonic plague, typhus, and spotted fever (Bollet 2004; Gładykowska-Rzeczycka 2009), to which the children were especially exposed. In the majority of houses, the hearth was built in the center of the room, and the

smoke escaped through the door, roof, a few small windows under the eaves and a louvre at the top. This ventilation was ineffective, thus persistent and ubiquitous smoke and soot were characteristic features of the mediaeval home in urban-type settlements. At night, the fire was covered with ashes to leave the coals to slowly smolder (Tyszkiewicz 1983; Dowiat 1985; Samsonowicz 2001a; b; Chwalba 2005; Miśkiewicz 2010).Unlike the development of cities in High Middle Ages, peasant culture was much slower to alter. The settlement structure of the Polish villages did not change from early medieval times until about 19th century (Buko 2011). Rural houses were usually made of timber, rubble, mud, and straw, and were roofed with thatch. They were warmed by an open hearth. In winter months, domestic animals were kept in the house for shelter. Near the house, there were open air hearths, which served for cooking and outdoor works, such as firing pottery and smoking food, almost all year round, except winters. The cottages commonly had a small back garden attached to the house (Tyszkiewicz 1983; Samsonowicz 2001a;b).The children were soon trained to work on the farm. They usually performed simple duties, such as feeding livestock, assisting in agricultural work, and tending a vegetable or herb garden. They also watched over their smaller siblings throughout the day (Dowiat 1985; Miśkiewicz 2010; Nowakowski 2015). From spring to autumn, older children and other family members, apart from the married couple and their youngest children, slept in the farmyard (Dowiat 1985). Peasant communities benefited from being in the open air, because the quality of water and air was undoubtedly higher in the villages than in the towns (Kuchowicz 1972;

Tyszkiewicz 1983). It appears that the living conditions in the rural environment were more advantageous for respiratory health than in the urban settlements, because of less dense building structures, much lower water contamination, and ambient air pollution. Generally, we expected a culturally induced (caused by lifestyle and building structure) higher prevalence of skeletal indicators of maxillary sinusitis in subadults from the stronghold compared to their counterparts from the village. For maxillary sinusitis we found a statistically non-significant tendency toward a higher prevalence of the condition in early urban Cedynia compared to rural Słaboszewo (Krenz-Niedbała and Łukasik 2016). We found almost 20% of the 4–11-year-olds from Cedynia to be affected as compared with about 6% from Słaboszewo. Children above 4–5 years of age likely lived much more independent lives. They were given more responsibility and were expected to work in some capacity (Mitchell 2007, p 155).Thus, their respiratory health was more dependent on outdoor air quality, poorer in urban than in rural sites. We think that the reason for failing to show significant differences was low sample size of the village subadults. However, the frequency of skeletal signs of otitis media, calculated per eroded ossicles, was found to be significantly higher in Cedynia than in Słaboszewo (Krenz-Niedbała and Łukasik, Early View). This time, a comparable number of the examined ear bones (slightly more than 80 in each sample) allowed us to verify our assumptions about poorer respiratory health in urban than rural settlements.In past populations from different chronological periods and geographical locations, a higher frequency of sinusitis was generally found in urban than in rural inhabitants (Lewis

et al. 1995; Roberts 2007). Several factors were suggested to explain this pattern, such as greater population density, work in local industries, and poorer air quality in the urban environment, leading to a greater risk of infection (Boocock et al. 1995a, b; Lewis et al. 1995, Sundman and Kjellström 2013a). However, Ribot and Roberts (1996) demonstrated that early medieval (Anglo-Saxon) rural children were exposed to stress more continuously and systematically than late medieval urban children, although the authors admitted that the latter represents a heterogeneous selected sample of poor and/or diseased population.Lewis et al. (1995) observed slightly higher prevalence of maxillary sinusitis in later medieval subadults aged 6–16 years, with 26% of the urban and 16% of the rural children affected. In a sample from medieval Poland Teul et al. (2013) found slightly more than 76% of rural adults and almost 74% of rural children aged less than 16 years affected by maxillary sinusitis, with the highest occurrence in the youngest age category (0–6 years). In another study on Polish medieval subadults, Teul (2015) showed very high frequencies of maxillary sinusitis, exceeding even 80%, though, when only proliferative changes were counted, their prevalences ranged approximately from 50% to 65%. Maxillary sinusitis in past human populations examined so far most commonly ranged from 30% to 50% (Boocock et al., 1995a, b; Lewis et al., 1995; Merrett and Pfeiffer, 2000; Roberts and Lewis, 2002; Roberts, 2007). Our results revealed a rather low number of subadults from medieval/early modern Poland who suffered from chronic maxillary sinusitis, though medieval and post-medieval writings mentioned a high frequency of upper respiratory tract infections in children living on Pol-

ish territory (Żołądź-Strzelczyk, 2002; Delimata, 2004). However, it should be emphasized that comparisons between results coming from different studies are not straightforward, because the studies differ in the age range of the examined subadults, so they include individuals at different stages of development of the maxillary sinuses. Furthermore, different types of bone lesions have been observed. The general prevalence of individuals with ossicular erosion indicative of otitis media was relatively high in our study (47.5%), as compared to other studies. Bruintjes (1990) reported 64% of affected individuals in age category 0–20 years old from a leper cemetery dated 12th–17th AD. The study of Cullen Doyle and Judd (2015) found 62.5% of eroded ossicles in individuals from the Byzantine period in Jordan. In contrast, approximately 10% of children from pre-Columbian Arizona showed signs of OM (Schultz et al. 2007), and c. 1% of eroded ear bones were found in two populations from mediaeval Denmark (Qvist and Grøntved 2000). In summary, it can be concluded that adverse factors associated with the urban settlement were more detrimental to respiratory health than those in the village. There is a variety of factors potentially responsible for this pattern, including exposure to dust, environmental and indoor pollution, wood smoke, fungi, occupation, trade contacts, population density, economy, sanitation, and quality of housing (Roberts 2000; Roberts and Lewis 2002).

Nutritional deficiencies

The quality of food in past human populations can be inferred from indirect evidence – paleopathological data (Ortner 2003; Kwiatkowska 2005; Kurek et

al. 2009; Kozłowski 2012; Kaczmarek 2013), and zooarchaeological data (Makowiecki and Makowiecka 2014) or direct data from chemical analyses of bony tissue (Roberts and Manchester 2005; Szostek et al. 1998; 2009; Tomczyk et al. 2013). In order to provide the socio-cultural context, the biological data should be confronted with archaeological and historical information.Written evidence related to daily life in medieval Poland including food consumption is scarce, especially in relation to the middle class and the poor. What is known to archaeologists and historians on the early Medieval Times is provided almost entirely through archaeological findings (Dembińska 1999). Food history research commonly divides the medieval society into four social groups: nobility, clergy, townspeople and peasants, but it does not work for understanding the real differences in eating habits in the Polish Middle Ages. The quality and quantity of food consumed were determined by the standard of living rather than arbitrary social categorizations (Dembińska 1999). Each social group was actually diverse. The nobility embraced royalty, magnates and nobles, state and court officials (not always of noble origin) and persons closely associated with the court. The clergy group consisted of rich (including landed prelates) and poor priests, monks and friars and the lowest rank of monks of peasant origin. Townspeople embraced urban patricians, middle-class merchants, craftsmen and the urban poor. The peasantry living in the countryside ranged from village administrators and rich farmers to middle-class peasants, rural craftsmen to herdsmen, tenants, rural poor, beggars and vagabonds. The people of comparable standard of living likely shared similar eating patterns. The highest group in the consumption hierarchy consisted of secular and church magnates, royalty, wealthy nobles, court officials, rich patricians, and their servants, minor officials and state clerks. The next group embraced landowners of small estates, knights, middle-class merchants, craftsmen, village administrators, wealthy farmers and the middle-income clergy. To the lowest category belonged, among others, urban and rural poor, friars and low-level servants. This poorest group was numerous, although invisible in the written accounts (Dembińska 1999). Only general archaeological and historical data are available on the diet of medieval and post-medieval Polish children. Upper-class infants and young children were given paps of porridge or bread with milk or water. The diet of the majority of lower-class people consisted mainly of grains such as millet, wheat, oats or barley. Lower-class children consumed the same but crushed food as their parents. In general, subadults' diet was limited, based on a few products, containing no or small amounts of vitamins. Children aged 4 years started to be given adult food (Żołądź-Strzelczyk 2002). Importantly, in Poland, winters are long, and the growing season for vegetables and fruits does not start until mid-June. Seasonal fluctuations in food availability and poor harvests often caused long periods of very poor nutrition, which most severely must have affected the children (Żołądź-Strzelczyk 2002; Lewis 2007; Pētersone-Gordina et al. 2013). Frequent crop failures, and two great famines in the 13th century were noted in the historical writings (Dowiat 1985).The newborn an infant rely on the special qualities of mother's milk to provide them with the nutrients and immunological protection. Mother's milk

contains over 100 components that are crucial for the child's health, growth and development, including a high number of immunoglobins. Those are produced by the mother's immune response to pathogens in her nearest environment, and thus enable defense of the child against pathogens they actually meet. The transition from an exclusively milk diet to one containing other foods is a particularly vulnerable time. Contamination and inadequacy of the complementary food together with decreased immunological protection during this critical period may increase the risk of faltering growth and nutritional deficiencies (Fleischer et al. 2000). Commonly, high frequencies of stress indicators and growth deficit identified through skeletal growth profiles in children between the ages of 2 and 4 years have been related to weaning stress (Lewis 2007). In medieval Poland breastfeeding was continued until the child reached 2–3 years of age (Żołądź-Strzelczyk 2002; Żołądź-Strzelczyk and Kabacińska-Łuczak 2012). The predominant supplementary foods were paps made of white or wholewheat bread, soaken in milk or water, with addition of eggs, honey or sugar or a porridge of flour or cereals with water and butter (Żołądź-Strzelczyk 2002; Musiał-Morsztyn et al. 2014). In poor families of peasants and workers a large portion of their daily diet was made up of grains such as millet, wheat, oats or barley. Children were given the same but crushed food as their parents. These historical data indicate low hygiene practices and serious nutritional deficiencies in the child's diet. It appears that the vitamin C status in the Polish territories was generally inadequate and improved only with the widespread consumption of potatoes starting in the 19th century (Leszczyński 2012).

The frequencies of lesions indicative of scurvy found in the Polish medieval subadults conform to the results of other studies from medieval and post-medieval Europe with prevalences ranging from 0 to approximately 7% (Brickley and Ives 2008: Table A1, pp. 72–74; Mays 2014: Table 2). Because the most common cause of scurvy is insufficient dietary intake of vitamin C, most cases of scorbutic lesions in archaeological samples are attributed to an inadequate diet (Lovász et al. 2013; Halcrow et al. 2014), with a possible strong influence of religious and child-rearing practices (Lewis 2010). Melikian and Waldron (2003) claim that scurvy was likely to have shown considerable seasonal variation in the past, being most prevalent in the seasons with least available fresh fruit and vegetables. Mahoney-Swales and Nystrom (2009) presumed that the scorbutic children in their early medieval British sample died during late winter or early spring, before they had time to recuperate from skeletal effects of vitamin C deficiency. High prevalence of subadult scurvy (35.8%), attributed to seasonal shortages of fresh fruit and vegetables, was found for a medieval population from Straubing, Germany (Kreutz, 1997 cited in Schultz 2001), although the methods of scurvy diagnosis used by the author and her associates raised some controversy (Mays 2014). Not only seasonality but also socio-economic factors may have predisposed to scurvy in the Middle Ages. The diet of working-class people prior to the 16th century, mainly based on grains supplemented with salted and/or dried meat or fish and very small amount of raw plant products, was presumed to have caused widespread scurvy (Prentice1939 cited in Hughes 2000). To our knowledge, only two studies have been published on childhood scurvy in

medieval Poland. The first study found only one of the 85 subadult skeletons with lesions consistent with scurvy (Agnew et al. 2008). The second study showed greater prevalence of the condition for three samples, ranging from approximately 3% in rural subadults, through almost 7% in children of lesser gentry, to slightly more than 7% in urban subadults (Kozłowski 2012). Importantly, complete obliteration of histological signs of scurvy may occur after 3 months of vitamin C treatment (Brickley and Ives 2006), thus the skeletal signs might have disappeared when even small amounts of this vitamin were ingested in late spring and summer, considering that the intake of vitamin C in the climatic conditions of the Polish territories is season dependent.

It was found that the risk of vitamin D deficiency can be increased by various effects of urban life, including factors such as overcrowding, sanitation, food availability and quality. Prior to urbanization and industrialization in the post-medieval period, the occurrence of rickets may be linked to living conditions, and dietary or cultural practices (Brickley and Ives 2008). The manifestation of this condition on the subadult skeleton is related to the general nutritional status of the child, age at occurrence, and the child's rate of growth and mobility (Lewis 2007). In archaeological record only a few cases of rickets have been reported, with the frequencies typically below 5% (Brickley and Ives 2006, Table A2, pp 134–142). In the medieval Polish subadults the prevalences of skeletal signs of rickets rarely exceed 3% (Table 3). This is also true for the examined samples from Cedynia, Ostrów, and Słaboszewo. The early changes of rickets are subtle, while more obvious extreme bowing deformities are later manifestations, and result from applying weight to the limbs. In consequence, the children may become immobile and, with associated whooping cough and gastrointestinal infections, they may not live long enough to develop clear skeletal traces (Lewis 2007).

Preferentially stressed subadults

It is commonly expected to find a high proportion of the youngest children with skeletal signs of stress and poor health in archaeological samples (Ribot and Roberts 1996). For example, infants and young children are particularly prone to develop defective blood vessels and show skeletal manifestations of scurvy than adolescents due to their rapid growth (Ortner et al. 2001; Brickley and Ives 2008). This is supported by the results of the study of Polish samples, where almost all scorbutic children ranged between the 1st and 7th years of age. With regard to respiratory infections we failed to demonstrate higher prevalence of maxillary sinusitis in the youngest subadults, likely because of small sample size in this age category, in contrast to Teul et al. (2013), who found the highest occurrence of maxillary sinusitis in the youngest children (0–6years) from medieval Poland. However, our research on otitis media showed a significantly higher frequency of eroded incudes in the age category 0–3 years old than in the category 4–11 years old.

Small children, up to about age 3, accompany their mothers in household indoor activities, such as cooking, which exposes them to smoke from the open hearth (Bruce et al. 2001; World Health Organization 2014). This was confirmed in modern studies, which found the highest prevalence of chronic sinusitis in the youngest age category (<3years of age) as compared with older children (Swischuk

et al. 1982). In medieval Poland small children stayed close to their mothers. Polish historical writings demonstrated the especially close mother-child bond until the child was 3–4 years old (Żołądź-Strzelczyk 2002), which was partly due to breastfeeding, lasting up to about 3 years of age in medieval Poland (Tyszkiewicz 1983; Żołądź-Strzelczyk 2002; Delimata 2004), similarly to other European medieval populations (Kaupová et al. 2014; Britton et al. 2015).

Stable and unstable environments

It should be considered whether the key factor in response to adverse environmental and socio-cultural factors in medieval Poland was the stability of life conditions in the village (Słaboszewo), which allowed the inhabitants to develop sufficient adaptive mechanisms. In contrast, the history of strongholds such as Cedynia, located near important trade routes, was marked by changes, in terms of political situation, military threats and migrations of people (see Kozłowski 2012). Life table parameters showed that average life expectancy of adults (e20) was much lower for Cedynia (20 years) than for Słaboszewo (26 years) (Piontek 1981; Piontek and Mucha 1983). This suggests poorer living conditions in the early urban than in the rural site, causing people from Cedynia to die at 40 years of age on average as compared with 46 years for Słaboszewo. Common childhood diseases with potential severe consequences, including respiratory infections, must have contributed to shortening of the average longevity of medieval people.

Historical writings and skeletal data

Human skeletal remains are an exceptionally valuable source of information on the genetic and physiological responses to the challenges exerted in the past by natural and socio-cultural environments. Knowledge about the recent human history is based on inferences gained through analysis of artifacts, documents, and other culture based sources. In contrast to physiological processes of growth, development, and acclimatization to environmental change such information is subject to bias and subjectivity. Unlike written records, human skeletal remains provide a direct source of evidence about the lives and deaths of past people (Walker 2008). Facts about the past inferred from available historical writings are frequently biased, through, among others, reflecting the preconceptions and interests of their authors or misinterpreting the evidence by modern scientists, because there isn't any objective standards of data interpretation. The survived evidence has often been preserved according the interests of past archivists, and not always can be considered a reliable source of knowledge about the past (McCullagh 2000).

Historical documents describing high frequencies of scurvy in late medieval and early historical Poland as contrasted with the skeletal research proved to be a culturally biased source of information. Late medieval writers reported exceptional 'organic susceptibility' of Polish people's to this disease (Kuchowicz 1972). Medical guides and herbals frequently informed about antiscorbutic treatment and medicines, and also, many real and quack doctors advertised themselves to be able to cure scurvy. Death records from the 18th/19th centuries listed scurvy among the causes of death. Historians assume that this condition was common in two contrasting social groups, members of the upper social class, because

of their limited diet, primarily based on meat, fat and alcohol, and among the poorest people, because of their general undernutrition (Kuchowicz 1972). Scurvy prevalence decreased much later, as a consequence of widespread cultivation of potatoes at the beginning of 19th century (Leszczyński 2012). Taking into account historical records, it was expected to find a relatively high proportion of scorbutic cases among the medieval and post-medieval Polish children. The obtained frequency of c. 4% appears neither high nor low compared with other medieval European populations (Brickley and Ives 2008: Table A1, pp. 72–74; Mays 2014: Table 2). Thus, it seems that historical accounts of particular susceptibility of inhabitants of medieval and postmedieval Poland to scurvy were exaggerated and maybe, other disorders (e.g. periodontal diseases) were mistaken for this disease.

Limitations of bioarchaeological subadult studies

A common limitation in the bioarchaeological subadult studies is under-representation of the skeletal remains (Henneberg 1977). The lack of reliable number of immature skeletons is mainly due to taphonomic, methodological and cultural factors, such as living conditions affecting survival rate, and funerary treatment (Buikstra and Ubelaker 1994). Some of these factors are population and/or site specific, and, not surprisingly, large numbers of subadult remains have been occasionally recovered from archaeological sites. On the basis of Weiss' (1973 cited by Lewis 2007) notion on modern pre-industrial societies, it is estimated that the proportion of subadult remains recovered from pre-

historic and early-modern cemeteries should at least amount to 30% of the total sample. There are quite numerous samples of medieval Polish subadults representing early-urban settlements, while relatively lower percentage of subadult remains have been recovered from rural cemeteries. Perhaps, such situation results from the lack of archaeological scientific programs of studying rural settlement structures in Poland, in contrast to Western Europe, where such research has been commonly conducted (Buko 2011). Importantly, many skeletal indicators are assessed on cranial elements, including cribra orbitalia, porotic hyperostosis, enamel hypoplasia, endocranial lesions, maxillary sinusitis, otitis media, and scurvy, while immature skulls usually present poorer preservation than more robust long bones or other postcranial elements. As a consequence, comparisons of health status and growth between urban and rural children has often limited statistical power.

Age-at-death of a child is a fundamental biological information used to make inferences about mortality rates, growth and development, morbidity, weaning, congenital and environmental conditions. Aging methods are based on assessment of physiological processes of dental or skeletal maturation, and on the accurate conversion of biological into chronological age (Lewis 2007). This conversion can be biased by individual variation, environmental effects, disease, secular changes and genetics (Saunders et al. 1993; Lewis 2007). There are chronological differences in the development of the dentition and skeleton between the sexes, while biological sex is seldom determined for immature remains (see the chapter below). Dental development remains under stronger genetic control

and is less subject to environmental influences than skeletal growth and maturation (Cardoso 2007; Saunders 2000), and tooth mineralization is the preferred method for age estimation. For dental aging, radiographic standards proposed by Moorrees and colleagues (1963a; b) for deciduous and permanent dentition are preferred, as they are based on a relatively large sample of deciduous and permanent teeth of White American males and females. Those data were refined and tabulated by Smith (1991, p. 160–161) and Lewis (1999, Appendix I). When the dentition is unavailable, age estimates rely on the development, growth and maturation of the skeleton, including the data on diaphyseal lengths, bone size, and the appearance and fusion of the secondary growth centres to the diaphyses. Bone fusion is used for older children, because it begins approximately at 11 years of age and ends at 17 years in females and 19 years in males (Scheuer and Black 2000; 2004; Schaefer et al. 2009). A limitation to age assessments of immature remains is then an unknown proportion of boys and girls in a sample and differential age they enter the pubertal spurt (Hoppa 1992; Lewis 2007).The sexually dimorphic features of the pelvis and skull do not become apparent until puberty, which makes assigning sex to subadult skeletons problematic. According to Scheuer and Black (2004, p. 1) morphological sex estimation on juvenile skeleton is "tentative at best". Assessment accuracy is expected to be at least 50% better than chance, which makes 75% (Saunders 2000), while in children, most aging methods fail to yield an accuracy of 70%, with the degree of overlap between male and female values and problems with reproducing accurate results on different populations (Lewis 2007). The application of a DNA analysis is promising for the future, but now high costs of such research still do not allow for population-level estimates. It should be also borne in mind that molecular sex analysis involves problems of contamination, consistency, control, false negatives and false positives.Sex estimation in subadults through morphological features would potentially benefit from two research areas, including an analysis of traits that show early signs of dimorphism and an analysis of the dimorphism in the rate/timing of development (Moore 2013).

Problems inherent to paleopathological research

Fundamental issue in interpretation of paleopathological data is the accurate differential diagnosis of diseases apparent in skeletal remains, while the response of bony tissue can take only five main forms: abnormal bone formation and destruction, abnormal bone size, shape, and density (Ortner 2003). Furthermore, some diseases leave no observable traces on the skeleton, and different diseases may overlap in their skeletal manifestations (Mays 2002; Gładykowska-Rzeczycka 2009). The diseases encountered in archeological human remains are commonly the result of chronic conditions, meaning survival with the disease for many months or years. The individuals without bone lesions may have been in fact the ones most severely affected by the disease, who died prior to formation visible skeletal response, and absence of skeletal disease may imply death due to acute conditions. On the contrary, evidence of skeletal disease may indicate a strong immunity to ensure survival to the chronic stage (Ortner 2003). In some

individuals a particular condition might not have been sufficiently advanced to be identified in the skeletal material or the affected person might have recovered before obvious traces became apparent (Roberts and Manchester 2005; Brickley and Ives 2008; Ortner 2003). Thus, the number of skeletons affected by a given condition may not accurately reflect the number of disease incidence, measured as the number of new cases per total population at risk (Waldron 1994; Roberts and Manchester 2005; DeWitte and Stojanowski 2015). Furthermore, disease prevalence, defined as the number of cases per total skeletal sample, may not represent the true prevalence in the once-living population, because the archaeological sample represents an accumulation of changes that occurred throughout the lives of the individuals. In result, higher frequencies of pathological cases are found in skeletal samples than in modern populations (Waldron 2009). Notably, both proliferative and resorptive changes in the child skeleton may actually be normal physiological responses, related to the processes of bone growth and remodeling. Abnormal porosity of infantile bones, which is a crucial observation in many conditions, is very difficult to differentiate from vascular holes in cortical bone being a normal anatomical feature (Ortner et al. 2001). Another pertaining problem are different methodologies used by the researchers to record and analyze paleopathological data, and it might be difficult to make any direct comparisons between the studies.

Taphonomy of the skeletal remains

The impact of taphonomic processes on the integrity of skeletal remains should be accounted for, because they may ob-scure the signs of disease and complicate pre-existing pathology. Destructive processes can be the result of postmortem changes due to the immediate burial environment, and problems during or after excavation. Extrinsic and intrinsic factors can influence bone preservation. Intrinsic factors include the chemistry, size, shape, density, porosity and age of the bone, whereas extrinsic factors such as groundwater chemistry, soil type, temperature, oxygen levels, flora and fauna play a role in diagenesis (Ortner 2003; Lewis 2007). Those agents can result in poor preservation, and also in the loss of certain skeletal elements. Having a complete skeleton available for the paleopathological diagnosis is often very important, because it allows for analyzing the pattern of pathological changes across the skeleton (Roberts and Manchester 2005; Brickley and Ives 2008). In our research on otitis media we found that the antemortem and postmortem bone erosion of the incudes co-occurred in 34.7% of cases, which indicates that the pathologically affected area is susceptible to postmortem environmental changes. Importantly, adult and subadult skeletons differ with regard to the effects of taphonomic changes. Robinson and colleagues (2003) have shown that immature faunal remains are more porous than adult bones, which makes them more vulnerable to decay. The high organic and low inorganic content and small size of subadult bones contribute to their high susceptibility to taphonomic processes (Lewis 2007).

Conclusions

The analysis of skeletal indicators of growth and health of medieval and postmedieval children and adolescents

from the Polish territories shows their relatively low-to-medium experience of stress events and nonspecific infections as compared to other European subadults. This finding suggest that they were rather well adapted to their both natural and cultural environments, while early-urban subadults presumably have been exposed to stress more intensely than the rural children and adolescents. It seems that the strongholds and villages particularly differed in factors predisposing to respiratory infections. Living conditions, which may be responsible for this pattern, include higher population density, lower quality of housing, higher water contamination, poorer air quality, and lower hygiene in early-urban than rural settlements. On the other hand, rural children had the shortest femora among all examined samples, which seems to be the response to poor nutrition. The children in medieval and early historical Poland also suffered from diet-dependent diseases, such as vitamin C deficiency, which mainly resulted from cultural reasons – strongly limited food composition. Moreover, seasonal fluctuations in food availability and poor harvests have caused long periods of very poor nutrition that were detrimental to child's growth and health.

Studies of children's skeletal remains have undergone a transformation from basically descriptive or methodical approaches to a problem-oriented perspective, as researchers began to assess the impact of agriculture, colonization and urbanization on child health. This transition was possible due to a significant contribution of auxological research to our understanding of human physical growth and development. Studies of living children from anthropological perspective demonstrate and explain the effects ex-erted by biological and socio-cultural factors on ontogenetic processes (Kaczmarek and Skrzypczak 2011; Kozieł and Bose 2012). In contrast, little is known about the agents underlying biological phenomena in past populations, which have been reconstructed by bioarchaeologists through skeletal analyses. Thus, the interpretations about past human societies are based on current auxological knowledge provided by large national, and commonly longitudinal, studies (Bogin 1999).

Conflict of interest

The Author declares that there is no conflict of interest regarding publication of this paper.

Corresponding author

Department of Human Evolutionary Biology, Institute of Anthropology, Faculty of Biology, Adam Mickiewicz University in Poznań, ul. Umultowska 89, 61-614 Poznań, Poland
e-mail address: martak@amu.edu.pl

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