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Research article

Prevalence of chronic maxillary sinusitis in children from rural and urban skeletal populations in Poland

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ABSTRACT

Maxillary sinuses of 100 subadults from Cedynia, an early-urban site (stronghold), dated to the 10th-14th centuries AD, and of 28 subadults from Słaboszewo, a rural site, dated to the 14th-17th centuries AD, were examined for bone formation indicative of chronic sinusitis in order to explore the effect of urban and rural environments on the occurrence of upper respiratory tract infections in the past. We expected a higher prevalence of sinusitis in subadults from a stronghold than from a village, because of such factors as crowding, rapid spread of infections, and pollution from workshops located in the streets. We found a statistically non-significant tendency toward a higher prevalence of the condition in Cedynia compared to Słaboszewo (18.0% and 7.1%, respectively). The majority of maxillary lesions were classified as spicules. Changes to bone morphology suggestive of sinusitis of dental origin were not found. The development of observed osseous lesions may be attributed to culturally determined risk factors such as low quality of housing, air pollution caused by smoke from the household hearth and street workshops, poor levels of hygiene, and water contamination.

1. Introduction

Sinusitis is an inflammation of the mucosa of the paranasal sinuses, involving both infectious and noninfectious mechanisms (Chan et al., 2006; File, 2006; Benninger, 2010). The medical term is "rhinosinusitis", because the disease affects the mucous membranes lining both the nose and the sinuses. The paranasal sinuses are air-filled cavities in the bones of the face and skull, all of which communicate with the nasal cavity through narrow openings (ostia). The ostium of the maxillary sinus, the largest paranasal sinus, is situated in the superior aspect of the medial wall. This opening enables the sinus to be both drained and ventilated, though the location of the ostium makes these functions difficult in an upright position (Kariyawasam and Scadding, 2011). The mucosa of the sinuses is lined with a surface layer of cilia, which enables transport of mucus and particulate matter (viruses, bacteria, foreign animal and plant proteins, irritants) into the nasal cavity and then the nasopharynx, where it is swallowed. This process is known as mucociliary clearance. There are three conditions which are necessary for normal functioning of the sinuses: ostiomeatal patency, adequacy of mucociliary clearance, and normal quality and quantity of secretions. Disruption of any of these components may result in thickening of the mucosal layer, epithelial dysfunction, obstruction of the ostia, retention of secretions, and finally sinusitis. Impaired mucociliary mechanisms can result in mucous stasis within the sinuses that can lead to chronic dysfunction and infection (Hertler et al., 2006).

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, like dust, ozone, sulfur dioxide, smoke). Acute maxillary sinusitis is caused by blockage of the ostium through edema and inflammation of the nasal mucosa mainly resulting from viral infections (File, 2006). When the condition becomes chronic, a bacterial infection may develop, predominantly caused by *Streptococcus pneumoniae*, *Haemophilus influenzae*, and, most commonly in children, *Moraxella catarrhalis* (Leung and Katial, 2008; Romeo and Dykewicz, 2014). Chronic sinusitis relates to an infection with symptoms (nasal blockage/discharge, facial pain) lasting longer than 12 weeks. It is not a chronological extension of acute sinusitis, but a complex inflammatory process that can result from single or multiple inde-

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pendent (or interdependent) etiologies (Leung and Katial, 2008; Benninger, 2010). Today it is a common condition, accounting for a substantial morbidity rate, especially in areas with much atmospheric pollution (Hamilos, 2011). Of all the respiratory infections rhinosinusitis belongs to the most common illnesses affecting a high proportion of the population (File, 2006), including 18%-45% of children (Fokkens et al., 2012). The prevalence of rhinosinusitis in Europe is 10.9%, with marked geographical variation, and 14% in the USA (Fokkens et al., 2012). In Poland the prevalence of chronic rhinosinusitis is approximately 16% in adult population (Hastan et al., 2011; Khaitov et al., 2015). The main direct cause of chronic maxillary sinusitis, frequently associated with bacterial invasion, is obstruction of the ostium. In children, the most common predisposing factor is upper respiratory infection (File, 2006; Hertler et al., 2006; Benninger, 2010), which leads to narrowing of the ostia, smaller in children as compared to adults (Chan et al., 2006; Hertler et al., 2006). Immaturity of the immune system also contributes to pediatric sinusitis (Lusk, 2012). Each child has three to eight colds per year, up to 80% of which are associated with rhinosinusitis (File, 2006). Bacterial maxillary sinusitis complicates up to 2% of all upper respiratory infections (Clement, 2006).

The role of environmental pollution is increasingly recognized as a cause of rhinosinusitis in children (Hertler et al., 2006). Air pollutants act as irritants causing, among other things, dryness and local inflammation (Jackman and Kennedy, 2006; Benninger, 2010). There is consistent evidence that both ambient and household air pollution cause upper (laryngitis, sinusitis) and lower (bronchitis, asthma, chronic obstructive pulmonary disease) respiratory diseases and other conditions, which can even be fatal (WHO, 2014). Wood smoke contains irritants, systemic toxins and carcinogens, and has been proven to have considerable polluting effects (Ezzati and Kammen, 2001). Many studies have found a significant association between the occurrence of respiratory health problems and exposure to wood smoke (e.g. Larson and Koenig, 1994; Riojas-Rodríguez et al., 2001), and to particulate pollution from agriculture (McCurdy et al., 1996). Burning of wood for heating, cooking, and lighting results in exposure to such pollutants as fine particles and carbon monoxide (WHO, 2014; http://www.who.int/heli/risks/indoorair/indoorair/en/). It was also found that high amounts of polycyclic aromatic hydrocarbons present in wood smoke produce high levels of free radicals, DNA damage as well as inflammatory and oxidative stress response gene expression (Danielsen et al., 2011). As shown for India, all household members in poorly ventilated dwellings are exposed to the adverse effects of wood smoke, but the highest risks occur among women and their youngest children, who spend the most time near the domestic hearth (Smith, 2000; Balakrishnan et al., 2004; WHO, 2014). Studies comparing high and low woodsmoke areas found statistically significantly higher levels of congestion and wheezing in 1- to 5-year-olds, supporting the notion that young children are particularly susceptible to the adverse effects of wood smoke (Naeher et al., 2007).

Apart from reliance on biomass fuels, the main factors contributing to poor air quality also include poverty and low quality of housing (inadequate ventilation, crowding, unsanitary conditions). In poorly ventilated homes, the harmful health effects of indoor air pollution are exacerbated, because smoke can exceed acceptable levels for fine particles a hundredfold. In developing countries, indoor air pollution generated by inefficient and poorly ventilated stoves burning biomass fuels such as wood is responsible for the deaths of 1.6 million people annually, with predominant incidence among children under five years of age (WHO, 2014; http://www.who.int/heli/risks/indoorair/indoorair/en/). The use of open fires causes greater health risks than a stove with a chimney (Schei et al., 2004).

As a result of chronic or repeated inflammation, bone changes within the maxillary sinuses may develop. The sinuses may also become infected because of dental disease (e.g. caries and periapical lesions), such as an abscess that perforates the sinus (Roberts and Manchester, 2005, p 176). The maxillary sinuses exhibit a two-phased growth spurt, between birth and 3 years and again from 7 to 12 years of age, and reach their adult size by age 15 (Chan et al., 2006; Hertler et al., 2006; Lorkiewicz-Muszyńska et al., 2015). However, they are well-developed and extensively pneumatized already at birth, with mean width of 12 mm and mean height of 12.5 mm in the age category 0–12 months (Scheuer and Black, 2000, p. 135). Thus, already at birth they are clinically significant and radiologically visible (Chan et al., 2006; Krouse and Stachler, 2006). Pathological changes in the form of bone deposition and/or resorption are most commonly found on the floor of the sinus (Roberts and Manchester, 2005, p 174; Lewis, 2007, p 137; Roberts, 2007; Waldron, 2009; p 114). The use of periosteal new bone formation as an indicator of maxillary sinusitis in past populations was first presented by Wells (1964). Later studies showed rather low frequencies of this condition, less than 10%. Diagnostic criteria were provided by Boocock et al. (1995a) and this study was one of the first to have reported a relatively high prevalence of maxillary sinusitis, exceeding 50%. This result was likely due to a specific sample, deriving from a leprosy hospital cemetery. Clinical studies revealed a greater frequency of sinusitis in lepromatous individuals, caused by the involvement of the nasal mucosa in leprosy (Boocock et al., 1995a).

Environmental factors affecting the prevalence of maxillary sinusitis are the derivatives of climate, settlement pattern, and socio-economic system of a population. The extent to which those factors can be inferred for skeletal populations depends, among other factors, on the available contemporary archaeological and historical data and documentation. In past populations maxillary sinusitis has been found to be more prevalent in urban sites (Lewis et al., 1995; Roberts and Lewis, 2002; Roberts, 2007), although not universally (Panhuysen et al., 1997; Lewis, 2007; p 137). It has been suggested that the urban environment exposed people to pollutants in the atmosphere, both internally in poorly ventilated houses, and externally (Camuffo et al., 2000; Roberts and Manchester, 2005, p 174).

Children are among the most vulnerable members of a society, and their health parameters reflect the ability of the whole population to adapt to environmental conditions. We hypothesize that the development of urban centers in Medieval Poland, characterized by overcrowded and unsanitary conditions, resulted in higher rates of infectious diseases in urban children compared to their rural counterparts. This study aims to compare the prevalence of chronic rhinosinusitis in the skeletons of subadults excavated at two cemeteries associated with an urban and a rural community.

2. Materials and methods

2.1. Materials

We chose to examine non-adult individuals from an early-urban and a rural site to assess whether urbanization had a harmful effect on their health. The signs of maxillary sinusitis were recorded in subadults (<20 years) from two sites located on the territory of Poland, Cedynia (52°52′45.30″ N, 14°12′07.99″ E) dated to the 10th–14th centuries AD, and Słaboszewo (52°47′21.82″ N, 17°57′59.06″ E) dated to the 14th–17th centuries AD (Fig. 1). The distance between these two sites is about 280 km, and both are located in lowland lake areas. Although the sites are not contemporaneous, they both reflect the living conditions in Medieval Poland, because the settlement structure of the villages remained unchanged from early to Late Medieval and Early Modern times (Piontek, 1981; Chwalba, 2005). There were, in total, 257 indi-

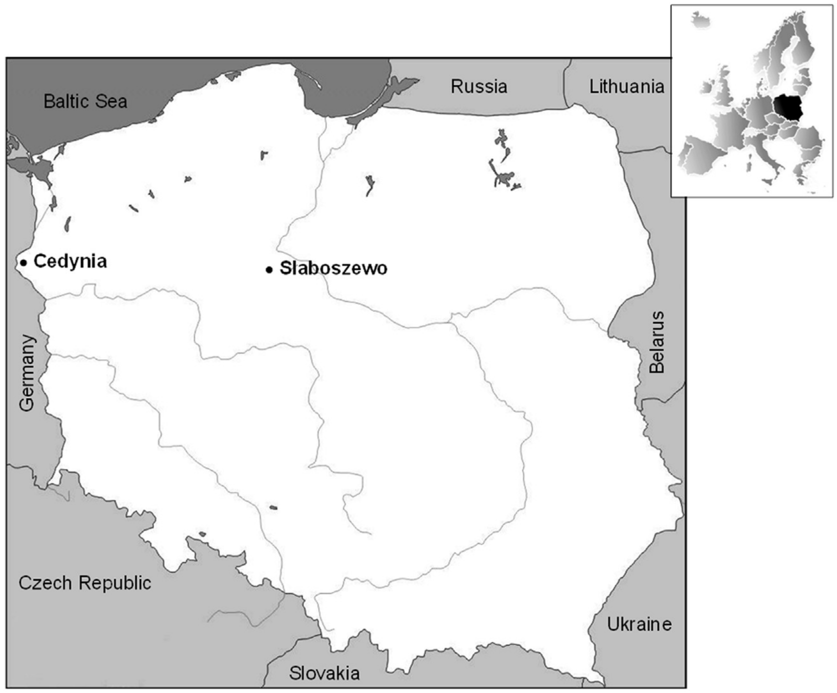

Fig. 1. Map of Poland with marked locations of the examined sites.

viduals from Cedynia and 178 individuals from Słaboszewo with available cranial and/or postcranial parts of the skeleton.

Medieval Cedynia was situated along two important trade routes, one riverine route leading from the north to the south of Poland and another, land route, leading to the east (Filipowiak, 1966; Porzeziński, 2006). The favorable location of the settlement promoted its rapid development and contributed to increasing trade contacts, advancement of the craft, and the growing wealth of its inhabitants. In the 10th century, Cedynia became a border-fortress of high military and strategic significance. From the end of the 11th to the beginning of the 12th century, the economic development of the site was particularly dynamic, as it became a metropolitan centre that gathered together people of high social status (Porzeziński, 2012). In the second half of the 13th century, a series of devastating wars impoverished the local population (Malinowska-Łazarczyk, 1982). Subsistence was based primarily on farming and livestock, and a large amount of fishing, while hunting was rather a tertiary activity of the inhabitants (Malinowska-Łazarczyk, 1982). The stronghold was built in the 10th century, and occupied an area of 150 m × 100 m, with usable interior space of 70 × 80 m (Porzeziński, 2012). The military character of the settlement was reflected in the construction of the wall, which was 12 m high and 25 m wide at the base, and in the tight arrangement of the wooden houses along the wall (Filipowiak, 1966).

At the turn of the 10th century a cemetery was located on a hill, 200 m northwest of the stronghold, and was used up to the end of the 11th century. Nearby, a second cemetery was established at the turn of the 11th century and was used until the first half of the 14th century. In the 13th century, a church was built in the highest, central part of the hill, which was not used for burial purposes. The cemeteries served as burial grounds for the inhabitants of both the stronghold and the surrounding urban settlement; thus the people buried there were socially stratified, including members of the magnate's court, merchants, craftsmen and paupers (Malinowska-Łazarczyk, 1982; Porzeziński, 2012). The deceased were deposited according to the religious rites of Latin Christianity, along the west-east axis, in extended and supine position (Malinowska-Łazarczyk, 1982). Grave goods were absent in the majority of the burials, and if present, they were rather scarce. Certain graves contained some items of daily use, and there were only a few burials with rich grave goods. This resulted partly from religious regulations that considered grave furnishing a pagan custom, and partly from the medium-to-low social status of the majority of the buried individuals. Only in the period from the end of the 11th century to the beginning of the 12th century were grave goods relatively more numerous, reflecting the prosperity of the site (Malinowska-Łazarczyk, 1982). Archaeological excavations at both cemeteries recovered approximately 1600 well preserved skeletons (Porzeziński, 2012), including the remains of about 250 subadults (<15 years of age) in different states of preservation. The percentage of subadult burials is then slightly less than 16%, which appears a significant under-representation, as the expected value is at least 30% (Lewis, 2007; p 22). No systematic information is available on the exact chronology of particular burials, nor the social status of the individuals.

By comparison, Słaboszewo was a rural site, a village, which belonged to the Gniezno archdiocese from the 15th century on (Piontek, 1977). It was first mentioned in historical sources in 1395 A.D. Unfortunately, only some general information has been published on its inhabitants. They were farmers representing a typical Late-Medieval local society (Piontek, 1981) that lived a rather harsh but stable life far from important trade routes. In the second half of the 14th century, the Słaboszewo parish consisted of 288 people, and occupied an area of 38.9 km^2 (population density 7.4 per km^2), while in the 18th century the number of inhabitants nearly doubled (Piontek, 1977). The cemetery was situated on a hill at the edge of the village. Archaeological studies of the area started in the 19th century and continued in the 20th century as a rescue excavation, preventing destruction caused by extraction of gravel. Because of partial damage to the burial ground it is impossible to establish its original size and the actual number of the people buried there. Approximately 550 skeletons, associated with the remains of a church dating from between the second half of the 14th century and the first half of the 17th century, were uncovered, with the majority of burials dating to the 15th and 16th centuries (Piontek, 1981). The arrangement of the skeletons in the graves corresponded

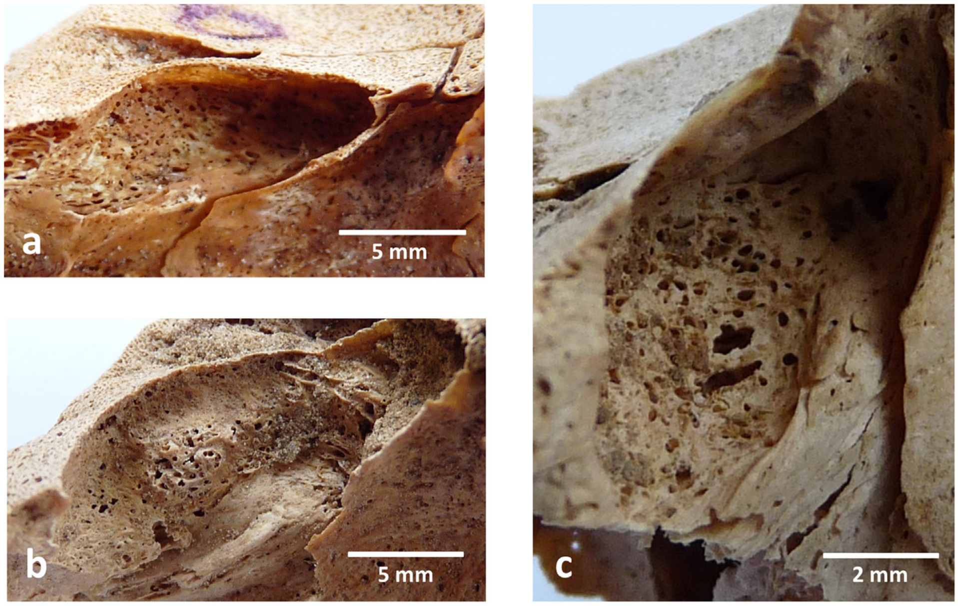

Fig. 2. Maxillary sinuses of the youngest children in the study, recovered from the cemetery in Cedynia; a – 6 months of age; b – 9 months of age; c – 1 year of age.

to the rites of Latin Christianity (Piontek, 1981). The cemetery was used intensively, and the deceased were buried in multiple layers, which led to considerable damage to the grave pits and the skeletons. Thus, establishing the chronology of particular burials was not possible (Piontek, 1981). Approximately 215 subadult (<15 years of age) skeletons in different states of preservation were recovered, which makes up about 39% of the deceased (Piontek, 1981).

2.2. Living conditions in a medieval stronghold and late Medieval/Early modern village

So far no scientific descriptions have been published on the settlement structures and detailed socio-economic features for either Cedynia or Słaboszewo. Thus, in this paper living conditions in the examined sites will be mainly inferred from the historical data, based on archaeological findings and Medieval written accounts, on the daily life of Polish Medieval stronghold's inhabitants of medium-to-low status, and Late Medieval/Early Modern poor rural people. Those data will be extrapolated to Cedynia and Słaboszewo, respectively.

The population of the Medieval stronghold was dense and lived in a network of narrow streets lined with tightly packed wooden buildings (houses, shops, workshops). In the particular case of Cedynia, it is known that the interior of the stronghold was built up densely, with the wooden houses tightly set along the wall (Filipowiak, 1966). The workshops, including metal smelting spots, tanneries, laundries, butcheries, malt houses, and steam houses, together with charcoal markets, produced smoke and dust. Water contamination by waste and feces and numerous rats in the streets contributed to the rapid spread of infectious diseases. 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 louver at the top. 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).

The settlement structure of the Polish villages established in the Early Medieval times endured until about the 19th century, thus no essential changes took place from Early to Late Medieval and Early Modern times. Rural houses were usually wooden, with the hearth built inside. In winter months they also provided shelter for domestic animals. Open air hearths close to the house served for cooking and outdoor works, such as firing pottery and smoking food, almost all year round, except winters. 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). The quality of water was undoubtedly higher than in the towns (Tyszkiewicz, 1983).

2.3. Demographic data

Age at death of the examined subadults was determined on the basis of dental development, according to standards proposed by Moorrees et al. (1963a,b) and tabulated by Smith (1991, p 160–161) and Lewis (1999, Appendix I). In cases where teeth were absent, the data from bone lengths and the degree of epiphyseal fusion were used, according to various studies gathered by Scheuer and Black (2000, 2004), and Schaefer et al. (2009). These non-dental criteria were applied in approximately 9% of the total sample, including c. 13%, 9% and 2% for 0–3.9, 4.0–11.9, and 12.0–19.9 age categories, respectively. The number of skeletons in different states of preservation aged below 20 years was 257 for Cedynia and 178 for Słaboszewo.

Maxillae were present in 141 subadults from Cedynia and 45 subadults from Słaboszewo. In our analysis, only the individuals with at least one complete floor of the maxillary sinus were included, which made the final number 100 for Cedynia and 28 for Słaboszewo. In accordance with Merrett and Pfeiffer (2000), the maxillae of all subadults, irrespective of their age at death, were examined. There were in total only 3 subadults below 1 year of age, but over 6 months of age, and in each case it was possible to observe the interior of the sinus (Fig. 2). The initial and final number of studied subadults and age at death distributions are presented in Table 1. In total 229 sinuses (114 right and 115 left) were macroscopically examined for new bone formation.

Table 1
Age-at-death distributions in the initial* and final** samples.

Age categories (years)	Cedynia 10th–14th AD				Słaboszewo 14th-17th AD				Total			
	Initial		Final		Initial		Final		Initial		Final	
	N	%	N	%	N	%	N	%	N	%	N	%
0–3.9	86	33.5	16	16.0	69	38.8	7	25.0	155	35.6	23	18.0
4.0–11.9	127	49.4	66	66.0	73	41.0	16	57.1	200	46.0	82	64.1
12.0–19.9	44	17.1	18	18.0	36	20.2	5	17.9	80	18.4	23	18.0
Total (0–19.9)	257	59.1	100	78.1	178	40.9	28	21.9	435	100.0	128	100.0

*total sample size of subadults; ** subadults with at least one complete floor of the maxillary sinus.

2.4. Skeletal manifestations of maxillary sinusitis

Maxillary sinusitis was assessed macroscopically on the basis of new bone formation within the floor and walls of the sinuses (Boocock et al., 1995a; Merrett and Pfeiffer, 2000; Roberts and Manchester, 2005, p 174; Sundman and Kjellstrom, 2013a,b) with the use of a videoendoscope. This technique is minimally invasive, as it does not require openings to be made into the bones, and uses natural foramina. The access through anterior and/or posterior nasal apertures proved possible in each case here because of the partial destruction of the medial walls of the maxillary sinuses.

There are two broad types of skeletal signs of maxillary sinusitis: bone deposition and bone resorption. The detailed classification of bone lesions was established by Boocock et al. (1995a), and then modified by Merrett and Pfeiffer (2000), and Sundman and Kjellström (2013a,b). The following categories of changes were distinguished: pitting, spicules, remodeled spicules, white pitted bone, plaque, lobules, and cysts. In subadults, however, inflammatory pitting is difficult to differentiate from developmental pitting. As the permanent molars develop, the floor of the sinus displays growth pits, as a result of expansion of maxillary alveolar bone which accommodates developing teeth (Lewis et al., 1995). Thus, we decided to record bone deposition only, including spicules, remodeled spicules, plaque, and lobules. "Spicules" refer to single or multiple bone depositions (projections) on the periosteal surface of the bone. They can develop bridging between the spikes and form stellate plates parallel to the surface. "Plaque" is a relatively flat, thin area of bone on a normal bone surface, either smooth and dense or porous, and lobules are rounded masses of bone (Ortner, 2003; p 50; Merrett and Pfeiffer, 2000). The meaning of particular categories of bone changes has not been explored yet, and our reason for recording them was to follow the procedure applied by other authors (Boocock et al., 1995a; Merrett and Pfeiffer, 2000; Sundman and Kjellström, 2013a,b) in case of future research on their significance for the studies of maxillary sinusitis. Each lesion was also recorded for its severity, in terms of the percentage of affected area of the sinus: <25%, 25%–50%, and >50% (not shown here because of low number of observed bone changes).

Both authors of this study examined maxillary sinuses. Interobserver error for lesion classification was tested on 30 sinuses, randomly chosen from the total sample. The scores for the presence/absence were identical in 95% of cases, and the scores for the categories of the lesions were identical in 90% of cases.

Inflammation of the maxillary sinus can also be caused by dental disease. To differentiate between dental and rhinogenous origin of the lesions, the alveolar bone surrounding the roots of the posterior teeth of the upper jaw was examined for periapical lesions and particularly traces of perforations of a dental abscess into the sinus. A differential diagnosis between granuloma, granuloma/cyst and chronic abscess was based on the indications given by Ogden (2008), related to the size and margin of the lesion. A granuloma is usually 2–3 mm in diameter, and a cyst is larger than 3 mm. Both lesions have a thin, sharp margin. A chronic abscess has a rounded or thickened margin, and the bone looks as if it has been frequently remodeled. Abscessing was determined through visual inspection as cloacae either to the buccal and lingual surfaces of the alveolar bone and an oroantral fistula was recorded when a direct connection between the tooth socket and the maxillary sinus was present. The dental source of infection was recorded in case of any abscessing or oroantral fistula (Panhuysen et al., 1997; Merrett and Pfeiffer, 2000; Roberts and Manchester, 2005, p 176; Roberts, 2007).

To explore differences in the presence of signs of maxillary sinusitis between the early-urban settlement of Cedynia and the rural site of Słaboszewo, and to test the prevalence differences between age categories, Fisher's exact tests (FET) and Chi-square tests were carried out. StatSoft Statistica software package version 10 was used. A p-value less than 0.05 was considered significant.

3. Results

3.1. Age at death

Table 1 presents age-at-death distributions in the initial and final sets of skeletons, for the total sample and separately for Cedynia and Słaboszewo. The differences in age-at-death distributions in these two populations are non-significant (Chi-square tests equal 2.996, $p = 0.223$, and 1.254, $p = 0.534$ for the initial and final samples, respectively). For the total sample, children aged between 4 and 11 years make up the largest group (64.1%), with the remaining groups (0–3 and 12–19 years of age) being equal in percentage (18.0%). The only general difference between the initial and final distributions is the lower number of children aged 0–3 years in the latter. This reflects the sampling criteria for this study, because the youngest subadults had relatively the lowest number of well-preserved maxillary sinuses.

Table 2
Prevalence of skeletal signs of maxillary sinusitis by age groups.

Age(years)	Cedynia 10th-14th AD									Słaboszewo 14th-17th AD								
	Right sinus			Left sinus			Right and left sinuses			Right sinus			Left sinus			Right and left sinuses		
	N	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N	n	%
0–3.9	12	0	0.0	14	1	7.1	16	1	6.3	5	0	0.0	6	0	0.0	7	0	0.0
4.0–11.9	62	8	12.9	61	10	16.4	66	13	19.7	12	0	0.0	13	1	7.7	16	1	6.3
12.0–19.9	18	3	16.7	17	3	17.6	18	4	22.2	4	1	25.0	5	0	0.0	5	1	20.0
Total	92	11	12.0	92	14	15.2	100	18	18.0	21	1	4.8	24	1	4.2	28	2	7.1

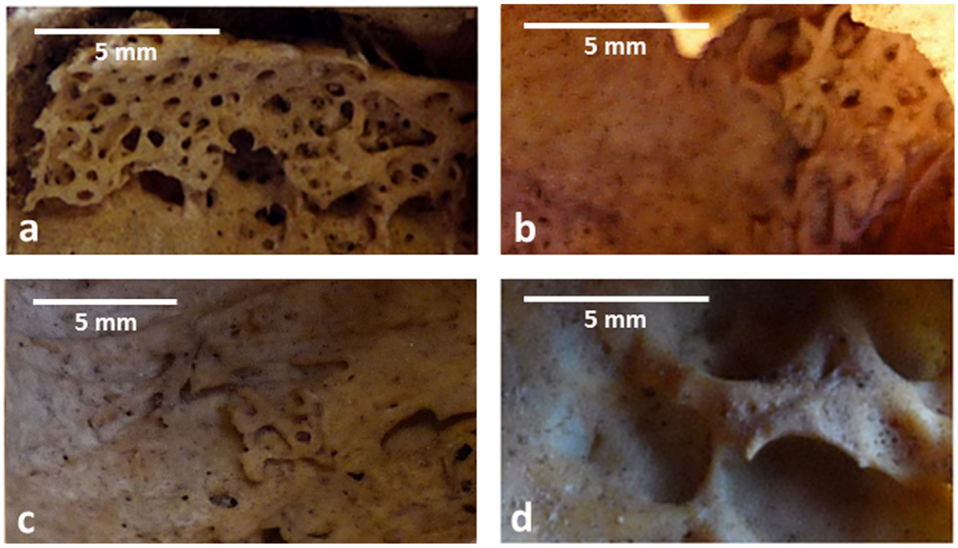

Fig. 3. Bone changes indicative of maxillary sinusitis in the subadults from Cedynia; a – plaque; b, c, d – spicules.

3.2. Skeletal indicators of maxillary sinusitis

Table 2 shows the detailed data on the occurrence of bone lesions indicative of maxillary sinusitis in subadults with at least one sinus by age categories in the two examined populations. Data are shown for right and left sinuses separately and jointly. Fig. 3 shows some examples of bone formation observed. The prevalence of bone changes is 18.0% for early-urban Cedynia and 7.1% for rural Słaboszewo. This difference is statistically non-significant (FET, $p = 0.2404$). The differences between the sites by age categories are also non-significant in Fisher's exact tests (0–3 years: $p = 1.0000$; 4–11 years: $p = 0.2831$; 12–19 years: $p = 1.0000$). In general, the subadults in the age category 12–19 years are the most affected, then those aged 4–11 years, followed by the individuals aged 0–3 years. This refers both to the combined sample and to the two populations treated separately, as well as for both right and left sinuses in Cedynia. Nevertheless, the differences between age categories in the combined sample and separately in Cedynia and Słaboszewo are non-significant (Chi-square tests equal 3.0013, $p = 0.2230$; 1.8428, $p = 0.3980$; 1.8038, $p = 0.4058$, respectively).

Table 3 presents the distribution of particular types of bone changes by age groups. Spicules (including remodeled spicules) were found to be the most frequent type of bone lesion, followed by plaque. Lobules were found only in two subadults from Cedynia, and were absent in Słaboszewo.

Not a single case of periapical abscessing or an oroantral fistula was found in any of the two populations examined. Thus, we inferred that there wasn't any case of dental origin of maxillary sinusitis here.

4. Discussion

4.1. Prevalence

Our study, unlike the majority of bioarchaeological studies of maxillary sinusitis, focused on non-adult skeletons instead of adult remains. Children deserve special attention, because modern studies showed that they are particularly susceptible to the adverse effects of poor air quality (Smith, 2000; Balakrishnan et al., 2004). On the other hand, a limitation to studying child skeletons is the lack of acceptable morphological methods of sex estimation (only aDNA analysis is accurate), although biological sex can be an important factor in the prevalence of sinusitis (Roberts, 2007). Maxillary sinusitis in past human populations examined so far most commonly ranged from 30% to 50% (Boocock et al., 1995a, 1995b; Lewis et al., 1995; Panhuysen et al., 1997; Merrett and Pfeiffer, 2000; Roberts and Lewis, 2002; Roberts, 2007). Occasionally, higher frequencies have been found. In an Iron Age population from Sweden, 88.4% of the adults had bone lesions diagnosed as traces left by maxillary sinusitis (Liebe-Harkort, 2012). In Medieval samples from Sweden (Sundman and Kjellström, 2013a,b) and Germany (Roumelis, 2007; after Sundman and Kjellström, 2013a) exceptionally high prevalences of this condition, exceeding 90%, were recorded. In a Late Medieval sample from England, slightly more than 70% of males were affected (Lewis et al., 1995), similarly to a Medieval Iroquoian population from Canada (Merrett, 2003; after Sundman and Kjellström, 2013a). Roberts and Lewis (2002) also demonstrated culturally driven low prevalences of sinusitis in post-Medieval high status children and adults from industrial London (18% and 3%, respectively). For 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).

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 Polish territory (Żołądź-Strzelczyk, 2002; Delimata, 2004). Lewis et al. (1995) found 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 the 14th-century Grasshopper Pueblo, Arizona, as much as 50.4% of the subadults older than five months were found to have suffered from inflammation of the maxillary sinuses (Schultz et al., 2007). 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. Teul et al. (2013) recorded not only bone deposition, but also bone resorption (pits and cysts) in their subadult sample (0–16 years of age), consisting of only 23 individuals in total. Moreover, these individuals were recovered from two sites, differing in socio-economic status, and probably in origin. In our opinion, the small size and heterogeneity of the sam-

Table 3
Types of bone changes by age categories.

Type	Cedynia 10th–14th AD								Słaboszewo 14th–17th AD							
	0–3.9 yrs		4–11.9 yrs		12–19.9 yrs		Total		0–3.9 yrs		4–11.9 yrs		12–19.9 yrs		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
1	0	0.0	3	4.5	0	0.0	3	3.0	0	0.0	0	0.0	0	0.0	0	0.0
2	1	6.3	5	7.6	3	16.7	9	9.0	0	0.0	0	0.0	0	0.0	0	0.0
3	0	0.0	7	10.6	1	5.6	8	8.0	0	0.0	1	6.3	1	20.0	2	7.1
4	0	0.0	2	3.0	0	0.0	2	2.0	0	0.0	0	0.0	0	0.0	0	0.0

1–spicules; 2–remodeled spicules; 3–plaque; 4–lobules.

ple, and including pits and cysts next to bone formation changes are responsible for the much greater frequency of skeletal signs of sinusitis found by those authors as compared to our study.

All cases observed by us are believed to be of respiratory origin, because neither abscessing in the alveolar bone of maxilla nor a fistula between the tooth socket and the sinus were found. This is not surprising, because it appears from other studies that dental diseases causing sinusitis started to be a problem in adulthood (Chan et al., 2006; Roberts, 2007; Liebe-Harkort, 2012; Sundman and Kjellström, 2013a,b) and this effect increased with age (Panhuysen et al., 1997). Moreover, dental origin of maxillary sinusitis in the majority of human populations is rather uncommon, and accounts for approximately 10% to 12% of cases (Maloney and Doku, 1968). In a sample of 31 subadults Merrett and Pfeiffer (2000) found abscessing in only two cases, and Teul et al. (2013) also observed only two specimens exhibiting dental pathology in 16–22-year-olds suffering from maxillary sinusitis, with no case below 16 years of age. However, dental origin of the bone changes found in our study cannot be entirely ruled out, because infection may spread from the mouth to the maxillary sinus through the middle meatus (Paju et al., 2003). Anyway, there is no basis to infer that dental disease caused bone changes indicative of maxillary sinusitis in our sample (see Roberts, 2007).

4.2. Urban and rural environments in the medieval times

In a review of studies carried out on populations of different periods and geographical locations, a higher frequency of sinusitis was generally found in urban than in rural sites (Roberts, 2007). Lewis et al. (1995) compared two Medieval sites located in the same area in northern England, and found a higher frequency of sinusitis in urban St Helen-on-the-Walls than in rural Wharram Percy. Several factors were likely responsible for 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). Bioarchaeological data show that already in Medieval times air pollution in urban settlements posed a serious health threat (Lewis et al., 1995; Roberts and Lewis, 2002; Sundman and Kjellström, 2013a,b). Sundman and Kjellström (2013a) convincingly showed the relationship between deterioration in air quality and increasing focus on crafts in the Medieval town of Sigtuna. In previous research on Medieval subadult remains from Polish territory, slightly lower prevalences of stress indicators, nonspecific infections and diet-dependent diseases (Krenz-Niedbała, 2009), and a significantly lower frequency of skeletal signs of otitis media (Krenz-Niedbała and Łukasik, 2016) were shown for rural sites compared to early-urban settlements, contrary to the study of Ribot and Roberts (1996), which demonstrated that Early Medieval (Anglo-Saxon) rural children were exposed to stress more continuously and systematically than Late Medieval urban children.

In the present study inhalation of smoke from the household hearth is believed to be one of the main causes of upper respiratory tract infections in the examined children. Constant burning of wood in open fires for heating, cooking, and lighting, together with ineffective ventilation, created a smoky and dusty indoor environment in Medieval and Early Modern houses (Tyszkiewicz, 1983; Dowiat, 1985; Samsonowicz, 2001a,b; Chwalba, 2005; Miśkiewicz, 2010). The key problem was undoubtedly poor ventilation (small windows and lack of chimneys), which normally provides the primary means for maintaining a proper indoor environment (Balaras, 2004). The situation was similar in urban and rural settlements, so the level of indoor air pollution was presumably comparable. On the other hand, outdoor air quality was presumably poorer in urban settlements than in rural ones, such as Cedynia in this study, because of the close proximity of narrow houses and crowding, aiding the spread of infectious diseases, and high outdoor pollution, resulting from, among other factors, charcoal burning, wood burning, wheat threshing, etc. Furthermore, higher population mobility in urban compared to rural centers contributed to increased exposure to pathogens leading to respiratory tract infections. Water contaminated by human feces was likely a vector for the transmission of human adenoviruses. They are among 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). It was found that young children are particularly sensitive to respiratory adenoviruses (Pond, 2005; p 195). It appears that the situation in the rural environment was more advantageous, because of less dense building structures, much lower water contamination, and ambient air pollution, especially for older children, who stayed outside for much of the time, performing farm duties (Dowiat, 1985; Miśkiewicz, 2010). However, rural children were likely more exposed than urban ones to such particulates as dust, fungi, and pollen (Roberts et al., 2012).

With regard to nutritional factors, only general archaeological and historical data are available on Medieval and Post-Medieval Polish children's diet. It is described as limited, poor in vitamins, and based mainly on cereals (Żołądź-Strzelczyk, 2002). From skeletal indicators of scurvy examined previously (Krenz-Niedbała, 2015) we can infer that the intake of vitamin C, known for preventing and relieving the symptoms of virus-induced respiratory infections (Gorton and Jarvis, 1999), was low and similar in strongholds and villages.

Generally, we expected a culturally induced (caused by lifestyle and building structure) higher prevalence of skeletal indicators of maxillary sinusitis in subadults from early-urban Cedynia compared to their rural counterparts from Słaboszewo. However, we found only a non-significant tendency toward a higher general prevalence of the signs of maxillary sinusitis in Cedynia. We claim that the low number of available maxillary sinuses from Słaboszewo did not allow us to obtain significant differences.

4.3. Exposure to air pollution in early and middle childhood

We expected a high proportion of the youngest subadults affected by maxillary sinusitis in our sample, because this is the case in developing countries today. Studies have shown that small children, up to about age 3, accompany their mothers in household indoor activities, such as cooking, and they are thus highly exposed to smoke from the open hearth (Bruce et al., 2001; WHO, 2014). Indeed, the highest prevalence of chronic sinusitis in modern children was found in the youngest age category (<3years of age) as compared with older children (Swischuk et al., 1982; see also Stenner and Rudack, 2014). Polish historical data emphasize the especially close mother-child bond until the child was 3–4 years old (Żołądź-Strzelczyk, 2002). Teul et al. (2013) found the highest prevalence of the bone lesions suggestive of maxillary sinusitis in the youngest age category in the Polish Medieval sample. In the study of the Medieval population from Netherlands, Panhuysen et al. (1997) found more females than males affected by chronic maxillary sinusitis, and stated that the women spent more time near smoke fires than the men.

Staying close to the mother is determined by, among other factors, breastfeeding, which according to historians lasted 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). Current studies from developing countries have clearly shown a causal association between elevated levels of atmospheric pollution and a variety of both acute and chronic respiratory diseases in children (Bruce et al., 2001; Schei et al., 2004; Fullerton et al., 2008; Perez-Padilla et al., 2010; Gordon et al., 2014; Goldizen et al., 2016). The role of exposure to smoke is increasingly recognized as a cause of rhinosinusitis in children (Hertler et al., 2006), and this condition was even called an urban disease (Clerico, 2001). In developing countries this kind of pollution ranks fourth in terms of risk factors contributing to disease and death (WHO, 2014; http://www.who.int/heli/risks/indoorair/indoorair/en/). However, we did not find an elevated number of children in the youngest age group affected by maxillary sinusitis. Unfortunately, in our study, the number of subadults with available maxillary sinuses was lowest in the age category 0–3 years (16 in Cedynia and 7 in Słaboszewo).

We found almost 20% of the 4–11-year-olds from early-urban Cedynia to be affected as compared with about 6% from rural 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 (see 2.2. and 4.2.). Our findings show only a statistically non-significant tendency toward greater prevalence of maxillary sinusitis in older urban than in rural children.

The complex and multifactorial etiology of maxillary sinusitis must be emphasized, with a variety of underlying systemic, local host and environmental factors, which make sinusitis rather a non-specific disease. However, in considering the housing conditions and social environments in urban and rural settlements we referred only to those factors which are described in archaeological and historical scientific publications. By necessity, we did not discuss other possible causes of maxillary sinusitis, which may have contributed to its comparable prevalence in the examined urban and rural children. Another limitation of our study was the relatively low number of available data for a Słaboszewo village, particularly in the age categories 0–3 and 12–19 years. Both examined populations differed in the initial number of individuals, but it was the availability of maxillary sinuses that most influenced the final dataset.

5. Conclusions

We found a rather low prevalence of bone changes indicative of maxillary sinusitis in Polish Medieval and Late Medieval subadults, though comparable to the findings of some other studies of Medieval European children. However, differences in the methods applied by various authors should be taken into account; for example, we did not examine resorptive changes, but only bone formation lesions, a more reliable indicator of sinusitis in skeletal children. We assumed that respiratory health differed between the examined early-urban and rural children, but we did not find significant differences in chronic maxillary sinusitis to support this assumption. In our opinion, low quality of housing, water contaminated by human respiratory adenoviruses, poor air quality, and low hygiene were the main factors that caused skeletal signs of sinusitis in the examined samples.

A limitation of this study is the size of the rural population, which made it difficult to find significant relationships between our samples. To increase the sample sizes, adults from both sites could be included in the analysis. However, this would require a permission to apply an invasive technique, necessary for direct observation of the interior of adult sinuses (Merrett and Pfeiffer, 2000). Our results should then be treated with caution. To arrive at firmer conclusions, more research should be done in the future, including an analysis of bone changes to the visceral surfaces of ribs, as an indicator of pulmonary infection. However, it should be noted, that rib lesions are less common findings in paleopathological research than maxillary sinusitis (Roberts et al., 1994, 1998).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijpp.2016.10.003.

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