CHAPTER 3

A Distant City: assessing the impact of Dutch socioeconomic developments on urban and rural health using respiratory disease as a proxy

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5 In this version of the article, references to “AD” have been updated to “CE” to align with the terminology consistently used throughout this dissertation. All other content remains unchanged from the original publication.

Abstract

Objectives: To investigate the prevalence of respiratory disease in several populations from the Netherlands across different time periods and socioeconomic conditions.

Materials: We analyzed 695 adult individuals from six different Dutch contexts of urban and rural settlements dating to different time periods (i.e., early-medieval, late-medieval, post-medieval).

Methods: For each individual, the presence/absence of chronic maxillary sinusitis, otitis media, and inflammatory periosteal reaction on ribs was recorded macroscopically according to accepted methods.

Results: Statistically significant associations were found in the presence of sinusitis diachronically (early-medieval to late-medieval period, and early-medieval to post-medieval period) both in rural and urban environments. Differences in prevalence rates of otitis media were found statistically significant when comparing rural to urban environments in the early-medieval and late-medieval periods.

Conclusion: Our results suggest that factors such as increased contacts between towns and countryside, higher population densities, and intensification of agricultural production impacted the respiratory health of past populations both in rural and urban settings.

Significance: Our study provides new insights into the impact of environmental changes and urbanization on respiratory disease prevalence, shedding light on the relationship between health and changing social and environmental contexts.

Limitations: Research limitations included the complex etiology of respiratory diseases, and the impact of uncontrollable factors such as hidden heterogeneity, selective mortality, and rural-to-urban migration.

Future research: Further research in different contexts is advised in order to continue exploring urbanization and its impact on human health across both time and space.

Keywords: Netherlands; Maxillary Sinusitis; Otitis Media; Rib Lesions; Periosteal Reaction; Medieval

3.1. Introduction

According to historical sources, urbanization dramatically altered Europe's economic, political, and social realities starting already from the 11th century (de Vries, 1984; Schmal, 2018; Scott, 2018). As cities gradually began to increase their economic production, many people migrated from the countryside to the newly formed urban centers in search of new opportunities. With great numbers of people flowing into cities, population densities increased, while necessary infrastructures (e.g., housing facilities, healthcare system, social support networks) failed, in most cases, to accommodate the needs of the growing population (Blockmans, 2010; Wintle, 2000). As a consequence, starting from the 16th century, problems such as overcrowding, precarious working conditions, and limited access to resources (i.e., clean water, nutritious food, healthcare) were common in many European centers (Benevolo, 1996; Clark, 2009; Wintle, 2000). In contrast, rural people lived in comparatively uncrowded communities, much less threatened by these specific factors, albeit likely exposed to several other hazards such as fungal spores, dust, and pollen (Krenz-Niedbała & Łukasik, 2020).

Because of its complex and varied nature, the urbanization phenomenon has been the center of many bioarchaeological studies aiming to reconstruct its impact on human wellbeing thorough a variety of methods (e.g., non-specific stress markers, dietary isotopes, stature, respiratory disease) (e.g., Betsinger & DeWitte, 2017; Lewis, 1999; Schats, 2016; Sundman & Kjellström, 2013; Western & Bekvalac, 2019). In most cases, it has been suggested that the challenges associated with the transition to urban life (e.g., inaccessibility to food and clean water, overcrowding, etc.) increased exposure to several risk factors such as malnutrition, sanitary hazards, and air pollution, leading to a general decline in human health and, similarly, to increased exposure to infectious diseases (Betsinger et al., 2020). In this framework, respiratory infections (i.e., chronic maxillary sinusitis, otitis media, and pulmonary diseases) have often been studied in relation to urbanization under the assumption that the general worsening of both living and working conditions would result in increased risk of respiratory stress among urban and later industrial populations, suggesting an association between prevalence rates of respiratory disease and certain risk factors such as air pollution, socioeconomic status, adverse climate conditions, and insufficient ventilation of living and working spaces (e.g., Boyd, 2020; Casna et al., 2021; Sundman & Kjellström, 2013). However, most published studies on the impact of urbanization on human respiratory health so far have focused on a particular point in time, rarely addressing changes in urbanization patterns through history (Betsinger & DeWitte, 2021). To fill this gap, we analyzed patterns of respiratory stress across time, assessing and comparing the presence of chronic maxillary sinusitis, otitis media, and inflammatory periosteal reaction on ribs in a large sample from both rural and urban environments, dating from the early-middle ages (300-1080 CE), the late-middle ages (1080-1500 CE), and the post-medieval era (1500-1850 CE). We aimed to test the hypothesis that the prevalence of respiratory stress markers gradually increased over time together with the transition to urban life in the Netherlands. Furthermore, since many bioarchaeological studies on respiratory disease did not observe significant changes between rural and urban populations (e.g., Bernofsky, 2010; Casna et al., 2021; Panhuysen et al., 1997), we hypothesized that prevalence rates of respiratory stress markers would progressively increase with time in rural samples as well.

3.1.1. Upper respiratory tract diseases

Upper respiratory tract diseases are a group of illnesses that affect the nose, throat, or larynx, typically caused by viral or bacterial infections. Aiming to produce comparable results, we collected data on those upper respiratory tract infections that are most often addressed in osteoarchaeology: chronic maxillary sinusitis and otitis media. Chronic maxillary sinusitis (CMS) is an inflammation of the lower paranasal sinuses, small air-filled chambers that surround the nasal passages and help protect them from inhaled fine dust and pathogens. CMS is caused by the accumulation of mucus in the sinus, which provides an ideal environment for bacterial growth and contributes to the inflammation of the mucosa and to the involvement of the bone surface in the form of either depositional and/or resorptive lesions (Boocock et al., 1995; Kocak et al., 2002; Slavin et al., 2005; Stannard & O'Callaghan, 2006). The etiology of sinusitis includes both genetic and environmental factors (e.g., viral and bacterial infections, allergies, and pollutants) (Slavin et al., 2005). As air pollutants act as irritants causing inflammation, the role of both indoor and outdoor air pollution is increasingly recognized as a cause of sinusitis, together with overcrowding and tobacco smoke (Behr & Nowak, 2002; Schwarzbach et al., 2020; Wee et al., 2021). Although CMS is generally not considered a life-threatening condition, if the inflammation spreads from the sinuses to the nearby Eustachian tubes (which connect the middle ear to the back of the throat), it can lead to fluid buildup and inflammation in the middle ear, resulting in otitis media.

Otitis media (OM) is a group of inflammatory diseases of the middle ear, differing in both symptoms and complications (Qureishi et al., 2014). The etiology of OM is complex and includes allergy, physiologic features related to the Eustachian tube, infections (viral and bacterial). Despite it being largely considered as a childhood condition, today chronic OM affects more than 4% of the adult population worldwide (Gisselsson-Solen, 2022).

Bone changes associated to OM include bone growth and resorption of the auditory ossicles, the middle ear cavity, the mastoid bone (i.e., mastoiditis), and of the petrous portion of the temporal bone (Estalrrich et al., 2020; Flohr & Schultz, 2009; Floreanova et al., 2020; Krenz-Niedbała & Łukasik, 2017; Qvist & Grøntved, 2001). Because of the difficulty in examining the middle ear osteologically and the lack of clear scoring criteria, bioarchaeological studies on OM are scant. The majority of the extant studies employed either radiography or light microscopy and observed prevalence rates varying between 6-83.4% (Flohr & Schultz, 2009; Gregg & Steele, 1982; Krenz-Niedbała & Łukasik, 2016; Qvist & Grøntved, 2001).

Despite differences in approaches and observed prevalence rates, most bioarchaeologists generally agree that in the past both CMS and OM tended to be more frequent in contexts associated with urbanization, low quality of housing and/or working environments, and lower levels of hygiene (e.g., Boyd, 2020; Qvist & Grøntved, 2001; Sundman & Kjellström, 2013). However, many bioarchaeological studies of CMS in both urban and rural environments have yielded varying results. In fact, while many have shown a higher prevalence of CMS in urban contexts when compared to rural ones (e.g., Fleischer, 2007; Merrett & Pfeiffer, 2000; Sundman & Kjellström, 2013), others have found no statistical differences between the two environments, suggesting that other causes such as climate, smoking, or exposure to animal dander may also have played a significant role in the spread of CMS and possibly of other upper respiratory tract diseases (e.g., Bernofsky, 2010; Casna et al., 2021; Panhuysen et al., 1997).

3.1.2. Lower respiratory tract diseases

Lower respiratory tract diseases are a group of illnesses that affect the lungs, bronchi, and other structures in the lower respiratory system. In bioarchaeology, inflammatory periosteal reaction on the cortical layer of the visceral surface of the ribs (IPR) has often been used as a marker for lower respiratory tract disease (Davies-Barrett et al., 2019; Roberts et al., 1994; Roberts, 2019). Several clinical studies have attested to the association between particulate matter inhalation and chronic lung inflammation, which may produce IPR on the visceral surface of ribs, where the pleura is in direct contact with the rib cage (Kyung & Jeong, 2020; Paulin & Hansel, 2016; Zanobetti et al., 2000). If chronically inflamed, the pleura can thicken and induce new bone formation (Eyler et al., 2013; Guttentag & Salwen, 1999). Despite the non-specific nature of IPR (i.e., it is caused by a variety of conditions, such as tuberculosis, pneumonia, and bronchitis), its presence in archaeological populations has often been considered as an indicator of the impact of environmental factors (e.g., poor air quality) on human respiratory health (Bernofsky, 2010; Boyd, 2020; Davies-Barrett et al., 2019; Lamber, 2002; Santos & Roberts, 2001; Western & Bekvalac, 2019).

3.2. Materials and methods

For this study, the total sample was composed of six different populations from the area today encompassed by the Netherlands (Table 3.1; Figure 3.1). They were selected because they represent a diachronic window into life in the Northern Low Countries in the early-medieval (300-1080 CE), late-medieval (1080-1500 CE) and post-medieval (1500-1850 CE) periods. Here, the traditional tripartition (early Middle Ages, 300-1000 CE; central Middle ages, 1000-1300 CE; and late Middle Ages, 1300-1500 CE) was adapted for the sake of clear arrangement, opting for a periodization in which emphasis is placed on transition from an era of land owners and isolated communities (300-1080 CE), to the rise of the cities in the medieval society (1080-1500 CE) (Blockmans & Hoppenbrouwers, 2007).

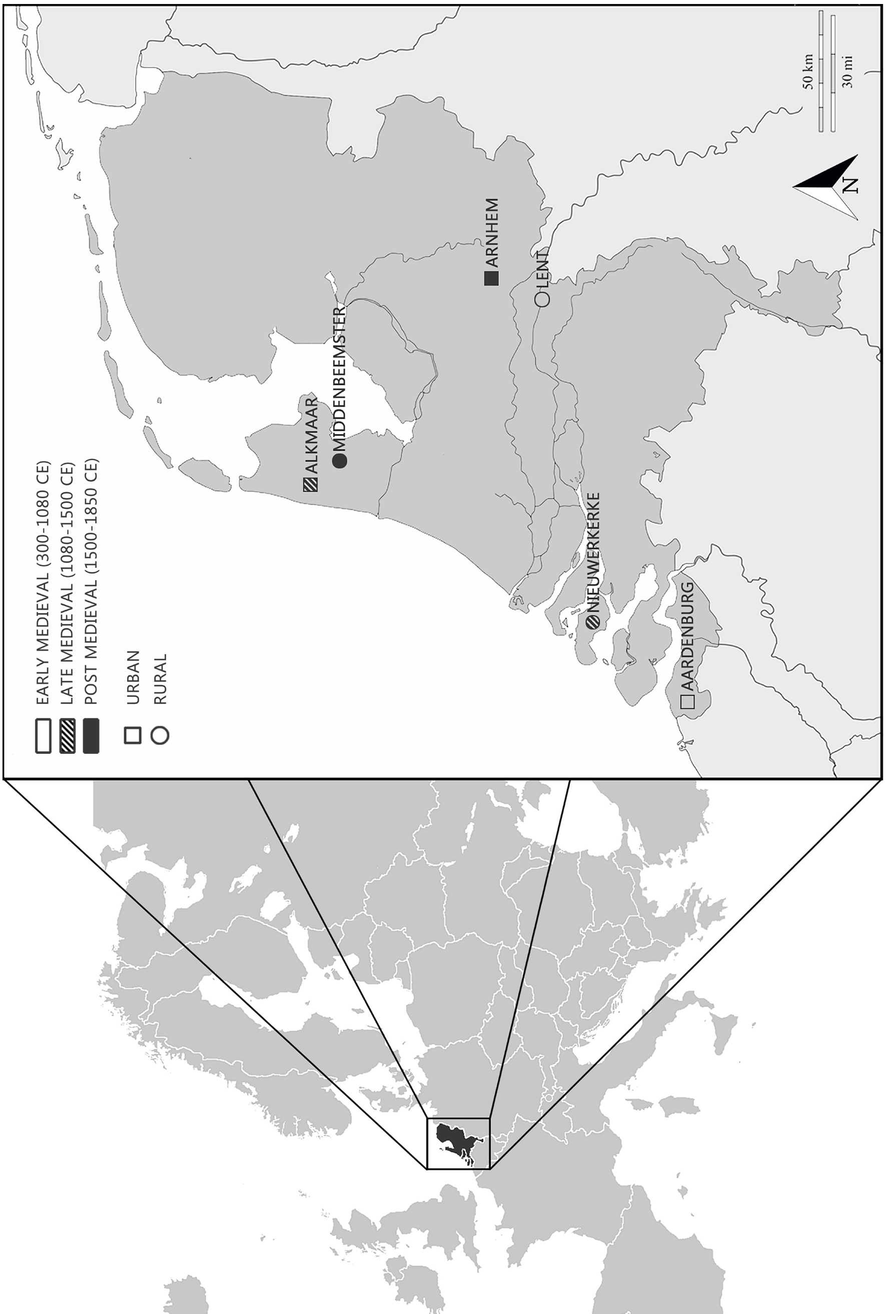

Figure 3.1. Map of the Netherlands showing the location of the sites under study. Image made by M. Casna.

Table 3.1. Skeletal collections included in this study.

	Collection	Dating	Subsistence economy
Early-medieval (300-1080 CE)	Lent	475-750 CE	Rural
	Aardenburg	1030-1200 CE	Urban
Late-medieval (1080-1500 CE)	Nieuwerkerke	1298-1576 CE	Rural
	Alkmaar	1448-1572 CE	Urban
Post-medieval (1500-1850 CE)	Middenbeemster	1829-1866 CE	Rural
	Arnhem	1626-1829 CE	Urban

3.2.1. Urban sites

The urban populations of Aardenburg (early-medieval), Alkmaar (late-medieval), and Arnhem (post-medieval) were selected as their preservation status and well-understood historical context allowed for a systematic, contextualized, and diachronic investigation of the respiratory heath in several urban populations located in the Netherlands.

The skeletal collection of Aardenburg was discovered and excavated in 1948 from the Sint-Baafskerk, following the structural damage that the Second World War caused to the church (Forbes, 1953). Due to the nature of the excavation, no reports were produced at the time and, therefore, no information is available on how many skeletons were originally recovered. For the same reason, the dating of these skeletons was not clear and was attributed to be 1030 CE (the year the church opened) up to 1200 CE, based on the symbols painted on the burial vaults (Cornelis, 1951, 1952; Wagenaar & van den Brink, 2011).

Formerly known as Rodanburg, Aardenburg was among the first Dutch centers to acquire city rights in 1187 CE (Henderikx, 2012a). In the medieval time, Aardenburg was a thriving commercial and industrious city whose cloth market extended not only to England, but also to the Baltic coast, Northern Spain, and Italy (de Pooter et al., 2000; Henderikx, 2012b). Because of its strategic position on the North Sea, already in 1000 CE Aardenburg was part of the London Hanseatic League, a commercial and defensive confederation of merchant guilds and market towns in Northern Europe that dominated maritime trade in the North and Baltic seas (Harreld, 2015). The individuals from Aardenburg included in this study lived during a particularly flourishing time for the city's economic development, albeit it is unlikely (due to the dating of the site) that they witnessed the rise of problems commonly associated with intense urbanization that were discussed above.

In contrast, the dating of the skeletons from Alkmaar suggest that this late-medieval population lived during one of the largest and fastest expansions of the city (Hakvoort et al., 2015; Kaptein, 2007). This skeletal assemblage was excavated in 2010 from the former Franciscan monastery cemetery. Originally, 189 individual coffin burials were recovered dating between 1448-1572 CE, when the monastery was closed during the Eighty Years' War and later demolished (Schats, 2015). At the time the burials took place, Alkmaar had suddenly become an important port for international trade and, as such, needed more space to expand (Streefkerk, 2004; van Nierop, 2000). Artificial land reclamation from the near waterside (today completely drained) had already started in the 14th century, but intensified between 1483-1516 CE, attracting several workers from the countryside (Bitter, 2007a). On a list kept by the parish church, people buried in the cemetery under study were '*ambachtslieden*', the commoners of Alkmaar, likely employed in various activities such as sail making, chalk production, peat digging, and dyke construction (de Raad, 2015; Kaptein, 2007). Although agricultural production was mainly concentrated among farms established in the dry land around the city, in the late-medieval period many people from Alkmaar still had access to a small garden outside town where they grew their own vegetables (Bitter, 2007b).

The post-medieval population of Arnhem consisted of approximately 350 skeletons excavated in 2017 in the courtyard of the Sint-Eusebiuskerk (the city's largest and most important Protestant church) and is considered as representative of the lower proto-industrial working class (van Laar, 1966; Zielman & Baetsen, 2020). Starting from 1795, systematic immigration caused the population to suddenly grow, making Arnhem almost as populated as other major Dutch centers (Lourens & Lucassen, 1997). People from the whole province came to the city in search of employment, which was mainly offered in small-scale industries such as tobacco production, shoemaking, and typography (Baetsen et al., 2020; van Laar, 1966). According to historical sources, being employed in these proto-industrial settings was particularly hard for both men and women, with working time commonly ranging between 12-20 h/day (Wintle, 2000). Factory conditions were generally very harsh and had a direct impact on health, as workers were often exposed to dust and chemicals and were involved in occupational accidents caused by unsafe working environments (van Braam, 1978; Wintle, 2000). Not only working spaces were considered harmful to the health of the Dutch post-medieval working class. Due to the prohibitive housing costs, employers typically provided living quarters for their employees and deducted the costs from their wages. These living spaces were hastily assembled to accommodate as many people as possible, with one room often housing two or more families (Van Laar, 1966). Starting from the end of the 18th century, many campaigns were launched aiming to improve the living conditions of lower-class citizens in many cities, and many engineers were tasked with testing the livability of both domestic and working spaces (van Laar, 1966; Wintle, 2000).

3.2.2. Rural sites

Three rural skeletal populations were analyzed: Lent (early-medieval), Nieuwerkerke (late-medieval), and Middenbeemster (post-medieval).

The skeletal sample of Lent comes from two different collections, respectively Lent Azaleastraat (excavated between 1972-1975) and Lentseveld (excavated in 2011). In total, the two collections combined included a total of circa 90 individuals. They were considered as one population as the sites were located less than a kilometer from each other and are both dated to the early medieval period (Lent Azaleastraat: 630-750 CE; Lentseveld: 475-600 CE), suggesting that they are representative of the same community (Hendriks & De Roode, 2012; van Es & Hulst, 1991). In the early-medieval period, Lent functioned as a vegetable garden for the nearby city of Nijmegen, where farmers were assigned a "standard" cultivable area whose proceeds had to partly be paid to the castle (Jansen, 1981). The population of Lent was likely exclusively employed in some early and exiguous form of agriculture, as suggested by the results of pollen surveys in the excavation area reporting limited human impact on the river landscape (Teunissen, 2016). Because the main economic activities of the region were concentrated around the city, it is believed that inhabitants of Lent depended from Nijmegen for any goods or services that were not produced through cultivation (Bots et al., 2005; Jansen & Willems, 1986).

Similarly to Lent, inhabitants of Nieuwerkerke were also mainly involved in the production of agricultural supply for the neighboring city of Zierikzee, that at the time was one of the largest towns in the whole province of Schouwen-Duiveland (Mijnhardt, 2012). The skeletal assemblage under study (originally comprised by circa 2000 individuals and dated 1298-1576 CE) was excavated in 1951 from what it is thought to be the former church cemetery (Burger, 1992). According to van Cruyningen (2012), late-medieval communities such as Nieuwerkerke were still prevalently based on the commercial farming scheme: crops and livestock were raised with the purpose of being sold to the city, with wheat, madder root, and barley being among the most demanded goods (van Cruyningen, 2012). Despite its economy being dependent on Zierikzee, it is clear from historical sources that Nieuwerkerke did dictate its own autonomy to some extent: in 1298 CE, the village had already grown so large that it could open its own school and cemetery (Meulenberg & Frentrop, 2004). However, Nieuwerkerke's church was demolished in the early 16th century, following a siege by the Spanish troops. Consequently, the cemetery was closed and the municipality later merged with another nearby village (Meulenberg & Frentrop, 2004).

The skeletal collection of Middenbeemster is representative of a post-medieval rural community from the province of North Holland. It was excavated from the church cemetery in 2011 and is comprised of more than 450 individuals dated between 1829-1866 CE (Griffioen, 2011). As this was the only cemetery active in the area, this population is believed to be representative not only of the village of Middenbeemster but of the surrounding countryside as well (Falger et al., 2012). In the early 17th century, Middenbeemster was one of the first villages established in the reclaimed Beemster polder, a former marshy lake artificially dried to increase local agricultural production (Falger et al., 2012). The reclamation of the Beemster polder is generally considered among the most ambitious artificial modifications of the Dutch soil. It was entirely financed by private investors to grow crops necessary for long sea journeys by the Dutch East India Company and, already in the 18th century, it figured among the most fruitful agricultural centers in the Low Countries (Aten, 2012). Once the Dutch East India Company was dissolved in 1799, Beemster produce (i.e., dairy products, cattle, crops) continued to be directed towards Amsterdam, where it was distributed among citizens and sold at international markets (Aten, 2012). It was calculated that, in 1800, 80% of Beemster dairy and meat production was exported to other countries such as England, Spain, Germany, and even Russia (van der Wiel, 2012a, 2012b). Due to the high demand for export, people in the Beemster area were almost exclusively involved in manual labor until the late 20th century (Falger et al., 2012). This was recently confirmed with osteoarchaeological research into activity reconstruction at Middenbeemster (Palmer et al., 2016; Vikatou et al., 2017).

3.2.3. Sample selection

The sample comprises a total of 695 individuals whose age-at-death was ≥ 18 years. Non-adults were excluded from this study as their sample size was too poor for meaningful and robust analysis to be carried out. They will however be considered in a future study when more data on this specific age group is collected.

3.2.4. Methods

For every individual, sex and age-at-death were estimated using standard osteoarchaeological methods. Biological sex was estimated using sexually dimorphic features of both the pelvis and skull (Buikstra & Ubelaker, 1994). To test the demographic comparability of the sample, age-at-death estimations were made based on ectocranial suture closure (Meindl & Lovejoy, 1985), morphologic characteristics of the pubic symphysis (Brooks & Suchey, 1990) and of the auricular surface (Buckberry & Chamberlain, 2002). The calculated average age-at-death of each individual was used to assign them to specific age categories adapted from Buikstra and Ubelaker (1994), and defined as early young adult (approx. 18-24 years), late young adult (approx. 25-34 years), middle adult (approx. 35-49 years), and old adult (50+ years). The original category described by Buikstra and Ubelaker (1994) as "young adult (20-35 years)" was here divided into early and late young adult groups in order to align with the established protocol for data collection at the Laboratory for Human Osteoarchaeology at Leiden University.

The presence of each lesion (i.e., chronic maxillary sinusitis, otitis media, and periosteal rib reaction) was macroscopically assessed for all individuals on both sides (i.e., right and left) and noted as either 'absent', 'present', or 'unobservable'. Prevalence rates of all conditions were calculated as individuals affected/individuals observed.

The presence of chronic maxillary sinusitis (CMS) was observed in all individuals with at least one sinus with a partial preservation of more than 25% of any of the six sinus walls. If the sinuses were present but not observable with the naked eye, they were examined with a flexible medical endoscope (Pentax, model: FNL-10RBS, ø=4mm; view angle=30°) inserted through minor breaks (Casna et al., 2021). A sinus without pathological changes presents smooth surfaces with little associated pitting and channels for blood vessels. Lesions associated with CMS, as defined by (Boocock et al., 1995), were recorded for each individual and classified as 'present' whenever either bone resorption or new bone growth were present (Figure 3.2, A). As dental disease (i.e., periodontal disease, abscesses, and granulomas) can influence the presence of maxillary sinusitis (Patel & Ferguson, 2012), individuals showing dental decay and/or antemortem tooth loss in the upper premolars and/or molars were excluded from analysis.

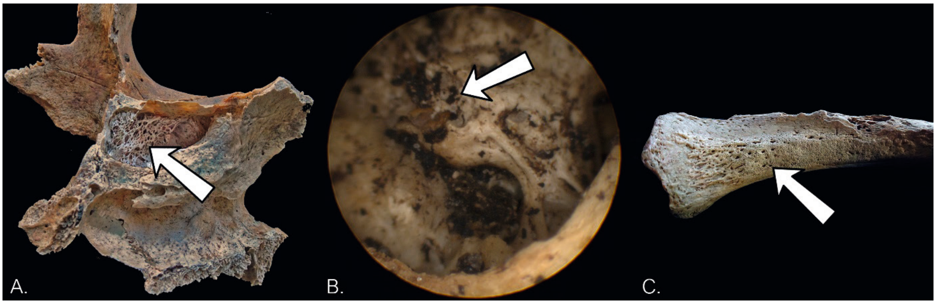

Figure 3.2. Examples of lesions observed in this research, respectively: A: chronic maxillary sinusitis; B: otitis media; and C: periosteal rib reaction. Lesions are indicated by the white arrows. Photographs by M. Casna.

Otitis media (OM) was identified using the criteria by Floreanova et al. (2020) and its presence observed on all individuals with at least one undamaged, accessible ear canal. The ear ossicles (when present) were removed, and the bony walls of the middle ear were carefully cleaned using a wooden tooth pick before the medial wall of the middle ear cavity (i.e., the promontory) was inspected with a medical endoscope. OM was scored as 'present' when the promontory surface showed either isolated bony overgrowth with clear margins or general interruption of the integrity of the promontory bony surface due to bone resorption (Figure 3.2, B). It was scored as 'absent' in cases when the promontory presented a smooth, unaltered surface (Floreanova et al., 2020).

Inflammatory periosteal reaction on ribs (IPR) was scored for every rib whose shaft was at least 50% complete. To avoid mistakes in seriations, ribs were allocated in four groups based on their most likely position within the rib cage: 'upper' (ribs #1-3), 'upper-middle' (ribs #4-6), 'lower-middle' (ribs #7-9), or 'lower' (ribs #10-12). IPR was scored as 'present' in groups in which at least one rib showed evidence of bone growth and where new bone formed a distinct layer on top of the original cortical surface, with clearly defined margins and/or a surface texture dissimilar to the original cortical bone (Davies-Barrett et al., 2019) (Figure 3.2, C). In cases where only one rib per group was present and did not show any sign of IPR, the group was considered as unobservable.

Results were analyzed statistically using SPSS for Windows, version 25.0. To test differences between prevalence rates of skeletal lesions, time period, and/or living environments, Pearson's chi-squared test was used. In cases where expected cell count was below 5, Fisher's Exact test was used instead. A p-value ≤0.05 was considered to be statistically significant. As multiple tests were conducted on the same samples, significance levels were adjusted using Bonferonni correction method to account for familywise error.

Table 3.2. Demographic composition of the sample included in this study.

	Males					Females				
	Early young adult (18-24 years) (%)	Late young adult (25-34 years) (%)	Middle adult (35-49 years) (%)	Old adult (50+ years) (%)	Total	Early young adult (18-24 years) (%)	Late young adult (25-34 years) (%)	Middle adult (35-49 years) (%)	Old adult (50+ years) (%)	Total
Lent	3 (12.5)	5 (20.8)	10 (41.7)	6 (25.0)	24	5 (16.1)	10 (32.2)	13 (41.9)	3 (9.8)	31
Aardenburg	6 (10.2)	19 (32.2)	26 (44.1)	8 (13.5)	59	16 (36.4)	16 (36.4)	9 (20.4)	3 (6.8)	44
Nieuwerkerke	26 (27.9)	26 (27.9)	30 (32.4)	11 (11.8)	93	27 (50.0)	10 (18.5)	12 (22.2)	5 (9.3)	54
Alkmaar	6 (18.2)	6 (18.2)	14 (42.4)	7 (21.2)	33	7 (19.5)	9 (25.0)	18 (50.0)	2 (5.5)	36
Middenbeemster	9 (12.5)	11 (15.3)	20 (27.8)	32 (44.4)	72	17 (19.3)	22 (25.0)	23 (26.1)	26 (29.6)	88
Arnhem	9 (10.6)	18 (21.2)	27 (31.8)	31 (36.4)	85	16 (21.6)	13 (17.6)	28 (37.8)	17 (23.0)	74
Total	59 (16.2)	82 (22.5)	127 (34.8)	95 (26.5)	365	88 (26.9)	80 (24.5)	103 (31.5)	56 (17.1)	327

3.3. Results

Of the total sample (*N*=695) (Table 3.2), 541 individuals were analyzed for CMS, 585 for OM, and 325 for IPR. Of these, 202 individuals (37.3%) showed signs of CMS, 120 (20.5%) of OM, and 18 (5.5%) of IPR.

3.3.1. Chronic Maxillary Sinusitis (CMS)

Within the total sample, CMS was most common in Arnhem (53.6%) and least common in Lent (11.3%) (Figure 3.3). No statistically significant differences were observed between rural and urban environments among any of the time periods under study. However, strongly significant relationships were noted between sinusitis and time period in both the rural and urban environments, with the lesions becoming more common over time. Separate analyses of the rural and urban sites show that the largest differences exist between the early medieval sites and late medieval/post-medieval sites. No statistically significant differences are found between the late medieval and post-medieval sites in CMS prevalence (Table 3.3).

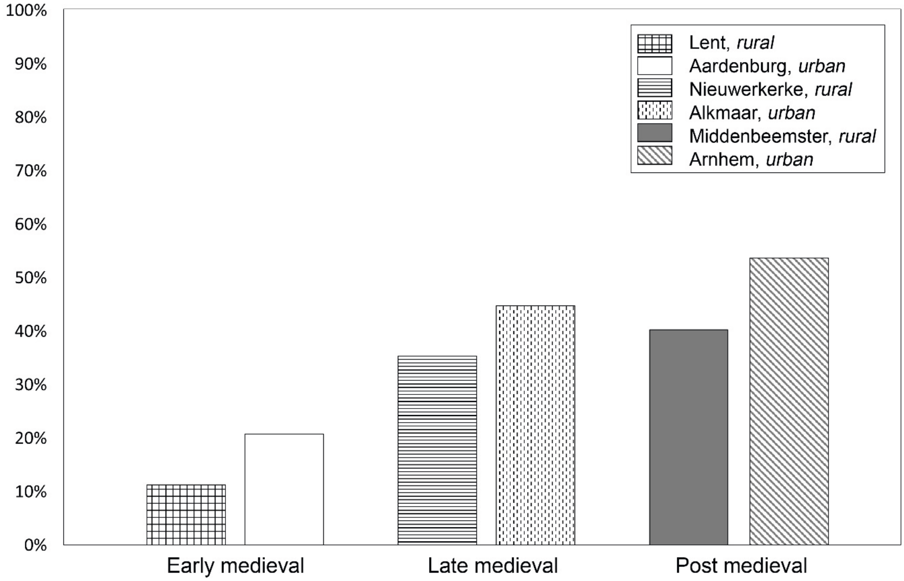

Figure 3.3. Prevalence of chronic maxillary sinusitis for all samples under study (*N*=541).

Table 3.3. Prevalence and statistical analysis of chronic maxillary sinusitis in different time periods and living environments.

Comparison	Skeletal assemblage	N	CMS (%)	χ2	*p*-value
Urban versus rural in early medieval period	Lent	53	6 (11.3)	1.751	0.186
	Aardenburg	53	11 (20.8)		
Urban versus rural in late medieval period	Nieuwerkerke	127	45 (35.4)	1.486	0.223
	Alkmaar	58	26 (44.8)		
Urban versus rural in post-medieval period	Middenbeemster	124	50 (40.3)	2.762	0.097
	Arnhem	126	64 (50.8)		
Changes through time in the rural environment	Lent	53	6 (11.3)	14.557	**0.001**
	Nieuwerkerke	127	45 (35.4)		
	Middenbeemster	124	50 (40.3)		
Changes through time in urban environments	Aardenburg	53	11 (20.8)	13.919	**0.001**
	Alkmaar	58	26 (44.8)		
	Arnhem	126	64 (50.8)		

Changes through time in rural environments (*continued*)

	Lent	Nieuwerkerke	Middenbeemster
Lent		χ2=10.707, ***p*=0.001**	χ2=14.439, ***p*<0.001**
Nieuwerkerke			χ2=0.638, *p*=0.425

Changes through time in urban environments (*continued*)

	Aardenburg	Alkmaar	Arnhem
Aardenburg		χ2=7.222, ***p*=0.007**	χ2=13.828, ***p*<0.001**
Alkmaar			χ2=0.566, *p*=0.452

N= total of individuals with observable feature; CMS= total of individuals showing lesions associated to chronic maxillary sinusitis. Values in bold indicate associations statistically significant by Chi-square test, with Bonferroni correction significance level set at *p*=0.017.

3.3.2. Otitis Media (OM)

With the exception of the late-medieval period, OM prevalence was higher in rural samples (Figure 3.4). Alkmaar had the highest prevalence rate of OM (35.2%), while Aardenburg had the lowest (12.0%). There were significant associations between OM and living environment (i.e., rural versus urban) in the early-medieval and late-medieval periods (Table 3.4). In addition, a statistically significant relationship was also observed between OM and time period within the urban sample. In the rural environment, OM prevalence rates were statistically significantly higher in Middenbeemster when compared to late medieval Nieuwerkerke.

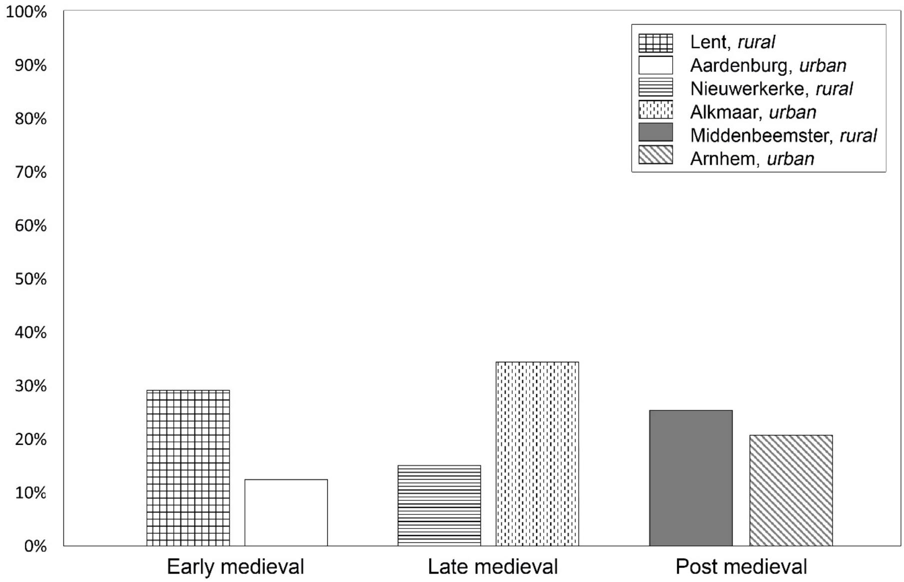

Figure 3.4. Prevalence of otitis media for all samples under study (*N*=585).

Table 3.4. Prevalence and statistical analysis of otitis media in different time periods and living environments.

Comparison	Skeletal assemblage	N	OM (%)	χ2	*p*-value
Urban versus rural in early medieval times	Lent	32	9 (28.1)	4.712	0.030
	Aardenburg	100	12 (12.0)		
Urban versus rural in late medieval times	Nieuwerkerke	123	18 (14.6)	9.585	**0.002**
	Alkmaar	54	19 (35.2)		
Urban versus rural in post medieval times	Middenbeemster	151	37 (24.5)	0.796	0.372
	Arnhem	125	25 (20.0)		
Changes through time in the rural environment	Lent	32	9 (28.1)	5.115	0.078
	Nieuwerkerke	123	18 (14.6)		
	Middenbeemster	151	37 (24.5)		
Changes through time in urban environments	Aardenburg	100	12 (12.0)	11.750	**0.003**
	Alkmaar	54	19 (35.2)		
	Arnhem	125	25 (20.0)		

Changes through time in rural environments (*continued*)

	Lent	Nieuwerkerke	Middenbeemster
Lent		χ2=3.213, *p*=0.073	χ2=0.184, *p*=0.668
Nieuwerkerke			χ2=4.115, *p*=0.043

Changes through time in urban environments (*continued*)

	Aardenburg	Alkmaar	Arnhem
Aardenburg		**χ2=11.724, *p*=0.001**	χ2=2.588, *p*=0.108
Alkmaar			χ2=4.690, *p*=0.030

N= total of individuals with observable feature; OM= total of individuals showing lesions associated to otitis media. Values in bold indicate associations statistically significant by Chi-square test, with Bonferroni correction significance level set at p=0.017.

3.3.3. Inflammatory periosteal reaction on ribs (IPR)

Among all recorded lesions, inflammatory periosteal reaction on ribs (IPR) was the least commonly observed (Figure 3.5). In both Lent and Aardenburg, no cases of IPR were recorded. Alkmaar and Middenbeemster showed the same prevalence rate (7.3%). No statistically significant relationships were observed between different time periods and rural-urban environments (Table 3.5).

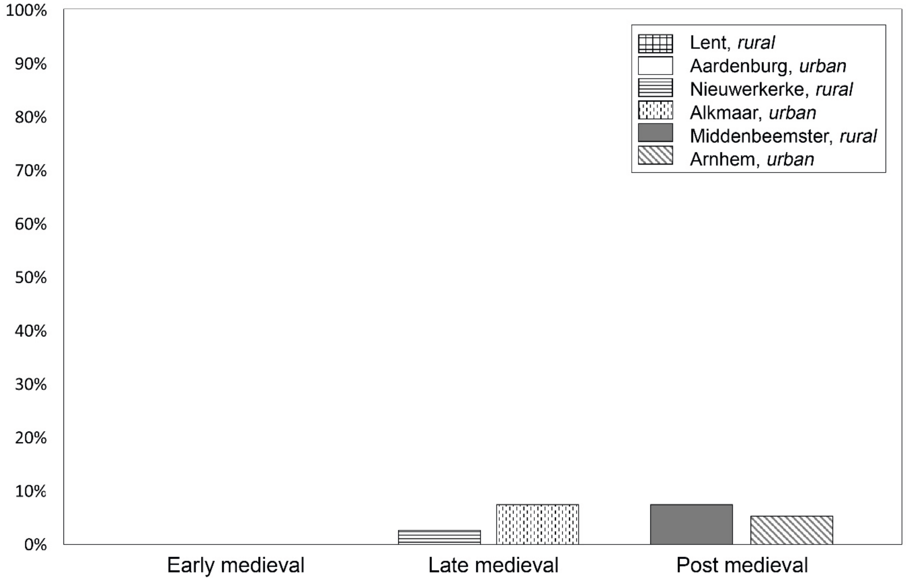

Figure 3.5. Prevalence of inflammatory periosteal reaction on ribs for all samples under study (*N*=325).

Table 3.5. Prevalence and statistical analysis of inflammatory periosteal reaction on ribs in different time periods and living environments.

Comparison	Skeletal assemblage	N	IPR (%)	χ2	*p*-value
Urban versus rural in early medieval times	Lent	23	0 (0)	N/A	N/A
	Aardenburg	6	0 (0)		
Urban versus rural in late medieval times	Nieuwerkerke	39	1 (2.6)	†0.951	0.616
	Alkmaar	41	3 (7.3)		
Urban versus rural in post medieval times	Middenbeemster	110	8 (7.3)	0.407	0.523
	Arnhem	115	6 (5.2)		
Changes through time in the rural environment	Lent	23	0 (0)	†2.753	0.252
	Nieuwerkerke	39	1 (2.6)		
	Middenbeemster	110	8 (7.3)		
Changes through time in urban environments	Aardenburg	6	0 (0)	†0.513	0.787
	Alkmaar	41	3 (7.3)		
	Arnhem	115	6 (5.2)		
Changes through time in rural environments (*continued*)					
	Lent	Nieuwerkerke		Middenbeemster	
Lent		†χ2=0.599, *p*=1.000		†χ2=1.780, *p*=0.350	
Nieuwerkerke				†χ2=1.125, *p*=0.447	
Changes through time in urban environments (*continued*)					
	Aardenburg	Alkmaar		Arnhem	
Aardenburg		†χ2=0.469, *p*=1.000		†χ2=0.329, *p*=1.000	
Alkmaar				†χ2=00.245, *p*=0.699	

N= total of individuals with observable feature; IPR= total of individuals inflammatory periosteal reaction on ribs; †=Fisher's exact test.

The occurrence of all lesions was also investigated for each context in relation to biological sex (see Table S.1 for all results). The only significant relationship observed was between IPR and sex in the urban population of Arnhem (χ^2=5.411, p=0.03), where males showed greater prevalence than females (males: 9.7%; females; 0%).

3.4. Discussion

This paper has investigated three skeletal lesions associated with respiratory stress to study the influence of living environment and time period. Despite small differences in prevalence rates between rural and urban environments, our analysis did not reveal any clear distinction between the two living environments. It therefore supports interesting patterns of occurrence that partly reflect what was previously observed in other osteoarchaeological studies: there is no correlation between urban settings and the presence of skeletally visible respiratory conditions (e.g., Bernofsky, 2010; Casna et al., 2021; Panhuysen et al., 1997; Schats, 2016). In fact, only few associations between rural and urban environments were statistically significant for any of the time periods under study, possibly indicating that past people's respiratory health was equally challenged regardless of where they resided.

Interesting to note is that significant correlations were observed when comparing CMS prevalence rates through time in rural and urban environments separately, as well as when comparing OM prevalence rates through time in urban settings. Previous studies on the impact of increasing urbanization on human health have observed similar patterns when addressing both stress indicators (Scott & Hoppa, 2018) and infectious diseases (Dangvard Pedersen et al., 2019). It was suggested that the expanding urban environment had an increasingly negative impact on people's health. This growth in health challenges may however have been more nuanced between the late-medieval and post-medieval period, as differences in both CMS and OM prevalence rates were found not to be statistically significant between Alkmaar (urban, late-medieval) and Arnhem (urban, post-medieval). This suggests that the largest change occurred between the early and late medieval periods. Historically, this may be explained by the fact that, during the lifetimes of the individuals under study, both cities faced rapid expansions, which probably caused several concerns due to lack of housing facilities and infrastructure (Hakvoort et al., 2015; van Laar, 1966). As suggested by DiGangi and Sirianni (2017), communal living (i.e., eating and sleeping in the same overcrowded, poorly-ventilated environments) exposed past populations to risk factors for respiratory disease. It is then plausible that the citizens of Alkmaar and Arnhem faced similar challenges in terms of lack of access to adequately ventilated and hygienic environments.

Interestingly, the analysis of CMS among rural populations revealed a similar pattern: no statistically significant association was found between Nieuwerkerke (late-medieval) and Middenbeemster (post-medieval), while there were strong differences between Lent (early-medieval) and Nieuwerkerke, as well as between Lent and Middenbeemster. Historical sources on Dutch urbanization indicate that the co-dependent relationship that characterized Dutch cities and countrysides had grown from being minimal in the late-Roman/early-medieval period to a strict co-dependence affiliation starting from the 14th century (Blockmans & Hoppenbrouwers 2007; Wintle, 2000). This may offer an explanation on why the patterns in CMS occurrence observed within urban samples extended to rural populations as well: as cities began to grow, their demand for food supplies grew alongside. Rural production quickly developed to satisfy the urban demand, shifting from local agricultural communities to big intensive realities able to provide resources not only to the city but also to the international market, which may have exposed people to risk factors for respiratory disease (van Cruyningen, 2012a; Wintle, 2000). So far, the occupational shift from local farming to large scale production has been rarely addressed in bioarchaeology, although it is likely that it had a significant impact on people's lived experiences. In over five hundred years of agriculture, the Netherlands developed from small, autonomous production communities in the early-medieval period to highly productive agribusiness complexes that relied heavily on technological innovation (e.g., enclosure, mechanization, selective breeding) (Bieleman, 2010; Harskamp, 2009). Such developments likely changed the way people lived and worked, suggesting that there may have been a swift in the risk factors for respiratory health that people living in the countryside were exposed to through time.

In the early-medieval and post-medieval periods, OM rates were found to be higher in rural samples compared to urban ones. As seasonality is today considered among the major risk factors for OM (Kong & Coates, 2009), we argue that people living in the countryside may have spent more time outside than their urban counterparts in the coldest and rainiest months, which may explain the higher rates of OM (Camenisch, 2015). In the early-medieval period, we observed great difference in OM prevalence rates between Aardenburg (urban) and Lent (rural). However, such difference mitigated in the post-medieval period between Arnhem (urban) and Middenbeemster (rural). In Middenbeemster, agriculture had developed to an efficient, intensive, and organized sector that worked predominately for the export market (Aten, 2012; Wintle, 2000). Bieleman (2010) argued that processes of agricultural intensification in the past often had large implications on social welfare: while few, large farmers were able to sensitively increase their capital, many others wage laborers remained landless and lived in indigent conditions. When comparing prevalence rates of OM among rural populations, we noticed a higher (albeit not statistically significant) incidence in Middenbeemster (post-medieval) as opposed to Nieuwerkerke (late-medieval). We suggest that our results may be indicative of rural working conditions worsening following the intensification of production in the post-medieval period (van Laar, 1966; Wintle, 2000).

Interestingly, the late-medieval period showed a reverse trend in OM prevalence rates, with Alkmaar (urban) being more affected than both Nieuwerkerke (rural) and the other urban sites. In the 16th century, Alkmaar was located in a lake area, surrounded by large marshy bodies of water in the process of being drained to allow the city to grow (Streefkerk, 2004; van Nierop, 2000). According to clinical literature, living in damp and cold environments can increase the risk for respiratory disease, especially otitis media (e.g., Haines et al., 2006; Lu et al., 2023). Since Alkmaar showed high rates of respiratory infections compared to the other samples under study (CMS: 44.8%, OM: 35.2%, IPR: 7.3%), it is possible that the vicinity to the draining land (as opposed to Arnhem, located inland, and Aardenburg, at the time located more than 20km away from the coast) negatively impacted their wellbeing.

In this study, IPR was the least common lesion, affecting only 18 individuals within the whole sample (*N*=325). Although the recording of IPR was often severely impacted by preservation status (e.g., only 6 individuals from Aardenburg had ribs that were suitable for analysis), it must be noted that the observed rates fit well within previous research on IPR (e.g., Bernofsky, 2010; Boyd, 2020). While there was an increase in IPR prevalence rates in the rural environments through time (Lent: 0%; Nieuwerkerke: 2.6%; Middenbeemster: 7.3%), this was difference was not statistically significant.

The apparent lower prevalence of lower compared to upper respiratory tract conditions is interesting. This difference may be explained by the fact that the skeletal lesions here referred to as IPR may be indicative of many conditions other than lower respiratory tract infections, which makes it difficult for archaeologists to contextualize their presence (Boyd, 2020; Davies-Barrett et al., 2019; Matos & Santos, 2006; Roberts et al., 1994). Important to note is that most of these conditions are quite challenging for the human organism in comparison to otitis and sinusitis. While even in the past it was probably unlikely for someone to die of either CMS and OM, conditions such as tuberculosis, bronchitis, and pneumonia claimed many lives before the antibiotic era (Huisman, 2018; Kenny, 2021); thus, many people could have died before their skeletons could show any sign of infection (DeWitte & Stojanowski, 2015). In addition, although lesions associated with CMS and OM are well-documented in paleopathology, instances of IPR in both the archaeological and clinical record are less common, indicating that only a small percentage of individuals with lung disease will develop these bony lesions (Ortner, 2003).

We argue that the absence of IPR in our sample is not necessarily indicative of people not suffering from pulmonary conditions, but rather of several individuals not showing signs of ongoing infections. These interpretations fall within what is known as ‘the osteological paradox’, and specifically under the concepts of hidden heterogeneity and selective mortality, as presented by (Wood et al., 1992). As these concepts lead to the possibility that individuals without bone lesions may have been the ones most severely affected, to deal with the osteological paradox it is recommended to utilize age-structured comparisons of disease data to check whether the results correspond to a “paradoxical” interpretation (DeWitte & Stojanowski, 2015). Table S.2 and Figure S.1 show how in most cases lesions are evenly distributed within our age-at-death groups, potentially supporting a “non-paradoxical interpretation of results” (Krenz-Niedbała & Łukasik, 2020).

An important limitation in this study, not just for the interpretation of IPR but also for CMS and OM, is the third concept of the osteological paradox, demographical nonstationary. Our sample derives from cemeteries that were in many cases used for several centuries, meaning that temporal variation in health experiences may have affected our results (DeWitte & Stojanowski, 2015). In addition, migration phenomena (i.e., urban-to-rural and rural-to-urban) were common throughout the late-medieval and post-medieval periods, possibly affecting our findings as well. For example, the presence of CMS and IPR in both Nieuwerkerke and Middenbeemster could be explained by the fact that, in time of urbanization and industrialization, people from the countryside still had to spend time in the city for seasonal work and markets, therefore exposing themselves to greater risk factors for infectious disease than people of Lent whose economy was mainly based on a one-way food exchange with the city (Henderikx, 2012a; Henderikx & De Roode, 2012; Wintle, 2000).

While this study provides an abundance of historical contextual information for the skeletal assemblages in order to accurately interpret the data derived from the individuals and reduce the influence of risk heterogeneity, selective mortality, or population non-stationarity, to completely overcome the osteological paradox is difficult due to the inherent nature of not only skeletal collections, but also of the complex etiologies of respiratory infections themselves. Factors such as seasonality and exposure to adverse climate conditions are difficult to address archaeologically, but are still likely to have had an impact on human respiratory wellbeing. Moreover, as exposure to tobacco smoke is today considered among the most common causes of respiratory infections, its spread across the Low Countries from the 17th century may have impacted OM and CMS rates in the post-medieval period (Gulya, 1994; Roessingh, 1979). This is further supported by the fact that Arnhem was one of the major tobacco production centers in the Netherlands (van Laar, 1966), which likely made access to tobacco very easy for Arnhem workers, potentially contributing to the overall high prevalence rates of respiratory disease in this skeletal population.

Methodological limitations are also likely to have impacted our results to some extent. For example, the preservation status of some individuals only allowed observation of lesions (i.e., CMS, OM, and IPR) on one side (i.e., left or right), therefore making it impossible to determine the laterality of such pathological alterations. Unbalanced sample sizes (e.g., early- and late-medieval periods), then, may have impacted our results to some extent, although we believe that our statistical analyses helped to mitigate the impact of this imbalance. Inclusion criteria and methodological choices (especially in the case of OM) also slightly affected the comparability of our results. Their relevance, however, remains significant and valuable in their own right, as they provide a unique contribution to the existing literature and offer novel insights into urbanization phenomenon.

3.5. Conclusions

This study aimed to investigate the impact Dutch urbanization and industrialization had not only on urban residents, but also on rural communities. The outcome of our analysis pointed out the importance to study urbanization not as a point in time, but rather as an ongoing process that continuously affected human health across centuries. Our results showed how respiratory health changed through time not only in urban samples, but also in rural ones, potentially suggesting that urbanization and intensification of agricultural production did influence life in the countryside as well. Furthermore, prevalence rates of both CMS and OM suggest that the influence of urbanization on human health did not gradually increase throughout the years, but rather affected communities more severely between the early-medieval and late-medieval periods, when the first cities significantly developed.

Bearing in mind the limitations of our study, which mainly related to the complex etiology of respiratory diseases and to the nature of bioarchaeological samples, we can conclude that our research shed light on a new, significant aspect of urbanization: its continuity across time and space, and the importance of addressing such aspects in future bioarchaeological studies of urbanization. Our results showed how generalizations about (respiratory) health in different populations should not be recommended when studying urbanization: rather, it is important to consider and to keep addressing the unique social, economic, and environmental factors that may have impacted the health of each population.

Supporting information

Supplementary materials for this paper are available on the publisher's website: https://doi.org/10.1016/j.ijpp.2023.07.003

Data availability statement

The datasets generated and analyzed during the current study are available at: Casna, Maia, 2022, "Data for: "A Distant City"", https://doi.org/10.17026/AR/9OHROE, DANS Data Station Archaeology.

References cited

Aten, D. (2012). Van water tot werelderfgoed. In K. Bossaers & C. Misset (Eds.), *400 jaar Beemster* (pp. 10–33). Stichting Uitgeverij Noord-Holland.

Baetsen, S., Baetsen, W., Defilet, M., & Zielman, G. (2018). Sint-JansbeekbrengtOude Kerkhof boven water. Graven bij Arnhemse Eusebiuskerk. Archeologie in de Nederland. *Archeologie in de Nederland*, 34–43.

Behr, J., & Nowak, D. (2002). Tobacco smoke and respiratory disease. *European Respiratory Monograph*, 161–179.

Benevolo, L. (1996). *La città nella storia d'Europa*. Laterza.

Bernofsky, K. S. (2010). *Respiratory health in the past: a bioarchaeological study of chronic maxillary sinusitis and rib periostitis from the Iron Age to the Post Medieval Period in Southern England*. [Doctoral dissertation, Durham University]. Retrieved from Durham e-Theses**.**

Betsinger, T. K., & DeWitte, S. (2017). Trends in mortality and biological stress in a medieval polish urban population. *International Journal of Paleopathology*, *19*, 24–36. https://doi.org/10.1016/j.ijpp.2017.08.008

Betsinger, T. K., & DeWitte, S. N. (2021). Toward a bioarchaeology of urbanization: Demography, health, and behavior in cities in the past. *Yearbook of Physical Anthropology*, *175*(S72), 79–118. https://doi.org/10.1002/AJPA.24249

Betsinger, T. K., DeWitte, S. N., Justus, H. M., & Agnew, A. M. (2020). Frailty, survivorship, and stress in medieval Poland: A comparison of urban and rural populations. In T. K. Betsinger & S. N. DeWitte (Eds.), *The biological, demographic, and social consequences of living in cities* (pp. 223–243). Springer.

Bieleman, J. (2010). *Five centuries of farming : a short history of Dutch agriculture 1500-2000*. Wageningen Academic Publishers.

https://doi.org/10.2/JQUERY.MIN.JS

Bitter, P. (2007a). Nederzetting op het zand. Landschappelijke dynamiek en menselijke bewoning. In J. C. Visser, P. Bitter, H. Kaptein, D. Aten, J. van Baar, J. Cox, P. Knevel, H. Holwijk, H. de Raad, & G. Valk (Eds.), *Geschiedenis van Alkmaar* (pp. 12–21). Waanders Uitgevers.

Bitter, P. (2007b). Woningen en werkplaatsen, leven en werken in Alkmaar. In D. Aten, J. Drewes, J. Kila, & H. de Raad (Eds.), *Geschiedenis van Alkmaar* (pp. 79–90). Waanders Uitgeverij.

Blockmans, W. (2010). *Metropolen aan de Noordzee: geschiedenis van Nederland, 1100-1560*. Uitgeverij Bert Bakker.

Blockmans, W., & Hoppenbrouwers, P. (2007). *Introduction to Medieval Europe*. Routledge.

Boocock, P., Roberts, C. A., & Manchester, K. (1995). Maxillary sinusitis in Medieval Chichester, England. *American Journal of Physical Anthropology*, *98*(4). https://doi.org/10.1002/ajpa.1330980408

Bots, J. A. H., Brabers, J. B. A. M., Klep, P. M. M., Kuijs, J. A. E., Willems, W., vam der Woude, C. C., Fox, E. G. J., Scheepers, E. J. J., & van Rijen, J. P. (2005). *Nijmegen. Geschiedenis van de oudste stad van Nederland*. Inmerc, i.s.m. de Stichting Stadsgeschiedenis Nijmegen.

Boyd, D. A. (2020). Respiratory Stress at the Periphery of Industrial-Era London: Insight from Parishes Within and Outside the City. In T. K. Betsinger & S. N. DeWitte (Eds.), *The Bioarchaeology of Urbanization. The Biological, Demographic, and Social Consequences of Living in Cities* (1st ed., pp. 379–402). Springer. https://doi.org/10.1007/978-3-030-53417-2_15

Brooks, S., & Suchey, J. M. (1990). Skeletal age determination based on the os pubis: A comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. *Human Evolution*, *5*(3), 227–238. https://doi.org/10.1007/BF02437238

Buckberry, J. L., & Chamberlain, A. T. (2002). Age estimation from the auricular surface of the ilium: A revised method. *American Journal of Physical Anthropology*, *119*(3), 231–239. https://doi.org/10.1002/AJPA.10130

Buikstra J. E., & Ubelaker, D. H. (1994). *Standards for Data Collection from Human Skeletal Remains*. Arkansas.

Burger, J. A. T. (1992). Antropologie in Zeeland. *Zeeland*, 76–77.

Camenisch, C. (2015). Endless cold: A seasonal reconstruction of temperature and precipitation in the Burgundian Low Countries during the 15th century based on documentary evidence. *Climate of the Past*, *11*(8), 1049–1066. https://doi.org/10.5194/CP-11-1049-2015

Casna, M., Burrell, C. L., Schats, R., Hoogland, M. L. P., & Schrader, S. A. (2021). Urbanization and respiratory stress in the Northern Low Countries: A comparative study of chronic maxillary sinusitis in two early modern sites from the Netherlands (AD 1626–1866). *International Journal of Osteoarchaeology*, *31*(5), 891–901. https://doi.org/10.1002/oa.3006

Clark, P. (2009). *European Cities and Towns: 400-2000*. Oxford University Press.

Cornelis, J. C. H. (1951). Merkwaardige grauen te Aardenburg en in de kerken te Sluis. *Zeeuws Tijdschrift*, 70–72.

Cornelis, J. C. H. (1952). Merkwaardige graven in de kerken te Aardenburg en te Sluis (II). *Zeeuws Tijdschrift*, 67–70.

Dangvard Pedersen, D., Milner, G. R., Kolmos, H. J., & Boldsen, J. L. (2019). The association between skeletal lesions and tuberculosis diagnosis using a probabilistic approach. *International Journal of Paleopathology*, *27*, 88–100. https://doi.org/10.1016/J.IJPP.2019.01.001

Davies-Barrett, A. M., Antoine, D., & Roberts, C. A. (2019). Inflammatory periosteal reaction on ribs associated with lower respiratory tract disease: A method for recording prevalence from sites with differing preservation. *American Journal of Physical Anthropology*, *168*(3), 530–542. https://doi.org/10.1002/ajpa.23769

de Pooter, O., de Roose, I., Meulemeester, J. L., & Willebordse, A. (2000). *Vorsten, burgers en soldaten. Romeinen en middeleeuwers in Oudenburg, Middelburg en Aardenburg*. Gemeente Maldegem, stad Oudenburg, Geemente Sluis.

de Raad, H. (2015). Het klooster van de minderbroeders. *Oud Alkmaar*, *39*(1), 10–14.

de Vries, J. (1984). *European urbanization: 1500-1800*. Methuen.

DeWitte, S. N., & Stojanowski, C. M. (2015). The Osteological Paradox 20 Years Later: Past Perspectives, Future Directions. *Journal of Archaeological Research*, *23*(4), 397–450. https://doi.org/10.1007/s10814-015-9084-1

DiGangi, E. A., & Sirianni, J. E. (2017). Maxillary Sinus Infection in a 19th-Century Almshouse Skeletal Sample. *International Journal of Osteoarchaeology*, *27*(2), 155–166. https://doi.org/10.1002/oa.2526

Estalrrich, A., González-Rabanal, B., Marín-Arroyo, A. B., Maeso, C. V., & González Morales, M. R. (2020). Osteolytic lesions on the os petrosum of a Bronze Age individual from La Llana cave (Northern Spain) compatible with a possible case of otitis media. A multifaceted methodological approach. *International Journal of Paleopathology*, *31*, 97–102. https://doi.org/10.1016/J.IJPP.2020.10.006

Eyler, W. R., Monsein, L. H., Beute, G. H., Tilley, B., Schultz, L. R., & Schmitt, W. G. H. (2013). Rib enlargement in patients with chronic pleural disease. *American Journal of Roentgenology*, *167*(4), 921–926. https://doi.org/10.2214/AJR.167.4.8819384

Falger, V. S. E., Beemsterboer-Köhne, C. A., & Kölker, A. J. (2012). *Nieuwekroniek van de Beemster*. Canaletto.

Fleischer, A. (2007). The Beemster Polder: conservative invention and Holland's great pleasure garden. In L. Roberts, L. Dear, & S. Schaffer (Eds.), *The mindful hand: inquiry and invention from the Late Renaissance to Early Industrialisation* (pp. 145–168). Koninklijke Nederlandse Akademie van Wetenschappen.

Flohr, S., & Schultz, M. (2009). Mastoiditis—Paleopathological evidence of a rarely reported disease. *American Journal of Physical Anthropology*, *138*(3), 266–273. https://doi.org/10.1002/AJPA.20924

Floreanova, K., Gilat, E., Koren, I., & May, H. (2020). Ear infection prevalence in prehistoric and historic populations of the southern Levant: A new diagnostic method. *International Journal of Osteoarchaeology*, *30*(4), 449–457. https://doi.org/10.1002/oa.2873

Forbes, R. J. (1953). Museum-Nieuws. *Bulletin Koninklijke Nederlandse Oudheidkundige Bond*, 147.

Gisselsson-Solen, M. (2022). Trends in adult otitis media incidence—A 20-year national observational study in Sweden. *Clinical Otolaryngology*, *47*(1), 238–242. https://doi.org/10.1111/COA.13886

Gregg, J. B., & Steele, J. P. (1982). Mastoid Development in Ancient and Modern Populations: A Longitudinal Radiological Study. *JAMA*, *248*(4), 459–464. https://doi.org/10.1001/JAMA.1982.03330040047030

Griffioen, A. (2011). *Inventariserend veldonderzoek te Middenbeemster, Middenweg 148*. Hollandia reeks 346.

Gulya, A. J. (1994). Environmental tobacco smoke and otitis media. *Otolaryngology--Head and Neck Surgery : Official Journal of American Academy of Otolaryngology-Head and Neck Surgery*, *111*(1), 6–8. https://doi.org/10.1177/019459989411100103

Guttentag, A. R., & Salwen, J. K. (1999). Keep Your Eyes on the Ribs: The Spectrum of Normal Variants and Diseases That Involve the Ribs. *Radiographics*, *19*(5), 1125–1142. https://doi.org/10.1148/RADIOGRAPHICS.19.5.G99SE011125

Haakma Wagenaar, W., & van den Brink, E. (2011). *De gemetselde graven in de Sint Bavokerk in Aardenburg*.

Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalan, C. (2006). Climate change and human health: Impacts, vulnerability and public health. *Public Health*, *120*(7), 585–596. https://doi.org/10.1016/J.PUHE.2006.01.002

Hakvoort, A., Griffioen, A., Schats, R., & Bitter, P. (2015). *Graven en begraven bij de Minderbroeders. Een archeologische opgraving op de Paardenmarkt in Alkmaar*. Rapporten over de Alkmaarse Monumenten en Archeologie 22.

Harreld, D. J. (2015). *A Companion to the Hanseatic League*. Brill Publisher.

Harskamp, jaap. (2009). The Low Countries and the English Agricultural Revolution. *Gastronomica*, *9*(3), 32–41. https://doi.org/10.1525/GFC.2009.9.3.32

Henderikx, P. (2012a). Politieke geschiedenis, bestuurlijke instellingen. In P. Brusse & P. Henderikx (Eds.), *Geschiedenis van Zeeland deel 1: van prehistorie tot 1550* (pp. 107–124). Uitgeverij Wbooks.

Henderikx, P. (2012b). Vroege middeleeuwen. In P. Brusse & P. Henderikx (Eds.), *Geschiedenis van Zeeland deel 1: van prehistorie tot 1550* (pp. 61–79). Uitgeverij Wbooks.

Hendriks, J., & De Roode, F. (2012). Het vroeg-Merovingische grafveld van Lentseveld. *Archeobrief. Vakblad Voor de Nederlandse Archeologie*, *16*(1), 20–26.

Huisman, F. G. (2018). De maatschappelijke reacties op ziekte. In H. F. P. Hillen, E. S. Houwaart, & F. G. Huisman (Eds.), *Medische geschiedenis: Ziekte, Kennis, Dokter en patiënt, Gezondheidszorg en maatschappij* (pp. 19–34). Bohn Stefleu van Loghum.

Jansen, H. P. H. (1981). *Geschiedenis van de Middeleeuwen*. Uitgeverij Het Spectrum.

Jansen, H., & Willems, J. (1986). *Lent*. Betuwse Boekerij.

Kaptein, H. (2007). Streekcentrum in wording. De economische ontwikkeling van een marktstad. In D. Aten, J. Drewes, J. Kila, & H. de Raad (Eds.), *Geschiedenis van Alkmaar* (pp. 91–103). Waanders Uitgevers.

Kenny, C. (2021). *The Plague Cycle: The Unending War Between Humanity and Infectious Disease*. Scribner.

Kocak, M., Smith, T. L., & Smith, M. M. (2002). Bone involvement in chronic rhinosinusitis. *Current Opinion in Otolaryngology and Head and Neck Surgery*, *10*(1), 49–52. https://doi.org/10.1097/00020840-200202000-00013

Kong, K., & Coates, H. L. C. (2009). Natural history, definitions, risk factors and burden of otitis media. *The Medical Journal of Australia*, *191*(9), S39. https://doi.org/10.5694/J.1326-5377.2009.TB02925.X

Krenz-Niedbała, M., & Łukasik, S. (2016). Prevalence of chronic maxillary sinusitis in children from rural and urban skeletal populations in Poland. *International Journal of Paleopathology*, *15*, 103–112. https://doi.org/10.1016/j.ijpp.2016.10.003

Krenz-Niedbała, M., & Łukasik, S. (2017). Skeletal Evidence for Otitis Media in Mediaeval and Post-Mediaeval Children from Poland, Central Europe. *International Journal of Osteoarchaeology*, *27*(3), 375–386. https://doi.org/10.1002/OA.2545

Krenz-Niedbała, M., & Łukasik, S. (2020). Urban-Rural Differences in Respiratory Tract Infections in Medieval and Early Modern Polish Subadult Samples. In T. K. Betsinger & S. N. DeWitte (Eds.), *The Bioarchaeology of Urbanization. The Biological, Demographic, and Social Consequences of Living in Cities* (pp. 245–274). Springer Nature Switzerland.

Kyung, S. Y., & Jeong, S. H. (2020). Particulate-Matter Related Respiratory Diseases. *Tuberculosis and Respiratory Diseases*, *83*(2), 116. https://doi.org/10.4046/TRD.2019.0025

Lambert, P. M. (2002). Rib lesions in a prehistoric Puebloan sample from southwestern Colorado. *American Journal of Physical Anthropology*, *117*(4), 281–292. https://doi.org/10.1002/AJPA.10036

Lewis, M. E. (1999). *The impact of urbanisation and industrialisation in Medieval and Post-Medieval Britain. An assessment of the morbidity and mortality of non-adult skeletons from the cemeteries of two urban and two rural sites in England (AD 850-1859).* [Doctoral dissertation, University of Bradford]. Retrieved from http://hdl.handle.net/10454/4196

Lourens, P., & Lucassen, J. (1997). *Inwonertallen van Nederlandse steden ca. 1300-1800*. Amsterdam University Press.

Lu, C., Li, Q., Liu, Z., Yang, W., Liao, H., & Liu, Q. (2023). Preconceptional, prenatal, and postnatal exposure to home environmental factors and childhood otitis media. *Building and Environment*, *228*. https://doi.org/10.1016/J.BUILDENV.2022.109886

Matos, V., & Santos, A. L. (2006). On the trail of pulmonary tuberculosis based on rib lesions: Results from the human identified skeletal collection from the Museu Bocage (Lisbon, Portugal). *American Journal of Physical Anthropology*, *130*(2), 190–200. https://doi.org/10.1002/AJPA.20309

Meindl, R. S., & Lovejoy, C. O. (1985). Ectocranial suture closure: A revised method for the determination of skeletal age at death based on the lateral-anterior sutures. *American Journal of Physical Anthropology*, *68*(1), 57–66. https://doi.org/10.1002/AJPA.1330680106

Merrett, D. C., & Pfeiffer, S. (2000). Maxillary sinusitis as an indicator of respiratory health in past populations. *American Journal of Physical Anthropology*, *111*(3), 301–318. https://doi.org/10.1002/(SICI)1096-8644(200003)111:3<301::AID-AJPA2>3.0.CO;2-0

Meulenberg, F., & Frentrop, P. (2004). Spitten naar skeletten op Schutje: opgravingen bij Nieuwerkerke in 1951. *Kroniek van Het Land van de Zeemeermin (Schouwen-Duiveland)*, *29*, 85–102.

Mijnhardt, W. (2012). Inleiding. In P. Brusse & W. Mijnhardt (Eds.), *Geschiedenis van Zeeland deel 2: 1550-1700* (pp. 7–14). Uitgeverij Wbooks.

Ortner, D. J. (2003). Identification of Pathological Conditions in Human Skeletal Remains. In *Identification of Pathological Conditions in Human Skeletal Remains*. Academic Press. https://doi.org/10.1016/B978-0-12-528628-2.X5037-6

3

Palmer, J. L. A., Hoogland, M. H. L., & Waters-Rist, A. L. (2016). Activity Reconstruction of Post-Medieval Dutch Rural Villagers from Upper Limb Osteoarthritis and Entheseal Changes. *International Journal of Osteoarchaeology*, *26*(1), 78–92. https://doi.org/10.1002/oa.2397

Panhuysen, R. G. A. M., Coenen, V., & Bruintjes, T. D. (1997). Chronic Maxillary Sinusitis in Medieval Maastricht, the Netherlands. *International Journal of Osteoarchaeology*, *7*(6), 610–614. https://doi.org/10.1002/(SICI)1099-1212(199711/12)7:6<610::AID-OA366>3.0.CO;2-Q

Patel, N. A., & Ferguson, B. J. (2012). Odontogenic sinusitis: An ancient but under-appreciated cause of maxillary sinusitis. *Current Opinion in Otolaryngology and Head and Neck Surgery*, *20*(1), 24–28. https://doi.org/10.1097/MOO.0B013E32834E62ED

Paulin, L., & Hansel, N. (2016). Particulate air pollution and impaired lung function. *F1000Research*, *5*. https://doi.org/10.12688/F1000RESEARCH.7108.1

Qureishi, A., Lee, Y., Belfield, K., Birchall, J. P., & Daniel, M. (2014). Update on otitis media – prevention and treatment. *Infection and Drug Resistance*, *7*, 15–24. https://doi.org/10.2147/IDR.S39637

Qvist, M., & Grøntved, A. M. (2001). Chronic Otitis Media Sequelae in Skeletal Material From Medieval Denmark. *The Laryngoscope*, *111*(1), 114–118. https://doi.org/10.1097/00005537-200101000-00020

Roberts, C. A. (2019). Infectious Disease: Introduction, Periostosis, Periostitis, Osteomyelitis, and Septic Arthritis. *Ortner's Identification of Pathological Conditions in Human Skeletal Remains*, 285–319. https://doi.org/10.1016/B978-0-12-809738-0.00010-7

Roberts, C., Lucy, D., & Manchester, K. (1994). Inflammatory lesions of ribs: an analysis of the Terry Collection. *American Journal of Physical Anthropology*, *95*(2), 169–182. https://doi.org/10.1002/AJPA.1330950205

Roessingh, H. K. (1979). Tobacco growing in Holland in the seventeenthand eighteenth centuries: A case study of the innovative spirit of Dutch peasants. In *The Low Countries history yearbook 1978: Acta Historiae Neerlandicae XI* (pp. 18–54). Springer.

Santos, A. L., & Roberts, C. A. (2001). A picture of tuberculosis in young Portuguese people in the early 20th century: A multidisciplinary study of the skeletal and historical evidence. *American Journal of Physical Anthropology*, *115*(1), 38–49. https://doi.org/10.1002/ajpa.1054

Schats, R. (2015). Graven en begraven bij de Minderbroeders. Een archeologische opgraving op de Paardenmarkt in Alkmaar. In B. Beerenhout, D. Brinkhuizen, S. van Daalen, R. Hermsen, R. Houchin, L. M. Kootker, D. Smeerdijk, & J. Zeiler (Eds.), *Graven en Begraven bij de Minderbroeders* (pp. 172–228). Gemeente Alkmaar.

Schats, R. (2016). *Life in transition: an osteoarchaeological perspective of the consequences of medieval socioeconomic developments in Holland and Zeeland (AD 1000-1600)*. [Doctoral dissertation, Leiden University]. Retrieved from https://hdl.handle.net/1887/43926

Schmal, H. (2018). *Patterns of European urbanisation since 1500*. Taylor & Francis.

Schwarzbach, H. L., Mady, L. J., & Lee, S. E. (2020). What is the Role of Air Pollution in Chronic Rhinosinusitis? *Immunology and Allergy Clinics of North America*, *40*(2), 215–222. https://doi.org/10.1016/J.IAC.2019.12.011

Scott, A. B., & Hoppa, R. D. (2018). The subtleties of stress: A comparative analysis of skeletal lesions between the Medieval and post-Medieval Black Friars cemetery population (13th to 17th centuries). *International Journal of Osteoarchaeology*, *28*(6), 695–702. https://doi.org/10.1002/OA.2691

Scott, H. M. (2018). *The Oxford Handbook of Early Modern European History, 1350-1750* (H. M. Scott, Ed.). Oxford University Press.

Slavin, R. G., Spector, S. L., Bernstein, I. L., Kaliner, M. A., Kennedy, D. W., Virant, F. S., Wald, E. R., Khan, D. A., Blessing-Moore, J., Lang, D. M., Nicklas, R. A., Oppenheimer, J. J., Portnoy, J. M., Schuller, D. E., Tilles, S. A., Borish, L., Nathan, R. A., Smart, B. A., & Vandewalker, M. L. (2005). The diagnosis and management of sinusitis: a practice parameter update. *The Journal of Allergy and Clinical Immunology*, *116*(6), S13–S47. https://doi.org/10.1016/J.JACI.2005.09.048

Stannard, W., & O'Callaghan, C. (2006). Ciliary Function and the Role of Cilia in Clearance. *Journal of Aerosol Medicine*, *19*(1), 110–115. https://doi.org/10.1089/JAM.2006.19.110

Streefkerk, C. (2004). De vrijheid van Alkmaar: Het stadsrecht van Alkmaar (1254) uitgegeven, vertaald en van een inleiding voorzien. In L. Noordgraaf (Ed.), *Alkmaar, stad en regio: Alkmaar en omgeving in de Late Middeleeuwen en Vroegmoderne tijd* (pp. 9–50). Uitgeverij Verloren.

Sundman, E. A., & Kjellström, A. (2013a). Chronic maxillary sinusitis in medieval Sigtuna, Sweden: A study of sinus health and effects on bone preservation. *International Journal of Osteoarchaeology*, *23*(4), 447–458. https://doi.org/10.1002/oa.1268

Sundman, E. A., & Kjellström, A. (2013b). Signs of sinusitis in times of urbanization in Viking Age-Early Medieval Sweden. *Journal of Archaeological Science*, *40*(12), 4457–4465. https://doi.org/10.1016/j.jas.2013.06.010

Teunissen, D. (2016). Palynological investigation of the late Roman single period fortification ditch at Nijmegen. In J. H. F. Bloemers (Ed.), *Four approaches to the analysis of (pre)Roman Nijmegen Aspects of cultural evolution, acculturation, contextual function and continuity* (pp. 203–208). Cultural Heritage Agency of the Netherlands.

3

van Braam, A. (1978). *Westzaandam in de tijd van de Republiek*. Gemeentearchief van Zaanstad.

van Cruyningen, P. (2012). Economie. In P. Brusse & W. Mijnhardt (Eds.), *Geschiedenis van Zeeland deel 2: 1550-1700* (pp. 51–75). Uitgeverij Wbooks.

van der Wiel, K. (2012a). Kaasmaken, een wetenschap. In K. Bossaers & C. Misset (Eds.), *400 jaar Beemster* (pp. 82–99). Stichting Uitgeverij Noord-Holland.

van der Wiel, K. (2012b). Melkkoeien, fokstieren en vette ossen. In K. Bossaers & C. Misset (Eds.), *400 jaar Beemster* (pp. 48–81). Stichting Uitgeverij Noord-Holland.

van Es, W. A., & Hulst, R. S. (1991). Das merowingische Gräberfeld von Lent, Amersfoort. *Nederlandse Oudheden*, *14*.

van Laar, E. (1966). *Hoop op gerechtigheid: De arbeiders en hun organisations in Arnhem gedurende de tweede helft van de negentiend eeuw*. Gemeentearchief.

van Nierop, H. F. K. (2000). Alkmaar in de Opstand. In N. van Foreest (Ed.), *Kort verhaal van het beleg van Alkmaar. Een ooggetuigenverslag* (pp. 7–18). Uitgeverij Ter Burg.

Vikatou, I., Hoogland, M. L. P., & Waters-Rist, A. L. (2017). Osteochondritis Dissecans of skeletal elements of the foot in a 19th century rural farming community from The Netherlands. *International Journal of Paleopathology*, *19*, 53–63. https://doi.org/10.1016/J.IJPP.2017.09.005

Wee, J. H., Min, C., Jung, H. J., Park, M. W., Park, B., & Choi, H. G. (2021). Association between air pollution and chronic rhinosinusitis: a nested case-control study using meteorological data and national health screening cohort data. *Rhinology*, *59*(5), 451–459. https://doi.org/10.4193/RHIN21.141

Western, G., & Bekvalac, J. (2019). *Manufactured Bodies. The impact of industrialisation on London health*. Oxbow Books.

Wintle, M. (2000). An Economic and Social History of the Netherlands, 1800–1920. In *An Economic and Social History of the Netherlands, 1800–1920*. Cambridge University Press. https://doi.org/10.1017/cbo9780511496974

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., Hutchinson, D. L., Jankauskas, R., Cesnys, G., Katzenberg, M. A., Lukacs, J. R., McGrath, J. W., Roth, E. A., Ubelaker, D. H., & Wilkinson, R. G. (1992). The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples [and Comments and Reply]. *Current Anthropology*, *33*(4), 343–370. https://doi.org/10.1086/204084

Zanobetti, A., Schwartz, J., & Dockery, D. W. (2000). Airborne particles are a risk factor for hospital admissions for heart and lung disease. *Environmental Health Perspectives*, *108*(11), 1071–1077. https://doi.org/10.1289/EHP.001081071