The air we breathe: a study into the impact of historical socioeconomic changes on the respiratory health of past Dutch populations (ca. 470-1850 CE)

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CHAPTER 6

Historical Trends and Risk Factors in Chronic Maxillary Sinusitis Prevalence Rates Among Dutch Non-Adults (475-1866 CE)

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Abstract

Objectives: This research examines the prevalence of chronic maxillary sinusitis in non-adults from multiple Dutch sites, while also considering the effects of associated risk factors such as time period (i.e., urbanization), living conditions, and socioeconomic status. Our aim was to investigate how different risk factors impacted childhood respiratory health throughout the Dutch medieval and Post-medieval periods.

Materials and Methods: We selected 13 sites representative of different time periods (475-1866 CE), living environments (i.e., rural and urban), and socioeconomic statuses to provide an in-depth overview of past Dutch societies. We macroscopically and endoscopically analyzed the maxillary sinuses of 227 non-adult individuals to identify paleopathological signs of sinusitis. Adult data on chronic maxillary sinusitis from 11 of these populations were available for comparison.

Results: Statistical analysis revealed that post-medieval non-adults were almost three times more likely to develop sinusitis than their early-medieval counterparts. Additionally, increasing age-at-death statistically increased the likelihood of sinusitis. Post-medieval adolescents were eight times more at risk than adolescents from earlier periods.

Discussion: Our findings highlight the interplay of risk factors affecting respiratory health in non-adults, contributing to a more comprehensive understanding of the historical burden of respiratory diseases in past populations. Despite concerns regarding the representativeness of our sample, we argue that factors such as increased population densities, limited access to resources, and the institutionalization of child labor in the Dutch post-medieval period significantly and negatively impacted the respiratory health of non-adults.

Keywords: Respiratory health; Non-survivors; Paleopathology; Urban development; Child labor

6.1. Introduction

Today, chronic respiratory diseases are among the most prevalent non-communicable diseases worldwide; this is likely a consequence of pervasive exposure to detrimental environmental, occupational, and behavioral factors (Labaki & Han, 2020). Due to their prevalence in contemporary society, respiratory diseases have often been the subject of bioarchaeological studies, as it is assumed that several risk factors (e.g., exposure to air pollution, poor hygienic conditions, and crowded living and working environments) prevailed in many historical contexts and likely negatively impacted the respiratory health of our ancestors (e.g., Boocock et al., 1995; Boyd, 2020; Davies-Barrett et al., 2021; Panhuysen et al., 1997; Riccomi et al., 2021). Previous research on respiratory diseases indicates that these health issues have been prevalent among human populations since at least 2000 BCE, persisting across various time periods and living conditions (Roberts, 2007; Wells, 1977).

According to historical sources, up until the 19th century respiratory diseases were the most common diseases affecting European children and the leading cause of their mortality (Shulman, 2004; Wintle, 2000). "Coughs", an umbrella term likely encompassing a variety of ailments such as influenza, bronchitis, tuberculosis, and pertussis, were frequently discussed in the earliest pediatric texts dating back to the 1500s, as (according to historical sources) they were prevalent among children of all socioeconomic backgrounds (Pancino, 2015). This is generally supported by the few osteoarchaeological studies focusing on non-adults specifically, which so far have reported respiratory diseases prevalence rates ranging from 10% to 66% (e.g., Krenz-Niedbała & Łukasik, 2020; Liebe-Harkort, 2012; Panhuysen et al., 1997). In most cases, the main aim of these studies has been to investigate how different living circumstances (e.g., urbanization, socioeconomic status) influenced respiratory health. For example, in their study on chronic maxillary sinusitis among non-adults in medieval Denmark, Bennike and colleagues (2005) identified socioeconomic status as a significant risk factor for sinusitis, as they observed higher prevalence rates of bony changes in individuals from economically disadvantaged backgrounds compared to their wealthier counterparts. Furthermore, in order to assess whether urbanization and industrialization impacted child health, Krenz-Niedbała and Łukasik (2020) examined sinusitis, otitis media, and pleural inflammation among 308 non-adult individuals from two medieval rural and proto-urban Polish populations (10th-17th centuries CE) and found that both otitis media and pleural inflammation were more common among urban children compared to rural ones. In contrast, when analyzing 831 individuals from four English sites dating to 850-1859 CE, Lewis (2002) observed higher rates of sinusitis in rural non-adults than in urban ones.

Divergences in results are common in bioarchaeological studies focusing on respiratory diseases and may often be attributed to the complex etiologies of these conditions (e.g., Casna et al., 2023; Collins, 2019; Lewis et al., 1995). It is widely acknowledged that identifying precise risk factors affecting respiratory health in historical populations poses significant challenges and is, in most cases, impossible (Lewis et al., 1995). Nevertheless, the abundance of both paleopathological and historical data available today for (adult) skeletal populations offers foundational insights

into how different risk factors interplayed with each other in past societies, shedding light on how human behavior affected disease and vice versa (e.g., Boyd, 2020; Casna et al., 2023; Casna et al., in press; Davies-Barrett et al., 2023; Roberts, 2007). While paleopathology has advanced our understanding of how various risk factors for respiratory disease interacted and contributed to its prevalence among adults, a comprehensive analysis of their influence on the respiratory health of non-adults is currently lacking. This gap in knowledge presents several issues as: 1) children are clinically disproportionately affected by respiratory diseases due to various physiological and behavioral factors (Ferkol & Schraufnagel, 2014; Zar & Ferkol, 2014); and 2) focusing paleopathological research solely on adults may hinder a comprehensive understanding of a population as a whole (Halcrow & Tayles, 2011). Furthermore, differences in developmental stages, immune system maturity, environmental exposures, and social/cultural behaviors may result in distinct risk factors affecting adults and non-adults differently, leading to different life and disease experiences based on age (Badley et al., 1973; Verhaegh et al., 2008; Zar & Ferkol, 2014). Although recent studies have partially bridged this gap by incorporating both adults and non-adults in their analyses, thereby providing an initial understanding of how past environments and living circumstances affected the respiratory health of past populations, it is currently unclear how these various risk factors interacted within non-adults specifically (Collins, 2019; Davies-Barrett et al., 2021; Zubova et al., 2020). As a consequence, our comprehension of the effects of respiratory diseases on the archaeological populations we examined remains limited, as does our understanding of the diverse influences of various risk factors across different phases of life.

To partially address this gap, the present study analyzed chronic maxillary sinusitis (here considered as a proxy for respiratory disease) in a sample of 227 non-adult individuals from 13 Dutch sites dating from 475 to 1866 CE. We examined the role of various risk factors (i.e., urbanization, living environment, and socioeconomic status) on the observed prevalence rates of sinusitis to investigate their impact and interplay within different populations. Our hypothesis was that urbanization and lower socioeconomic status would correlate with higher prevalence rates of sinusitis among non-adults, reflecting differential exposure and susceptibility to environmental and social factors.

6.2. Materials and methods

6.2.1. Materials

For the purpose of this study, we selected 13 skeletal populations from various regions across the Netherlands (Figure 6.1). Our primary motivation for studying these specific non-adult assemblages was the existing data on chronic maxillary sinusitis in adults from the same groups, enabling us to compare prevalence rates across 11 of the populations under study (Table 6.1). Moreover, these sites benefit from a substantial amount of historical data, as well as a well-understood osteoarchaeological context (see Supporting Information S1 for a comprehensive historical background for all populations included in this study). Together, these skeletal populations offer the most complete overview of past Dutch societies, as they not only span

diverse time periods (from the early to post-medieval periods), but they also encompass various living environments (i.e., rural and urban), and represent a wide range of socioeconomic statuses.

Figure 6.1. Map of the Netherlands showing the location of the sites under study.

Table 6.1. Skeletal collections included in this study. Data on chronic maxillary sinusitis in adult individuals were retrieved from: 1=Casna et al. (2023); 2=Casna & Schrader (2024); 3=Casna & Schrader (2022).

Skeletal collection	Dating	Living Environment	Socioeconomic Status	Observed Chronic Maxillary Sinusitis Prevalence Rate in Adults
Lent, Azaleastraat and Lentseveld	Early-medieval (475-750 CE)	Rural	Middle-low	11.3%[1]
Aardenburg, Sint-Baafskerk	Early-medieval (1030-1200 CE)	Urban	Middle-high	20.8%[1]
Nieuwerkerke, 't Schutje	Late-medieval (1298-1576 CE)	Rural	Middle-low	35.4%[1]
Vlissingen, Oude Markt	Late-medieval (1300-1590 CE)	Urban	Middle-low	27.8[2]
Alkmaar, Paardenmarkt	Late-medieval (1448-1572 CE)	Urban	Middle-low	44.8%[1]
Vlissingen, Scheldekwartier	Post-medieval (1600-1800 CE)	Urban	Low	46.3%[2]
Delft, Nieuwe Kerk	Post-medieval (1624-1821 CE)	Urban	High	n/a
Arnhem, Eusebiuskerk	Post-medieval (1626-1829 CE)	Urban	Low	50.8%[1]
Nijmegen, Klooster Hessenberg	Post-medieval (1638-1725 CE)	Urban	Low	n/a
Eindhoven, Sint-Catharinakerk (outside the church)	Post-medieval (1650-1850 CE)	Urban	Middle-low	35.0%[3]
Eindhoven, Sint-Catharinakerk (inside the church)	Post-medieval (1650-1850 CE)	Urban	Middle-high	59.1%[3]
Zwolle, Broerenkerk	Post-medieval (1681-1828 CE)	Urban	Middle-high	54.2%[3]
Middenbeemster, Keyserkerk	Post-medieval (1829-1866 CE)	Rural	Middle-low	40.3%[1]

To ensure comparability to previously published data, the sites under study were categorized into early-medieval, late-medieval, and post-medieval periods using the same periodization framework presented by Casna and colleagues (2023). This framework emphasizes the transition from an era characterized by landowners and isolated communities (early-middle ages, 300–1080 CE), to the emergence of cities (late-middle ages, 1080–1500 CE), to the rise of industry (post-medieval times, 1500-1850 CE) (Blockmans & Hoppenbrouwers, 2007; Wintle, 2000). Furthermore, differences in socioeconomic status were attributed for each skeletal population following the same methodology outlined by Casna and Schrader (2022), where we distinguished, informed by historical sources, four socioeconomic classes: 1) 'low', composed by individuals with almost no possessions, often employed in dependent unspecialized work and socially insignificant at the eyes of the municipal administrations; 2) 'middle-low', small businessmen, artisans, and market vendors; 3) 'middle-high', the administrative force of the city (e.g., enriched merchants, financers, etc.); and 4) 'high', clergy, nobles, and gentry families.

6.2.1.i. Social and economic developments in historical Netherlands

Between 300 and 1080 CE, Dutch society lacked a unified social and political identity. Instead, it was predominantly organized around kinship ties and familial bonds, with power concentrated in the hands of wealthy local leaders and landowners (Blockmans & Hoppenbrouwers, 2016). While a few cities such as Aardenburg were flourishing thanks to the rise of early market trades (de Vries, 1968), most people in the Low Countries were still employed in subsistence farming (Besteman, 1997; Hoppenbrouwers, 2002). The division between urban and rural lives was then likely already quite significant and marked by distinct economic opportunities that possibly reinforced socioeconomic differences across the region (de Pooter et al., 2000; Henderikx, 2012). While international trade in urban centers allowed craftsmen and merchants to thrive, rural communities such as Lent continued to heavily rely on agriculture and pastoralism and people there often remained tied to the land under feudal obligations (Dumolyn, 2002).

During the period following 1200 CE, the Low Countries experienced significant socioeconomic transformation, resulting in a shift from a cluster of economically disconnected agricultural villages to a network of small urban centers (Hoppenbrouwers, 2002). Work opportunities available in towns spurred exponential population growth and, by 1514 CE, nearly half of Holland's population resided in urban areas (Blockmans et al., 1980; Hoppenbrouwers, 2001). While towns in the late-medieval period may have still retained a relatively rural character (e.g., most citizens from Alkmaar owned a small vegetable garden to grow their own food), they expanded over time, shifting from self-sufficiency to more market-oriented economies (Bitter, 2007; Hoppenbrouwers, 2002; van Bavel, 2010). As the international trade market intensified in the 14th and 15th centuries, several products such as beer, cheese, and butter began to be regularly exported internationally (Hoppenbrouwers, 2002). Rural realities became then increasingly intertwined with nearby cities, as their purpose increasingly became to satisfy the demands of the growing centers and markets (Mijnhardt, 2012). Social structures were also likely impacted by the rise of the international market: in the late-medieval period, wealthy merchants

and specialized craftspeople started to gain great economic and political influence, challenging the traditional social dominance of the nobility (Dumolyn, 2002).

The rise of this new urban elite continued throughout the post-medieval period. With the expansion of market routes beyond the European continent and the begin of the industrial era, merchants, investors, and bankers accumulated significant wealth, exacerbating socioeconomic disparities (ten Hove, 2005; Wintle, 2000). The newborn industry offered an enormous number of work opportunities, prompting people to flock to the cities (de Vries, 1984). In many cases, municipalities found themselves unable to accommodate the influx of immigrants, leading to overcrowded and inadequate living conditions (van der Woud, 2010; van Laar, 1966). Industry work was notoriously unregulated, and often led to hazardous environments where accidents and diseases were common (Wintle, 2000). Children, who had previously traditionally accompanied their parents in their daily activities, started to be systematically hired in factories already by the age of ten (Smit & Korevaart, 2018). These developments marked the emergence of a new poor class, whose life experiences greatly differed from those of the elites who still lived in spacious, refined mansions located in dedicated areas away from pollution and from the struggles of lower-class communities (ten Hove 2005). It is generally believed that social stratification was less pronounced in rural areas, where agricultural production was still the primary focus of the economy (Bieleman, 2010). However, disparities in land ownership and wealth may still have existed in contexts such as Middenbeemster, where agriculture had evolved into a highly efficient, intensive, and organized sector catering primarily to the export market during the post-medieval period (Aten, 1992; Bieleman, 2010; Wintle, 2000).

6.2.2. Methods

For every analyzed individual, age-at-death was estimated by observing dental development, dental eruption patterns, as well as epiphyseal-diaphyseal fusion (AlQahtani et al., 2010; Cunningham et al., 2016; Demirjian et al., 1973; Moorrees et al., 1963; Schaefer et al., 2009). Skeletal sex was not determined because established macroscopic methods for sex estimation are not applicable to non-adults, as their bones have not yet developed secondary sex traits (Cunningham et al., 2016).

6.2.2.i. Chronic Maxillary Sinusitis

The typical non-pathological visual aspect of the sinus cavity is characterized by its smooth and uniform surface, with channels extending along its walls, which during life would have housed nerves and blood vessels (Whyte & Boeddinghaus, 2019). In bioarchaeology, changes observed on the sinus surface (e.g., bone resorption, bony spicules, cobweb-like lesions) and thickening of sinus walls are typically interpreted as indicators of chronic sinusitis (Boock et al., 1995; Lewis et al., 1995; Merrett & Pfeiffer, 2000; Sundman & Kjellström, 2013a). However, in non-adults, the maxillary sinuses naturally expand and remodel to accommodate the developing permanent dentition (Lorkiewicz-Muszyńska et al., 2015). This remodeling process creates large pits on the sinus floor, which can be mistaken for pathological changes and potentially lead to an overestimation of sinusitis prevalence rates (Lewis, 2018). For this reason, in the present study,

we did not consider bone resorption as indicative of sinusitis. Rather, sinusitis was scored as 'present' based on the presence of either bony spicules and/or cobweb-like lesions on any of the sinus walls (Figure 6.2) (Lewis, 2018). Thickening of the sinus walls was initially included in our criteria, but not observed in any of the individuals under study.

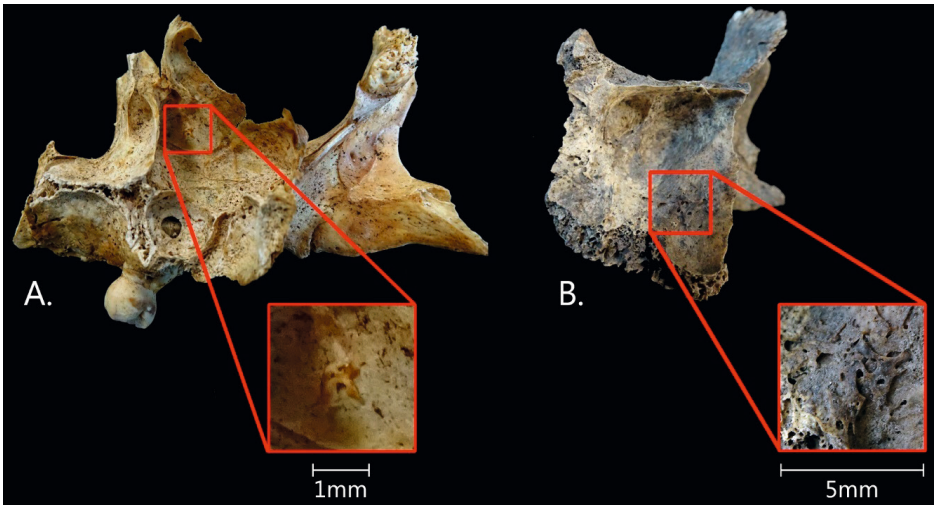

Figure 6.2. Examples of lesions indicative of chronic maxillary sinusitis observed in this study: (a) bony spicules, (b) cobweb-like lesion. Photographs and figure by M. Casna.

The presence of chronic maxillary sinusitis was observed in all individuals with at least one sinus with a partial preservation of more than 25% of the total sinus surface. To ensure accurate examination, sinuses were carefully brushed and, if necessary, cleaned with water before inspection. If the sinuses were not visible to the naked eye, they were examined using a flexible medical endoscope (Pentax, model: FNL-10RBS, ø=4 mm; view angle=30◦) inserted whenever possible through existing post-mortem breaks (Casna et al., 2021).

6.2.2.ii. Statistical Analysis

Statistical analysis was conducted using SPSS version 29.0 for Windows. We used binary logistic regression to investigate the relationship between various risk factors for respiratory disease (i.e., time period, subsistence economy, and socioeconomic status) and the presence of chronic maxillary sinusitis at the level of the individual (Harris, 2021). Age-at-death was also added as a covariate as previous studies suggested that sinusitis may show an increase with age (Lewis, 2018). In binary logistic regression, a 95% confidence interval with an upper limit below 1 indicates that the group in question is significantly less likely to be associated with the disease compared to the reference group. Conversely, a lower limit above 1 signifies that the group is significantly more likely to be associated with the disease than the reference group. *P*-values of ≤0.05 were considered to be statistically significant.

6.3. Results

A total of 227 non-adult individuals were analyzed for both age-at-death and for the presence of chronic maxillary sinusitis. Among them, 107 individuals (47.1%) showed evidence of chronic maxillary sinusitis, which was observed less frequently in children (37.1%) compared to juveniles (54.0%) and adolescents (50.0%) (Table 6.2; Figure 6.3). In most cases, the overall prevalence rates observed in non-adults were higher than those previously observed in adults (Figure S2).

Table 6.2. Observed prevalence rates of chronic maxillary sinusitis in the sample under study.

Skeletal population	Age-at-death			
	Child (4-7 years) (N)	Juvenile (8-11 years) (N)	Adolescent (12-19 years) (N)	Total (N)
Lent, Azaleastraat and Lentseveld	4 (9)	1 (2)	2 (5)	**7 (16)**
Aardenburg, Sint-Baafskerk	0 (1)	0 (0)	1 (4)	**1 (5)**
Nieuwerkerke, 't Schutje	3 (10)	2 (8)	7 (14)	**12 (32)**
Vlissingen, Oude Markt	0 (0)	0 (1)	2 (3)	**2 (4)**
Alkmaar, Paardenmarkt	0 (0)	0 (1)	1 (2)	**1 (3)**
Vlissingen, Scheldekwartier	2 (4)	1 (2)	1 (1)	**4 (7)**
Delft, Nieuwe Kerk	2 (8)	5 (7)	4 (8)	**11 (23)**
Arnhem, Eusebiuskerk	4 (11)	4 (10)	10 (31)	**18 (52)**
Nijmegen, Klooster Hessenberg	1 (5)	0 (2)	2 (2)	**3 (9)**
Eindhoven, Sint-Catharinakerk (outside the church)	5 (7)	3 (9)	2 (6)	**10 (22)**
Eindhoven, Sint-Catharinakerk (inside the church)	0 (2)	2 (4)	3 (3)	**5 (9)**
Zwolle, Broerenkerk	0 (2)	6 (6)	1 (1)	**7 (9)**
Middenbeemster, Keyserkerk	5 (11)	10 (11)	11 (14)	**26 (36)**
Total (N)	**26 (70)**	**34 (63)**	**47 (94)**	**107 (227)**

N: Total number of analyzed individuals.

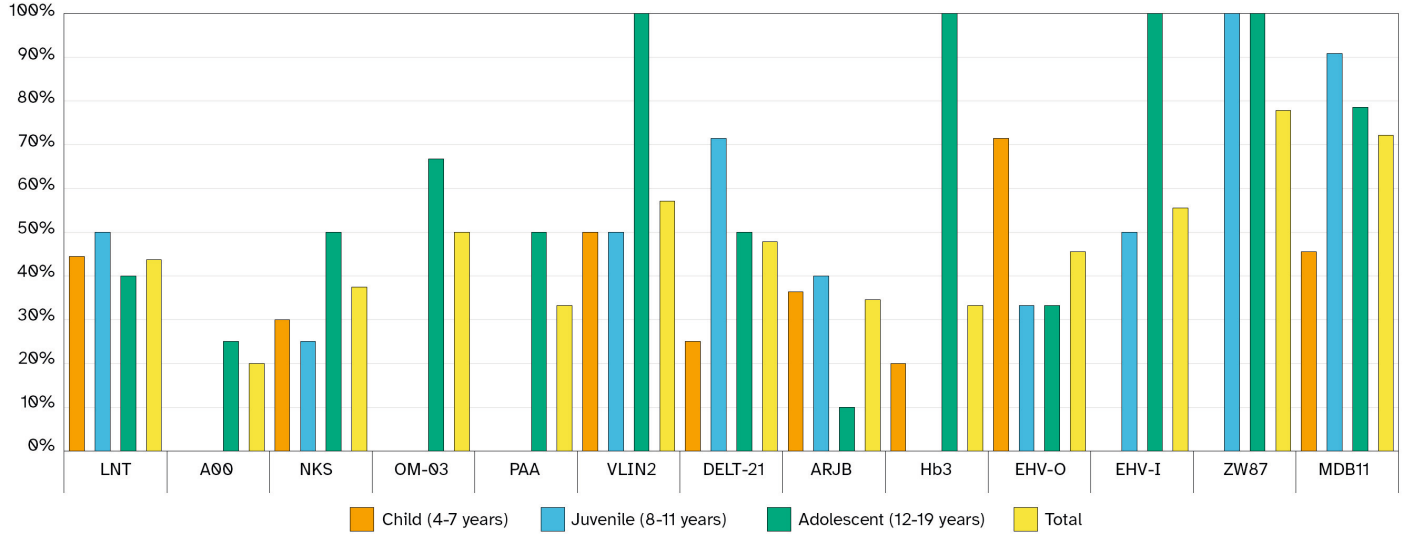

Figure 6.3. Prevalence of chronic maxillary sinusitis for all samples under study. LNT=Lent; A00=Aardenburg; NKS=Nieuwerkerke; OM-03=Vlissingen, Oude Markt; PAA=Alkmaar; VLIN2=Vlissingen, Scheldekwartier; DELT-21=Delft; ARJB=Arnhem, Hb3=Nijmegen; EHV-O=Eindhoven, Outside the church; EHV-I=Eindhoven, Inside the church; ZW87=Zwolle; MDB11=Middenbeemster.

Our statistical analysis indicates that time (i.e., urbanization) significantly impacted the prevalence of chronic maxillary sinusitis in the populations under study (p=0.011) (Table 6.3). While individuals from the early-medieval and late-medieval periods exhibited similar prevalence rates, those from the post-medieval period (1600-1866 CE) were almost three times more likely to present with chronic maxillary sinusitis compared to early-medieval populations (p=0.045) (Figure 6.4).

Table 6.3. Outcomes of binary logistic regression. Constants: Time period=Early-Medieval; Subsistence economy=Rural; Socioeconomic status=Low; Age-at-death=Child. OR=Odds ratio; CI=Confidence Intervals; *= indicates p-value ≤0.05.

		OR	CI for OR		*p*-value
			Lower	Upper	
Time period					*0.011
	Late-Medieval	1.152	0.388	3.419	0.798
	Post-Medieval	2.892	1.023	8.176	*0.045
Living environment		0.460	0.185	1.144	0.095
Socioeconomic status					0.671
	Middle-low	1.196	0.480	2.980	0.700
	Middle-high	1.934	0.683	5.475	0.214
	High	1.164	0.428	3.170	0.766
Age-at-death					0.098
	Juvenile	1.885	0.909	3.911	0.089
	Adolescent	1.979	1.021	3.839	*0.043

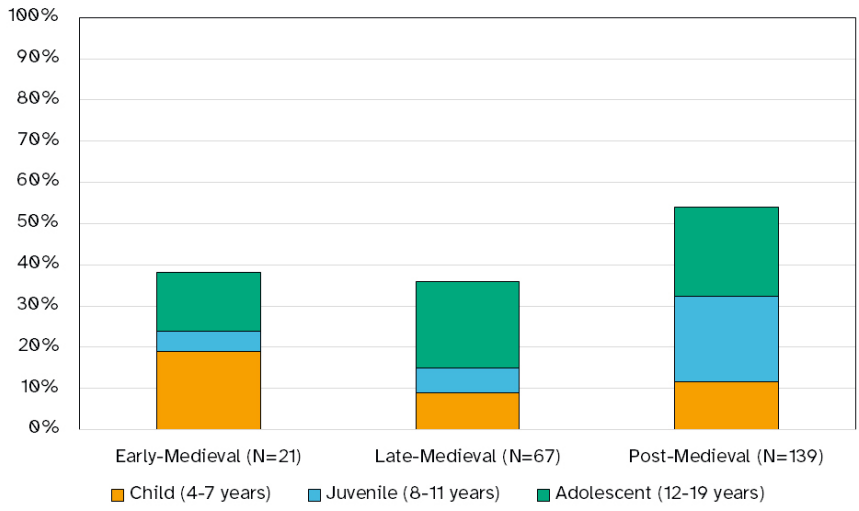

Figure 6.4. Prevalence of chronic maxillary sinusitis in the historical periods under study.

Neither living environment nor socioeconomic status was found to significantly impact chronic maxillary sinusitis in the populations under study. Although rural sites showed a slightly higher overall prevalence of sinusitis compared to urban sites, this difference was not statistically significant (Figure 6.5). Similarly, no statistically significant relationship was observed between sinusitis and socioeconomic status, though individuals from middle-low and middle-high socioeconomic groups exhibited higher overall rates of sinusitis compared to those from low and high socioeconomic groups (Figure 6.6).

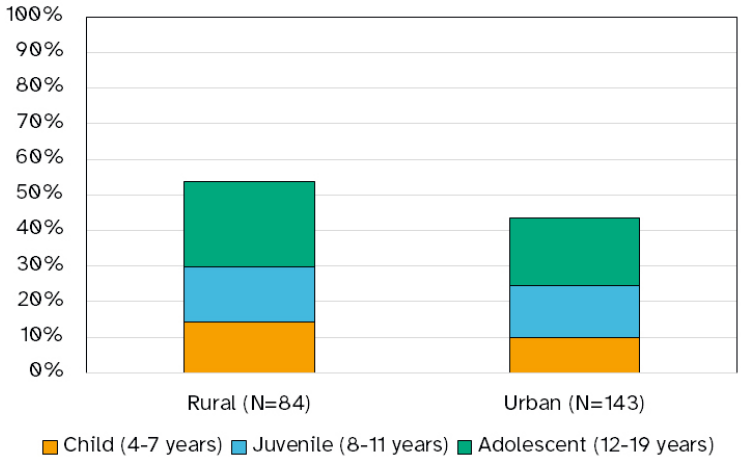

Figure 6.5. Prevalence of chronic maxillary sinusitis in rural and urban populations under study.

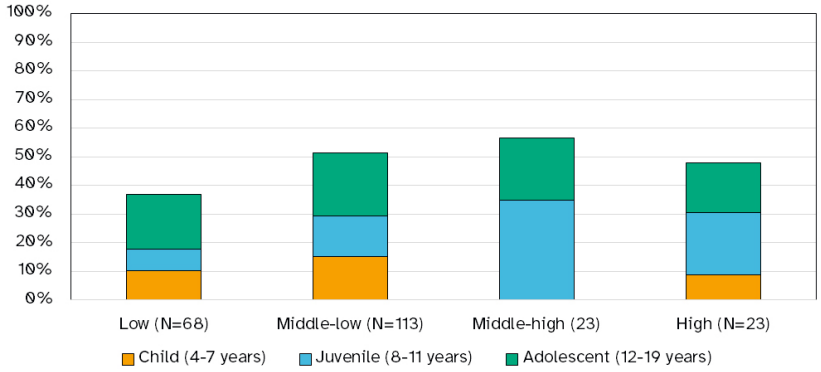

Figure 6.6. Prevalence of chronic maxillary sinusitis in different socioeconomic status groups.

Overall, age-at-death was not found to significantly impact chronic maxillary sinusitis in the populations under study (p=0.098). However, both juveniles and adolescents were almost twice as likely than children to present bone changes indicative of sinusitis, with this being statistically

significant in adolescents only (p=0.043). This is partly reflected in Table S3, which presents the results of binary logistic regression divided by age group. While no risk factors appeared to influence sinusitis in children and juveniles, adolescents from the post-medieval era were eight times more likely to present sinusitis than adolescents from the early-middle ages (p=0.026).

6.4. Discussion

The aim of this study was to explore the impact of various risk factors (i.e., time period, living environment, and socioeconomic status) on the respiratory health of multiple non-adult Dutch populations, using chronic maxillary sinusitis as a proxy. Our results showed that sinusitis was a common condition throughout the medieval and post-medieval periods in the Netherlands, ranging from 20.0% to 77.8% in the populations under study. This is consistent with historical literature, which reports that, up until the 19th century, "coughs" (i.e., respiratory diseases) were among the most prevalent childhood conditions and were frequently cited as the leading causes of death (Pancino, 2015; Shulman, 2004; Wintle, 2000). Furthermore, chronic maxillary sinusitis had already been observed among adults in most of the assemblages under study, further attesting to the presence of risk factors for respiratory diseases in these populations (Casna et al., 2023; Casna & Schrader, 2022, 2024).

Among all risk factors under study, time period was the only variable to have a statistically significant impact on chronic maxillary sinusitis in non-adults. This finding aligns with our earlier observations of sinusitis in adults, in which neither rural/urban differences nor socioeconomic status were found to have had an impact on the respiratory health of the populations under study (Casna et al., 2023; Casna & Schrader, 2022). An initial inference that could be drawn from this is that comparable rates of sinusitis indicate similar levels of exposure to risk factors, implying that disparities in living conditions between city and countryside and socioeconomic backgrounds were not pronounced. This appears implausible, as it contradicts most historical sources (e.g., Brusse & Mijnhardt, 2011; Kuiper & Lengkeek, 1994; van der Woude, 1972; Wintle, 2000). We argue that, while lived experiences changed considerably between different environments and socioeconomic groups, risk factors for respiratory disease to which people were exposed also varied alongside, impacting respiratory health to a significant extent regardless of the variables analyzed (Casna et al., 2021; Casna & Schrader, 2022). For example, lower socioeconomic classes lived and worked in more precarious conditions, often with limited access to resources and in crowded, unsanitary environments (Jansen, 1974; Wintle, 2000). These circumstances naturally exposed them to greater risk factors for infectious disease. However, wealthier individuals, despite their more comfortable lifestyles, often spent significant time indoors near open fires, frequently indulging in hazardous behaviors (e.g., tobacco smoking in the post-medieval period), which also likely facilitated respiratory diseases (Holwerda & Verleden, 2017; ten Hove, 2005). The same variability in risk factors possibly also applied to the differences we observed between rural and urban sites, which were found not to significantly influence sinusitis prevalence rates.

Due to a variety of historical and social factors, urban settlements have frequently been perceived as unhealthy and unsanitary settings where life is continually endangered, especially in contrast to rural environments (Betsinger & DeWitte, 2021; Schell, 2018). Moreover, most bioarchaeological studies on sinusitis have observed higher rates of sinusitis in urban samples compared to rural ones (e.g., Lewis et al., 1995; Panhuysen et al., 1997; Sundman & Kjellström, 2013b). In the present study, we found sinusitis to have a higher prevalence rate in rural populations than in urban ones, despite living environment not significantly impacting the risk for sinusitis, as mentioned earlier. This finding is consistent with that of both Lewis (2002) and Williams and Galley (1995), who also observed higher rates of respiratory disease in rural non-adults compared to urban counterparts. Williams and Galley (1995) specifically discuss the impact of allergic reactions triggered by close contact with animals and exposure to biological particulates in the air (i.e., pollens, molds, and dust produced by agricultural activities) on sinusitis. They argue that these factors account for high prevalence rates of sinusitis in rural areas, contrasting with overcrowding in living environments, general limited access to resources, and air pollution, which may trigger sinusitis in urban areas (Williams & Galley, 1995).

Another factor that could have influenced sinusitis prevalence rates across different environments and socioeconomic statuses is the healthcare dedicated to children. While in poorer households the care of sick children was mostly entrusted to family members who relied on either experience or popular knowledge, historical sources indicate that, as early as the medieval period, it was somewhat common for wealthier children to have a doctor (or, more commonly, a midwife) attending to them during their early years (Pancino, 2015; van Poppel, 2018). However, it should be noted that, at least until the 1700s, respiratory disorders were treated (regardless of the socioeconomic status of the patient, or the living environment) with homemade infusions of herbs, a spoon of animal fat, or (in the post-medieval period) with a paste of tobacco leaves (Pancino, 2015). While these remedies may have alleviated symptoms, it is difficult to believe that they could effectively cure any viral or bacterial infection. We argue that the lack of knowledge regarding how to identify, prevent, and effectively treat respiratory diseases, rather than access to healthcare, may contribute to explain why sinusitis prevalence does not significantly differ between the different populations under study.

In previous studies on historical sinusitis in the Netherlands, it was observed that the transition from the early-medieval to the post-medieval period had the most significant impact on sinusitis prevalence rates (Casna et al., 2023; Casna & Schrader, 2024). This was reflected in our results, as individuals from the post-medieval period were found to be almost three times more at risk for sinusitis than early-medieval ones (p=0.045). It was suggested that, while the expanding urban environment had an increasingly negative impact on people's health (regardless of their living environment), this growth in health challenges may however have been more nuanced between the late-medieval and post-medieval period, as differences in sinusitis prevalence rates did not vary significantly (Casna et al., 2023). Historically, this may be explained by the fact that, while urban expansion had already started in the late-medieval period, it was during the post-medieval era that cities developed the most typical urban characteristics that posed

significant challenges to the lives and health of their citizens (e.g., overcrowding, inadequate housing facilities, limited access to resources, fluctuating economy, and unregulated factory work) (Hakvoort, 2013; van Laar, 1966; Wintle, 2000). Moreover, the introduction and wide popularization of tobacco in the 17th century likely contributed to the prevalence rates we observed, as both active consumption and exposure to secondhand smoke are recognized as significant risk factors for respiratory disease (Snelders, 2021; van der Rijst & Garfield, 2023). By 1700 CE, tobacco had become ubiquitous in the Netherlands among all socioeconomic classes, and recent traces of consumption on adult human dentition were identified by Casna and colleagues (2024) in three of the populations under study, with prevalence rates of smokers ranging between 15.6-43.7%. Recording tobacco consumption among non-adults populations fell beyond the scope of this study. However, considering the potential significant impact of tobacco on the respiratory health of past populations (Casna et al., *in press*), we argue that the observed increased risk for sinusitis in the post-medieval period may be partly correlated with the introduction of tobacco to Europe. Further research is warranted to investigate the specific impact of tobacco on non-adult populations.

While looking at the impact of time period among different age groups, it was interesting to note that post-medieval adolescents were eight times more likely to present sinusitis than their early-medieval counterparts (p=0.026) and twice more likely to present sinusitis regardless of time period, living environment, and socioeconomic status (p=0.043). This was not surprising, as similar patterns were previously observed by both Merrett and Pfeiffer (2000) and Lewis (2002), who noted that sinusitis was more common among older non-adults in the samples they analyzed. DeWitte and Stojanowski (2015) previously addressed the higher frequency of lesions in older age groups, suggesting that non-adults should be viewed not as representative of the population but rather as 'non-survivors.' According to the osteological paradox, vulnerable individuals may have succumbed to disease before their skeletons developed observable responses, implying that younger children without lesions should not be seen as indicative of a population free from sinusitis. Instead, this group likely includes both healthy individuals and those who died before their skeletons could manifest any sign of bone reaction (DeWitte & Stojanowski, 2015; Wood et al., 1992). While this offers an interesting perspective on our data, it should be noted that, in most cases, sinusitis prevalence rates were higher among our non-adult samples than among adults. This suggests a "non-paradoxical" nature to our observations, as they lack a positive relationship between sinusitis and age (Bennike et al., 2005; Holland, 2014). Further support for this view comes from our previous study (Casna et al., 2023), in which we observed that sinusitis was mostly uniformly distributed across age-at-death categories. This suggests that, even if sinusitis is considered a marker for compromised immune response (Liebe-Harkort, 2012), it does not appear to have significantly impacted longevity in the populations under study. Rather, we argue that the higher prevalence of sinusitis in adolescents may be a consequence of the fact that, throughout European history, they were effectively considered adults and thus engaged in adult activities (Pancino, 2015). In fact, by the age of ten it was common for children to participate in daily tasks and, later in the post-medieval era, to be formally employed (Vleggeert, 1964; Wintle, 2000). Engaging in the life of adults likely exposed

adolescents to the same risk factors for disease, resulting in similar prevalence rates of sinusitis. This was likely even more exacerbated in the post-medieval period, when the rise of the industrial age made child labor salaried, systematic, and institutionalized (Smit & Korevaart, 2018; van Nederveen Meerkerk, 2009). Children from lower socioeconomic strata were then commonly employed in either factories or rural settings performing specific, dedicated tasks for several hours a day (Smit & Korevaart, 2018; Vleggeert, 1964; Wintle, 2000). We argue that this may have negatively impacted the respiratory health of young workers, observed in our findings as a heightened incidence of sinusitis among post-medieval adolescents.

Our results and historical contextualization offer evidence for a "non-paradoxical" view of factors impacting respiratory disease in the populations under study. However, it is clear that this evidence is not sufficient to fully address the potential impact of the osteological paradox (Wood et al., 1992). As suggested by DeWitte and Stojanowski (2015), more research could be conducted to analyze how different non-specific and specific stress markers responded to the same variables under study. This approach would offer a more comprehensive overview of past disease experiences than relying on sinusitis alone. It is also important to note that, despite sinusitis being observed archaeologically since the 1970s, we still lack a complete understanding of the formation processes of bony lesions such as spicules which may impact the interpretation of results (Mays et al., 2024; Wells, 1977). Furthermore, while we did our best to keep sample sizes even, adolescents were much more represented in the final sample than children and juveniles. Adolescents were also often better preserved, which may have impacted our ability to accurately score sinusitis (Sundman & Kjellström, 2013a). Although we believe that our statistical analysis helped mitigate the impact of these imbalances, our findings may still have been influenced to some extent by the uneven distribution of demographic categories. Specifically, there were fewer individuals from the early and late medieval periods compared to those from the post-medieval period. Additionally, the number of rural individuals was smaller than that of urban individuals, and the proportion of middle-high and high socioeconomic status individuals was relatively smaller than that of low and middle-low status individuals. This specific limitation is inherent to the nature of osteoarchaeological assemblages, making it unlikely that we will ever completely be able to address it. However, the use of biomolecular methods in future research on infectious disease may help identify pathogens in larger samples, providing more comprehensive insights into the challenges and health experiences of our ancestors. Future research should consider integrating biomolecular techniques with traditional osteoarchaeological analysis to uncover more detailed information about pathogen presence and immune responses. Additionally, expanding the scope of studies to include other markers for disease (e.g., non-specific stress markers, other respiratory conditions) could help balance sample representation, offering a clearer picture of how varying living circumstances affected the health experiences of past populations.

6.5. Conclusions

Our study aimed to investigate the impact of various risk factors (i.e., time period, living environment, and socioeconomic status) on chronic maxillary sinusitis among thirteen non-adult populations from the Netherlands. Our findings revealed that sinusitis was prevalent throughout the medieval and post-medieval periods in the Netherlands, aligning with historical and bioarchaeological literature (Casna et al., 2023; Casna & Schrader, 2022, 2024; Pancino, 2015; Shulman, 2004; Wintle, 2000).

Among the risk factors under study, only time period had a statistically significant impact on chronic maxillary sinusitis. This mirrors our earlier observations in adults, where neither rural/urban living environments nor socioeconomic status significantly affected respiratory health (e.g., Casna et al., 2023; Casna & Schrader, 2022). This suggests that, despite varying living conditions and socioeconomic backgrounds, exposure to varying respiratory disease risk factors remained consistent across different social groups. Rather, our findings highlight that the transition from late-medieval to post-medieval periods significantly impacted sinusitis prevalence, likely influenced by factors such as urbanization, tobacco popularization, and institutionalization of child labor (Hakvoort, 2013; Smit & Korevaart, 2018; Snelders, 2021). Among the total sample, adolescents were more susceptible to sinusitis than younger demographic groups. This may be indicative that adolescents lived and worked as adults and were consequently exposed to the same risk factors for sinusitis.

In conclusion, while our study offers insights into respiratory health among non-adult Dutch populations across different historical periods, living environments, and socioeconomic groups, it acknowledges limitations both in sample size distribution and the non-stationary character of osteological assemblages. Moreover, ongoing challenges in understanding osteological lesion formation suggest the need for interdisciplinary approaches in future research on respiratory diseases in archaeological contexts. Future studies may partially overcome these limitations through biomolecular methods, which could enhance our understanding of respiratory pathogen presence in larger samples. While we argue that our findings provide valuable insights, they also undoubtedly underscore the complexity and ongoing evolution of respiratory health research in archaeological and historical contexts.

Supporting information

Supplementary materials for this paper are available on the publisher's website: https://doi.org/10.1002/ajpa.70050

Data availability statement

The datasets generated and analyzed during the current study are available at Casna, Maia, 2024, "Data for "Historical Risk factors for childhood sinusitis"", https://doi.org/10.17026/AR/ZVPNZS, DANS Data Station Archaeology

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