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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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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 contact 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.

1. Introduction

According to historical sources, urbanization dramatically altered Europe's economic, political, and social realities starting 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 and 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 through a variety of methods (e.g., non-specific stress markers, dietary isotopes, stature, respiratory disease) (Betsinger and DeWitte, 2017; Lewis, 1999; Schats, 2016; Sundman, Kjellström 2013a,2013b; Western and 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

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Table 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

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 (Boyd, 2020; Casna et al., 2021a,2021b; Sundman, Kjellström 2013a,2013b). 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 and 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 (Bernofsky, 2010; Casna et al., 2021a,2021b; Panhuysen et al., 1997), we hypothesized that prevalence rates of respiratory stress markers would progressively increase with time in rural samples, as well.

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., 1995a, 1995b; Kocak et al., 2002; Slavin et al., 2005; Stannard and 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 and 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, and infections (viral and bacterial). Despite it being largely considered 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 process of the temporal bone (i.e., mastoiditis), and the petrous portion of the temporal bone (Estalrrich et al., 2020; Flohr and Schultz, 2009; Floreanova et al., 2020; Krenz-Niedbała and Łukasik, 2017; Qvist and Grøntved, 2001). Because of the difficulty in examining the middle ear osteologically and the lack of clear scoring criteria, bioarchaeological studies of OM are scant. The majority of the extant studies employ either radiography or light microscopy and observed prevalence rates varying between 6% and 83.4% (Flohr and Schultz, 2009; Gregg and Steele, 1982; Krenz-Niedbała and Łukasik, 2016; Qvist and 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 (Boyd, 2020; Qvist and Grøntved, 2001; Sundman, Kjellström 2013a,2013b). 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 (Fleischer, 2007; Merrett and Pfeiffer, 2000; Sundman and Kjellström 2013a,2013b), 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 (Bernofsky, 2010; Casna et al., 2021a,2021b; Panhuysen et al., 1997).

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 tract. In bioarchaeology, inflammatory periosteal reaction on the cortical layer on 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 and Jeong, 2020; Paulin and Hansel, 2016; Zanobetti et al., 2000). If chronically inflamed, the pleura can thicken and induce new bone formation (Eyler et al., 2013; Guttentag and 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 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; Lambert, 2002; Santos and Roberts, 2001; Western and Bekvalac, 2019).

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 1; Fig. 1). They were selected because they represent a diachronic window into life in the Northern Low Countries in the early-medieval (300–1080

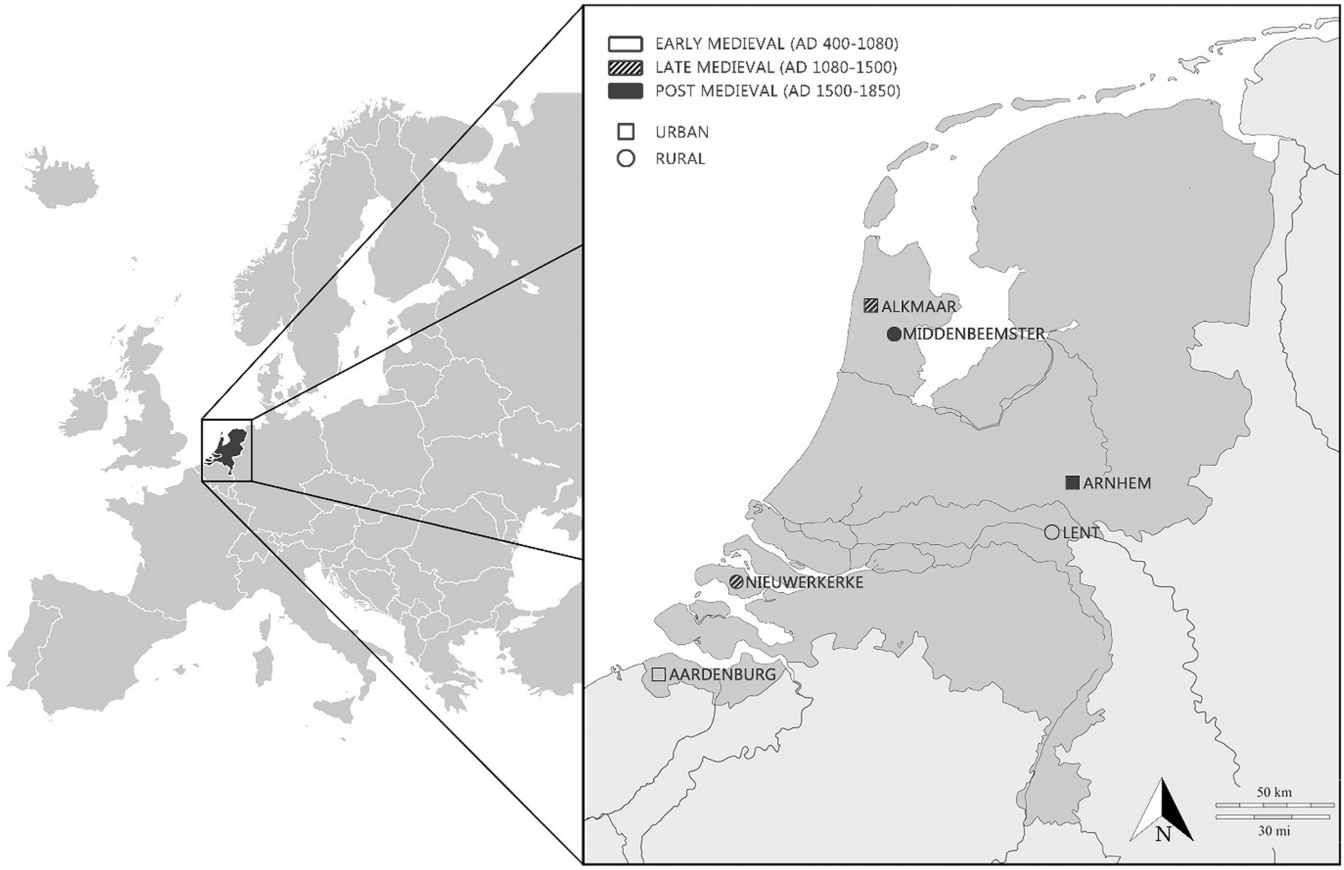

Fig. 1. Map of the Netherlands showing the location of the sites under study. Image made by M. Casna.

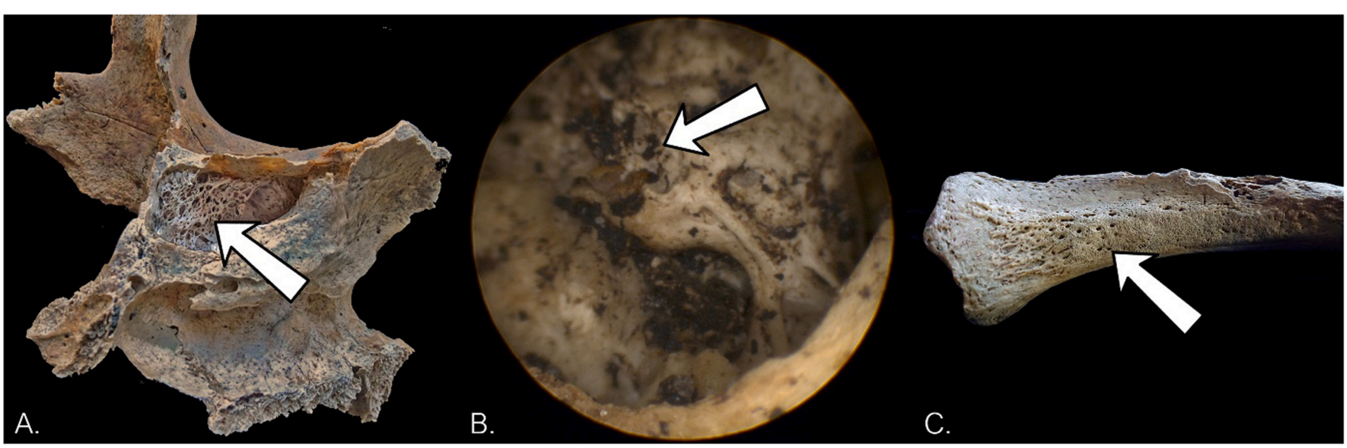

Fig. 2. Examples of lesions observed in this research: (a) chronic maxillary sinusitis, (b) otitis media, and (c) periosteal rib reaction. Lesions are indicated by the white arrows. Photographs by M. Casna.

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 and Hoppenbrouwers, 2007).

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,

Table 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

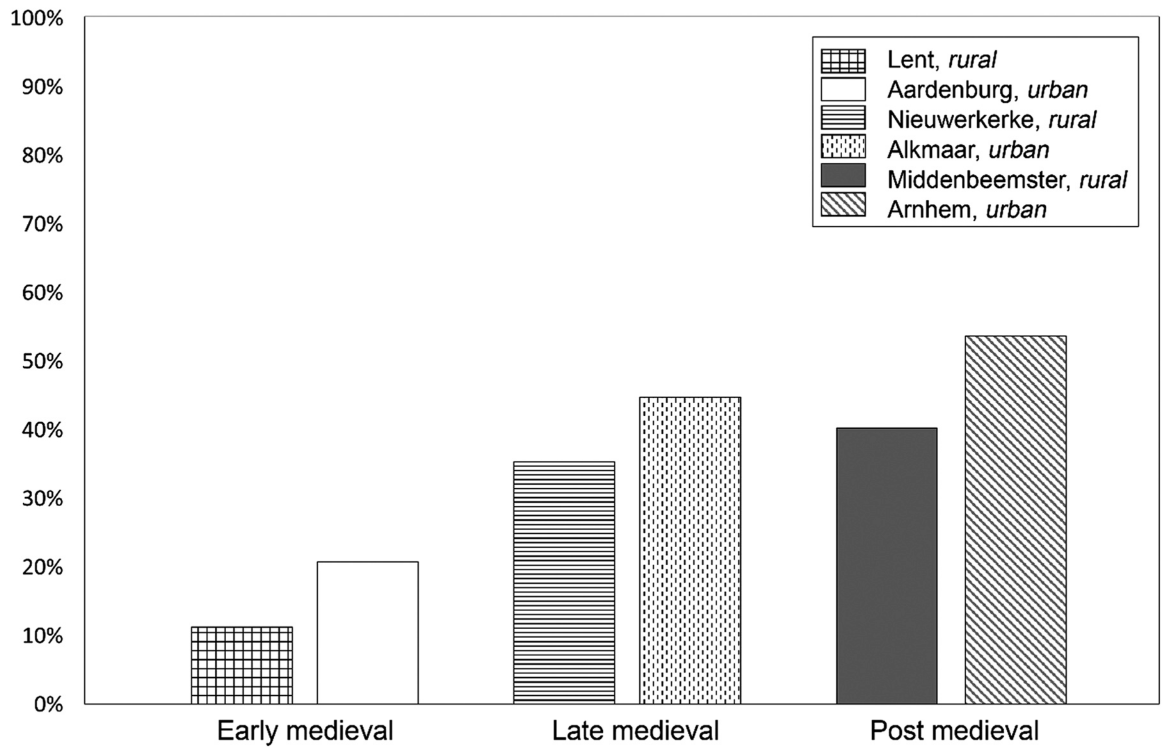

Fig. 3. Prevalence of chronic maxillary sinusitis for all samples under study ($N = 541$).

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; Haakma Wagenaar and 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 in 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-

Table 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 $p = 0.017$.

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 and Baetsen, 2020). Starting from 1795, systematic immigration caused the population to suddenly grow, making Arnhem almost as populated as other major Dutch centers (Lourens and 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., 2018; 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 and 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 but 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).

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 and 1975) and Lentseveld (excavated in 2011). In total, the two collections combined included a total of approximately 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 and De Roode, 2012; van Es and 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 be partly 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 and Willems, 1986).

Similar to Lent, inhabitants of Nieuwerkerke were also mainly involved in the production of agricultural supply for the neighboring city of Zierikzee, which 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 of approximately 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 and Frentrop, 2004). However, Nieuwerkerke's church was demolished in the early 16th century, following a siege by Spanish troops. Consequently, the cemetery was closed and the municipality later merged with another nearby village (Meulenberg and 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

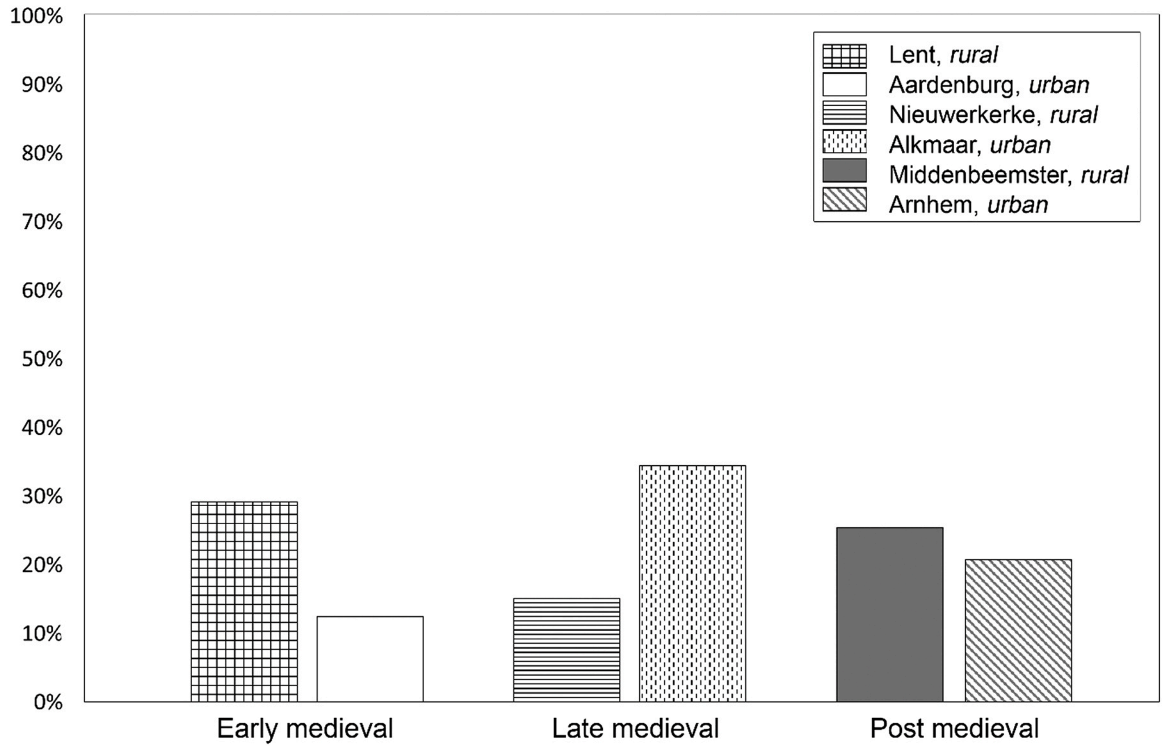

Fig. 4. Prevalence of otitis media for all samples under study ($N = 585$).

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 osteoarcheological research into activity reconstruction at Middenbeemster (Palmer et al., 2016; Vikatou et al., 2017).

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.

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 and Ubelaker, 1994). To test the demographic comparability of the sample, age-at-death estimations were made based on ectocranial suture closure (Meindl and Lovejoy, 1985), morphologic characteristics of the pubic symphysis (Brooks and Suchey, 1990) and of the auricular surface (Buckberry and 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=4 mm; view angle=30°) inserted through minor breaks (Casna et al., 2021a,2021b). 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., 1995a,1995b), were recorded for each individual and classified as ‘present’ whenever either bone resorption or new bone growth were present (Fig. 2, a). As dental disease (i.e., periodontal disease, abscesses, and granulomas) can influence the presence of maxillary sinusitis (Patel and Ferguson, 2012), individuals showing dental decay and/or antemortem tooth loss in the upper premolars and/or molars were excluded from analysis.

Otitis media (OM) was identified using criteria outlined 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 (Fig. 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 seriation, ribs were allocated to 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

Table 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		$\chi2 = 3.213$, $p = 0.073$		$\chi2 = 0.184$, $p = 0.668$	
Nieuwerkerke				$\chi2 = 4.115$, $p = 0.043$	
Changes through time in urban environments (continued)					
	Aardenburg	Alkmaar		Arnhem	
Aardenburg		**$\chi2 = 11.724$, $p = 0.001$**		$\chi2 = 2.588$, $p = 0.108$	
Alkmaar				$\chi2 = 4.690$, $p = 0.030$	

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 $p = 0.017$.

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) (Fig. 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.

3. Results

Of the total sample ($N = 695$) (Table 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.

3.1. Chronic maxillary sinusitis (CMS)

Within the total sample, CMS was most common in Arnhem (53.6%) and least common in Lent (11.3%) (Fig. 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).

3.2. Otitis media (OM)

With the exception of the late-medieval period, OM prevalence was higher in rural samples (Fig. 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 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.

3.3. Inflammatory periosteal reaction on ribs (IPR)

Among all recorded lesions, inflammatory periosteal reaction on ribs (IPR) was the least commonly observed (Fig. 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 5).

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 ($\chi^2 = 5.411$, $p = 0.03$), where males showed greater prevalence than females (males: 9.7%; females; 0%).

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 osteoarcheological studies: there is no correlation between urban settings and the presence of skeletally visible respiratory conditions (Bernofsky, 2010; Casna et al., 2021a,2021b; 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 and 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

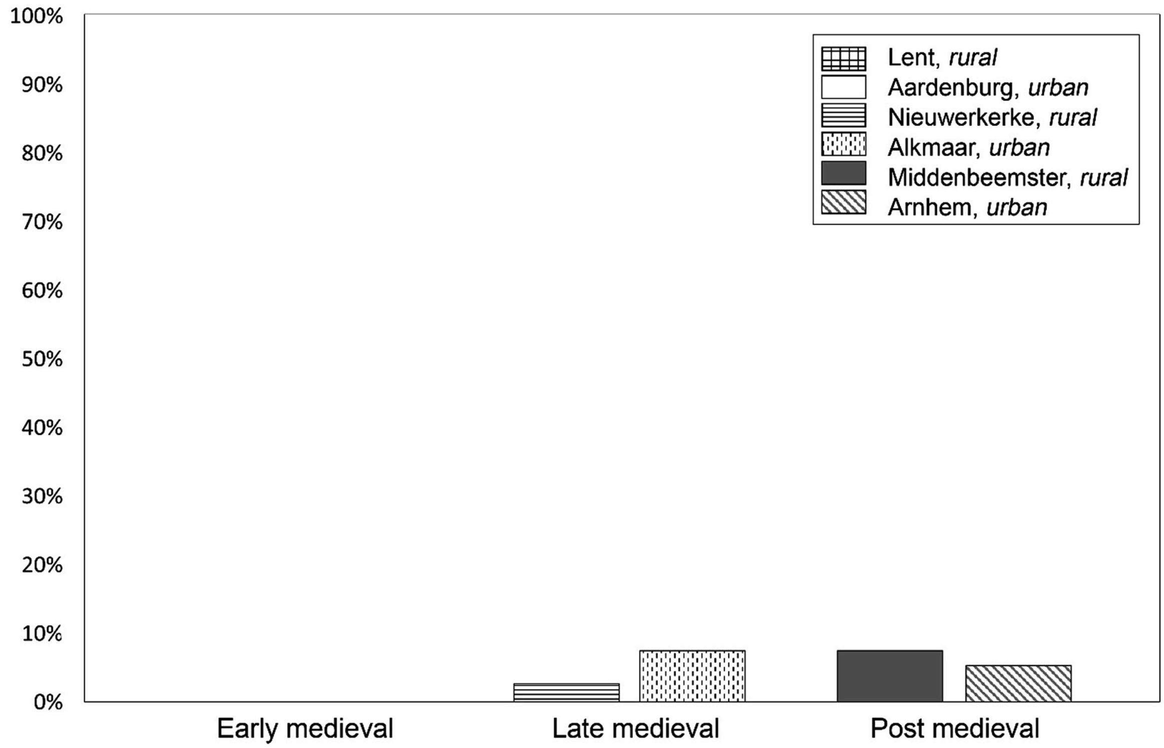

Fig. 5. Prevalence of inflammatory periosteal reaction on ribs for all samples under study ($N = 325$).

Table 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		†$\chi 2 = 0.599$, $p = 1.000$		†$\chi 2 = 1.780$, $p = 0.350$	
Nieuwerkerke				†$\chi 2 = 1.125$, $p = 0.447$	
Changes through time in urban environments (continued)					
	Aardenburg	Alkmaar		Arnhem	
Aardenburg		†$\chi 2 = 0.469$, $p = 1.000$		†$\chi 2 = 0.329$, $p = 1.000$	
Alkmaar				†$\chi 2 = 00.245$, $p = 0.699$	

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

medieval periods. Historically, this may be explained by the fact that, during the lifetimes of the individuals under study, both cities faced rapid expansiof, 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 of 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 and Hoppenbrouwers, 2007; Wintle, 2000). This may offer an explanation as to 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, as well. 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, 2012; 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 agri-business 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 and 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, this difference was mitigated in the post-medieval period between Arnhem (urban) and Middenbeemster (rural). In Middenbeemster, agriculture had developed into 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 other 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 at 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).

It is also of interest that 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 modern clinical literature, living in damp and cold environments can increase the risk for respiratory disease, especially otitis media (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 near to the draining land (as opposed to Arnhem, located inland, and Aardenburg, at the time located more than 20 km 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 (see 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 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 bioarchaeologists to contextualize their presence (Boyd, 2020; Davies-Barrett et al., 2019; Matos and Santos, 2006; Roberts et al., 1994). Important to note is that most of these conditions are quite challenging for the human organism to battle 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 and 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 and 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 and 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 and 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 at both Nieuwerkerke and Middenbeemster could be explained by the fact that, in time of growing 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; Hendriks and 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 heterogeneity of risk, 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. 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 phenomena.

5. Conclusion

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 influenced 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 why generalizations about (respiratory) health in different populations is 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.

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Declaration of Competing Interest

The authors have no conflict of interest to declare.

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Supporting information

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.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijpp.2023.07.003.

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