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 9

Conclusions

Over the past decade, the study of respiratory diseases in historical populations has provided valuable insights into how various social and economic processes shaped the health and wellbeing of past societies (e.g., Boyd, 2020; Davies-Barrett et al., 2023; DiGangi & Sirianni, 2017). The data presented in this dissertation significantly contributes to this growing body of research by providing a comprehensive analysis of respiratory disease prevalence in historical Dutch populations while investigating the complex and multifaceted interplay between socioeconomic factors and health outcomes. By integrating bioarchaeological observations with data on historical and socioeconomic contexts, this research examines various populations across different timeframes, offering a nuanced, diachronic exploration of how historical changes (e.g., urbanization, the institutionalization of child labor, and the effects of tobacco consumption) affected the prevalence of respiratory diseases in the populations under study.

Analyzing and contextualizing data spanning over a thousand years of human history is inherently complex. In the case of the Netherlands, this task is particularly challenging due to its unique trajectory, which diverged significantly from the experiences of the United Kingdom and other European countries during the medieval and post-medieval periods (de Vries, 1984; Wintle, 2000). In fact, in the Netherlands, several factors, including political fragmentation, substantial geographical transformations (e.g., land reclamation), frequent wars, and the rise of localized industries, contributed to an asynchronous urban and economic development. As a result, throughout the country, cities and regions experienced cycles of growth and decline at different times (Brusse & Mijnhardt, 2011; de Vries, 1984). This makes the Netherlands a particularly compelling case study, as previous bioarchaeological research has demonstrated how socioeconomic changes from the medieval period to the industrial era affected populations all over Europe in diverse ways across different demographic groups (Betsinger & DeWitte, 2020). The results presented in this dissertation show that in the Netherlands, as in other European contexts, these shifts played a role in shaping health patterns, including the prevalence of respiratory diseases.

The present study is the first in the Netherlands to examine respiratory disease prevalence across such a broad geographic and temporal framework, aiming to reconstruct the impact socioeconomic changes had on historical respiratory health. To do so, four research questions were developed:

Research Question 1: *How did increasing urbanization in the Netherlands influence rates of respiratory diseases in different environments (e.g., rural, urban) in the time period under study?*
Research Question 2: *What are the differences in the prevalence, risk factors, and outcomes of respiratory diseases among urban populations of differing socioeconomic status?*
Research Question 3: *To what extent did urbanization and socioeconomic developments affect the respiratory health of children in the Northern Low Countries?*

Research Question 4*: To what extent did tobacco consumption contribute to the burden of respiratory disease in past Dutch populations?*

Research Question 1 is addressed in Chapters 3 and 5, where rates of respiratory disease are analyzed across different populations over time and geographic regions. The results reveal a progressively worsening impact on health, with more subtle distinctions between the late-medieval and post-medieval periods, and the most severe decline observed between the early-medieval and post-medieval periods. Notably, for each time period analyzed, no significant differences were found between urban and rural populations, indicating an economy that maintained strong connections between city and countryside through time. This suggests that factors beyond air pollution, such as changes in lifestyles, housing conditions, and increased competition for resources due to population growth, may have contributed to the overall decline in respiratory health (Blockmans, 2011; Schmal, 2018; Wintle, 2000).

Research Question 2 is discussed in Chapter 4 by analyzing the prevalence of sinusitis and non-specific stress markers across four post-medieval populations of varying socioeconomic status. Among these groups, the middle-lower socioeconomic class, primarily composed by small businessmen and market stall owners, exhibited among the lowest prevalence rates observed in the total sample. It is likely that the distinctive lifestyle of this socioeconomic stratum significantly contributed to these outcomes: unlike the industrial working class, who endured rigid schedules in poorly ventilated environments, or the upper classes, which were frequently confined to office and domestic settings, the middle-lower class spent substantial time outdoors in environments more favorable to respiratory health (e.g., marketplaces). This group's autonomy over their time and working settings may have afforded them greater flexibility to regulate their exposure to harmful conditions, contributing to better overall health outcomes. Although no consistent trends emerged between socioeconomic status and stress indicators or sinusitis across the urban sites of Arnhem, Zwolle, and Eindhoven, the results suggest that susceptibility to respiratory and other diseases was influenced more by daily life and environmental exposure than by wealth or socioeconomic status alone. Urban settlements did not exclusively endanger the poor, but instead presented distinct health challenges to all social groups, highlighting the intricate interplay between urbanization, socioeconomic status, and health.

Research Question 3 is addressed in Chapter 6, where the impact of several factors (i.e., time period, living environment, and socioeconomic status) on 13 non-adult populations is investigated. The findings reveal a noticeable increase in sinusitis prevalence over time in both urban and rural contexts, with a particularly significant shift from the late-medieval to the post-medieval periods. This shift aligns with the broader historical effects of urbanization, the popularization of tobacco, and the institutionalization of child labor starting from the 17th century (Smit & Korevaart, 2018; Snelders, 2021; Vleggeert, 1964). Among the risk factors analyzed, only time period had a statistically significant impact on sinusitis, a pattern consistent with earlier observations in adults, where neither rural or urban living environments nor socioeconomic status significantly influenced prevalence rates (Casna et al., 2023; Casna & Schrader, 2022).

This suggests that exposure to respiratory disease risk factors was relatively consistent across different social groups, despite varying living conditions and socioeconomic backgrounds. Adolescents were particularly susceptible to sinusitis compared to younger demographic groups, likely due to their living and working conditions resembling those of adults, which exposed them to similar risk factors.

Lastly, Research Question 4 is addressed in Chapters 7 and 8, which analyze the relationship between tobacco smoke and respiratory disease across four diachronic populations. The findings reveal that smokers were more likely to develop respiratory diseases than non-smokers, but only if their lifestyle did not already expose them to significant environmental risk factors. Notably, smokers from a maritime community of sailors, who spent much of their time outdoors, had nearly five times the likelihood of developing respiratory disease compared to local non-smokers. In contrast, smokers from an industrial workers population (who likely spent most of their time indoors) did not show significantly increased risk of respiratory disease compared to non-smokers. This suggests that, while the harmful effects of tobacco are undeniable, the environmental conditions individuals live and work in may have had a more profound impact on their health, potentially overshadowing the effects of smoking.

9.1. Limitations

One of the primary limitations of this study arises from the inherent challenges in defining environments and socioeconomic contexts in a consistent, scientific, and meaningful way. As noted by Betsinger and DeWitte (2021), distinguishing between urban and rural settings can be particularly problematic, especially when examining diachronically diverse settlements where the definition of 'urban' may vary significantly. Furthermore, even within the same time period, cities can embody vastly different models of urbanization and industrialization (Reba et al., 2016). For example, as discussed in Chapter 8, the contexts of Arnhem and Vlissingen presented distinct living conditions (i.e., industrial and maritime), leading to different health outcomes for their inhabitants. Similarly, defining socioeconomic classes involves comparable difficulties. In fact, as argued by Peterson and Drennan (2018), the conceptualization and implications of wealth frequently evolve across temporal and spatial dimensions, meaning that the factors that constitute affluence for one individual may not necessarily confer wealth upon another in a different location or historical period. This variability has often been a subject of concern for archaeologists studying inequality in the past, as temporal and contextual variations present challenges both in consistently categorizing populations and in interpreting results (Peterson & Drennan, 2018). Despite efforts to ensure consistency in classifying skeletal populations, it is important to acknowledge that categories such as 'urban', 'rural', or 'low/high socioeconomic class' are inherently human constructs and lack rigid, universally applicable definitions (Smith, 2020). This may imply some degree of interpretive uncertainty into and should be considered when evaluating results.

This research has also been limited to certain extents by the availability of skeletal remains, particularly with regard to specific demographics or social groups. Although the final sample included over 1200 skeletons from 13 different sites, certain groups (such individuals from early-medieval cemetery sites) were in most cases poorly preserved and highly fragmented. The sample size for non-adults was especially limited, with only 227 individuals available for analysis to investigate the impact of socioeconomic changes on children's respiratory health over more than a millennium of history. While statistical analysis helped to mitigate this limitation, in several cases poor preservation further hindered the ability to collect consistent data, particularly regarding ear infections and rib lesions, thus preventing a comprehensive analysis.

Moreover, while data on sinusitis, infectious middle ear disease, and pleural inflammation were collected following established diagnostic criteria for comparability across studies, relatively few investigations have assessed the inter- and intra-observer reliability of these methods (e.g., Malina-Altzinger et al., 2015; Timmenga et al., 2002), leaving the extent of potential variation in observations somewhat unclear. While in this dissertation intra-observer variability testing was not conducted in a systematic manner, preliminary efforts were undertaken to assess data consistency. An intra-observer test was conducted on 42 maxillary sinuses from Middenbeemster, comparing sinusitis scores recorded during the first year of doctoral research with those recorded during the third year (Davies-Barrett et al., 2024). Results indicated moderate agreement between the two sets of observations. Additionally, an inter-observer test for sinusitis was undertaken, comparing data collected at different points during this project with observations made by a more experienced researcher. This comparison demonstrated that agreement increased with growing experience in diagnosing sinusitis, an encouraging result that suggests enhanced familiarity with diagnostic criteria contributed to improved consistency and accuracy of observations over time for this project (Davies-Barrett et al., 2024).

Finally, the osteological paradox (Wood et al., 1992) represents a significant limitation of this study. Despite applying statistical analyses, including non-adults in the total sample, and examining bony lesions across several sub-groups (e.g., socioeconomic classes, age-at-death categories, and sexes), addressing the challenges posed by demographic nonstationarity, selective mortality, and heterogeneous frailty remained complex. Several factors linked to the osteological paradox, such as transient historical events (e.g., disease outbreaks, famines, and natural disasters) and genetic predispositions to disease, could not be fully accounted for (DeWitte & Stojanowski, 2015; Wood et al., 1992). Additionally, many of the populations analyzed spanned multiple centuries, meaning that individuals grouped together may have experienced diachronically distinct risk factors and lived through varying environmental and social conditions (Wilkinson, 1992; Wood et al., 1992).

While Wood et al. (1992) emphasizes the need for a deeper understanding of lesion formation processes at the osteological level, clinical literature provides only limited evidence of the skeletal manifestations of respiratory infections, further complicating interpretations. Recent studies utilizing computed tomography to examine bone involvement have begun addressing

remodeling associated with infectious processes (e.g., Kandukuri & Phatak, 2016; Qiao et al., 2022; Wiatr et al., 2021). However, many lesions, particularly smaller and less discernible spicule formations in the sinuses or within the ear canal, remain poorly understood. Recent debates in paleopathology have questioned whether these formations truly indicate an infectious process, as similar features are not observed elsewhere in the skeleton (e.g., Flohr et al., 2023; Mays et al., 2024). While some evidence supports an association with inflammation and/or infection (see section 2.1.3), it is equally plausible that, in some cases, these changes arise from normal physiological remodeling, aging, or environmental factors such as exposure to cold weather (e.g., Davies-Barrett et al., 2019; Ramakrishnan et al., 2010). Although these alternative explanations do not undermine the conclusions of this dissertation, the potential influence of non-pathological factors on the prevalence rates of observed lesions warrants careful consideration when interpreting the results of this research.

9.2. Future research

This study explored the prevalence of respiratory diseases over time in several Dutch populations, emphasizing the importance of studying urbanization not as a sole point in time, but rather as an ongoing process that continuously affected human health across centuries. While this research has shed light on distinct historical contexts, it highlights the need for future studies to continue investigating diverse populations, both within and beyond the Netherlands, while acknowledging their specific socioeconomic, environmental, and cultural contexts. In this framework, an important aspect would be to develop a better understanding of how the various factors analyzed in this research interplayed with each other (Appleby, 2024). While this study made preliminary efforts to explore these interactions, a more comprehensive examination of risk factors is essential to fully understand how these elements converged at the individual level, rather than being limited to population-level analyses. Biomolecular approaches are particularly promising in this regard, as emerging frameworks continue to enhance our understanding of disease processes (e.g., Gaeta, 2021; Warinner et al., 2022). As these methodologies become increasingly accessible to paleopathologists, they should be utilized not only to confirm the presence of specific diseases in the individuals we analyze, but also to provide broader insights into how diseases interacted with each other, shedding light on how they impacted the burden of morbidity within a specific population (Larsen & Crespo, 2022; Robb et al., 2021).

Moreover, it should be noted that paleopathology (and, thus, the present study), typically focuses on visible markers of disease in skeletal remains and their prevalence within a population (Roberts, 2016). However, many (respiratory) diseases may not leave any osteological evidence, despite having a significant impact on human health (Van Schaik et al., 2014). Recently, there has been a notable increase in paleopathological studies that employ statistical models to estimate the broader health burden of such diseases at a given point in time (e.g., Robb et al., 2021; Van Schaik et al., 2014). These models integrate modern clinical data with contextual information from historical settings, allowing for a more comprehensive understanding of how specific diseases impacted past populations. Future paleopathological research on respiratory diseases

in the Netherlands could greatly benefit from adopting this approach. By not only examining the prevalence of respiratory conditions but also estimating their overall contribution to the historical health burden, researchers could provide a more nuanced and complete picture of how these diseases shaped past Dutch populations.

9.3. Concluding remarks

Despite the respiratory system being one of the most exposed to environmental conditions, there has been a notable lack of paleopathological studies focusing on respiratory disease (Roberts, 2020). This gap in research may, in part, stem from the inherent complexity of studying them. Their multifaceted etiologies, the often unclear link between infectious processes and bone involvement, and the fact that even modern clinicians struggle to fully understand how the respiratory tract responds to disease, all contribute to the reluctance paleopathologists may feel when approaching this subject. While this hesitation is entirely understandable, I believe that this complexity inherently reflects the intricate nature of human societies and, as such, needs to be fully addressed when studying our shared human past. As individuals, we are continuously shaped by a multitude of factors: our living conditions, working environments, socioeconomic status, family ties, habits (whether harmful or healthy), passions, and hobbies, all of which continue to impact our health and wellbeing throughout our lives. Studying respiratory diseases in the past requires careful consideration, as interpreting prevalence rates involves dealing with two distinct layers of complexity. On one hand, there are the multifaceted and sometimes elusive etiologies of respiratory diseases discussed in Chapter 2. On the other, there is the elaborate web of humanity itself, with all its environmental, social, and personal factors.

The results presented in this dissertation contribute to our ever-growing understanding of how the environment shaped the health of our ancestors, while offering important reflections on how environmental and social factors continue to influence health outcomes today. Being able to analyze diachronic populations was particularly valuable in this regard, as it highlighted several observable differences over time (or lack thereof), including changes in living conditions (Chapters 3 and 5), the environmental, economic, and political challenges people faced (Chapters 3, 4, 5, and 6), and even shifts in smoking habits (Chapters 7 and 8). The deep connection we share with our environment is most notably reflected in the ways our bodies respond to it, with disease serving as one of the most telling indicators of this relationship (Western & Bekvalac, 2019). Just as no two environments are alike, the effects on our health are equally unique, shaped by the distinct circumstances of each individual and community, both in the present and throughout history. In this way, I hope that my dissertation has opened new avenues for future research, encouraging more nuanced explorations of the deep, ever-lasting, ever-changing connection we share with our living environments and our health.

After all, we are the air we breathe.

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