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LIFE IN TRANSITION

An osteoarchaeological perspective of the consequences of medieval socioeconomic developments in Holland and Zeeland (AD 1000-1600)

Rachel Schats

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An osteoarchaeological perspective of the consequences of medieval socioeconomic developments in Holland and Zeeland (AD 1000-1600)

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S·N·M·A·P

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Introduction

What is the city but the people? – William Shakespeare (ca. 1604–1608)

1.1 MEDIEVAL DEVELOPMENTS AND THEIR IMPACT

This research investigates the impact of socioeconomic developments on the physical condition of medieval populations in Holland and Zeeland between AD 1000 and 1600 through the analysis of human skeletal remains from three archaeological sites. In a relatively short period of time, Holland and Zeeland developed from scarcely populated areas to a region characterised by urban centres and flourishing trade systems (van Zanden and van Bavel 2004). Historical and osteoarchaeological data from other studies focusing on similar processes in different areas of Europe suggest that these developments, urbanisation in particular, had adverse effects on the inhabitants. Woods (2003), for example, researching urban-rural mortality differences in several areas of the world, notes a clear penalty in terms of life chances for urban residents. The comparison of mortality and fertility rates demonstrates that deaths outnumbered births in many pre-modern cities (e.g., Galley 1995; Woods 2003), an observation which became known as the 'urban graveyard effect' (van der Woude 1982). Roberts and Cox (2003), comparing skeletal remains from different living environments in the United Kingdom, found a negative impact on the inhabitants of the newly formed medieval towns in terms of health. In contrast, Rawcliffe (2013), focusing on public health in England, found that living conditions in medieval urban centres were not as bad as had been previously assumed. This is supported by osteoarchaeological research by Lewis (1999), who notes only small differences between rural and urban children in the medieval period.

While the socioeconomic developments of the medieval period in Holland and Zeeland have been studied in detail from a broad historical perspective (e.g., van Bavel 2010; de Boer 1978, 1988; Dumolyn and Stabel 2012; Hoppenbrouwers 2001, 2002; Renes 2005), there is a paucity of data concerning the impact of these developments on the people themselves. In Holland and Zeeland (figure 1.1), medieval developments occurred rapidly and the urbanisation rate was high (van Zanden and van Bavel 2004), which likely had an effect on the citizens of the two counties. However, based on historical research alone, the nature of this impact on medieval citizens is difficult to assess considering that individual data are often missing. Hence, this research proposes a different approach to this subject which allows a detailed examination of the physical consequences of medieval developments in Holland and Zeeland by investigating the process from an osteoarchaeological perspective.

Osteoarchaeology, the contextual analysis of human skeletal remains from archaeological sites, aims to study the lives of past individuals by looking at the remnants of their body (Beck 2006:83). The research field integrates information from human skeletal remains, such as sex, age-at-death, stature, and pathology, with cultural, social, and economic aspects of the person's living environment (Martin *et al.* 2013:5). This bottom-up approach provides a different method of reconstructing past lifeways. In combination with historical data, osteological information on individual people will help to gain a better understanding of socioeconomic developments in medieval times.

Figure 1.1: Map of the current Netherlands with the study area (Holland and Zeeland) indicated.

1.2 HISTORICAL CONTEXT

The aim of this study is to integrate skeletal data with historical evidence on the socioeconomic developments during the medieval period to research the effects on the populations. This section provides a brief overview of the historically documented socioeconomic developments in Holland and Zeeland to serve as a solid framework for the human skeletal remains under study. Firstly, a characterisation of medieval society and its main developments between AD 1000 and 1200, the central medieval period, is presented. This first period can be described as an era of socioeconomic change and growth during which the foundations were laid for the large scale urbanisation that followed in the subsequent late medieval period. The second part of this section focuses on the socioeconomic developments between AD 1200 and 1600 when towns started to emerge and both the rural agricultural systems and urban industries were intensified and commercialised in response to several local and international stimuli.

1.2.1 Holland and Zeeland in development (AD 1000-1200)

Land reclamation: the creation of a human-made environment

After the fall of the Roman Empire in the 4th century AD, many regions in the Low Countries experienced a substantial decline in population size (van Bavel 2010; Henderikx 1997). This demise of the population is commonly related to the chaos and insecurity associated with the dissolution of Roman power (van Bavel 2010). Climate changes and related problems with water as well as soil exhaustion may have also played a role in the near abandonment of the region (van Bavel 2010; Besteman 1997; Henderikx 2001). Although most areas in the Low Countries, especially the loess regions (van Bavel 2010), experienced reoccupation and population growth from the 6th century onwards, habitation in Holland and Zeeland lagged behind. In Holland, the peat rich soils made habitation difficult (figure 1.2) (van Bavel 2010; Beenakker 1988). While some of the peatlands were used for grazing, extraction for fuel, dietary supplements in the form of fish and poultry, and hunting of small game, habitation and arable farming were generally limited to the elevated sandy ridges along the coast (van Bavel 2010; Ettema 2005; Rippon 2002). In Zeeland, where soils predominantly consisted of sea clay, habitation was also challenging due to constant flooding of the area (Henderikx 2012). As is visible in figure 1.2, in AD 800, Zeeland was characterised by tidal and river plains. As a result of the difficult living circumstances, most of the area of Holland and Zeeland remained fairly empty until human action made large-scale habitation possible in these wetlands.

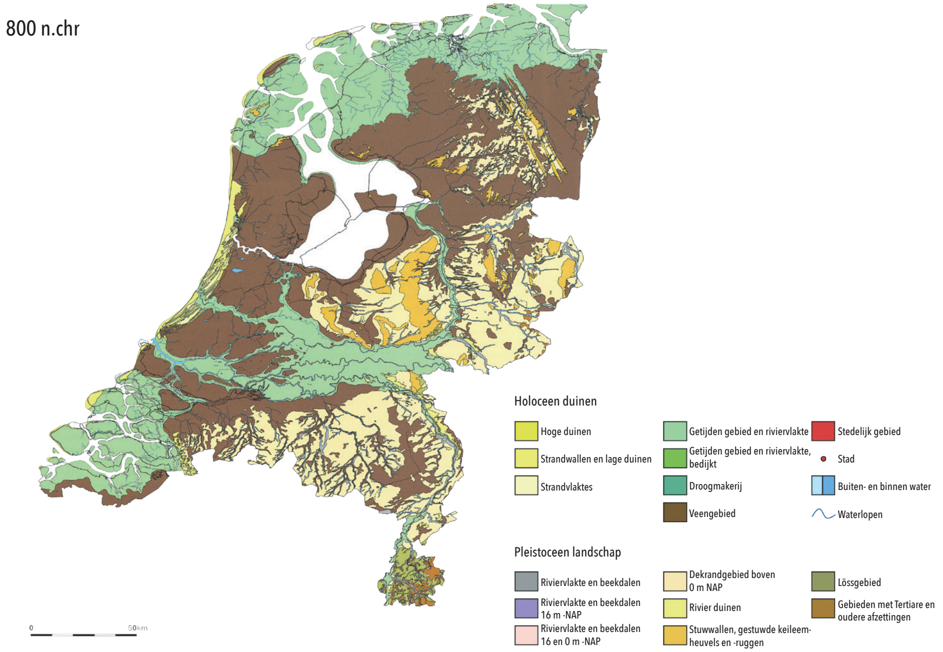


Figure 1.2: Palaeogeological map of The Netherlands in AD 800 (after Vos and Weerts 2011, p. 67).

The 10th century AD marked the beginning of the reclamation of massive areas of peat creating a new, human-made landscape (Borger 1992; van Bavel 2010). As was the cases in other areas of Europe, the coast of Holland was transformed and became characterised by artificial ecosystems (Hoffmann 2014). Even though some peat lands were drained in earlier periods in order to make habitation possible, nothing can be compared to the scale with which this was done from AD 1000 onwards (Hoppenbrouwers 2002). There are many explanations for this sudden and massive expansion into the wetlands. The drier climate in the 10th century, influencing the hydrological circumstances in the peatlands, is thought to have been to be an important reason for the large scale reclamations (Besteman 1997; Hoppenbrouwers 2002; van der Linden 1982). Moreover, deforestation, overexploitation, and wind erosion of the sandy ridges along the coast may have been responsible for population pressure in the coastal settlements, forcing the inhabitants to colonise the wetlands (Besteman 1997).

At an early stage, land reclamations were controlled by local communities, which in their turn, were controlled by local lords or even regional rulers, such as counts or prince-bishops (Henderikx 1997). From the twelfth century onwards, these lords started to act like they were the private owners of waste lands by offering them 'for sale' as private sellers (*vercopers* in Middle Dutch) to buyers (*copers* in Middle Dutch; *locatores* in Latin) (van der Linden 1982; Buitelaar 1993). The latter usually were middlemen from the lower aristocracy, who then attracted peasant-colonists to carry out the actual reclamation labour. Requirements and obligations of the *copers* or *locators* were stated in an agreement, known as a *cope-contract*, which regulated boundaries and measurements, public duties, and taxes (*cijns*) to be paid (Hendrikx 1998; van der Linden 1955, 1982).

Since peat consists of 80% water, the main reclamation task was the creation of adequate drainage by digging ditches which made the surplus water flow into an existing body of water. Dikes to protect the newly formed land from the surrounding water were built on the edges of the reclaimed areas.

Living on the peat

Living in these newly created rural settlements had an individualistic character. The excavation of Assendelft, a typical peat settlement dating to the 11th and 12th centuries AD, has given insight into life in a, locally organised, reclamation village. The farmhouses were spread out over separate strips of land with large spaces in between. The plots were artificially raised multiple times in order to deal with the subsidence of the soil and associated flooding issues. Although the house types are similar to those found in other coastal areas, the inhabitants of Assendelft had adapted their house construction to cope with the unstable reclamation subsoils. For example, the wall posts were placed on wooden boards (*sloffen*) to create more stability (Besteman 1997). The farmhouses in Assendelft combined the living quarters and stables in one space (Besteman 1997; Hoppenbrouwers 2002). It is estimated that this type of village was relatively small. Based on the remains found in Assendelft, the researchers calculated that about 70 people lived in the village, spread out over a relatively large area, resulting in low population densities.

Similar conclusions can be drawn from the excavation of a farmhouse in the Oostpolder, near Gouda. Again, evidence of artificial raising of the house floors is encountered; researchers estimate that this happened every 30 years (Kok 1999). In this case, no other farmhouses were located within 320 m to the east and 140 m to the west, supporting the idea that these farmhouses were standing in rows, with interspaces of several hundreds of meters, and each of them located on the head of an elongated plot of land (Kok 1999). The house in the Oostpolder had a similar layout and size as those excavated in Assendelft (figures 1.3 and 1.4). The wooden boards used to stabilise the wall posts were also found. The excavation of the Oostpolder house also indicates the combination of the stable and living space in one room (figure 1.4).

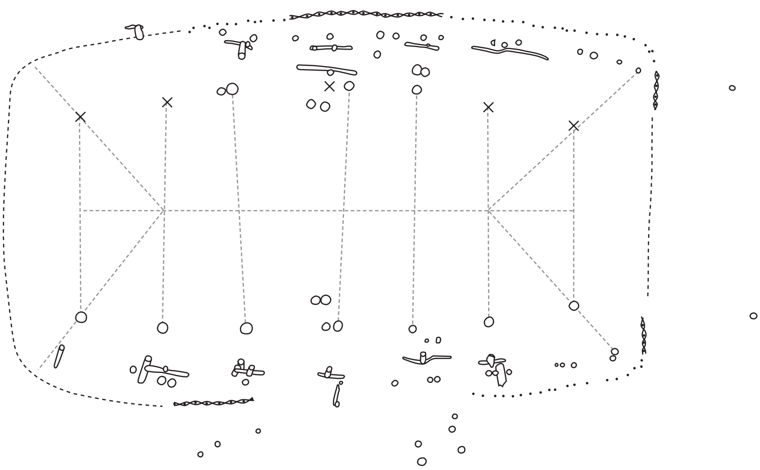


Figure 1.3: Floor plan of the Oostpolder farmhouse, 1:150 (after Kok 1999, figure 23, p. 46).

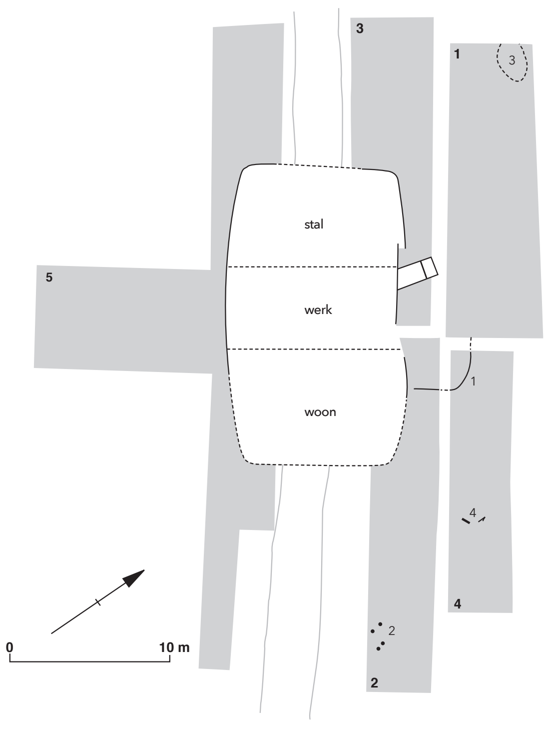


Figure 1.4: Spatial layout of Oostpolder farmhouse and surroundings (stal=stable, werk=work, woon=living, larger numbers indicate excavation trenches, smaller numbers: 1=fence, 2=small wooden posts, 3=bone pit (animal), 4=horse burial) (after Kok 1999, figure 32, p. 57).

Although some individuals were definitely involved with tasks associated with land reclamation and construction of works for flood protection, agriculture, both arable and pastoral farming, was the main occupation of the inhabitants of the rural villages in Holland and Zeeland (Besteman 1997; Hoppenbrouwers 2002). Both men and women were most likely involved in these activities. It is assumed that a gendered division of labour was present in the rural villages in Holland and Zeeland, although this is mainly based on later sources from the countryside in England (Jewell 2007; Whittock 2009). It is reported from the UK that women in the medieval countryside were charged with the household (estimated four to five persons) and smaller agricultural tasks such as sowing and weeding, while men were tasked with the heavier ploughing and other activities which required hard manual labour (Jewell 1996). Especially peat digging is considered to have been a difficult and labour intensive task which was exclusively reserved for men (Borger 1992).

Archaeobotanical research indicates that several cereals were cultivated in the wetlands. Although rye is commonly found in other areas of The Netherlands, as of yet, there is no reliable archaeobotanical evidence for the cultivation of this particular crop in the coastal parts and wetlands of the Western Netherlands before AD 1200 (Bakels *et al.* 2000). Rather, emmer wheat is commonly found, and oats and barley also tend to be present, although to a lesser extent (Bakels *et al.* 2000). The archaeobotanical evidence suggests that these types of cereals were locally cultivated. Although buckwheat has been found in some samples, it is unclear if this crop was locally grown to a substantial scale prior to the 16th century (Bakels *et al.* 2000). Archaeozoological evidence indicates that several animal species were present in the villages, cattle being by far the most common (van Bavel 2010; Ettema 2005; van Dasselaar 1999). The relatively young age of the remains suggests that the animals were bred and kept for meat (Ettema 2005). Pig and sheep/goat are also commonly found and cut marks on the bones suggest that they were consumed as well (van Dasselaar 1999).

Impact of reclamation

Although habitation on the wetlands created new possibilities for the villagers, living on the newly formed lands was associated with many problems. As Hoffmann (2014:167) has eloquently put it: "*Nature struck back*". As a result of oxidation and drainage, the ground level deceased substantially, up to half a metre per century (Borger 1992; Henderikx 1997). This required the inhabitants of the reclamation to constantly create protection against the surrounding water in order to prevent flooding (van Bavel 2010; Henderikx 1997). Deepening of the ditches, raising of the dikes, and construction of floodgates were all measures taken to fight the water (Henderikx 1997). Some reclamations could not be saved and were surrendered to the water. Additionally, the subsidence of the soil made crop cultivation very difficult: at the end of the 13th century the peat farmers in Holland had to adopt a different strategy to be able to survive on the peatlands (Borger 1992; Ettema 2005). This development and its relationship with urbanisation are discussed further below.

1.2.2 Urbanisation and commercialisation (AD 1200-1600)

Rural development and urbanisation

In the period after AD 1200, development of the socioeconomic system in Holland and Zeeland resulted in a remarkable change of the landscape (de Boer 1988). Once solely comprised of small agricultural villages, during the late medieval period small urbanised centres started to emerge in the region. Although it is difficult to assess what the actual driving forces behind urbanisation in this period were, the developments between AD 1000 and 1200 in the rural areas must have contributed to the urban expansion (Hoppenbrouwers 2002).

The problematic nature of peat farming as a result of soil subsidence is considered to have been an important factor in the process of urbanisation. In the centuries that followed AD 1200, the peat soils became less and less suitable for grain cultivation, as shown by the research of de Boer (1978). He compared the *korentienden* (the percentage of revenues that had to be paid to the landlords, which can be indicative for the total grain yields) between AD 1343 and 1415. While the harvests appeared to have been stable on the *geest* lands, he notes a prominent decrease in yields of the peat areas, which he relates to flooding issues (de Boer 1978:223). Although grain cultivation most likely did not become completely impossible (Ettema 2005), profitable arable farming definitely became problematic in the peat areas. As a result of this, peat farmers moved away from arable farming and became more focused on cattle breeding. This is supported by the *Informacie* of AD 1514, from which it is evident that arable farming was only important in small areas in the *Noorderkwartier* (North of the river IJ) and that stock breeding was more significant (van der Woude 1972).

Since pastoral farming requires less work and an uneven seasonal distribution, not much work was required in fall and winter (Kaptein 2007). This shift in activity gave rise to a labour surplus in many parts of the countryside which triggered permanent migrations to the towns (Blockmans 1993). Therefore, the labour surplus is considered to have been an important causal factor for urbanisation, as is advocated by many scholars (e.g., Hoppenbrouwers 2002, Slicher van Bath 1960, van Zanden 1991). However, Ettema (2005) argues that there are too many uncertainties about the specific activities following the abandonment of grain cultivation in addition to cattle breeding to make any inferences about labour requirements. Van Bavel and van Zanden (2004) note that, while the ecological issues are definitely an essential element in the changes during this period, the most serious problems in arable farming only occurred after AD 1400 when the process of commercialisation and urbanisation had already began. They therefore argue that the ecological crisis did not initiate the developments but most likely did accelerate them.

Additionally, it is argued that decreasing grain demand may have been a factor in the decline in production as a result of reduction of population size due to the plague epidemics in the late medieval period (van Bavel and van Zanden 2004; Boroda 2008). However, it appears that the impact of the plaque on the Dutch wetlands was less dramatic in comparison to other European countries, therefore limiting the effect on agricultural production (van Bavel and van Zanden 2004; Blockmans 1980, Jansen 1978). By studying the arable output in relation to population numbers, van Bavel and van Zanden (2004) are able to clearly show that the decrease in grain production is not correlated with a decline in population size. They state that *"population developments did not dictate the ups and downs of agricultural output, or vice versa"* (van Bavel and van Zanden 2004:571).

The ecological circumstances that prevented arable farming in Holland were absent in Zeeland. Its clay subsoils were suitable for crop cultivation and subsidence was not a problem (Beenakker 1988). Farms in late medieval Zeeland were focused on food production for the markets, but also on the productions of raw materials for the urban industries. Particularly madder (*meekrap*) cultivation, used to obtain red dye, was of great importance in Zeeland (van Steensel 2012b). Although the peasants would have possessed animals for their own use, large-scale pastoral farming was not present in Zeeland (van Steensel 2012b). In this region, therefore, a labour surplus caused by a transition to pastoral farming is not likely to have been a causal factor in the rapid urban expansion. For Zeeland, it is argued that population growth and associated increased agricultural productivity caused a surplus of people and products on the countryside, which led to movement to the new towns (van Steensel 2012a).

Urban expansion

Even though there is still some debate about what triggered the migration of rural residents to the newly formed urban centres, it is clear that towns and their populations grew quickly during the three centuries following AD 1200. Blockmans (1993) estimates that at the beginning of the 14^{th} century AD, Holland counted about 260,000 individuals of which only 60,000 (23%) resided in urban centres. Data from AD 1514 show that by then already 44% of the population was living in towns (Blockmans *et al.* 1980; Blockmans 1993; Hoppenbrouwers 2001).

Information on population numbers in Holland comes from data collected by the central authorities for tax purposes (van der Woude 1972). The *Enqueste* of AD 1494 and the *Informacie* AD 1514 give information with regards to population size by counting the number of hearths (i.e., houses) multiplied by the average number people in one household (Fruin 1866; van der Woude 1972), which is estimated to be in the range from 4 to 4.5 individuals (Blockmans 1993: 4, Hoppenbrouwers 2001: 4-4.5, Blockmans *et al.* 1980: 4). Table 2.1 shows the total population size calculated using the number of (non-clerical) hearths taken from the *Informacie* (Fruin 1866) of the largest towns in Holland (minimum of 3000 inhabitants). Considering the count was done for tax purposes, it was beneficial for the towns to have fewer numbers of inhabitants on record in order to minimise the tax that had to be paid (van Oosten 2014). Therefore, the population numbers displayed in table 1.1 are likely underestimating the actual population sizes.

Table 1.1: Population numbers for the largest urban centres in Holland in AD 1514.

Town	Population estimate AD 1514[1]	
	Hearths	Size range (4-4.5)
Alkmaar	889	3556-4001
Amsterdam	2507	10,028-11,282
Delft	2616	10,464-11,772
Dordrecht	1500	6000-6700
Gouda	1680	6720-7560
Haarlem	2714	10,856-12,231
Hoorn	1118	4472-5031
Leiden	3017	12,068-13,577
Rotterdam	1118	4472-5031
The Hague	1198	4792-5391

[1]Fruin 1866. Hearths are multiplied by 4 and 4.5 to show size range.

Even though the population numbers for the towns in Holland in the 16th century are low in comparison to those of other European cities during this same time period (Paris: 225,000 Lisbon: 70,000, Ghent: 55,000 (Bairoch *et al.* 1988:278)), population densities might have been relatively high considering the small dimensions of the Dutch towns. Visser (1985) analysed the density of several towns between AD 1300 and 1560. He calculated that in AD 1300, the urban centres had an average of 75.5 inhabitants per hectare, while in AD 1560 average population density had increased to 126.5 (Visser 1985). Figure 1.5 shows the population densities of three cities in Holland at three moments in time (Visser 1985). Interestingly, even though Amsterdam has the most inhabitants in AD 1560, because of its size it did not have the highest population density. Dordrecht, which had substantially fewer inhabitants than Amsterdam, had a higher population density as a result of its relatively small dimensions (Visser 1985). Although Paris had a higher population density (512 inhabitants per hectare), in AD 1500, London only had a population density of approximately 192 and Gent of 262 (Bairoch *et al.* 1988). This suggests that, even though the total number of inhabitants was lower than that in other cities of Europe, the population densities in Dutch towns were similar and in some cases even higher.

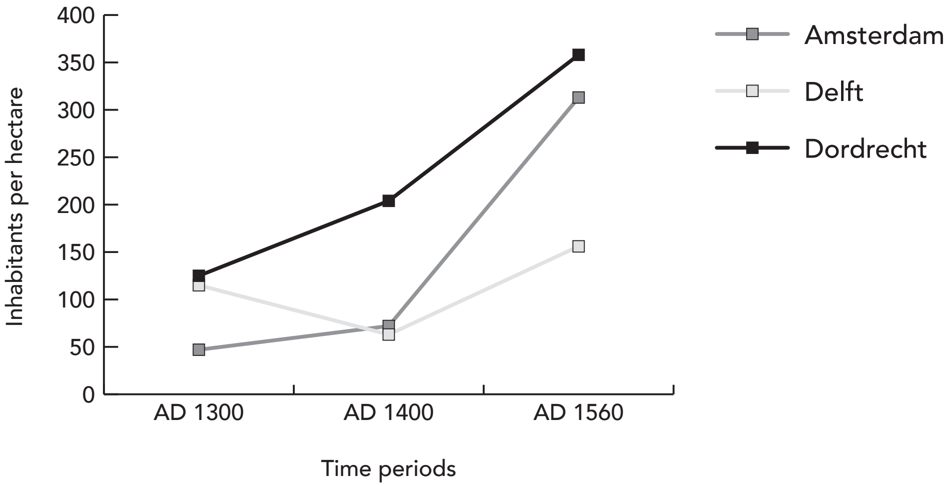


Figure 1.5: Population density in Amsterdam, Delft, and Dordrecht at three moments in time (AD 1300, AD 1400, and AD 1560) (after Visser 1985, figure 5, p. 16).

Living in these newly formed towns was different than in the countryside. Even though during the beginning of urbanisation, towns would have had a relatively rural character, later in time as the centre grew, the layout changed. Interestingly, the original structure of the village usually remained visible and, more importantly, dictated development (Sarfatij 2008). Dordrecht is a great example of this: the town began as a small land reclamation village and transformed into a large urban centre with the new layout determined by the original outline of the settlement (Sarfatij 2008). Moreover, instead of wooden construction, most houses in the new towns were constructed out of stone materials. In Dordrecht, houses were made from brick early in its urban development (Sarfatij 2008).

Rural commercialisation and urban industries

As mentioned above, the abandonment of grain cultivation and the subsequent focus on cattle breeding are assumed to have resulted in a labour surplus in the countryside. In response, many peasants moved to the newly formed towns. However, the labour surplus was also solved by combining agricultural work with other activities (Blockmans 1993; Hoppenbrouwers 2001). Both the *Enqueste* and *Informacie* demonstrate that shipping and fishing for sea and shellfish were important sources of income for rural inhabitants, possibly even exceeding the importance of stock breeding in many villages (van der Woude 1972). Commercial excavation of peat as a source of fuel was also an important activity in the late medieval countryside (Hoppenbrouwers 2002). Although likely of lesser significance, to meet the demands of the *'draperye'* (cloth industry) in the towns, spinning and weaving were important activities (Blockmans 1993). In addition, ship-building has been noted as a main activity in the rural areas (van der Woude 1972). In Zeeland, fishing was a significant activity in addition to agricultural tasks (van Steensel 2012b). Most of these activities were focused on the regional and supra-regional market. The fact that the peasants were occupied with a broad range of activities, but very focused on the market, has led several scholars to conclude that the rural economy in the 15th century was highly commercialised, yet simultaneously not very specialised (van Bavel 2010; Hoppenbrouwers 2001:59; Noordegraaf 1985; van Zanden 1988).

The urban inhabitants, on the other hand, were much more specialised (Blockmans *et al.* 1980), often focusing on a single occupation. Additionally, agriculture was not an activity commonly undertaken by town residents, although some citizens may have had access to small gardens where they cultivated foods for their own use (Dijkman 2010). Detailed accounts from Leiden and Dordrecht demonstrate that only three percent of the urban population was involved in agriculture. In contrast, 59% of the labour force was engaged in industrial activities (van Bavel 2010), which can be divided into a number of labour sectors of which the importance differed per town. Leiden, for example, was mainly focused on textile production which is demonstrated by the high percentage of the labour force working in this sector (34%) (Blockmans *et al.* 1980). Dordrecht, on the other hand, was more focused on international and national trade and, consequently, most of its labour force worked in this sector (32.1%), while only four percent were employed in the textile branch (Blockmans *et al.* 1980). Men and women had separate tasks depending on the focus of the town and their social class. Spinning appears to have been a common activity for the poorer women in late medieval towns (Jewell 2007). Trade activities were more commonly taken up by men (Jewell 2007).

Market and trade

In the late medieval period, self-sufficiency disappeared (van Bavel *et al.* 2004; van Bavel 2010). The villagers in the countryside of Holland and Zeeland became more market oriented (van Bavel *et al.* 2004; Hoppenbrouwers 2002) resulting in a commercialisation of production and the beginning of a market economy. During the 14th and 15th centuries, international trade intensified in Holland and Zeeland. Products such as linen from Leiden and Haarlem, beer from Gouda and Delft, and of course cheese and butter, were shipped to many places outside the counties (Hoppenbrouwers 2002). Now, both villagers and townspeople became dependent on products of the market, which offered staple foods and other commodities, but also new, more exotic items such as fruits, sugars, and spices became more widely available during the late medieval period. It is however likely that these luxury items were only available for more wealthy individuals (Jansen-Sieben and van Winter 1989). Additionally, commercial fishing, especially for herring, increased in the late medieval period (van Steensel 2012b; Unger 1978) which is also indicated in the *Enqueste* and *Informacie* (van der Woude 1972). While it is assumed that meat and bread remained the main components of a medieval meal in both town and country (Baudet 1904; Jansen-Sieben and van Winter

1989), the socioeconomic developments in the late medieval period may have changed the diet adding different types of protein and carbohydrates.

1.3 RESEARCH QUESTIONS: IMPACT OF MEDIEVAL DEVELOPMENTS

The sections above have demonstrated that, from a historical perspective, much is known about the socioeconomic developments in the Central and Late Middle Ages. However, the impact of these developments on the medieval peoples themselves is difficult to assess using historical data alone. While the changes in living conditions, occupations, and food production could have influenced people substantially, in both negative and positive ways, the historical data do not provide the level of detail necessary to determine this. Therefore, the aim of this research is to assess the impact of the medieval developments by studying the skeletal remains of rural and urban populations focusing on three aspects of life: disease, activity, and diet. Using the historical information above, a series of research questions can be formulated.

The main research question is:

- In which ways do human skeletal remains reflect the key socioeconomic developments, urbanisation and commercialisation, in the medieval period in Holland and Zeeland, and how do the results contribute to a better understanding of the impact of these developments?

The following subquestions outline the separate components of this research:

- Which changes in patterns of disease and systemic stress levels can be observed? Are there differences between the skeletal remains of rural inhabitants dating before and after AD 1200 medieval times? In which ways do the rural skeletal collections differ from the urban collection?

- In which ways did changes in physical activity patterns during the medieval period and especially during urbanisation impact the bodies of the citizens? Which differences can be observed between inhabitants of villages and towns? Is it possible to observe differences in the division of labour?

- Which evidence exists for a change in dietary patterns? Are there differences in consumed food types between the earlier and later medieval rural collections? In which respect does the rural diet differ from the urban diet? Is there evidence for a change in nutritional stress levels through time or as a result of urban living?

1.4 OSTEOARCHAEOLOGY AND THE IMPACT OF SOCIOECONOMIC DEVELOPMENTS

1.4.1 Previous osteoarchaeological research into medieval developments

Research into the consequences of medieval socioeconomic developments using skeletal remains has been performed in several parts of the world. Calvin Wells (1977), studying maxillary sinusitis from the Bronze Age through the late medieval period in Britain, noted an increase in prevalence through time which he relates to higher population densities and sedentism (Lewis 1999, 2002; Wells 1997). More specifically focusing on medieval urbanisation, Mary Lewis and colleagues (1995) continued the work of Wells and compared the prevalence of maxillary sinusitis between urban and rural populations. Later, Lewis (1999, 2002) developed this line of research for her PhD and studied the impact of medieval and post medieval developments by assessing morbidity and mortality patterns of non-adult individuals. She compared skeletal data collected from four different rural and urban sites (AD 850-1859) in order to assess changes in child health (Lewis 1999, 2002). She found that industrialisation had a larger impact on health than did urbanisation (Lewis 1999). Similar research was carried out in Sweden by Anna Kjellström (2005). Although she did not compare rural with urban skeletal collections, she studied human remains from six cemeteries in the town of Sigtuna dating from the end of the 10th until the early 16th century. The skeletal material was divided into three phases of chronological development, coinciding with the establishment of the town, the peak of its prosperity, and its decline. Kjellström found a deterioration of health and a change in activity and dietary patterns, which she links to the establishment of the true urban settlement in the later period (Kjellström 2005; Kjellström *et al.* 2005).

In yet another part of Europe, Poland, Tracy Betsinger (2007) studied multiple facets of the urbanisation process by investigating human remains from three different cemeteries in the town of Poznań. The individuals she researched dated to three different phases (AD 950-1025, 1025-1150, 1150-1250), which allowed her to assess changes through time as a result of intensified urbanisation in the town. Betsinger, just like some of the other researchers, noted a mild decline in health in the later periods. Additionally, she observed changes in diet and activity patterns (Betsinger 2007). Most recently, Kim Quintelier (2013) studied the urban population of Tongeren, Belgium, through time in order to assess the influence of increased urbanisation. Interestingly, she observed no changes in stress levels, even though population densities increased.

These studies are examples of the successful application of an osteoarchaeological approach to study of the consequences of urbanisation and commercialisation in the past. The researchers were able to collect data on disease patterns and systemic stress as well as information about activity and diet, not readily available in historical literature. This shows the great potential for this type of research, as well as the need for local analysis, since the researchers obtained different results while studying similar processes. The multiple variables involved with the socioeconomic developments in medieval times dictate that their effects would have varied in different populations. Therefore, each region must be analysed independently. In The Netherlands, although osteoarchaeological methods are applied to archaeological studies on a regular basis (e.g., Alders and Van der Linde 2011; Lemmers *et al.* 2012; Maat *et al.* 1998; Schats *et al.* 2014; Schats 2015a), this approach has not been employed to study the impact of medieval socioeconomic developments in this region.

1.4.2 Current research

The present study developed out of the need to address the potential consequences of medieval socioeconomic developments on the populations in Holland and Zeeland. This study analyses individuals from two rural and one urban skeletal collections (figure 1.6). Since the land reclamation village of Blokhuizen (AD 1000-1200) in Holland predates urban development in the area, its inhabitants can serve as a rural baseline to which the other skeletal assemblages can be compared. The second skeletal assemblage in this study is associated with the rural village of Klaaskinderkerke in Zeeland, dating to the late medieval period (AD 1286-1573) when urbanisation was well on its way. This skeletal collection provides a rural perspective on urbanisation. A skeletal collection from the town of Alkmaar (AD 1448-1572) provides the urban perspective in the present study. This research is placed in a broader perspective by including the results of four comparative skeletal collections already analysed by other researchers in the discussion of the current results.

Figure 1.6: Map of the current Netherlands with the study area and site locations indicated.

This study focuses on the comparison of three key aspects of life between the three skeletal collections, which could have been impacted by the socioeconomic developments in the medieval period: disease, diet, and activity. Changes in the medieval period, especially urbanisation, are commonly associated with alterations in disease patterns and stress levels. Shifting living conditions towards more densely populated urban centres could have influenced the prevalence of respiratory infections such as bronchitis and tuberculosis. Rural populations may have been more subjected to infections such as malaria, brucellosis, and bovine tuberculosis, as a consequence of land reclamation and intensification of pastoral farming. Furthermore, the medieval socioeconomic developments may have altered activity patterns. Changes to the rural and urban economies in the late medieval period could have influenced activity levels within the populations. The decrease of arable farming in Holland and shift to more market orientated activities could have been responsible for different patterns, impacting the physical body in a different way. Additionally, diet could have changed as a result of the developments. Although staple foods most likely remained the same through time and space, the increased trade and market dependence could have altered the available foods and, consequently, the diet of the late medieval rural and urban individuals.

1.5 DISSERTATION STRUCTURE

This dissertation is divided into seven chapters. Chapter two provides the historical and archaeological contexts of the sites and excavation history of the skeletal collections under study to be able to interpret the skeletal data correctly and in line with the context. Chapter three outlines the skeletal indicators studied in this research. This chapter provides a palaeopathological background and discusses the way in which these pathological conditions can help to assess the physical consequences of urbanisation. Additionally, the osteological paradox is addressed and discussed. Chapter four discusses the methods used in this research to collect the necessary data from the skeletal remains. Chapter five presents the results of the skeletal analysis. The data are presented separately per site as well as in comparison with the other skeletal collections. Chapter six discusses the results of the skeletal analysis combining the data with the historical information presented in chapter one. The final chapter presents the conclusions of this study and answers the research questions posed above. This chapter ends with a discussion of possibilities for future research.

2

Materials

2.1 INTRODUCTION

This chapter discusses the skeletal collections analysed in this research to assess the influence of the socioeconomic developments in Holland and Zeeland during the Central and Late Middle Ages. In all, this study includes 362 individuals from three different skeletal assemblages (see table 2.1 for an overview). These specific collections were chosen because together they are able to reflect the socioeconomic developments in the period and geographic area under study. Furthermore, the skeletal assemblages were available for study and could be analysed within the time frame of this research.

The human remains from Blokhuizen represent individuals from a cemetery associated with a reclamation village from the central medieval period. The skeletal collection from Blokhuizen represents the only assemblage of this type and from this time period excavated in Holland and Zeeland. Even though the preservation of the remains is somewhat poor, the study of these skeletons gives insight in life in a reclamation village during the central medieval period before large-scale urbanisation and associated changes took place in the area.

The skeletal remains from the later village of Klaaskinderkerke allow research into the influence of the socioeconomic developments on the rural residents in the late medieval period. This skeletal collection is one of the few rural cemeteries excavated in the study area from this particular time period, and currently the only one available for study. Although its sample size is relatively small in comparison with the other collections, the excellent preservation of the remains allows detailed research of the skeletons. Furthermore, it can be assumed that the Klaaskinderkerke individuals had a similar social status as the individuals from Blokhuizen, making them comparable in this regard. Thus, the comparison of the Blokhuizen to Klaaskinderkerke potentially reveals the impact of the socioeconomic processes in the countryside in the late medieval period.

The skeletons from the late medieval town of Alkmaar have been selected for this research in order to represent the urban perspective. In a relatively short period of time, Alkmaar grew in terms of number of inhabitants and size, and transformed into a true urban settlement. The Alkmaar individuals are expected to have had a similar socioeconomic background as the individuals from Blokhuizen and Klaaskinderkerke, thereby ensuring that any differences observed in this research are not due to status variations. Other urban collections from the same time period and study area available for analysis are either from hospital sites or known to consist of individuals who had a higher social economic status. Even though Alkmaar is not the largest town in the study region, its relatively high population density and urban character make this skeletal collection a good case study within the framework of this research.

Table 2.1: Human skeletal collections used in this research.

Site	Date	Type	# of individuals
Blokhuizen	AD 900-1194	Rural	119
Klaaskinderkerke	AD 1286-1573	Rural	54
Alkmaar	AD 1448-1572	Urban	189

The skeletal collections are currently stored at the Faculty of Archaeology, Leiden University under the site name, feature number/box number, and find number/skeletal number. This information per individual can be found at http://dx.doi.org/10.17026/dans-zkt-8y3h. The various contexts of the archaeological sites, such as location, occupation history, specific context of the human remains as well as excavation and curation history, are discussed below. In addition, short paragraphs on the skeletal assemblages used for comparative analysis are presented at the end of this chapter.

2.2 BLOKHUIZEN

2.2.1 Site context

The archaeological site of Blokhuizen is located in the current province of North-Holland (figure 2.1). In the 10th century AD, this area consisted mainly of peat interspersed by some sandy ridges, as was briefly discussed in chapter one (Beenakker 1988). Living on the peat was thought to be impossible, because the soil furnished no stable foundations on which houses could be built (Borger 1992). However, archaeological evidence from the Roman era suggests that in this period the peat in Holland was used for habitation. It has been hypothesised that the engineering skills of the Romans created sufficient drainage to make the peat suitable for housing and other activities. Interestingly, for the period after Roman occupation there is no evidence for settlements on the low-lying peat of Holland (Borger 1992). It is clear that habitation started again in the 9th century AD. Large-scale land reclamation with artificial drainage systems made the area habitable (Besteman 1997; Borger 1992). During this period, small settlements started to emerge (Beenakker 1988), of which the village associated with the skeletal remains found at the archaeological site of Blokhuizen was one.

The name of the archaeological site 'Blokhuizen' derives from the presence of 'block'-shaped houses on maps from the 16th century. It is, however, the current understanding that these houses were not related to the archaeological remains found in 1983. These '*blok huizen*' were most likely constructed after AD 1318, post-dating the finds encountered during the excavation (Diederik 1989). Historical research suggests that the human skeletal remains and other finds from this site could belong a village called Geddingmore (or Geddenmore) (Diederik 1989; Beenakker 1988), although other researchers locate this village more to the North (Beenakker 1988:173).

Unfortunately, little is known about the village to which the archaeological remains belonged. Archival research indicates that the village was most likely part of a manor of the abbey of Egmond, as was most of the land in this area, that belonged to the autonomous 'peasant republic of Westfriesland until the incorporation into the County of Holland by the end the 13th century. The village appears to have been fairly small with only a few farm houses, a church and cemetery, and some farmland (Diederik 1989). The inhabitants of the village, whether it was Geddingmore or not, were most likely agriculturalists considering the material found at comparative locations. Although exact information on the crops they cultivated and the animals they kept is unavailable since only part of the cemetery was excavated, from comparable reclamation villages in the peat area, it is known that emmer wheat was locally cultivated and that cattle breeding was important.

The reclamation of the land resulted in subsidence of the soil, which made the area more vulnerable (Beenakker 1988). Until large dikes and water mils had been constructed in the area in order to protect the land from incoming water, many villages were lost as a result of flooding (Beenakker 1988). It appears that this is also what happened to this village: at the end of the 12th century storms caused the area to be flooded and the settlement was abandoned as a result of this (Diederik 1989). Considering the uncertainty about the original name of the village associated with the skeletal remains, the name of the archaeological site and its early modern name, Blokhuizen, is used in this study.

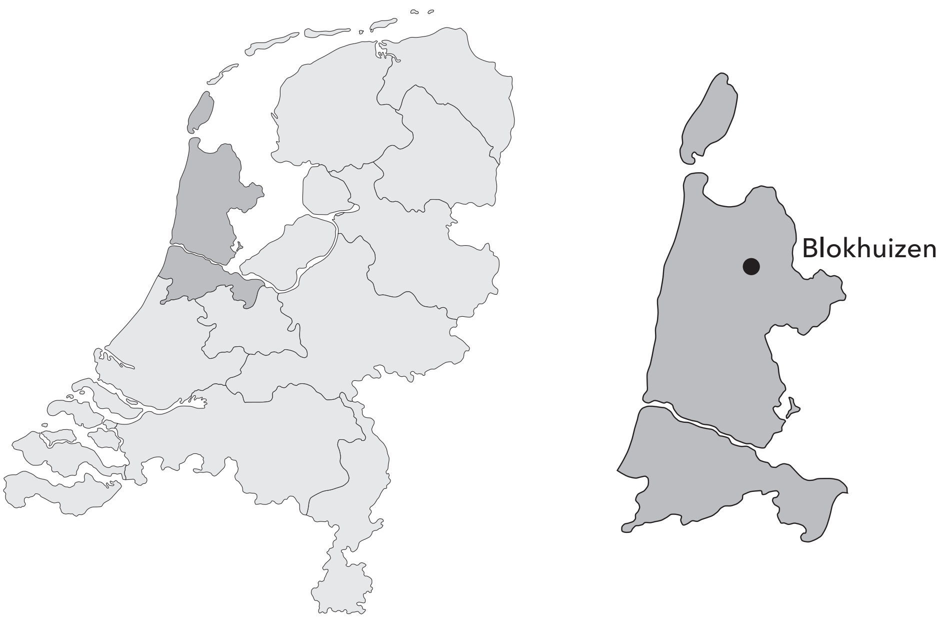


Figure 2.1: Map of The Netherlands with the province of North-Holland and location of Blokhuizen indicated.

2.1.2 Excavation history

In 1982, archaeological remains, such as 11th and 12th century ceramics, sand stone fragments, and human bones were encountered during agricultural work. These finds suggested that this site used to be the location of a church and associated cemetery. Since archaeological sites of this type from this time period are rare, it was decided to excavate the area (Woltering 1983, 1984). In 1983, the excavation was carried out by The Netherlands Archaeological Working Community (*Archeologische Werkgemeenschap voor Nederland*) and was supervised by the Dutch Cultural Heritage Agency (*Rijksdienst voor het Oudheidkundig Bodemonderzoek*).

The excavation confirmed the initial hypothesis: a rectangular cemetery with many primary interments (figure 2.2 and 2.3), surrounded by small ditches, was encountered. The exact location of the church could not be confirmed; pieces of sand stone and tuff were found throughout the excavation area. Other finds such as pottery suggested that the cemetery was most likely in use from the 10th to the 12th centuries. The area ceased to be used for burial when the rising water drove the inhabitants away and flooded the area (Diederik 1989; Woltering 1984). In all, 130 primary inhumations were completely excavated and lifted. Additionally, 40 other individuals were excavated but not lifted; only bone samples were collected. Before transport to Leiden University in 2012, the material was curated in the depot of the province of North-Holland. The present study includes 119 primary inhumations. The remaining inhumations were too incomplete or poorly preserved to be of use in this research.

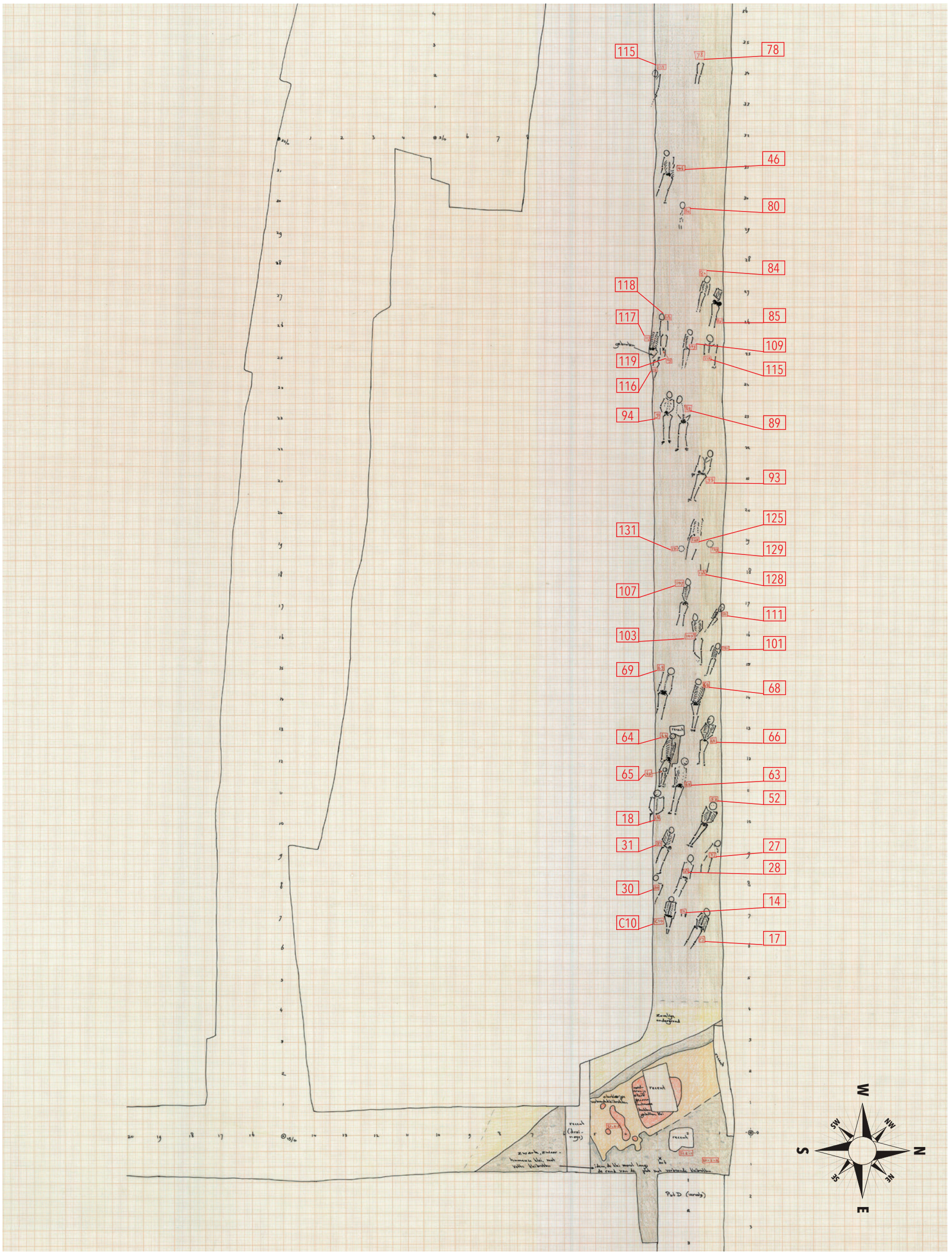


Figure 2.2: Drawing of layer 2 of the excavation unit in Blokhuizen (adapted from drawing G. Alders, 1983).

Figure 2.3: Human skeletal remains encountered during the excavation of the Blokhuizen site (photo: F. Diederik, 1983).

2.3 KLAASKINDERKERKE

2.3.1 Site context

The village of Klaaskinderkerke was located in the southwest of The Netherlands in the current province of Zeeland, on the island Schouwen-Duiveland (figure 2.4). The village was founded on a naturally elevated ridge and first mentioned in a treaty of AD 1286. Archaeological research suggests that at this time, the area of the cemetery and church was artificially enlarged and raised to create better protection from the sea. It is assumed that the church was built after AD 1286 and that the cemetery was first used some years afterwards (Trimpe Burger and Huizinga 1964). The palaeogeological map of Zeeland (figure 2.5), as it was supposed to have been around AD 1300, shows Klaaskinderkerke in the northernmost part of Schouwen (*Scouden*). It is clear that most of Zeeland consisted of clay (green), and some small areas of sand (yellow).

Since only the cemetery and church remains were excavated, there is limited information on the village of Klaaskinderkerke itself. Fortunately, more general historical sources on the county give insight into rural life in Zeeland in the late medieval period. While pastoral farming, especially of sheep, was important in the 10^{th} and 11^{th} centuries, the focus shifted towards labour-intensive crops for the urban centres during the late medieval period. As discussed, soil subsidence, which was so problematic in Holland, was not an issue in Zeeland (van Steensel 2012b). Considering this, it can be assumed that the people of Klaaskinderkerke were mainly involved in (commercial) arable farming with additionally some pastoral farming for their own use on the side.

In AD 1570, despite all efforts to protect the area with dikes, Zeeland was struck by a heavy storm which resulted in flooding of the entire island of Schouwen. It appears that the inhabitants of Klaaskinderkerke did not return to the village thereafter (Trimpe Burger and Huizinga 1964).

Figure 2.4: Map of The Netherlands with the province of Zeeland and location of Klaaskinderkerke indicated.

Figure 2.5: Reconstruction map ‘Zeeland in 1300’ by A.A. Beekman (1921) (after Beekman 2012: 192). Klaaskinderkerke is indicated by the red circle.

2.3.2 Excavation history

In 1953, large parts of the province of Zeeland, including the cemetery site of Klaaskinderkerke, flooded during a severe storm which resulted in the removal of the local topsoil, subsequently exposing the cemetery’s human remains. Although it was attempted to keep the area as a historical monument and preserve the remains in situ, this proved to be very difficult. It was therefore decided to excavate the entire area in order to prevent further damage. In 1959, the area of the cemetery was completely excavated by the Dutch Cultural Heritage Agency (*Rijksdienst voor het Oudheidkundig Bodemonderzoek*) (Trimpe Burger and Huizinga 1964).

During the excavation it became clear that little was left of the church: only remnants of the foundation of the western wall were found. In addition, patches of debris, marking the rough outline of the church, were found. As a result of various inundations during World War II and during the great flood of 1953, many graves had become disturbed: only 54 in situ burials were identified at the site. In addition, 57 isolated crania and several other disturbed skeletal parts were encountered and recovered (Trimpe Burger and Huizinga 1964). After excavation, the remains were curated in the depot of the province of Zeeland. In the context of the current research, only the 54 in situ burials are included in the analysis.

2.4 PAARDENMARKT, ALKMAAR

2.4.1 Site context

Alkmaar is located in the north-western part of The Netherlands in the current province of North-Holland (figure 2.6). The area consists of several sandy ridges which made early habitation possible in this predominantly wet environment (Bitter 2007a; Hakvoort *et al.* 2015). Habitation in the Alkmaar region probably dates back to the Early Bronze Age (1700 BC) and occupation of the area continued into the Iron Age and Roman Period (Bitter 2007a; Hakvoort *et al.* 2015). It appears that occupation ceased in the region during the 4th century AD, which is possibly related to the disintegration and eventual fall of the Roman Empire. From the 7th century AD onwards, evidence for habitation is observed again, although archaeological remains dating to the early medieval period are scarce in Alkmaar (Bitter 2007a; Cordfunke 1973; Hakvoort *et al.* 2015).

Figure 2.6: Map of The Netherlands with the province of North-Holland and location of Alkmaar indicated.

From the 10th century onwards, Alkmaar expanded (Hakvoort *et al.* 2015), and the town received city rights from Count Willem II of Holland in AD 1254 (Cox 2007; Streefkerk 2004). During this early period, the majority of the Alkmaar inhabitants were most likely still working as farmers, cultivating crops and breeding cattle and other animals. Archaeological remains from this time period suggest that the Alkmaar inhabitants occupied farm houses, similar to those in the countryside (Hakvoort *et al.* 2015). During the 13th and 14th centuries, Alkmaar developed: the town increased in size and canals for fortification were dug (figure 2.7) (Hakvoort *et al.* 2014). The population of Alkmaar grew substantially in the centuries that followed; many people previously living on the surrounding countryside moved into the town (Kaptein 2007). At the end of the 16th century, Alkmaar was a town with approximately 8000 inhabitants (Kaptein 2007; Lucassen 2002). While it was still relatively small in size and had a relatively open character in comparison with other towns in Holland, Alkmaar had a fairly average population density of 136 inhabitants per hectare. Strategically, Alkmaar was of great importance since it represented the only way of passage to the northern part of Holland, making it an important port for international trade (van Nierop 2000; Streefkerk 2004).

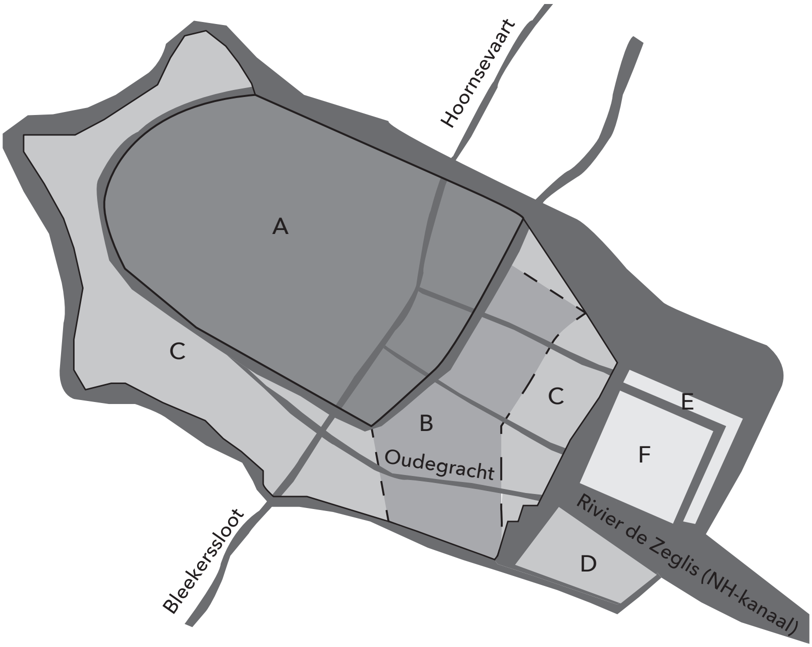


Figure 2.7: Expansion of the city of Alkmaar. A) AD 1325, B) Expansion in AD 1400 (36 hectares), C) Expansion in 16th century (59 hectares) (after van Oosten 2014).

The skeletal remains analysed in the context of this research were buried in a cemetery which belonged to the Franciscan monastery of Alkmaar. This monastery was founded in AD 1448 at a location known as *Het Heilighe Velt* ('The Holy Field') in the northern part of the town (figure 2.8) (Alders 2009; Bruinvis 1893; Hakvoort *et al.* 2015). In AD 1481, the old chapel was replaced by a new cruciform church which was consecrated in AD 1486. Even though most of the Alkmaar citizens were buried in or outside of the larger parish church, some inhabitants chose to be interred with the Franciscans. Most likely, people sympathised with the beliefs of the Franciscans (Bitter 2015). Both the church itself and the cemetery were used as a location for burial, although the individuals included in this research were all interred outside. There is little information on the cost for burial at the Franciscan friary, although 20 nickels had to be paid to the parish church to pay of their right to bury the citizens of Alkmaar (Bitter 2010, de Raad 2015).

Bruinvis (1893) indicates that both poor and wealthy citizens were buried with the Franciscans. On a list kept by the parish church, 108 people are buried at the cemetery of the Franciscan friary most of which were '*ambachtslieden*', the commoners of Alkmaar (Bitter 2010, de Raad 2015). It is unclear if the individuals on the list are included in the sample. However, since the list also notes occupations for some of the individuals, it is a valuable source of information. Appendix 1 shows the list of names, the occupations (if listed), and if they were buried inside or outside the church (if listed).

Burial at this location ceased in AD 1572 as a result of the Eighty Years' War when protestant followers of William of Orange captured the friars and destroyed large parts of the monastery. The monastery church, however, survived the Eighty Years War and was demolished in AD 1574 (Alders 2009; Bruinvis 1893). It appears that the cemetery was used again as a burial site for victims of the siege of Alkmaar in AD 1573 (Hakvoort *et al.* 2015; Schats *et al.* 2014; Schats 2015a).

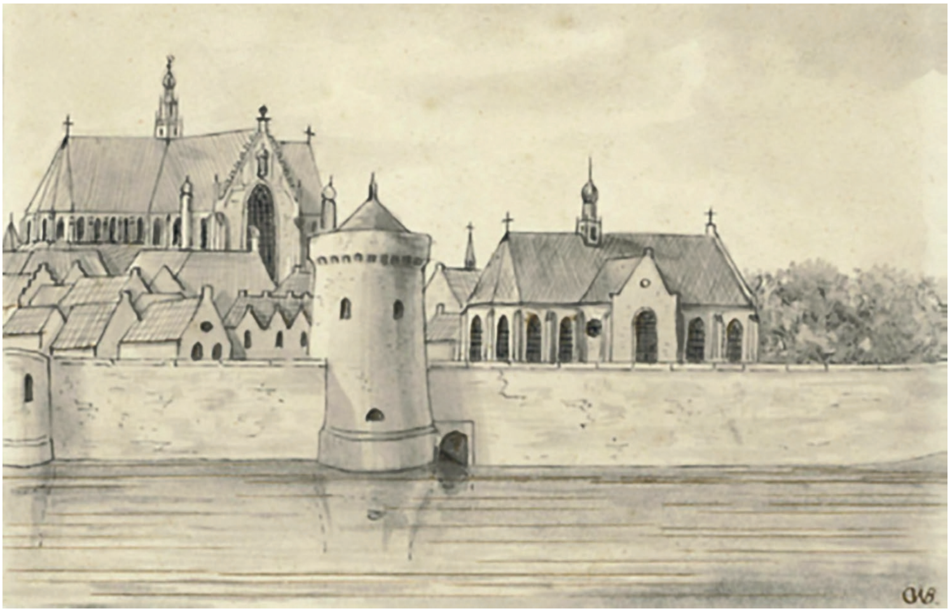


Figure 2.8: The church of the Franciscan monastery, directly behind the town wall. Pen drawing by C.W. Bruinvis, c. 1860, after the situation around AD 1570 (Regional Archives Alkmaar).

After the destruction of monastery and church, the area was used as an animal market in the 17th and 18th centuries. As a result, the site became known as the *Paardenmarkt* ('horse market'), even though other animals were sold here as well. In the 19th century, a gas factory was built at the location of the former monastery (Bruinvis 1893). Most recently, the area was used as a parking lot of a supermarket. Today, the area still holds the name *Paardenmarkt* and outlines of the graves have been made visible in the pavement.

2.4.3 Excavation history

The first excavations of the monastery area were undertaken in 2005 by the firm Hollandia Archeologen, commissioned by the municipality of Alkmaar. The city of Alkmaar planned to reorganise this area and therefore ordered exploratory excavations in order to study the archaeological importance of the Paardenmarkt. During this particular excavation campaign, Hollandia Archeologen excavated six 2x2m trenches. Four of them yielded human skeletal remains, indicating that at least part of the cemetery was still intact and would be destroyed if any underground construction would take place. Therefore, complete excavation of the area was deemed necessary before the reorganisation of the area could commence (Vaars 2005).

In June 2010, large-scale excavations started on the Paardenmarkt under the responsibility of Hollandia Archeologen. The excavation of human remains was carried out by a large team of osteology students of Leiden University, who were supervised by Prof. Dr. Menno L.P. Hoogland. The burials were all excavated by hand and documented thoroughly with skeletal recording forms and photography. The burial taphonomy was described in great detail. In total, 189 primary inhumations, several ossuaries and loose bones from disturbed contexts were found. The primary inhumations were coffin burials; this was indicated by the still visible outline of the coffin and coffin nails, as well as by the position of the bones in the grave which suggested decomposition in an open space (Duday 2009). Figure 2.9 shows a map of the excavation. Examples of typical burials at the site of the Paardenmarkt are shown in figure 2.10.

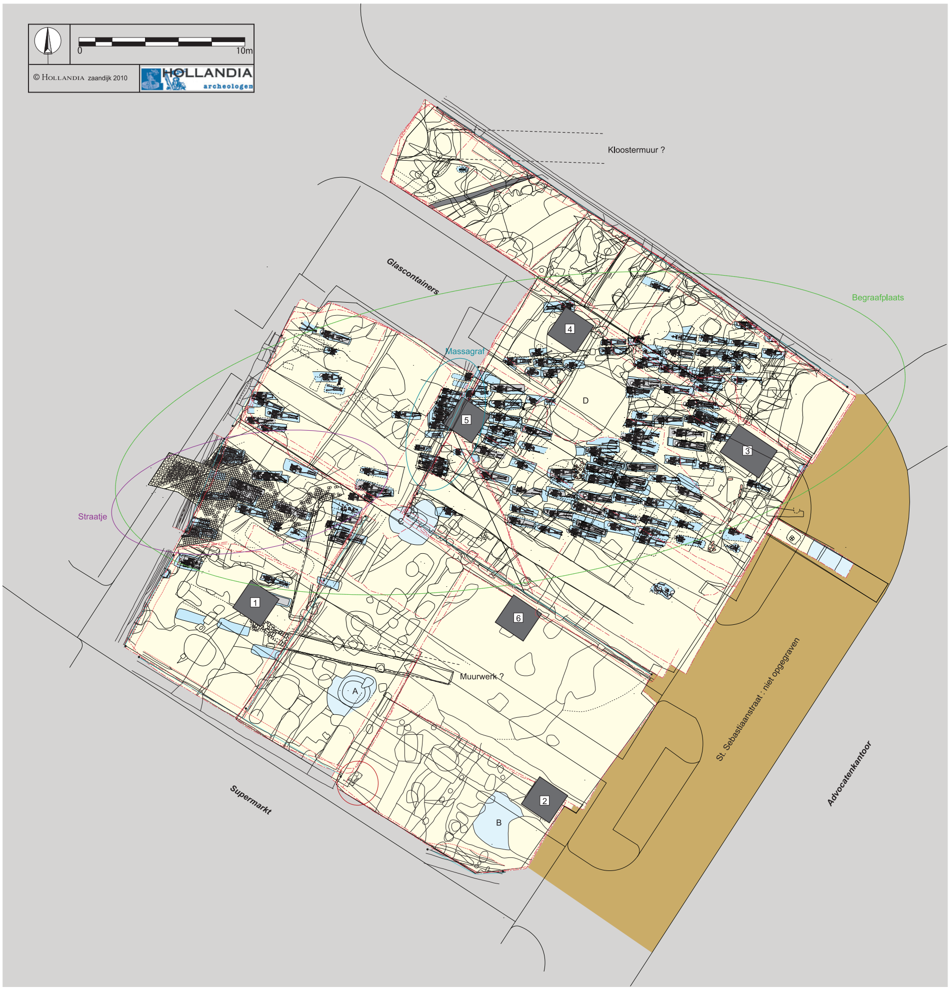


Figure 2.9: Map of the Paardenmarkt excavation (Hollandia Archeologen).

Figure 2.10: Four coffin burials in the Alkmaar cemetery. Note that the coffin outlines are still visible in the ground (photo: Laboratory for Human Osteoarchaeology, Leiden University, 2010).

In addition to the primary inhumations, two mass graves containing victims of the siege of Alkmaar, comprising 22 and nine individuals respectively, were identified. Considering the context of the mass graves, it cannot be assumed that the individuals are representative of the Alkmaar population. Therefore, these remains are not included in the present study. For a detailed discussion on the mass grave remains see Schats (2015a) and Schats *et al.* (2014).

2.5 COMPARATIVE HUMAN SKELETAL MATERIAL FROM THE NETHERLANDS

2.5.1 Introduction

The human skeletal material discussed above allows for study into the influence of the socioeconomic developments during the medieval period in Holland and Zeeland. The individuals from the Blokhuizen, Klaaskinderkerke, and Alkmaar collections are analysed by the author in order to create comparable results. Additionally, data from other skeletal assemblages, collected by other researchers, are used to supplement the skeletal information and place the discussion of the current results in a broader context (chapter six).

For comparison, results from already published skeletal analyses of various other medieval sits in Holland and Zeeland have been used. Specifically, skeletal collections from Vronen, Cruyskerke, Delft, and Dordrecht are selected for use in this research (figure 2.11). These assemblages are suitable for comparison since they are from Holland, date to the medieval period, represent individuals from both rural and urban environments, and are expected to have had a similar socioeconomic status. The incorporation of this additional osteoarchaeological data increased the sample size and provides a broader context geographic context. Although not all data were collected in the same way, hence the reason why the results are only incorporated in the discussion and not the results section, the combination of published data with the results from new skeletal analyses not only gives more depth to this research, but it also allows for more nuanced and informed conclusions.

In total, published data on the remains of 946 individuals are used for comparison in the discussion (chapter six) in this research. For Dordrecht, Cruyskerke, and Vronen the skeletal data have been recently published and available to be used for comparison. The skeletal data for the Delft material are not published as of yet, however, Mike Groen has kindly agreed to supply the necessary results. The information on the comparative human skeletal assemblages is summarised in table 2.2.

Table 2.2: Human skeletal remains used in this research for comparative analysis

Site	Dating	Type	# of individuals
Vronen	AD 1000-1297	Rural	132
Cruyskerke	AD 1200-1421	Rural	316
Delft	AD 1251-1572	Urban	182
Dordrecht	AD 1275-1572	Urban	316

Figure 2.11: Map of The Netherlands with the provinces of Holland and Zeeland and the locations of the sites analysed by the author (black) and those used for comparison (gray) indicated.

3

Skeletal indicators

3.1 INTRODUCTION

Using historical and archaeological data, chapter one outlined the socioeconomic developments during the central and late medieval periods. This chapter presents potential ways of observing and analysing the consequences of these developments using human skeletal remains. Before discussing the specific skeletal indicators used in this research, this chapter addresses the concept of the 'osteological paradox'. This conceptual framework explores issues inherent to the field of osteoarchaeology which are necessary to consider in the light of the topics discussed in this chapter.

After this initial overview, the skeletal indicators used to study medieval socioeconomic developments are outlined. The text is divided thematically, and addresses indicators of disease, activity, and diet under separate subheadings. The chapter concludes with a discussion of non-specific skeletal indicators of systemic stress. These markers are presented separately since the direct causative agent of these skeletal lesions cannot be deduced. Nevertheless, they are particularly valuable to assess levels of stress in skeletal populations and are therefore suitable to study in the context of this research.

3.2 THE OSTEOLOGICAL PARADOX

In this research, samples of deceased individuals are used to reconstruct the lives of once-living people. Although this approach provides a wealth of information, it has some inherent problems, especially when studying disease, which are summarised within a concept known as the osteological paradox (DeWitte and Stojanowski 2015). Coined by James Wood and colleagues of Pennsylvania State University in 1992 (although difficulties were already noted before, see for example Cook and Buikstra (1979) and Sattenspeil and Harpending (1983)), the issues outlined in their osteological paradox paper sparked a large debate about the reliability and validity of inferences derived from mortality profiles and disease prevalence based on human skeletal remains. The paper by Wood *et al.* (1992) highlighted three key conceptual issues that influence osteoarchaeological research of human skeletal assemblages: 1) demographic nonstationarity, 2) selective mortality, and 3) hidden heterogeneity in risk (also see Boldsen and Milner 2012; DeWitte and Stojanowski 2015; Wright and Yoder 2003).

The first concept addresses the theory of demographic nonstationarity, which reflects the fact that skeletal assemblages can be derived from populations that underwent temporal changes in mortality and fertility and experienced migration. Some more traditional palaeodemographic studies have worked under the assumption that populations were stationary (e.g., Howell 1982, Owsley and Bass 1979). This allowed the researchers to construct a life table using the age-at-death of the individuals, to assess for example life expectancies or force of mortality at certain ages. If, however, a population is influenced by migration or fluctuations in fertility or mortality, the estimates are likely to be unreliable (DeWitte and Stojanowski 2015; Sattenspiel and Harpending 1983; Wood *et al.* 1992). Additionally, common problems with archaeological skeletal populations such as post-depositional processes and selective burial may further hinder palaeodemographic analyses (Waldron 1994).

The first concept of the paradox is an important issue with the present study. It is highly unlikely that the populations in the present study were stationary: changes in mortality and fertility rates migration, especially in Alkmaar, are likely to have occurred. In addition, because none of the cemeteries included in this research were fully excavated, it can be expected that this influenced the sample. Therefore, to overcome the aspect of demographic nonstationarity of the osteological paradox, it was decided to refrain from the construction and comparison of life tables. Ages-at-death are compared between the skeletal collections but only to assess the representativeness of the sample and the validity of the results of subsequent comparisons.

The second issue, selective mortality, deals with one of the more obvious aspects of skeletons: they represent dead individuals who died for a reason. Not everyone at risk of disease or death at a certain age will actually die. This results in a bias in the sample: the cemetery assemblage is not necessarily reflective of the once-living population (DeWitte and Stojanowski 2015; Wood *et al.* 1992). The third concept, hidden heterogeneity in risk, is closely related to the second one. It argues that skeletal populations consists of individuals who will vary in their susceptibility or frailty to disease and death as a result of several, often unidentifiable, factors such as genetic predisposition, socioeconomic differences, or micro-environmental variation. Combined with the second concept, it is argued that a high prevalence of pathological lesions in a skeletal assemblage does not have to point to an unhealthy population. Rather, a high frequency of skeletal lesions can be an indication of a population which survived long enough to develop bony changes. In contrast, a skeletal assemblage without or with very few skeletal lesions can be indicative of individuals with little resistance to the risks they were subjected to, and that died before developing any changes in their skeletons. However, Wood and colleagues do emphasise that the traditional interpretation of bony changes (i.e., lesions=poor health; no lesions=good health) is not necessarily wrong. Rather, they urge researchers to consider this as a possibility (DeWitte and Stojanowski 2015; Wood *et al.* 1992; Wright and Yoder 2003).

The issues outlined by Wood and colleagues have been fiercely debated (e.g., Boldsen and Milner 2012; Cohen 1994; Goodman and Martin 2000; Milner *et al.* 2008; Pinhasi and Bourbou 2008; Wood and Milner 1994; Wright and Yoder 2003). The discussions mainly focused on the question of how, if at all, osteoarchaeologists can use skeletal data to study the lives of past individuals. Although not always seen this way, the paper by Wood and colleagues did not suggest dismissing the field of osteoarchaeology as a whole. Rather, it demonstrated the imperfect nature of the research field and suggested methods which in the future may resolve the paradox (van Schaik *et al.* 2014; Wright and Yoder 2003). Wood and colleagues argue that an important way to overcome the problems associated with the osteological paradox is to improve our understanding of the cultural context of the human remains under study. By integrating archaeological and historical contextual information, with osteoarchaeological data derived from the human skeletal remains, past selective mortality and risk heterogeneity can be explored and the implications of the osteological paradox may be minimised (DeWitte and Stojanowski 2015; Wood *et al.* 1992).

Therefore, to overcome the issues outlined in the paradox, this research provides an abundance of historical and archaeological contextual information for the skeletal assemblages under study, in order to be able to accurately interpret the data derived from the individuals and reduce the influence of risk heterogeneity and selective mortality. Moreover, an effort has been made to select skeletal assemblages with a similar socioeconomic status and background (i.e., general population) ensuring that the observed differences were not caused by large inherent variations between populations. As discussed it chapter two, the cemetery populations under study are expected to be composed of the general population, making large differences in socioeconomic status unlikely. In addition, this research focuses on multiple stress indicators as well as on aspects of diet and activity patterns in the populations. This approach has been argued for by Goodman (1993:285) in his response to the osteological paradox and more recently by Wright and Yoder (2003). Since different indicators reflect different aspects of the lives of individuals, studying multiple types of skeletal indicators could reduce the effects of the osteological paradox (DeWitte and Stojanowski 2015; Goodman 1993). Although completely overcoming the paradox is difficult due to the inherent nature of the skeletal collections under study, taking into account the historical context and multiple lines of evidence will allow for the construction of robust and coherent interpretations.

To reduce the effects of the osteological paradox further, this research refrained from using the term health. Health in itself is a complex concept and not just the absence of disease (Temple and Goodman 2014). With the limited amount of diseases and stressors osteoarchaeologists can actually detect in skeletal remains, it is potentially dangerous to infer health from what is visible in a skeleton. As Temple and Goodman (2014:189) state: "*skeletal indicators of stress capture moments in time but differ significantly from evaluations of "health" in living communities."* Instead of linking the presence or absence of disease or stress markers to health, good or bad, this research aimed to be more descriptive in nature. By indicating prevalence rates and not jumping to conclusions about the health of the populations studied, a more nuanced image is presented.

3.3 INDICATORS OF DISEASE

3.3.1 Introduction

This research aims to study if the socioeconomic developments in the Central and Late Middle Ages influenced disease prevalence. However, unfortunately for osteoarchaeologists, many diseases common in the medieval period, such as gastrointestinal, bacterial, and viral infections that kill the host quickly or are only visible in the soft tissue, will not leave their marks on the human skeleton (Ortner 2003; Waldron 2009). The plague or Black Death was one of the most devastating infectious diseases in the medieval period, but does not result any skeletal changes mainly because time between infection and death is usually short, preventing a skeletal response to the bacteria. The pathological conditions which are visible in the human skeleton are chronic diseases, those that progress slowly and, importantly, are not necessarily cause of death.

Additionally, diseases that do affect the skeleton often have morphologically similar appearances as a result of the limited ways the skeleton can respond to disease. Since the skeleton is only capable of forming or destroying bone (or a combination of both) in response to stimuli, it can be difficult to distinguish diseases based upon lesions in the skeleton alone (Ortner 2003). Fortunately for osteoarchaeologists, there are variations in the distribution and type of bony lesions which often allows for differentiation between certain diseases (Ortner 2003). Of the specific diseases affecting the skeleton, brucellosis and tuberculosis are considered to be important in this research, since the prevalence of these infections could have been influenced by the socioeconomic developments in the medieval period. The subsequent paragraphs will solely focus on these two specific pathological conditions and their causes and recognition.

3.3.2 Tuberculosis

Tuberculosis is a chronic infection caused by bacteria of the *Mycobacterium* complex comprising several species with different primary hosts. Of these species, *M. tuberculosis* and *M. bovis* (humans are secondary host) are the most likely to affect humans, although others are known to have been responsible for tuberculosis infections in humans (see Roberts 2012 and Roberts and Buikstra 2008 for more detail). Considering its air-borne transmission, tuberculosis is a disease commonly associated with poverty, malnutrition, and overcrowding (Waldron 2009), hence, it is often associated with urbanisation and later industrialisation.

M. tuberculosis is transmitted from human-to-human by the inhalation of infected droplets released from the lungs of an infected person into the respiratory tract. Once inhaled, the droplets trigger a complex primary immune response which is usually asymptomatic. In about 90% of infected individuals, provided that they are able to mount the necessary immune response, the primary infection will be contained, but can remain dormant in the lungs (Aufderheide and Rodríguez-Martín 1998; Ortner 2003; Roberts 2012; Roberts and Buikstra 2008). Years after primary infection, a person can become infected again as a result of the reactivation of the bacteria in the lungs or by re-exposure via more infected droplets. The secondary response to infection is characterised by an aggressive inflammatory reaction, resulting in a progressive pulmonary infection which spreads to other parts of the body through the blood stream, and eventually even to the skeletal system (Aufderheide and Rodríguez-Martín 1998; Ortner 2003; Roberts and Buikstra 2008; Waldron 2009).

M. bovis, also termed the bovine form of tuberculosis, has a wider host range affecting both humans and other animal species. This form of tuberculosis most likely became more common in both human and animals as a result of herding and domestication of animals (Waldron 2009). The bovine form of tuberculosis primary is a lung disease in cattle. Humans are mainly infected by ingesting milk, milk products or meat from an infected animal. From the intestines, the bacteria can spread to the lymphatic system and from there it can spread to other parts of the body including the skeleton (Roberts and Buikstra 2008; Waldron 2009). It is estimated that *M. bovis* today is the cause of tuberculosis in six percent of the cases (Donoghue 2008), however, smaller estimates of only 0.5% are also reported (Pfeiffer 2008). Differences are most likely related to the cultural context of the populations under study. It is estimated that currently *M. tuberculosis* is responsible for most human tuberculosis infections. However, it is unclear if this was the case in the past (Roberts 2012).

Both *M. tuberculosis* and *M. bovis* can cause skeletal lesions making it possible to identify the tuberculosis in the archaeological record. However, not all individuals affected by tuberculosis develop osteological lesions consistent with the infection. Waldron (2009) states that only two to five percent of infected individuals will develop bone lesions in response to the disease (Waldron 2009). This is similar to the observations of Ortner (2003) who noted that skeletal involvement only occurs in three percent of all tuberculosis cases. Aufderheide and Rodríguez-Martín (1998) and Steinbock (1976) are slightly more generous; they state that the frequency of skeletal involvement in pre-antibiotic times averaged five to seven percent of all tuberculosis cases (Aufderheide and Rodríguez-Martín 1998; Steinbock 1976). In contrast to these low percentages, Steyn and colleagues (2013), who studied a modern skeletal collection in South Africa, found that 21% of individuals with tuberculosis had skeletal involvement. Still, even the higher percentages suggest that the reported osteoarchaeological cases of tuberculosis are a gross underestimation of the real prevalence of the disease. DNA research and the analysis of mycolic/mycoserosic acids has proven to have been very valuable for the diagnosis of tuberculosis in skeletal remains (e.g., Gernaey *et al.* 2001; Mays and Taylor 2003; Mays *et al.* 2001; Minnikin *et al.* 2010; Redman *et al.* 2009) and might be able to approximate the real prevalence if untaken on a large scale. However, this is currently not applied on a population scale due its high cost.

Skeletal lesions associated with tuberculosis are most often found in the spine, mainly the lower thoracic and lumbar vertebrae (Aufderheide and Rodríguez-Martín 1998; Waldron 2009). The lesions are largely confined to the bodies of the vertebrae with neural arches usually spared. The infection can cause complete destruction of the vertebral bodies resulting in a characteristic collapse of the spine causing kyphosis known as Pott's disease (Ortner 2003; Waldron 2009). Other skeletal parts can be affected as well; the knee, elbow, and hip joints are common site for tuberculous skeletal lesions. In addition, hands and feet are also regularly affected (Ortner 2003). The lesions, both in the spine and in extra-spinal locations, are generally lytic (destructive) in nature. In contrast to other common bone infections, tuberculosis is characterised by little to no new reactive bone formation (Aufderheide and Rodríguez-Martín 1998; Roberts and Buikstra 2008; Waldron 2009). One exception to this is the formation of periosteal new bone on the visceral surface of the ribs. Several authors have argued that this lesion, although not pathognomonic, is very common in individuals with a tuberculosis infection (e.g., Kelley and Micozzi 1984; Roberts *et al.* 1998; Santos and Roberts 2006). However, other chronic lung diseases, such as bronchitis or pleuritis, may result in similar bony changes and can therefore not be ruled out (Waldron 2009). Even though it could be very informative, distinguishing between bovine or human tuberculosis is not possible macroscopically since the morphology of skeletal changes is the same (Waldron 2009).

The presence of tuberculosis, whether *M. tuberculosis* or *M. bovis*, will be examined in the remains of the three skeletal collections under study in order to assess differences in prevalence. Such data may indicate if the developments in the central and late medieval period, urbanisation in particular, influenced the frequency of this specific infection and may lead to new insights into medieval living conditions.

3.3.3 Brucellosis

Brucellosis is an infectious disease, with domestic animals as primary host, caused by bacteria of the *Brucella* genus of which four species are pathogenic to humans, each with a different animal host. *B. abortus* affects cattle, *B. melitensis* is found in goats and sheep, *B. canis* in dogs, and *B. suis* affects pigs (Young 1995). In northern Europe, most brucellosis infections spread from cattle to humans, mainly as a result of inhaling infected aerosols, handling infected blood, or consuming infected raw meat or milk (Waldron 2009). Goats and sheep could have been an important host for brucellosis for humans in the medieval period in Europe as well. Infection from the pig form of the disease occurs mainly in North America, *B. canis* infections are rare in humans and if humans are infected the symptoms are mild and usually do not involve the skeleton (Young 1995). Brucellosis does not spread from human-to-human (Aufderheide and Rodríguez-Martín 1998; Young 1995).

In humans, the disease presents itself as a chronic infection of the lungs and other internal organs, such the spleen, liver, lymph nodes, and bone marrow (Aufderheide and Rodríguez-Martín 1998; Chelli Bouaziz 2008; Ortner 2003). While skeletal lesions are one of the more common complications of the infection, the majority of affected individuals will not develop bone lesions. Aufderheide and Rodríguez-Martín (1998) state that skeletal involvement is only present in ten percent of cases. Ortner (2003) mentions that skeletal lesions occur in 2% to 70% of infected individuals. Clinical studies report osteoarticular involvement in 8% to 20% of the cases (Namiduru *et al.* 2004; Young 1995). The large differences in reported percentages of bone involvement can partly be related to the type of *Brucella* species causing the infection: it is noted that people infected by *B. melitensis* are more likely to develop bone lesions (Ortner 2003). Since goat and sheep were common as livestock in Holland and Zeeland (Ettema 2005; van Dijk 2010), this *Brucella* species could have been responsible for skeletal brucellosis.

Vertebrae and the sacroiliac joint are the most often affected in individuals with brucellosis (Waldron 2009). Clinical studies report that the joints often show signs of osteoarthritis; this is, however, a non-specific skeletal pathology (Young 1995). Long bones and flat bones are rarely affected (Aufderheide and Rodríguez-Martín 1998; Namiduru *et al.* 2004; Ortner 2003). The spinal lesions are initially lytic in nature and are confined to the vertebral bodies, especially those of the lumbar vertebrae. Lysis of the anterior vertebral body margin may be related to brucellosis as well (Mays 2007). In contrast to tuberculosis, the vertebral lesions caused by brucellosis do not commonly result in vertebral collapse or kyphosis. In addition, since the skeletal manifestations develop slowly, there is time for the body to develop new bone. As a result, the fusion of vertebrae is common and this may also explain why spinal collapse is uncommon (Aufderheide and Rodríguez-Martín 1998; Ortner 2003; Waldron 2009). It is estimated that brucellosis was common in the past considering the contact and close proximity to animals and their products. However, only a handful of cases are reported in the archaeological literature suggesting that the actual prevalence is massively underestimated (Waldron 2009).

The presence of brucellosis will be studied in the three skeletal collections under study to identify possible differences in prevalence. This frequency of specific infection is studied to assess if the medieval socioeconomic developments had an impact on contact with animals or consumption of meat products.

3.4 INDICATORS OF ACTIVITY

3.4.1 Introduction

This study aims to assess the influence of medieval socioeconomic developments on the activity patterns of the populations. Since bone has the capability to remodel in response to mechanical stimuli, past activities can be researched by analysing certain skeletal markers. Julius Wolff, a nineteenth century German anatomist, was one of the first to note the great ability of bone to respond to mechanical loading by altering its size and shape. This concept, later termed Wolff's law, is currently commonly used to study the activity patterns during life (Larsen 1997; Ruff 2008; Ruff *et al.* 2006). Although the full process of bone remodelling is not completely understood, the effects of activity on bone are clear and use of this concept has been demonstrated in numerous studies (e.g., Larsen 1997; Ruff *et al.* 2006; Sofaer Derevenski 2000). Below, two skeletal markers of activity, osteoarthritis and bone morphology, are discussed.

3.4.2 Osteoarthritis

Osteoarthritis is a disease that affects all mammals with synovial joints. These specific joints, also known as diarthroses, are encapsulated by a membrane and the space between the joint surfaces is filled with a lubricating synovial fluid making them extremely mobile. Examples of synovial joints are the shoulder, knee, and hip, and also include the facet joints of the spine. Synovial joints are the most common type of joint in the human body and also most regularly affected by disease (Rogers 2000; Waldron 2009).

Osteoarthritis primarily affects the articular cartilage covering the joint surfaces. As the disease progresses, the cartilage is broken down resulting in exposure of the bone underneath. In response, more bone is produced in an effort to stabilise the joint which will result in new bone around the joint margin (osteophytes), new bone on the joint surface, and changes in the contour of the joint. Finally, eburnation, a highly polished area on the joint surface as a result of bone-to-bone contact, is produced. Pitting or porosity of the joint surface is also commonly seen in joints affected by osteoarthritis (Rogers 2000; Waldron 2009), however, others have argued that this may have a different aetiology since there appears to be no clinical correlation with osteoarthritis (Rothschild 1997; Sofaer Derevenski 2000).

Apart from dental disease, osteoarthritis is the most common pathological condition found in human skeletal remains (Rogers 2000; Waldron 2009; Weiss and Jurmain 2007). Many predisposing factors including genetics, body weight, living environment, and climate are associated with the condition, which causes variation in patterns of osteoarthritis (Larsen 1997; Waldron 2009). However, one of the most important contributing factors is mechanical stress (Larsen 1997). Movement of the joint is essential in the production of osteoarthritis: joints that do not move will not develop osteoarthritis (Waldron 2009). Therefore, the condition has been used to reconstruct past activities and activity patterns. Different occupations, hence different types of mechanical loading, will result in different patterns of osteoarthritis. However, due to the many predisposing factors that can be associated with the production of the condition, the link between osteoarthritis and specific physical activity cannot be made directly. Waldron (2009) argues that the aetiology of the disease is almost always multifactorial and that attributing particular occupations to skeletons on the basis of presence and distribution of osteoarthritis is futile (Waldron 2009:29). Subsequently, inferring specific types of behaviour from joint disease is very difficult, if not impossible. However, studying activity in a more general sense by comparing the prevalence and distribution of osteoarthritis can allow insights into broad activity levels and types (Larsen 1997; Weiss and Jurmain 2007).

Several researchers have studied differences in activity between populations and groups by comparing the prevalence and distribution of osteoarthritis in human remains and have demonstrated the value of this type of approach. Lieverse *et al.* (2007) researched patterns of mobility and activity in the Cis-Baikal region in Siberia to study possible adaptive strategies through time. Bridges (1991) looked at differences in activity levels between hunter-gatherers and agriculturalists to assess changes in mechanical stress as a result of alteration of the subsistence strategy. Inskip (2013) studied variation in activity patterns between pre-Islamic and Islamic populations in Spain to research changes in activities associated with religious identity. Osteoarthritis has also been used to study the differences between rural and urban populations. Jordan and colleagues (1995) compared the prevalence of knee and hip osteoarthritis in urban and rural communities in the North-Carolina, USA. They found that the prevalence of the joint disease was higher in the rural individuals who may be related to their specific activities, however, more research taking into account non-sociodemographic factors is necessary.

Although there are multiple factors involved in the aetiology of osteoarthritis, the fact that mechanical loading is an important aspect allows for the comparison of activity levels between the three collections under study. Previous research has shown that this type of approach is valuable in answering similar questions. Osteoarthritis data may contribute to a better understanding of the influence of the socioeconomic developments on medieval activity patterns.

3.4.3 Bone morphology

Although bone size and shape can also be influenced by several non-mechanical influences such as age-related changes, nutrition, and pathological conditions, the study of long bone morphology or shape has proved to be particularly valuable in osteoarchaeology for reconstructing past activities. As with osteoarthritis, the analysis of bone shape works under the assumption that bone responds to mechanical stimuli (Ruff 2008). Figure 3.1 shows the functional adaptation of bone based on mechanical deformation, or strain (Ruff 2008). If strain is increased, new bone is deposited to withstand mechanical loading. If strain is decreased, bone is removed to keep the optimal level.

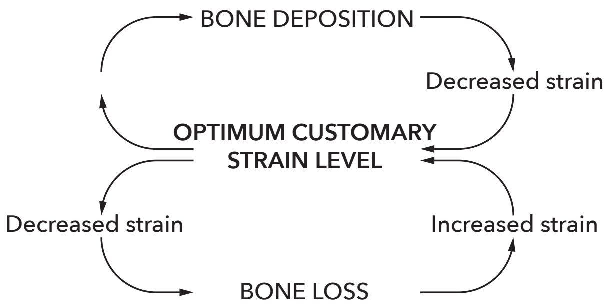


Figure 3.1: A model of functional adaptation of bone (adapted from Ruff 2008, figure 6.1, p. 184).

Ruff (2008) discusses that bones can be understood and modelled akin to engineering beams. Just like those beams, bones have to be rigid (resist deformation) and strong (resist breaking) to be able to withstand mechanical loading, mainly torsional and bending forces (Inskip 2013; Larsen 1977; Ruff 2008). The strength and rigidity of bones is related to the cross-sectional properties which can be analysed by expressing the shape in indices by dividing the anterior-posterior diameter by the medio-lateral diameter (Ruff 2008).

This concept of functional adaption of bone has been used in several osteoarchaeological studies, for both the upper and lower limbs. Steele and Mays (1995), for example, studied directional asymmetry in the size of the humerus at the site of Wharram Percy, England and could clearly link size and shape variations to differences in mechanical loading. Differences in the lower limbs are more suggestive of differential mobility. Populations with rounder leg bone morphology are considered to have experienced less strain on their bones than individuals with bone flattening indicating directional muscle action and associated bone deposition (Pomeroy and Zakrzewski 2009; Wanner *et al.* 2007; Wescott 2006). This was noted by Pomeroy and Zakrzewski (2009) who found marked differences between male and female bone morphology in Spain and England, mainly in the lower limbs, suggesting different activity patterns.

Results from studying upper limb bone morphology are difficult to interpret due to the multifunctionality of the arms in humans (Pomeroy and Zakrzewski 2009, Weiss 2003). The morphology of the lower limb bones, as they are weight bearing and thus used in locomotion, is assumed to relate mainly to mobility patterns. Considering the interpretational difficulties associated with the upper limb morphology, this study focuses on the lower limbs to be able to detect differences in mobility patterns between the skeletal populations. Specifically, this research studies the proximal flatness of the femur (platymeric index) and the flatness of the tibia at the nutrient foramen (platycnemic index) since both have proved to be valuable for reconstructing mobility patterns in archaeological populations (Bridges *et al.* 2000; Pomeroy and Zakrzewski 2009;). Although the robusticity index has been shown to give meaningful results as well (Pomeroy and Zakrzewski 2009; Wanner *et al.* 2007), since this measurement requires a complete femur, it was not possible in this research due to the fragmented nature of the Blokhuizen collection.

The analysis of lower limb morphology in the three skeletal collections under study will allow for a comparison of strain levels and associated compensation. Specifically, the data that will be gathered can shed light on the activity patterns of the different populations, especially increased or decreased walking activities. This may lead to conclusions about the influence of the medieval developments on activity and possibly a better understanding of labour division, if present at all.

3.5 INDICATORS OF DIET

3.5.1 Introduction

This research aims to study how the socioeconomic developments in the central and late medieval period influenced available food types and dietary practices. Diet, and especially an inadequate diet, can impact the human body in a number of ways, some of which leave marks in the skeleton. Dental health is heavily influenced the consumed food types. Different amounts of protein and carbohydrates can be responsible for certain patterns of oral pathology. Dental caries is a great example of this, and, since teeth survive well in the archaeological record, a good indicator to study for dietary analysis. Additionally, a diet deprived of certain elements may result in nutritional deficiencies. While most likely not fatal, nutritional deficiencies can cause serious problems and would undermine the body's resistance to disease. Although not all nutrient shortages leave specific skeletal marks, vitamin D and C deficiencies can be responsible for characteristic lesions in the skeleton. Both dental caries and the studied nutritional deficiencies are discussed below.

3.5.2 Dental caries

Dental caries is a destruction of tooth enamel, dentine, and/or cementum by the acids produced by bacteria present in dental plaque. Carious lesions can form on all surfaces of the tooth including the roots, although grooves and pits in the enamel where food can get trapped are favourable locations. Firstly, acids produced by bacteria will dissolve the enamel, leaving a small translucent spot on the tooth. If the destruction continues, the enamel will be completely dissolved and the dentine will be affected as well, causing a clearly visible cavity. If left untreated, carious lesions can result in the complete destruction of a tooth, and can give rise to other infectious processes such as abscesses. Eventually, the affected tooth is likely to fall out (Aufderheide and Rodríguez-Martín 1998; Hillson 1996).

Diet and the manner in which the food is prepared have often been related to the prevalence of carious lesions in archaeology and can therefore be used to study shifts in subsistence strategies. In many areas of the world, an increase in caries prevalence was noted when diet became more carbohydrate rich (Aufderheide and Rodríguez-Martín 1998; Cohen and Armelagos 1984; Larsen 1995; 1997). This is related to the fact that oral bacteria responsible for the dental caries flourish in the presence of carbohydrates (Cucina *et al.* 2011; Larsen 1997). Numerous scholars have documented higher caries rates in agriculturalists in comparison with hunter-gatherer populations (see Larsen 1995, 1997 for references). Agriculturalists would indeed have a more carbohydrate rich diet including products such as grains, maize, and rice. This clear difference between hunter-gatherers and agriculturalists with regards to carious lesions indicates that it is possible to detect major dietary shifts through the analysis of dental health.

Turner (1979), studying several populations with different subsistence strategies from around the globe, noted a clear differences in caries frequency between groups. He noted that, on average, hunter-gatherers had 1.72% of their teeth affected by caries while agriculturalists had an average of 8.56%. Populations with a mixed economy have rates in between, with an average of 4.37% of their teeth affected by caries lesions (Turner 1979:622). Even though the increase in caries rates is evident, it should be noted that these are only averages. Frequencies within the categories, especially in the agricultural group, are highly variable (Larsen 1995; 1997). In addition, Tayles and colleagues (2000) note that even though rice is rich in carbohydrates, the intensification of rice agriculture in Southeast Asia did not have an effect on the caries rates. Diets which are high in protein on average have lower caries rates. Proteins increase the pH level of the dental plague supressing bacterial growth. Therefore, populations with a protein rich diet should have lower caries rates than those more dependent on carbohydrates (Hillson 1996). For example, populations largely dependent on marine resources such as fish have lower caries rates, as was found during research on skeletal assemblages form the Arabian Gulf (Littleton and Frolich 1993).

In addition to the food types that are consumed, the way in which food is prepared is linked with the prevalence of caries lesions. This may also explain the differences in caries prevalence between agricultural populations: small variations in food processing can have a large effect on the development of carious lesions (Larsen 1995; 1997). For example, the boiling of foods makes them soft and sticky requiring less masticatory action to consume them, therefore promoting oral bacterial growth (Larsen 1995).

Important to note here is the relationship between dental wear and carious lesions. Several authors have found a negative correlation between wear frequencies and caries of the occlusal surface (e.g., Maat and Van der Velde 1987; Powell 1985). High degrees of occlusal wear can cause the caries to be worn away before it takes over and can erase evidence of its presence. Conversely, other researchers (e.g., Meiklejohn *et al.* 1992) found a positive relation between dental wear and caries: the teeth that were worn the most were also severely affected by carious lesions. Meiklejohn and colleagues note that dental caries and wear are not directly dependent on each other and that both most likely correlate with the consumed diet (Meiklejohn *et al.* 1992).

Research has shown that the study of dental caries can contribute to a better understanding of dietary practices. Specifically, clear shifts in dietary patterns are visible through the analysis of this oral pathology. In this research, the prevalence and frequency of dental caries will be compared between the three studied skeletal collections. Such data may reveal if the socioeconomic developments in the medieval period influenced the consumed food types.

3.5.3 Nutritional deficiencies

Vitamin D deficiency

Vitamin D is essential for skeletal health and plays a vital role in mineral metabolism, immune reaction, and cell growth (Brickley and Ives 2008; Holick 2007). Specifically, the human skeleton is dependent on vitamin D since it regulates the absorption of the necessary elements for bone metabolism from the intestines. A lack of vitamin D hampers adequate mineralisation of bone which can result in bone deformation (Brickley and Ives 2008). Humans depend on exposure to sunlight or on their diet, especially fish and eggs, for the acquisition of vitamin D. Hence, a deprivation of sunlight as a result of working indoors or occlusive clothing, and/or an insufficient diet can lead to a shortage (Brickley and Ives 2008; Holick 2007; Ortner 2003). The bony changes in non-adults are different than those in adults, therefore, they will be discussed separately.

In children, vitamin D deficiency is termed rickets (once growth ceases: osteomalacia). This disease was most likely common in the past, especially in cities during the period of industrialisation because of narrow streets and smoke-filled air, which would inhibit sunlight from reaching the skin. However, the disease has been found in earlier periods and is often linked to a combination of poor diet and other types of shielding from the sun (Brickely and Ives 2008). Vitamin D deficiency has serious effects on the skeletons of children since they need vitamin D to mineralise their growing bones. During growth, bone turnover is rapid and the poorly mineralised bone is unable to support the weight of the individual resulting in bending deformities. In addition, other non-weight bearing areas of the skeleton where bone turnover is high will show changes. The ribs of affected children display swelling of the sternal ends as a result of an accumulation of unmineralised cartilage and bone, a deformity termed a rachitic rosary. Similar changes can be seen in other places of the skeleton where endochrondral growth takes place such as metaphyseal areas of the long bones (Brickely and Ives 2008; Ortner 2003; Waldron 2009). It is important to note that children often recover from rickets; if diet becomes adequate again or if sufferers receive more sunlight, skeletal changes can disappear. Therefore, rickets is only visible in children or adults who were unable to completely undo the damage caused by the vitamin D deficiency before death suggesting that the prevalence in archaeology is most likely underestimated (Waldron 2009).

When the deformities from childhood vitamin D deficiency are still visible in adults this is termed residual rickets. It is important to keep in mind that these skeletal changes do not indicate an active form of the vitamin deficiency. However, studying the individuals with these deformities allows for a better understanding of rickets in childhood. While it is not possible to study sex differences in disease prevalence in childhood (considering the problems with estimating sex in non-adult individuals, see chapter four), studying adults displaying a childhood disease permits research along those lines (Brickley and Ives 2008; Brickley *et al.* 2010).

The active adult form of vitamin D deficiency is termed osteomalacia. The skeletal changes associated with osteomalacia are very different from rickets due to the fact that the skeleton of an adult individual is no longer growing. In skeletally mature individuals, although the bone is not growing, remodelling still takes place. Inadequate amounts of vitamin D will disrupt the remodelling process: the newly deposited bone is poorly mineralised making the bones light and vulnerable. Fractures, especially in the ribs and pelvis, can occur regularly as a result of stress exerted on weakened bone. The macroscopic identification of osteomalacia in dry bone is difficult; x-rays and histology are often needed. On radiological images, areas of poorly mineralised bone with a sclerotic margin (Looser's zones), which are indicative of osteomalacia, can be seen. On histological slides unmineralised bone can sometimes be identified (Brickley and Ives 2008; Brickley *et al.* 2007; Ortner 2003; Waldron 2009).

The presence of a vitamin D deficiency, both in adults and children, can reveal information about the nutritional value of the consumed diet and/or exposure to sunlight. The prevalence of this deficiency is compared between the different skeletal assemblages to study if socioeconomic developments influenced the nutritional value of the diet or resulted in behavioural changes such as working indoors.

Vitamin C deficiency

Scurvy is a common disease when people consume a diet with inadequate vitamin C. In contrast to several other mammals, humans are not able to synthesis or store vitamin C making them dependent on food to avoid shortages. Most fresh vegetables and fruits contain enough vitamin C to remain scurvy free, however, during famines (Geber and Murphy 2012) and long sea journeys (Maat 2004) when those products were not available scurvy flourished.

Vitamin C plays an important role in the synthesis of collagen, the body's main structural protein. Since collagen is the major component of all connective tissue, including bone, the skeleton can also be affected by scurvy. As with rickets, the skeletal changes related to a vitamin C deficiency are more apparent in non-adults since their bones are growing. The non-adult changes are different from the skeletal lesions observed in adults. Therefore, they will be discussed separately below.

Primary skeletal changes related to scurvy in non-adult individuals are most apparent in bones that grow rapidly which include the sternal rib ends and long bones metaphyses. The skeletal lesions are the result of decreased osteoblastic activity which leads to a build-up of unmineralised bone and cartilage on the ends of the long bones and ribs. In severe cases, this immature bone can fracture, possibly resulting in dislocation of the epiphysis (Ortner 2003). The secondary changes in scurvy are mostly related to vascular vulnerability. Since the formation of collagen is inadequate, scurvy is associated with weakness of the blood vessels walls resulting in haemorrhaging. Bleeding near the periosteum will trigger new bone growth. In addition, this process may provoke a localised inflammatory reaction which may result in a porous bone surface (Brickley and Ives 2008; Mays 2008; Ortner 2003). In the skeleton, these lesions can be found macroscopically as areas of porous new bone which are commonly located on the femur, tibia, and scapula, and in the skull, especially on the sphenoid, maxilla, and orbital roofs (Mays 2008; Ortner 2003).

In adults, skeletal lesions associated with scurvy are less common (Ortner 2003). Ortner (2003) notes that the bony changes are limited to transverse fractures of the sternal ends of the ribs, although an inflammatory reaction may be present on the alveolar bone of the maxilla and mandible as a result of chronic haemorrhaging of the gingiva. Van der Merwe *et al.* (2010) used ossified haematomas and the presence of widespread bilateral subperiosteal bone apposition, as well as periodontal disease to identify scurvy in adults. Since haematomas can resemble lesions caused by other pathological conditions such as cancer, treponematosis, or non-specific bone infections, the authors performed histological sectioning confirming that the lesions were indeed ossified haematomas (Van der Merwe *et al.* 2010).

As with vitamin D deficiency, research on the prevalence of scurvy can give information about the nutritional value of the diet of the individuals under study. Such data may indicate the influence of medieval developments on available food products. In combination with the data on dental caries, the nutritional deficiencies may shed light on the consumed diet.

3.6 INDICATORS OF NON-SPECIFIC STRESS

3.6.1 The concept of stress and adaptation

This research aims to study how the socioeconomic developments in the central and late medieval period influenced the individuals in Holland and Zeeland. As was discussed in the chapter one, the lifeways of the medieval individuals, both rural and urban, were likely altered in response to and as a result of various developments in these periods. Adaptation and change can be physically and psychologically demanding, often resulting in stress, provoking a physiological stress response in people (Goodman and Armelagos 1989; Goodman *et al.* 1988). The skeletal changes discussed in the paragraphs above can be related to a specific type of stress, i.e., diseases, mechanical loading, and diet/nutritional stress. Additionally, however, the skeleton may demonstrate alterations which cannot be directly attributed to a specific cause. These bony reactions do, however, indicate that the individual experienced some form of stress, such as episodes of disease or malnutrition, at some point during their life. Therefore, even though the exact cause of the stress cannot be identified, skeletal indicators of non-specific stress are a valuable source of information to assess levels of systemic pathological stress between populations.

The concept of stress and its physiological response has been extensively used in studies of human history. In anthropological and historical studies, stress is often defined as *"the biobehavioural response to environmental conditions"* (Goodman *et al.* 1988:171). Adaptation, the process of change and adjustment to increase an individual's or population's chance of survival, can be both a result and cause of stress.

This way of using the concept of stress is mainly derived from the work of Seyle (1976) who defines stress as *"the nonspecific response of the body to any demand"* (Seyle 1976:55). He came to this definition when he noticed several similar morphological changes in mice in response to diverse noxious stimuli, which in turn predisposed them to specific stress responses. This indicates that, while the stressors can be varied and many, the body's response to these stimuli is similar. Seyle proposed that the morphological changes he observed were the result of a general endocrinological process which he termed the *general adaptation syndrome* or GAS. In this syndrome, Seyle recognised three stages: 1) the initial alarm reaction, 2) resistance, and eventually, 3) exhaustion. During the first stage, i.e., initial exposure, the individual has no resistance against the stimuli provoking an excessive response. After prolonged exposure, the body has built up resistance and is able to at least partially ward off the stressor(s). However, after still longer exposure, the acquired resistance is lost due to exhaustion and the body enters the final phase during which the symptoms are similar to the initial alarm phase (Goodman *et al.* 1988; Goodman and Armelagos 1989; Lewis 1999; Seyle 1976).

In current populations, stress is assessed by measurement of the levels of certain hormones in urine or saliva (Lewis 1999). Although stress levels cannot be directly measured in past populations, certain skeletal changes can be used to infer stress. Goodman and colleagues (1988) have devised a model, based on the Seylean concept of stress, to be used in osteoarchaeology. This model illustrates the complex interplay between environment, culture, and host resistance factors which may eventually result in a stress response. Figure 3.2 displays the model the authors created. From the image, it becomes clear that the environment can both be the cause as well as the buffer of stress. The same is true for culture: it allows society to gain resources essential for survival, but it may cause stress as well (Goodman *et al.* 1988; Goodman and Armelagos 1989; Lewis 1999; Martin *et al.* 2013). For example, the development of agriculture had many positive effects in terms of calorie production in relation to human expenditure; however, other associated developments such as increased population density and several ecological changes appears to have had negative effects on overall health (Martin *et al.* 2013).

Additionally, the impact of environmental and cultural stressors or buffers is different depending on host resistance factors such as age, sex, and overall physical condition of the individual. Infants and elderly may respond more poorly to nutritional stress than healthy adults. In addition to biological resistance factors, it is also important to keep in mind that cultural factors such as economic status and access to resources can play an important role in buffering or predisposing people to stress (Goodman *et al.* 1988; Martin *et al.* 2013). If individuals are unable to mount an adequate response to environmental and cultural stressors, a physiological stress response can occur which can be observed by studying certain skeletal changes. Below, several generalised skeletal changes, i.e., small stature, dental enamel hypoplasia, and cribra orbitalia and porotic hyperostosis, frequently studied in this type of research to assess systemic stress levels in skeletal populations, are discussed.

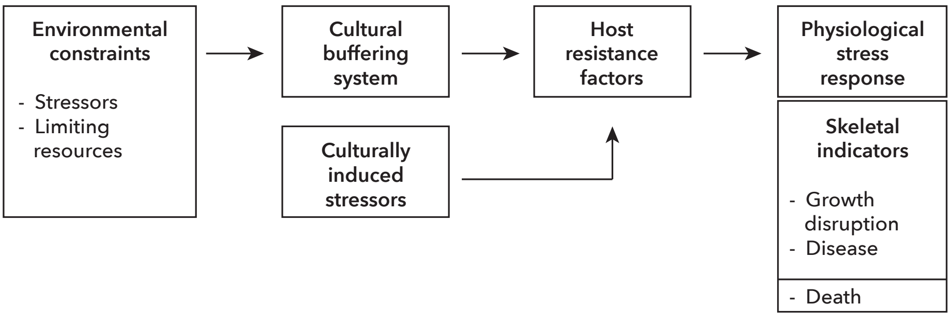


Figure 3.2: Biocultural model of stress and adaption adopted for use with skeletal populations (after Goodman *et al.* 1988, figure 2, p. 172).

3.6.2 Stature

Stature is the body height of a human in an upright position, which changes throughout life as a result of growth and processes associated with ageing. In the last 150 years, human populations across the world have experienced an increase in height and weight (Cole 2003). This is nicely illustrated by average adult Dutch male stature over time. The average height changed from 165cm in AD 1860 to 181cm in 1990 (Cole 2003; Maat 2005). Genetics play an important role in determining final stature; 80% of the height variations are under genetic control (McEvoy and Visscher 2009). However, environmental conditions are very influential in determining if an individual reaches their genetically predetermined stature (McEvoy and Visscher 2009). Poor living environments, where nutrition is inadequate and diseases are rampant, affect individual growth resulting in shorter stature compared to individuals with good living standards (Humphrey 2000; Larsen 1997). Humphrey (2000:23) states that several environmental and cultural stress factors can be responsible for disrupting growth including: "*a change in subsistence patterns, technological innovation (affecting, for example, food production, storage and preparation or sanitation), changing social structures, political unrest, environmental degradation and climatic disasters or fluctuation.*" The socioeconomic developments in the medieval period may have been associated with some or several of the factors mentioned by Humphrey, suggesting that changes in stature could be visible over time.

Several researchers have demonstrated the clear relationship between living conditions and height. Komlos and Kriwy (2002) compared the average height of males and females from West and East Germany (birth cohorts of 1919-1980) and found that the more favourable living conditions in the West contributed to a taller stature for both the men and women. After unification of Germany when living conditions became similar in both areas, the differences in height disappeared indicating that environmental factors are important in determining adult stature (Komlos and Kriwy 2002). Wright and colleagues (1992) compared height and weight of English children from economically deprived and prosperous areas. They were able to determine that children living in deprived areas were markedly shorter and lighter demonstrating the influence of economic conditions on growth (Wright *et al.* 1992). Lambert (1993) researched the health of the prehistoric Santa Barbara Channel Islanders (USA) in relation to a subsistence shift that occurred. She noted that as other stress indicators became more apparent, the stature of the individuals became shorter indicating that the subsistence shift caused health and nutritional problems (Lambert 1993).

In addition, there appears to be a relationship between age-at-death and stature. Some studies show that short individuals die younger (e.g., Gunnell *et al.* 2001, Kemkes-Grottenthaler 2005, Smith *et al.* 2000). This height-mortality association is often explained as childhood stress having a long term influence into adulthood (Gunnel *et al.* 2001). Kemkes-Grottenthaler (2005), however, argues that the relationship between survival advantage and stature is not a causal one, but coincidental. She argues that tall people have better health and that short stature is associated with poor socioeconomic status as well as with all kinds of other risk factors (Kemkes-Grottenthaler 2005).

These examples demonstrate the potential of using variation in stature to study differences in living environments and factors impacting growth. Although it is difficult to relate this to specific causes such nutritional stress or disease, differences in mean stature between the skeletal populations under study can shed light on the impact of the socioeconomic developments in the medieval period.

3.6.3 Dental enamel hypoplasia

Dental enamel hypoplasia is a defect in the development of tooth enamel. The formation of the enamel is initiated by the ameloblasts (enamel producing cells) after the first layer of dentin is formed. In the first phase of formation, the ameloblasts secret an enamel matrix composed of organic and inorganic material. During the second phase, the ameloblasts start to break down the organic component of the enamel. The minerals deposited in the initial phase expand creating the mature dental enamel which is almost entirely (>97%) composed of inorganic salts (Hillson 1996; Larsen 1997). Like bone, enamel formation is susceptible to disruptions in the form of nutritional deficiencies, disease, or other stressful episodes. However, in contrast to bone, dental enamel will not be remodelled after the formation is complete; disruptions during formation (i.e., childhood) will remain visible into adulthood. Therefore, dental enamel is an excellent source for studying past periods of systemic stress during childhood (Larsen 1997).

As a result of the sensitive nature of ameloblasts, systemic stress during enamel formation, whether disease, nutritional, or another stress factor (see Hillson 1996 for review of causes), can result in visible defects in the dental enamel. Enamel hypoplasia, a deficiency of enamel thickness, is the most common macroscopically visible defect of the tooth enamel (Hillson 1996; Larsen 1997). This defect can take many forms; the most common type is the linear enamel hypoplasia which is observable on the outer layer of the enamel as a horizontal line. The other types include pit-like and the plane-type defects (Hillson 1996). The anterior teeth of the dentition, the incisors and the canines, are most prone to develop enamel hypoplasia (Goodman and Armelagos 1985, 1989; Lovell and Whyte 1999). This is most likely related to time of development (Goodman and Armelagos 1985). However, stability in development also appears to be an important factor as well. Interestingly, teeth which are less developmentally stable such as premolars and molars are more resistant to ameloblastic disruption, since these tooth types have the ability to respond to stress by decreasing size or altering developmental timing (Goodman and Armelagos 1985).

Several researchers have shown a link between enamel hypoplasia and stress. Goodman and colleagues (1991) compared the prevalence of enamel hypoplasia in modern Mexican children who did and did not receive nutritional supplements. They found a substantially higher frequency of enamel hypoplasia in the children without nutritional supplements (74% versus 39%) indicating the link between inadequate nutrition and dental defects (Goodman *et al.* 1991). Nikiforuk and Fraser (1981) demonstrated a clear relationship between the development of enamel hypoplasia and low calcium content in the blood, which can be a result of a vitamin D deficiency (Nikiforuk and Fraser 1981). In addition, other non-nutritional disruptions such as disease can be responsible for dental defects commonly identified in human skeletal remains (Ford *et al.* 2009).

In osteoarchaeology, dental enamel hypoplasia is often used in combination with other stress markers to study past health and living conditions (e.g., Gowland and Redfern 2010; Lewis 2002; Liebe-Harkot 2012; Palubeckaitė *et al.* 2002; Ribot and Roberts 1996; Watts 2013). In this research, the prevalence of enamel hypoplasia is studied to assess differences between the skeletal populations under study. Such data may provide insights into the influence of the medieval socioeconomic developments on childhood stress.

3.6.4 Porotic hyperostosis and cribra orbitalia

Porotic hyperostosis, a term first introduced by Angel (1966), is used to describe a pathological condition characterised by sponge-like lesions found predominantly on the parietal and the occipital bones of the skull. A similar condition is known as cribra orbitalia in which the orbital roofs have the porous, pitted appearance. Both the orbital and calvarium changes result from the expansion of the diploë as a result of abnormal enlargement of the bone marrow. Due to this expansion, the outer cortical bone becomes thinner, exposing the inner trabecular bone and giving the bone surface a porous, sieve-like appearance (Aufderheide and Rodríguez-Martín 1998; Keenleyside and Panayotova 2006; Walker *et al.* 2009). Currently, the exact relationship between the two pathological conditions is unclear. Some authors argue that both conditions are part of the same pathology in which cribra orbitalia is the first stage and porotic hyperostosis the subsequent stage as the disease progresses (Keenleyside and Panayotova 2006; Walker 1985). This is, however, not supported by the frequent finding of crania with porotic hyperostosis but without cribra orbitalia. Age-related changes in the location of marrow production and difference in speed of remodelling may explain the difference in observability of the two conditions (Walker *et al.* 2009).

Despite the controversy concerning the relationship between the two pathological lesions, both porotic hyperostosis and cribra orbitalia are most often seen as the result of anaemia, a reduction in red blood cells and/or haemoglobin in the blood. The skeletal changes associated with anaemia are the result of the effort of the bone marrow to increase red blood cell production by hyperplasia. It is important to note here that anaemia is not a specific disease, but a pathological symptom and can be related to many causal factors (Walker 1985; Walker *et al.* 2009) which have been extensively debated over the last few years. Iron-deficiency has often been associated with both cribra orbitalia and porotic hyperostosis (e.g., Larsen 1997;

Roberts and Manchester 2007; Walker 1985). This explanation, however, has been disputed by others (e.g., Waldron 2009; Walker *et al.* 2009). These researchers claim that since there is almost no expansion of bone marrow associated with iron deficiency anaemia, it is unlikely that this is the cause of the pathological conditions frequently seen in archaeological human remains (Waldron 2009; Walker *et al.* 2009). Walker and colleagues (2009) argue that an inherited anaemia, or a vitamin B12 or folate deficiency are far more likely explanations. Conversely, although not disputing the causes suggested by Walker *et al.* (2009), Oxenham and Cavill (2010) state that iron deficiency anaemia should not be completely dismissed as a possible cause. They argue that a lack of iron in the human body has the potential to result in the hypertrophy of the bone marrow, making it a plausible cause of porotic hyperostosis and cribra orbitalia (Oxenham and Cavill 2010). Additionally, vitamin D and C deficiencies can be responsible for a porotic appearance of the orbits, although this is the result of a different disease process (Brickley and Ives 2008).

Another possible cause of anaemia, in addition to vitamin deficiencies, has to be considered. An infection with a parasite of the *Plasmodium* genus, better known as malaria, can cause a type of anaemia responsible for the skeletal lesions associated with porotic hyperostosis and cribra orbitalia (Gowland and Western 2012). Malaria is transmitted through mosquitos of the *Anopheles* species and currently presents a major health problem in parts of Africa, South-America, and Southeast Asia (Aufderheide and Rodríguez-Martín 1998). Currently, the climate in Northern Europe does not sustain malaria transmitting mosquitos, however, this was different in the past. Historical sources indicate that malaria was endemic in Europe up to the mid-twentieth century especially in marshy areas (Aufderheide and Rodríguez-Martín 1998; Bruce-Chwatt & de Zulueta 1980, Gowland and Western 2012; Schats 2015b; Seventer 1969). Gowland and Western (2012) demonstrate a clear correlation between cribra orbitalia and marshy areas in the United Kingdom. A similar correlation is found by the author for The Netherlands (Schats 2015b). Considering the geographical locations of the sites under study, malaria has to be taken in to account as a plausible cause of the porotic lesions on the cranial vault and in the orbits.

Many researchers have used cribra orbitalia and porotic hyperostosis to study disease patterns in ancient populations. Liebe-Harkort (2012) used cribra orbitalia in combination with other skeletal stress markers to assess nutritional and environmental stress in Iron Age Sweden. Lewis (1999, 2002) studied differences in cribra orbitalia prevalence between rural, urban, and industrial populations to analyse the effects of these socioeconomic developments on past health. Betsinger (2007) used both porotic hyperostosis and cribra orbitalia to study the consequences of urbanisation in medieval Poland.

These studies demonstrate the potential of cribra orbitalia and porotic hyperostosis for studying past stress. In this research, the prevalence of the two lesion types will be assessed in the skeletal populations under study. This, in combination with the other studied non-specific stress markers, may shed light on the impact of socioeconomic developments on stress levels in medieval society.

4

Methods

4.1 INTRODUCTION

This research aims to assess the impact of the socioeconomic developments in Holland and Zeeland in the central and late medieval period by studying human skeletal remains. Therefore, as discussed in chapter three, skeletal indicators of disease, activity, diet and stress are studied. This chapter outlines the methods employed in this research in order to record, document, and analyse these indicators. As this research also focuses on differences between men and women, sex estimation of the skeletal remains is considered to be vital for understanding and interpreting the results. Additionally, differences between non-adults and adults, and also between adult age groups are deemed important in this research. Therefore, this chapter discusses the methods used to estimate sex and age-at-death prior to discussing the methods for documenting and analysing the chosen skeletal indicators.

4.2 COMPLETENESS AND PRESERVATION

The extent to which data can be inferred from skeletal material strongly depends on the completeness and preservation. Skeletal remains are exposed to many taphonomic processes such as disturbance of the grave by construction works, tree roots, other post-burial disturbances, and to several chemical processes which influence preservation and completeness (Nawrocki 1995). Therefore, the completeness and preservation of skeletal material is assessed to make inferences about its quality and data obtained from it. Variable preservation can influence the comparability of skeletal collections. The preservation of the material is assessed macroscopically and takes into consideration the degree of cortical bone degradation, abrasion of bone edges and post-mortem fractures. The skeletal remains are placed in one of three different preservation categories: good, fair, and poor. The completeness of a skeleton is based on the presence of skeletal elements and is expressed in stages of presence: 0-25%, 25-50%, 50-75% and 75-100%.

4.3 ESTIMATION OF SEX

4.3.1 Introduction

The terms 'sex' and 'gender' have been used as synonyms in the anthropological and medical literature. They are, however, not equivalent and should not be used interchangeably. Sex refers to the biological differences between males and females determined at the moment of conception (Armelagos 1998). Gender is an aspect of a person's social identity, a matter of culture: the social significance attributed to sexual differences (Mays and Cox 2000; Oakley 1985). The sex of skeletal remains is estimated using specific methods and standards. On their own, these results reveal nothing about the gender roles and values which were assigned to men and women in the past. However, biological sex is often considered "*an important hook upon which to hang interpretations by making associations between sexed individuals and gendered artefacts*" (Sofaer 2006:155). This research firstly focusses on biological sex, but aims to make inferences about gender by analysing skeletal indicators of activity, disease, and diet in relation to the biological sex of the individuals.

The anatomical differences between males and females are extreme in some soft tissue areas, especially in the genital region. Differentiation on the basis of skeletal remains is more difficult, but usually clear differences between male and female skeletons exist and can be used to estimate the sex of an individual. Osteologists have focused on specific skeletal elements, mainly the skull and the pelvis, in which the sex differences in humans are the greatest (White *et al.* 2012). Generally speaking, female skeletal elements will be smaller and more gracile, and male elements will be larger and more rugose. However, normal individual variation will lead to small and gracile males and large and robust females, making a 100% accuracy impossible to achieve.

The estimation of sex in non-adult remains (<19 years old) is highly problematic (Scheuer and Black 2004). Most morphological traits used for the estimation of sex are only completely developed when an individual is fully grown. Nevertheless, several methods have been developed to estimate the sex of immature individuals (e.g., Molleson *et al.* 1998; Schutkowski 1993). The reliability of these methods is lower than methods used for adult remains. In addition, Scheuer (2002) and Cardoso and Saunders (2008) show that intra- and inter-observer agreement for the scoring of these traits is poor. Due to the problematic nature of the sex estimation of non-adult remains, it will not be attempted in this research.

Below, the morphological methods for estimating sex from the cranium, mandible, and pelvis are discussed. Several standards are used in this research to allow for comparison with both national and international research. Firstly, the methods outlined by the 1980 Workshop for European Anthropologists (WEA) are addressed, since these are the standards currently employed in The Netherlands. Afterwards, other methods used in this research for estimating sex are outlined. Lastly, bone measurements used for the estimation of sex are discussed.

4.3.2 Estimating sex from the cranium

Estimation of sex based on the cranium focuses on specific morphological features which differ in size and shape between males and females. Male crania are more robust: ridges and eminence on the skull are generally more prominent. The standards described by the WEA (1980) have been used for the analysis of many skeletal collections in The Netherlands and are based on the system of Acsádi and Nemeskéri (1970). The cranial features included in the WEA method are given unequal weights since this method deems some features to be more reliable than others (WEA 1980). The WEA method scores the features according to a scale ranging from −2 (hyperfeminine) to +2 (hypermasculine). When traits occur bilaterally, both left and right are scored. These scores combined with the weights of the features are used to calculate the degree of sexualisation. The scores are multiplied by the weights and then summed. The resulting number is divided by the sum of all the weights. Individuals with a score greater than zero are considered to be male and individuals with a score less than zero are considered to be female. In practice, individuals ranging from −0.25 and 0.25 are considered to be too ambiguous to assign a sex estimate. Individuals in this range will be placed in the indeterminate category. An overview of the cranial features and the corresponding weights can be found in table 4.1.

Table 4.1: Cranial features scored by the WEA method with associated weights (1980:523).

Cranial features	Weight
Glabella	3
Mastoid process	3
Nuchal crest	3
Zygomatic process	3
Supercilary arch	2
Frontal and parietal tuberosities	2
External occipital protuberance	2
Zygomatic bone	2
Frontal inclination	1
Orbit shape	1

In addition, to make this research comparable to non-Dutch skeletal reports, the methods described by Buikstra and Ubelaker (1994) are used. Their standards focus on five cranial features, also used by the WEA: the robusticity of the nuchal crest and the size of the external occipital protuberance, the size of the mastoid process, the sharpness of the supra-orbital margin, and the prominence of the supra-orbital ridge. All features are given equal weights and are scored according to a five-point scale in which (1) is female, (2) is probable female, (3) is indeterminate sex, (4) is probable male, and (5) is male (Buikstra and Ubelaker 1994). See figure 4.1 for an illustration of the four cranial features scored in the Buikstra and Ubelaker standards.

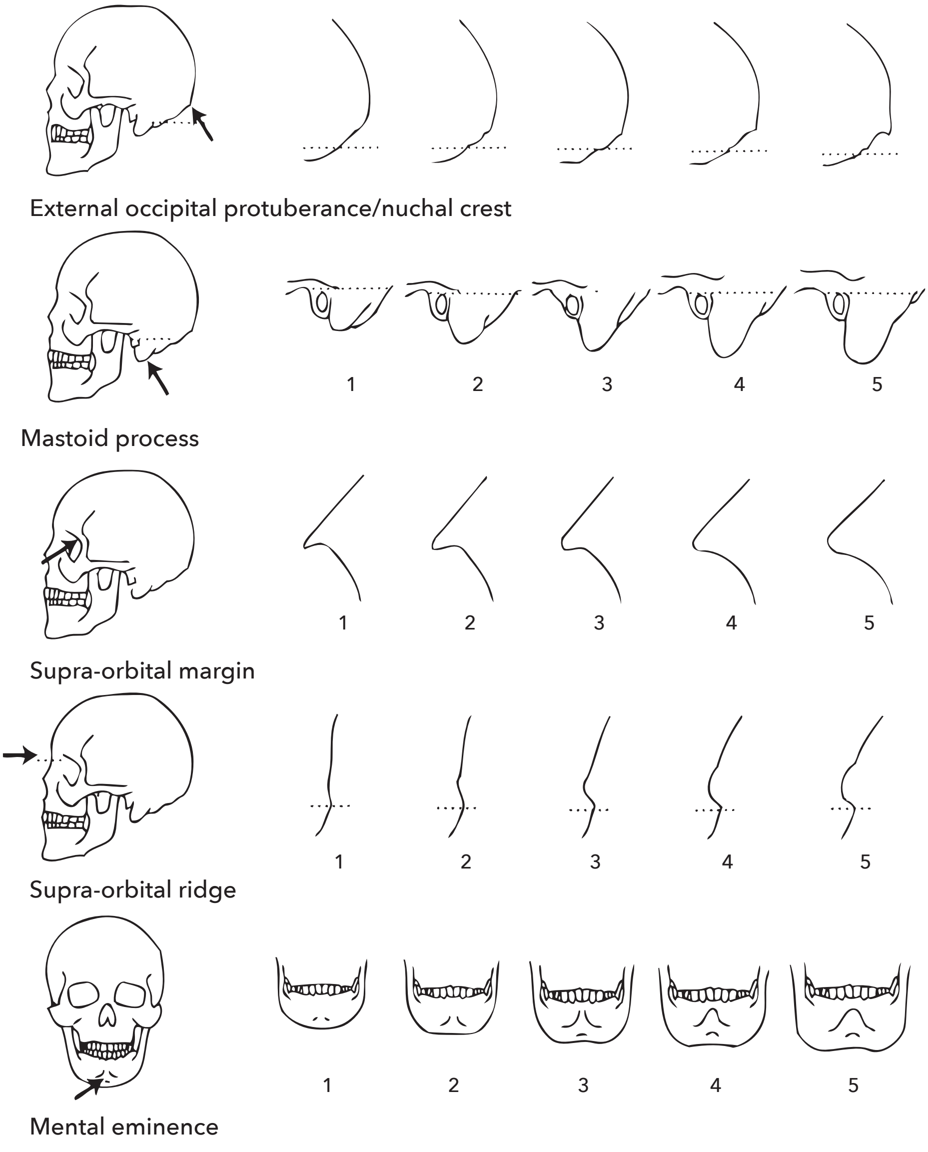


Figure 4.1: Sexually dimorphic cranial features: (1) Female, (2) Probable female, (3) Indeterminate, (4) Probable male, (5) Male (after Buikstra and Ubelaker 1994, figure 4, p. 20).

4.3.3 Estimating sex from the mandible

The WEA (1980) recommends several morphological features of the mandible for the estimation of sex. Table 4.2 displays the features and associated weights. The features are scored on the same scale as is used for the cranium (–2 to +2). Again, these scores are used to calculate the degree of sexualisation. Buikstra and Ubelaker (1994) only score one trait on the mandible: the projection of the mental eminence. Even though the mandible is scored for the estimation of sex in this research, restraint is necessary. Females in the Low Countries appear to have very masculine mandibles. Maat and colleagues (1997) demonstrated that more than half (51.6%) of individuals with female pelves had mandibles that were classified as male. Therefore, the mandibles in this research are used for the estimation of sex with caution. Sex of an individual will not be estimated exclusively based upon a mandible.

Table 4.2: Mandibular features scored by the WEA method with associated weights (1980).

Mandibular features	Weight
Total aspect	3
Mental eminence	2
Mandibular angle	1
Inferior margin	1

4.3.4 Estimating sex from the pelvis

The os coxa is considered to be the most reliable bone for the estimation of sex in the human skeleton (e.g., Buikstra and Ubelaker 1994; White *et al.* 2012) with accuracy rates ranging from 83% to 96% (Mays and Cox 2000). There are very clear functional differences between the pelvic anatomy of males and females which extend to the skeleton. Moreover, these functional differences are found in all modern human groups (Buikstra and Ubelaker 1994; Mays 1998; White *et al.* 2012). In general, the male pelvis is narrower than that of the female. A narrow pelvis is more effective for locomotion. However, this shape will create life-threatening problems during childbirth. Therefore, it is assumed that the evolution of sexual dimorphism of the human pelvis is due to natural selection in relation to the fact that females give birth (Mays 1998).

The WEA developed the same scoring system for the pelvic bones as for the cranium and mandible. The features scored according to this method and their associated weights are displayed in table 4.3. If possible, both the left and the right os coxa are scored. The WEA method scores similar features as other methods, although nomenclature and scales used are somewhat different.

Table 4.3: Pelvic features scored by the WEA method with associated weights (1980).

Pelvic features	Weight
Preauricular sulcus	3
Greater sciatic notch	3
Pubic angle	2
Arc compose	2
Innominate bone	2
Obturator foramen	2
Ischial body	2
Iliac crest	1
Iliac fossa	1
Pelvic inlet	1

Buikstra and Ubelaker (1994) focus on only two specific pelvic features: the greater sciatic notch and the preauricular sulcus, also scored by the WEA (1980). The greater sciatic notch (see figure 4.2) is generally wider in females than in males and can be scored according to the five-point scale shown below. The preauricular sulcus represents a groove just below the auricular surface with various expressions, which is more common in females, most likely resulting from differences in pelvic shape and size (MacLaughlin and Cox 1989).

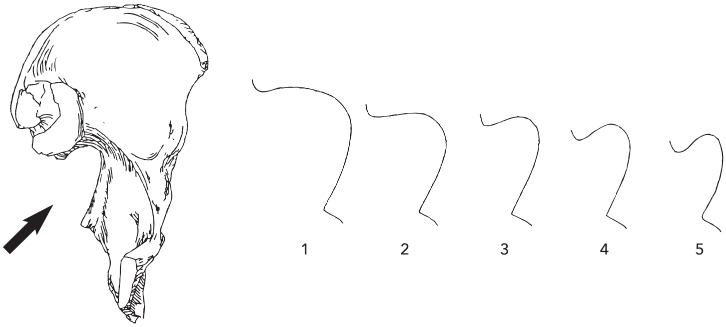


Figure 4.2: Greater sciatic notch scoring: (1) Female, (2) Probable female, (3) Indeterminate, (4) Probable male, (5) Male (after Buikstra and Ubelaker 1994, figure 2, p. 18).

In 1969, Phenice published a method for the estimation of sex based on three distinct features of the pubic bone (figure 4.3). The ventral arc, a bony ridge on the anterior aspect of the pubis, is only present in females. The subpubic concavity refers to the angle the pubic bone makes with the ischio-pubic ramus which is much wider in females. The last trait, the ischio-pubic ramus ridge, refers to the bony extension directly inferior to the pubic symphysis on the medial aspect. This ridge is sharp and well-defined in females while it is virtually absent in males. The Phenice method has a high accuracy ranging from 96% to 100%. Although this is the highest precision rate ever achieved in skeletal material (Phenice 1969), other researchers have found somewhat lower accuracy rates (e.g., MacLaughlin and Bruce 1990; Sutherland and Suchey 1991).

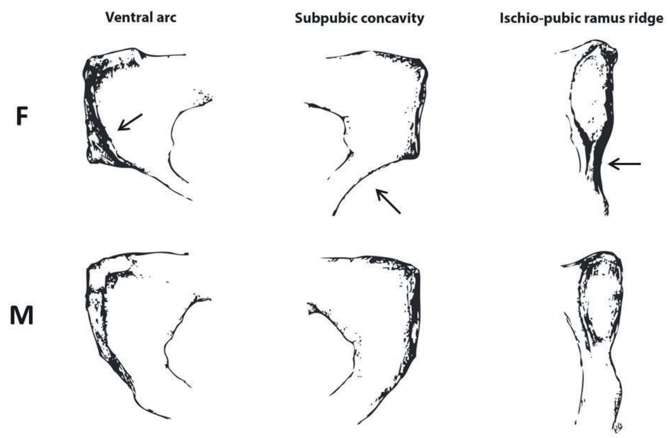


Figure 4.3: Phenice traits: top row, female expression; bottom row, male expression (after Phenice 1969, figure 1, p. 299).

4.3.5 Metric sex estimation

In addition to morphological sex estimation based on the cranium and pelvis, this research will also make use of several osteometric techniques. As discussed above, males are generally larger than females and this difference can be expressed metrically. Several skeletal elements are measured with a sliding calliper and the results will be compared with known female and male ranges. Measurements are rounded up to the nearest millimetre. Since there is a considerable degree of variation in size and degree of sexual dimorphism in different populations, only population specific comparisons can be consulted. This study will only make use of measurements which have shown to be sexually dimorphic in European white individuals and are therefore most applicable to the skeletal samples under study. The measurements, cut-off points (< = female, > = male) and method sources included in this research are listed in table 4.4.

Table 4.4: Description of the measurements used for the estimation of sex.

Measurement	Cut-off points	Sources
Vertical head diameter of the humerus	45 mm	Stewart 1979
Maximum diameter of the head of the femur	45 mm	Stewart 1979
Maximum breadth of the distal humerus	60 mm	Steyn and Iscan 1999
Maximum circumference of the deltoid tuberosity	68 mm	Steyn and Iscan 1999
Maximum length of the clavicle	145 mm	McCormick *et al.* 1991
Circumference of the clavicle	35 mm	McCormick *et al.* 1991
Maximum length of the scapula	46 mm	Bainbridge and Genovés Tarazaga 1956

4.3.6 Final sex estimation

In order to estimate sex with as much accuracy and precision as possible, the various skeletal elements and methods discussed above are combined. Ideally, this would result in a sex estimate for all individuals. However, a number of factors can make this impossible. Due to taphonomic processes some skeletal elements may have been lost, impairing sex estimation. Furthermore, morphological features and measurements can be ambiguous, resulting in an individual who is not convincingly male or female. The final sex of an individual is assigned by combining the morphological sex estimates of cranium, mandible, and pelvis with the metrical sex estimation. If the results are conflicting, the score given to the pelvis is given preference, since this is the most sexually dimorphic area of the skeleton. The individuals are initially placed into five categories: Male, Probable Male, Indeterminate, Probable Female, and Female. However, to be able to use these data for statistical analysis and to create large enough sample sizes, the individuals estimated to be male and those estimated to be probable male are grouped together. The same is done for individuals estimated to be female and probable female. When the results are discussed in chapter five, individuals are placed in one of three categories: Male, Indeterminate, or Female.

4.4 ESTIMATION OF AGE-AT-DEATH

4.4.1 Introduction

The estimation of the age-at-death of an individual aims to correlate developmental age of the skeletal remains to chronological age of the individuals (Gowland and Thompson 2013; White *et al.* 2012). During life, elements of the skeleton undergo several changes as a result of bone development. In infancy, bony changes mainly involve the appearance of specific skeletal elements. During childhood and adolescence, changes mainly relate to the fusing of certain skeletal elements. After skeletal maturation, the changes involve the further ossification in specific bones and joints. This sequential progression forms the basis for estimation of age-at-death of the skeleton. However, as with the estimation of sex, it is important to keep in mind that there is substantial individual variation, especially in adults. Individuals with different degrees of development can actually have the same chronological age as a result of genetic, nutritional, and environmental factors. In addition, there are some population differences in the rates of development, although these are less marked than population differences in sexual dimorphism (White *et al.* 2012). To overcome these imprecisions and to reduce errors due to intra- and inter-population variation, individuals are placed into large age categories based on the average estimated age-at-death produced by combining several ageing methods.

Due to the many developmental changes occurring during growth and maturation, it is possible to place non-adult individuals into slightly more narrow age categories than the adult individuals. There are many different schemes for categorising non-adult individuals. This study uses five age categories for non-adults based on the scheme of Buikstra and Ubelaker (1994), with the addition of the perinate category, since these categories provide the level of detail necessary in this research and allow for comparison with published research. The used age groups are listed below.

- Foetus: <38 weeks in utero
- Perinate: 38–42 weeks in utero
- Infant: 2 post-natal weeks up to 3 years
- Child: 4–12 years
- Adolescent: 13–18 years

Adult individuals, with the exception of young adults, have larger age categories. When the remains of an adult individual are incomplete or too damaged to be assigned to a specific age category, the individual will be placed in the 18+ years category. The age categories applied in this study are based on the age groups by Bekvalac, published in the 'Human Osteology Method Statement' of the Museum of London (2008), and are listed below. These age groups give sufficient detail and accuracy necessary for the present research, and allow for comparison with published studies. Additionally, the advantage of using these specific four age categories is that individuals can be grouped into two groups if necessary (see next section).

- Young adult: 19–25 years
- Young middle adult: 26–35 years
- Old middle adult: 36–45 years
- Old adult: 46+ years

Poor preservation and incompleteness of the skeleton may result in the inability to place the individual into one of the age categories. Therefore, larger adult age categories may be employed to enlarge sample size in order to make it statistically relevant when studying differences between age categories. For this purpose, the young adult and the young middle adult categories, and the old middle adult and old adult categories are combined. This results in two new larger age groups:

- Younger adults: 19–35 years
- Older adults: 36–46+ years

4.4.2 Estimating non-adult age-at-death

The age-at-death of non-adult remains (<19 years) is estimated using a variety of methods focusing on different parts of the skeleton. The inability to estimate sex for non-adult individuals may present a problem for the age-at-death estimation since there are differences in the timing of skeletal maturation between males and females. Generally, females reach puberty at an earlier age and will therefore show certain skeletal changes before male individuals. Therefore, adolescent girls may be estimated to be older than they really are, and for boys this may be the other way around (Scheuer and Black 2004). However, considering that rather broad age categories are used in this study, it is assumed that the possible differences between males and females will not influence the estimation of age-at-death.

For immature remains, dentition represents a very reliable source of information regarding age-at-death. The development of the teeth is more closely related to chronological age than is the maturation of other skeletal parts (Hägg and Mattson 1985; Lewis and Garn 1960). Due to the fact that teeth form and erupt at set moments during non-adult life and because teeth survive very well in the archaeological record, dental development is the most common technique used for the ageing of non-adult skeletal remains (Scheuer and Black 2000). Several methods have been developed and this research will make use of the dental development scheme of Ubelaker (1999) (based on Schour and Massler 1941), which focuses on dental formation and eruption. This scheme is widely applied in osteoarchaeology which enhances the comparability of the present research. In addition, a complementary system focusing on permanent tooth formation, developed by Moorrees *et al.* (1963), is used since it is can be used on isolated teeth as well. This method divides tooth development into 14 stages and scores the formation of every tooth separately, providing an age range.

In addition to dental development and formation, non-adult age-at-death is estimated based on epiphyseal closure and long bone length (Scheuer and Black 2004). Epiphyses of the post-cranial skeleton fuse at a known age. The fusion of an epiphysis is scored as unfused, partially fused (fusion line still visible), or fused (fusion line completely obliterated) (Scheuer and Black 2004). Since different epiphyses fuse at different times, an age range can be estimated for an individual (figure 4.4). Specifically, the degree of fusion of the medial border scapula, iliac crest, heads and tubercles of the ribs, and annular rings vertebrae were used to determine if someone was a non-adult or an adult. Even though there is substantial individual variation, long bone length is also used to estimate non-adult age-at-death. For foetal and perinatal remains, use it made of the ageing standards developed by Fazekas and Kósa (1978). For infants, children and adolescents, this research makes use of the standards developed by Maresh (1955), who based her reports on measurements from radiographs of healthy non-adults of European descent (Maresh 1955; Schillaci *et al.* 2012). Additionally, the maximum length of the clavicle (standards based on the Spitalfields skeletal collection from England) is employed in this research to estimate age-at-death of non-adult individuals (Scheuer and Black 1996).

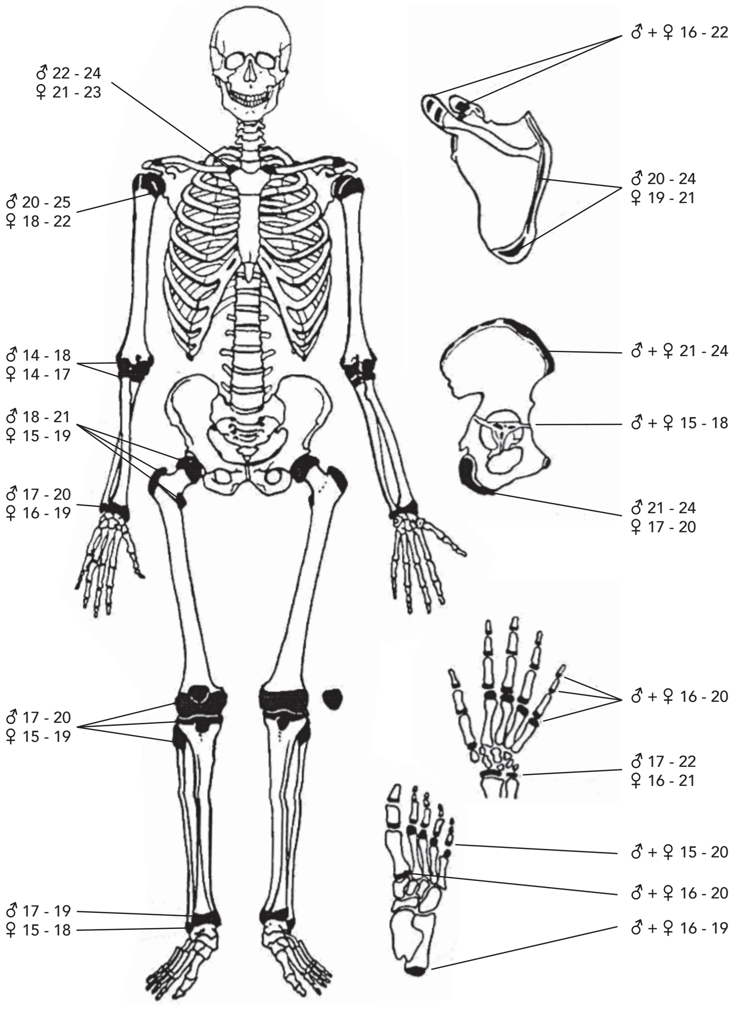


Figure 4.4: Age ranges of epiphyseal fusion (after WEA 1980, figure 6, p. 531).

4.4.3 Estimating adult age-at-death

The estimation of age-at-death of adult individuals is performed using several methods, mainly focusing on maturation and ossification of different parts of the skeleton. One of the most widely employed indicators are the changes occurring in the symphyseal surface of the pubic bone of the os coxae. The metamorphosis of this surface continues into old adulthood. A young adult will have a pubic symphysis which is rugged and shows clear transverse grooves. With age, the surface loses relief and starts to show degenerative changes. Even though there are various methods which assess age from the pubic bone (e.g., Meindl et al 1985, Todd 1921), this research will make use of the six-stage system developed by Suchey and Brooks (Brooks and Suchey 1990) since it has been shown to be accurate (Cox 2000) and is widely used. In addition, the system has separate standards for males and females which is necessary in this research. Figure 4.5 shows the development of the pubic symphysis with age in males.

Figure 4.5: Development of the male pubic symphysis with age. The youngest is on the left and the oldest symphysis is located on the right (after Buikstra and Ubelaker 1994, figure 8, p. 24).

In addition to the pubic bone of the os coxa, the auricular surface of the ilium can be used to estimate age-at-death in adults. Since this part of the pelvis is more likely to preserve than the pubic bone, it is often used in osteoarchaeological and forensic studies (Buckberry and Chamberlain 2002). As with the pubic symphysis, the auricular surface is billowed with clear transverse organisation in young individuals. With age, the granularity of the surface becomes coarser, billowing and transverse organisation are reduced, and defects in the surface become apparent. In 1985, Lovejoy and colleagues divided the age changes into eight phases. For each phase specific characteristics of the auricular surface were described (Buikstra and Ubelaker 1994; Lovejoy *et al.* 1985; White *et al.* 2012). Buckberry and Chamberlain (2002) revised the Lovejoy method to make it more user-friendly. This revised method uses the same surface changes but scores them separately. The scores result in a composite score which can be used to place the individual into a specific age range (Buckberry and Chamberlain 2002). Both methods have been evaluated and found to have strengths and weaknesses (Mulhern and Jones 2005). Therefore, in this research both methods are used in combination in order to gain the highest possible accuracy.

In addition, the suture obliteration of the cranium is employed for the age-at-death estimation. The sutures between the various cranial bones fuse progressively as age increases. In 1985, Meindl and Lovejoy developed a method which scores 1 cm segments at specific points on the cranial sutures as (0) open, (1) minimal closure, (2) significant closure, and (3) closed (Meindl and Lovejoy 1985:58-60). The scores result in a composite score which places the individual within an age range. The work of Key *et al.* (1994) demonstrated that there are considerable sexual and interpopulational differences in the rates of suture closure. Therefore, caution is required when using this method.

Additionally, patterns of dental wear are studied for age-at-death estimation since teeth generally survive well in the archaeological record. From the moment a tooth erupts and comes into occlusion, it starts to wear down. Most populations have shown a strong correlation between wear of the permanent teeth and age (Maat 2001; Walker *et al.* 1991). However, dietary differences, culinary practices, and non-dietary tooth use can significantly influence the rate of dental wear (Walker *et al.* 1991). Therefore, it is important that culturally specific practices are taken into consideration. Hence, the current research will score molar wear according to the method described by Maat (2001). He developed a scheme specifically for medieval Dutch populations (figure 4.6) (Maat 2001). However, since dental wear is dependent on many different factors, it is insufficient to confidently use for the estimation of age-at-death on its own. This method is therefore combined with the other ageing methods described above.

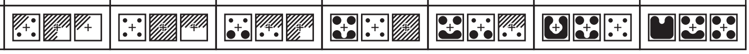
AGE INTERVAL (years)	14 - 17			17 - 25			25 - 35			35 - 45			45 - 55			55 - 65			65 - 70+		
MOLAR	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
NUMERICAL CLASSIFICATION	3^+	$2^-/2$	1^+	$3^+/3$	2	$1^+/2^-$	$3/3^+$	$2^+/3^-$	$2^-/2$	4^-	$3^-/3$	$2/2^+$	4	$3/3^+$	$2^+/3^-$	$4^+/5^-$	4^-	3	$5^-/5$	4	3^+
WEAR PATTERN																					

Figure 4.6: Dental attrition in relation to age (after Maat 2001, figure 3, p. 20).

Lastly, sternal rib end morphology is employed in the present study for estimating age-ate-death. İşcan and colleagues (1984; 1985) developed a method using specific features of the sternal end of the fourth rib. In young individuals, the surface of the sternal end is smooth and shows no wall or rim. As age increases, a bony wall develops and a pit is created (figure 4.7). There are some problems with this method, especially when dealing with bone from archaeological contexts (i.e., identification of the fourth rib when ribs are fragmented or missing). However, when analysing well preserved and complete skeletons, this method can be useful for establishing age-at-death and is therefore used in this research whenever possible.

Figure 4.7: Development of the sternal rib ends (Osteoware, Smithsonian Institute, Washington DC).

4.5 INDICATORS OF DISEASE

4.5.1 Infectious diseases

Table 4.5 shows the specific infections and associated diagnostic features studied in this research as described by Auferderheide and Rodríquez-Martín (1998) and Waldron (2009). A definitive diagnosis is made when lesions pathognomonic lesions for the disease are observed. It is important to note, however, that the presence is not confirmed using ancient DNA. Since both infections mainly affect the thorax, the majority of the ribs and vertebrae have to be available for study to be able to indicate if the disease is present or absent. By only studying the true prevalence, the impact of differential preservation can be limited.

Table 4.5: The studied infectious diseases with associated diagnostic features employed in this research.

Infectious disease	Diagnostic features	
Tuberculosis	*Definitive cases:*	Lytic lesions in the vertebral bodies without new bone formation (sparing of posterior elements)
	Additionally:	Vertebral collapse AND/OR angular kyphosis (Pott's disease) AND/OR extra spinal unifocal lesions without new bone formation
	Possible cases:	Periosteal new bone on the visceral surface of the ribs
Brucellosis	Lytic lesions in the vertebral bodies (mostly lumbar vertebrae) with new bone formation	
	Additionally:	Sacroilitis AND/OR monoarticular arthritis AND/OR lysis of the vertebral margin (Mays 2007)

Definitive=pathognomonic lesions are observed.

4.5.2 Comparative analysis of disease indicators

To be able to answer the research questions related to disease prevalence presented in chapter one, three data comparisons are made. The following paragraph outlines the different comparisons and discusses their importance in relation to the research topics.

1. Analysis of differences in infectious disease prevalence between the skeletal collections:

   As it is the aim of this research to study the influence of socioeconomic developments on medieval populations, infectious disease prevalence is compared between the studied collections in order to analyse if the frequency changed as a result of developments in living environment or population density. Such data may provide insight into shifts through time as well as into differences between rural and urban skeletal assemblages.

2. Analysis of differences in infectious disease prevalence between males and females in the skeletal collections:

   The comparison of male and female disease prevalence is made to study if risks of developing disease among males and/or females changed as a result of socioeconomic developments in the medieval period based upon sex. Shifts through time and between rural and urban living environments can be assessed which may shed light on differences in biological susceptibility or possible differences in disease exposure due to behavioural variations.

3. Analysis of differences in infectious disease prevalence between the age groups in the skeletal collections:

   As with the comparison of sex differences, the comparison between age groups of the different skeletal assemblages is made to study if the risks of developing disease at a certain age changed as a result of medieval socioeconomic developments. Comparisons are made between adults and non-adults as well as between younger and older adults. Such data will allow differences between rural and urban skeletal collections, as well as changes through time, to be observed.

4.6 INDICATORS OF ACTIVITY

4.6.1 Osteoarthritis

Activity can result in different loading of the joints in the skeleton, which may leave a mark on joint surfaces in the form of osteoarthritis in adults (Jurmain 1999). In this research, a joint in a skeleton is considered present when more than 50% of it is observable. For example, the knee joint is deemed present when either patella and distal femur, proximal tibia and distal femur, or patella and proximal tibia are available for analysis. If the joint consists of two bones, such as the acromial-clavicular joint or the sternal-clavicular joint, only one of the two surfaces needs to be observable for the joint to be considered present. The spine is present when at least one of each vertebral type or more than eight vertebrae are present. Individuals with signs of trauma are excluded from the sample.

Osteoarthritis is recorded as present or absent in all synovial joints using the operational definition as described by Waldron (2009). Osteoarthritis is considered present when eburnation is present, or at least two of the following bony changes: marginal osteophytes, new bone on the joint surface, pitting on the joint surface, and alteration of the joint contour (Waldron 2009).

Results will be analysed by number of affected individuals (crude prevalence) as well as by number of affected joints (true prevalence) to counter possible effects of differential preservation. Additionally, all joints will be analysed separately as well as in two groups (upper limb: shoulder, elbow, wrist, hand; lower limb: hip, knee, ankle, foot).

4.6.2 Bone morphology

As shown in chapter three, several biomechanical studies have demonstrated that size, shape and thickness of long bone shafts are related to the mechanical loading that is placed on the bone. To study possible differences in mechanical loading the platymeric and platycnemic indices in adults are calculated. These indices express the shape of the femur and tibia numerically.

The platymeric index, the degree of anterior-posterior subtrochantric flatness of the femur, is calculated by dividing the anterior-posterior subtrochantric diameter by the medial-lateral subtrochantric diameter, multiplied by a hundred. The results may range from below 70 to over 100 (table 4.6). The platycnemic index, which expresses the medial-lateral flatness of the tibia, is calculated by dividing the medial-lateral diameter at the nutrient foramen by the anterior-posterior diameter at the nutrient foramen, multiplied by a hundred. These results can range from below 55 to over 70 (table 4.7) (Bass 1987). Bone measurements are taken according to Buikstra and Ubelaker (1994).

Table 4.6: Platymeric index (Bass 1987).

Platymeric index	Shape	Range
Platymeric	Extreme anterior-posterior flattening	<84.9
Eurymeric	Moderate anterior-posterior flattening	85.0–99.9
Stenomeric	No anterior-posterior flattening	>100

Table 4.7: Platycnemic index (Bass 1987).

Platycnemic index	Shape	Range
Hyperplatycnemic	Extreme medial-lateral flattening	<54.9
Platycnemic	Moderate medial-lateral flattening	55.0–62.9
Mesocnemic	Slight medial-lateral flattening	63.0–69.9
Eurycnemic	No medial-lateral flattening	>70.0

4.6.3 Comparative analysis of activity indicators

To be able to answer the research questions related to activity presented in chapter one, three data comparisons are made. The following section outlines the different comparisons and discusses their importance in relation to the research topics.

1. Analysis of intra-site sex differences in the prevalence of osteoarthritis and bone morphology:

   Differences in activity markers between males and females within the collections can help assess if a gendered division in activities was present in the populations. In combination with the historic information presented in chapter one, such data can shed light on the types of activities carried out in the different populations.

2. Analysis of inter-site differences in the prevalence of osteoarthritis and in bone morphology:

   The analysis of differences in activity markers between the sites helps to assess if socioeconomic developments in the medieval period influenced activity. Differences between rural and urban environments as well as shifts through time can be studied.

3. Analysis of inter-site sex differences in the prevalence of osteoarthritis and in bone morphology:

   The analysis of sex differences in the activity markers between the sites contributes to a better understanding of the influence of the medieval developments on activity, specifically focusing on the men and women separately. Such data may shed light on changes in labour division as a result of socioeconomic developments, as well as point to specific changes in activity for men and women.

4.7 INDICATORS OF DIET

4.7.1 Dental caries

A detailed dental inventory is necessary to adequately record dental pathology. The dental inventory consists of a count of all present and absent teeth. This is important to be able to calculate the true prevalence of dental caries. Teeth can be either: present (P), missing (M, both tooth and socket are missing), lost ante-mortem (AML), lost post-mortem (PML), congenitally absent (CA), or unerupted (UE). The present study will make use of the FDI (*Fédération Dentaire Internationale*) two-digit system to record dentitions. This system was devised in 1970 and is widely used in modern dentistry. The FDI system (see figure 4.8) divides the mandible and maxilla into four quadrants (clockwise from upper right to lower right) which are represented by the first number. The second digit indicates the position of the tooth within the quadrant (from the midline backwards). For example, the first permanent maxillary molar on the left will be assigned the number 2.6. Deciduous teeth are assigned a higher quadrant digit (e.g., the first deciduous mandibular molar on the left will be given the digits 7.4).

Dental caries is visible in the dentition as a cavity which can take many shapes and sizes, and can form on all surfaces of a tooth including the roots (Hillson 1996). Dental caries is scored as present or absent per tooth and the locations of the lesions are noted. Both the caries prevalence (i.e., number of individuals with one or more caries lesions) and the caries frequency (i.e., the number of teeth affected by caries) are calculated. Only erupted teeth are included in the data.

Deciduous dentition	Upper right	Upper left
	55 54 53 52 51	61 62 63 64 65
	85 84 83 82 81	71 72 73 74 75
	Lower right	Lower left

Permanent dentition	Upper right	Upper left
	18 17 16 15 14 13 12 11	21 22 23 24 25 26 27 28
	48 47 46 45 44 43 42 41	31 32 33 34 35 36 37 38
	Lower right	Lower left

Figure 4.8: FDI-system for recording deciduous and permanent teeth.

4.7.2 Metabolic diseases

In addition to the infectious diseases, the prevalence of metabolic diseases is studied to assess the presence of nutritional stress. Table 4.7 shows the studied metabolic diseases and associated diagnostic features used in this research as described by Brickley and Ives (2008). As with the specific infections, detailed descriptions of the lesions and a differential diagnosis are provided for the metabolic diseases.

Table 4.8: The studied metabolic diseases with associated diagnostic features employed in this research.

Metabolic disease	Diagnostic features
Scurvy	*Non-adults:* Abnormal porosity of the cortex of the sphenoid, mandible, maxilla, orbits, and scapulae *Additionally:* New bone formation in the orbits and cranial vault, and on the ends of the long bones *Adults:* New bone formation in the orbits and cranial vault, and on the ends of the long bones *Additionally:* Transverse fractures at the osteocartilaginous junction of the ribs
Rickets	Flaring and swelling of the distal metaphyses long bones, fraying bone margins, porosity, and cupping deformities of the growth plate, bending of long bones, enlargement costochondral junction (rachitic rosary) *Additionally:* New bone formation on the cranium, angulation mandibular ramus, kyphosis or scoliosis
Residual rickets	Thickening and bending of the long bones *Additionally:* Kyphosis or scoliosis, lateral narrowing of the pelvis with a ventral projection of the sacrum and bulging at the pubic symphysis, medio-lateral widening of proximal femora
Osteomalacia	Psuedofractures with irregular margins in ribs, sternum, pelvis, scapulae, and long bones *Additionally:* Concave compression of the vertebral bodies, both the superior and inferior surfaces, bending of femora and sternum

4.7.3 Comparative analysis of diet indicators

To be able to answer the research questions related to diet presented in chapter one, three data comparisons are made. The following paragraph outlines the different comparisons and discusses their importance in relation to the research topics.

1. The analysis of differences in the prevalence of caries and metabolic disease between the different skeletal collections:

Differences in caries prevalence and frequency as well as the prevalence of metabolic diseases are assessed in order to study the influence of socioeconomic developments in the medieval period on diet and nutritional value of the consumed food products. The comparison may reveal differences between the rural and urban environments as well as shifts through time.

2. The analysis of sex differences in the prevalence of caries and metabolic disease between the different skeletal collections:

Sex differences in caries and metabolic disease prevalence between the sites are studied separately to assess if the medieval developments resulted in differential biological susceptibility. Additionally, gender-specific dietary practices can be brought to light when the sexes are studied separately.

3. The analysis of age differences in the prevalence of caries and metabolic disease between the different skeletal collections:

Age differences in caries and metabolic disease prevalence between the sites are also studied separately in order to assess which age groups were most at risk for developing disease. Comparisons are made between adults and non-adults as well as between younger and older adults. For caries specifically, differences in prevalence between the age groups can point to dietary differences. For example, a high percentage of young individuals with caries suggests an early onset of the lesions, hence a cariogenic diet.

4.8 INDICATORS OF NON-SPECIFIC STRESS

4.8.1 Stature

As discussed in chapter three, adult body height can be an indication of non-specific stress. Several methods for the calculation of living stature have been used. This research makes use of a mathematical method to estimate stature. The advantage of this method is that only one complete bone is needed to calculate stature making it ideal for reconstructing stature using incomplete skeletal remains. Comparing stature between the populations increases sample size, since multiple bone can be used to calculate this. In this study, the Trotter and Gleser (1958) and Trotter (1970) regression formulae will be employed. These formulas use maximum long bone lengths measured on an osteometric board to estimate stature. The research is based on males who died during the Korean War and World War II; female regression formulae were derived from the Terry Collection which is composed of skeletons donated to science. Several formulae for different ethnic backgrounds were devised. The European-American 'white' formulae are used to estimate stature in this research since it is expected that these are the most applicable to medieval Dutch populations. If possible, the femur is used to calculate stature, since the formula for this bone has the lowest standard deviation, thus providing the best approximation of stature. In the Trotter and Gleser (1958) article, the regression formula for the tibia was also included. However, in 1995, Jantz and colleagues showed that this formula was based on mismeasured tibiae. Because of this problem with the tibia, the bone is excluded from this research.

4.8.2 Dental enamel hypoplasia

As discussed in chapter three, enamel hypoplasia is an indicator of stress during the period when the enamel is forming. The hypoplastic defects will be scored as present or absent by macroscopic assessment only. The appearance of the defect (i.e., pits or lines) and location will be described and indicated on a diagram. No measurements of the defects are taken since documenting the presence or absence of the dental defect is sufficient to answer the research questions.

As outlined in chapter three, the anterior teeth, the incisors and canines, are more prone to develop enamel defects. Therefore, at least three of these teeth need to be present to be able to determine if the lesion is absent; individuals with fewer anterior teeth are excluded from analysis. The lesion is considered present when defects are visible on at least two non-adjacent teeth in order to rule out local trauma to the teeth during formation. Only permanent teeth are assessed for enamel hypoplasia. Old adults (46+ years) are excluded from analysis since advanced dental wear may have obscured the dental defects. Enamel hypoplasia is calculated per individual. Available number of teeth for inspection is compared between the collections in chapter five, as well to rule out differences as a result of differential preservation.

4.8.3 Cribra orbitalia and porotic hyperostosis

Cribra orbitalia and porotic hyperostosis are considered to be caused by expansion of the diploë as a result of anaemia which can be related to several types of stress, such as nutritional problems, malabsorption, parasite infections, and other health issues. The presence or absence of cribra orbitalia is scored when at least one orbit is present; porotic hyperostosis is scored when at least half of the cranial vault is present. In this study, the presence or absence of the lesions is macroscopically assessed, and if the lesion was active or healed is recorded. The assessment of whether a lesion was active or healing/healed is based on the descriptions of Mensforth *et al.* (1978). They note that a lesion is active when the margins of the pits are sharp and clearly defined, and healed or healing when the margins are smooth and with some bone filling of the peripheral foramina (Mensforth *et al.* 1978).

This study will not make use of the commonly used grading scheme by Stuart-Macadam (1991). Since this study does not focus on the severity of the condition, recording only the presence or absence of the lesions and if they are active or healed provides sufficient data to be able to answer the proposed research questions.

4.8.4 Comparative analysis of stress indicators

To be able to answer the research questions related to general stress presented in chapter one, three data comparisons are made. The following section outlines the different comparisons and discusses the importance in relation to the research topics.

1. The analysis of differences in prevalence of enamel hypoplasia, cribra orbitalia, and porotic hyperostosis between the different skeletal collections:

   Differences in prevalence of enamel hypoplasia, cribra orbitalia and porotic hyperostosis between the skeletal assemblages are assessed in order to study the influence of the socioeconomic developments on general stress in the medieval period. The comparison may reveal differences between the rural and urban environments as well as shifts through time.

2. The analysis of sex differences in stature and prevalence of enamel hypoplasia, cribra orbitalia and porotic hyperostosis between the different skeletal collections:

   Males and females are compared in order to assess differences in prevalence by sex of enamel hypoplasia, cribra orbitalia, and porotic hyperostosis between the sites. This may reveal differences in biological susceptibility as a result of the medieval socioeconomic developments.

3. The analysis of age differences in prevalence of enamel hypoplasia, cribra orbitalia and porotic hyperostosis between the different skeletal collections:

   Age differences in stature and prevalence of enamel hypoplasia, cribra orbitalia and porotic hyperostosis between the sites are also studied separately. Comparisons are made between adults and non-adults as well as between younger and older adults. For stature specifically, correlation of body height with age-at-death may reveal information on the influence of stress on adult longevity.

4.9 DOCUMENTATION METHODS

4.9.1 Skeletal recording forms

For the documentation of the skeletal remains, standard skeletal recording forms designed by the author are used. Different forms are employed for infants, children, adolescents, and adults since the recording methods differ per age category. In general, the recording forms consist of a diagram of a skeleton on which the absent bones can be indicated, a depiction of the dentition for the dental inventory, and several sheets for recording measurements, the estimation of sex, and the estimation of age-at-death. On the final pages, pathological lesions and commingled remains can be recorded. In appendices 2-5, the skeletal recording forms can be found.

4.9.2 Photography

To supplement the data on the skeletal recording forms, all human skeletal remains are photographed. All individuals are laid out in anatomical order and photographed from above. In addition, pathological lesions and/or other notable features are photographed in detail. All photographs are taken with a Leica D-Lux 4 camera.

4.9.3 Database

A database was designed using Microsoft Access to be able to quickly access, organise, and analyse the data recorded on the skeletal forms. The database consists of one main table with four sub-tables. The main table is used to record the basic information about the individual, such as completeness, preservation, stature, age-at-death, and sex. The four sub-tables are used to record more specific data from each individual, including a detailed skeletal inventory, dental status and dental pathology, non-metric traits, and pathology. Data from multiple tables can be combined in one query table allowing for direct statistical analyses. For easy entry of the data, a form instead of a table is used.

4.10 STATISTICAL ANALYSIS

4.10.1 Data types

The variables used in this research are both qualitative and quantitative. Qualitative variables can be dived into two subtypes: nominal variables and ordinal variables. Variables measured on a nominal scale have no numerical value or inherent ordering while ordinal variables have an inherent ranking or ordering. A good example of a nominal variable is the sex of an individual; the only possible values are male, female or indeterminate. Examples of variables measured on an ordinal scale are the preservation of the remains and the age group of an individual. In this research, the preservation is scored as good, fair or poor. Fair is in between poor and good, so there is a clear ranking, although there is no fixed distance between the categories. The age groups used in this study are also clearly ranked: a young adult is substantially younger than an old adult, but again the distance between the categories, in this case the amount of years, is not fixed (Fletcher and Lock 2005; McDonald 2009; Sokal and Rohlf 2012). Qualitative variables are usually analysed statistically using non-parametric tests.

Quantitative variables can be counted or measured and can be divided into interval variables and ratio variables. Interval variables are similar to ordinal variables with the exception that the distance between the values is equal. An example is scoring pain on a scale from 1 to 10. In this study, no variables measured on the interval scale are used. Ratio variables are the true measurements with a meaningful zero point. Examples of variables that are measured on a ratio scale are indices and stature (Fletcher and Lock 2005; McDonald 2009; Sokal and Rohlf 2012). Except in the case of small sample size, quantitative variables are usually analysed using parametric statistical tests, explained in more detail below.

4.10.2 Probability value

The main goal of statistical analysis is to determine if the recorded values are significantly different from expected values under the null hypothesis. The null hypothesis states that the observations are the same as the theoretical expectation (McDonald 2009). To assess this, the probability value or p-value, which expresses the chance that the observed difference happened randomly, is calculated. When the p-value is very small, it is highly unlikely that the difference observed happened by chance; in this case the null hypothesis can be rejected. A high p-value indicates that the results could have happened randomly and are therefore not statistically significant (Fletcher and Lock 2005; McDonald 2009).

The convention in archaeological and osteological research is to use a significance level of 5% ($p<0.05$). Therefore, to ensure comparability, this will be the case in this study. If the p-value is less than or equal to 0.05, the difference can be considered statistically significant. This indicates that there is a less than five per cent chance that the observed difference happened randomly. When the p-value is larger than 0.05, the difference is not statistically significant. It is, however, worth noting that the significance level of 5% is an arbitrary threshold, and it does not have any specific inherent meaning. It is better to view the p-value as a way of measuring the strength of the evidence against the null hypothesis (Fletcher and Lock 2005; Sterne and Smith 2001). It is important to note that sample size can influence the p-value. When the sample size is small, it is more difficult to get a rejection of the null hypothesis, while a large sample size makes it easier to find significant results (Royall 1986).

4.10.3 Parametric statistical tests

Parametric statistical tests are used when the variables are measured on a ratio or interval scale and are normally distributed. Parametrical tests are generally more powerful than non-parametric tests, because the mathematical properties of normal distribution are used to assess sets of data. Therefore, it is important that the data tested with parametric tests are normally distributed. If not, it is better to use non-parametric tests and avoid inaccurate results. To check for normality, a Shapiro-Wilk test can be performed. In addition, in the case of a small sample size, it is better to use non-parametric tests, even if the data are normally distributed (Fletcher and Lock 2005; Shapiro and Wilk 1965; Sterne and Smith 2001).

4.10.4 Non-parametric tests

Non-parametric tests are used when sample size is small and when the data are nominal or ordinal and/or are not normally distributed. They are considered to be less powerful since the shape and parameters of the data distribution are not taken into account (Sokal and Rohlf 2012). However, this does mean that non-parametric tests are less likely to falsely identify a significant difference. Especially in bioarchaeology, where sample sizes are often small, non-parametric tests can be particularly valuable. In general, every parametric test has and non-parametric counterpart. Table 4.9 shows the types of analysis used in this research and lists the appropriate parametric tests with the equivalent non-parametric tests (Fletcher and Lock 2005; McDonald 2009; Sokal and Rohlf 2012). All statistical tests in this research are run with the IBM SPSS Statistics 21 Software.

Table 4.9: Type of analysis, sample size, and the appropriate parametric and non-parametric tests (McDonald 2009; Sokal and Rohlf 2012).

Type of analysis	Sample size	Parametric tests	Non-parametric tests
Comparison of observed frequencies to expected frequencies (one nominal variable)	<5	-	Fisher's exact test
Comparison of observed frequencies to expected frequencies (one nominal variable)	>5	-	Chi-square test for goodness-of- fit
Comparison of observed frequencies to expected frequencies (two or more nominal variables)	>5	-	Chi-square test of independence
Comparison of the means between two distinct groups	-	Independent (two sample) t-test	Mann-Whitney U-test
Comparison of the means between three or more distinct groups	-	Analysis of variance (One way ANOVA)	Kruskal-Wallis test
Estimation of the correlation between two variables	-	Pearson's coefficient of correlation	Spearman's coefficient of rank correlation

5

Results

5.1 INTRODUCTION

This chapter presents the results of the skeletal analysis per site and compares the three skeletal collections in order to determine similarities and differences. The chapter starts with the results for completeness and preservation, after which the results of the sex and age-at-death estimations are presented. Subsequently, the results for the skeletal indicators of disease, activity, and diet are discussed. Finally, the results for the non-specific indicators of stress are considered. All raw data these results are based on are deposited in EASY, the online archiving system of Data Archiving and Networked Services (DANS). Please follow http://dx.doi.org/10.17026/dans-zkt-8y3h to view the data.

5.2 COMPLETENESS AND PRESERVATION

The completeness and preservation of the individual skeletons were assessed in order to estimate the extent to which osteological data can be collected from the available material. The remains from the Blokhuizen collection are relatively incomplete: from the majority of individuals (47.1%), only 0–25% of the skeleton is available for study, which limits the amount of information that can be gained from these individuals. The low completeness of the individuals is most likely related to the excavation strategy and bone preservation. The majority of the remains are at a fair level of preservation (62.2%).

The completeness of the remains from Klaaskinderkerke is generally high; 59.3% of the skeletons are 75–100% complete. For all individuals, more than 25% is available for study. In addition, the majority of the individuals (57.4%) were well preserved. Only two individuals (3.7%) were poorly preserved in the Klaaskinderkerke collection.

The human remains from Alkmaar are fairly complete, with 42.9% of the skeletons being 75–100% complete. Only in 15.2% of cases, 0–25% of the skeleton remained. The preservation of the human remains from Alkmaar is fair to good; 50.8% and 30.7%, respectively. Only 18.5% of the individuals are determined to be poorly preserved. Table 5.1 presents an overview of the completeness and preservation of the skeletons from the studied sites.

Table 5.1: Overview of the completeness and preservation of the skeletal remains from the Blokhuizen, Klaaskinderkerke, and Alkmaar collections.

Completeness	Blokhuizen (n=119)		Klaaskinderkerke (n=54)		Alkmaar (n=189)	
	n	%	n	%	n	%
0-25%	56	47.1	0	0.0	29	15.3
25-50%	25	21.0	6	11.1	38	20.1
50-75%	21	17.6	16	29.6	41	21.7
75-100%	17	14.3	32	59.3	81	42.9
Preservation						
Poor	28	23.5	2	3.7	35	18.5
Fair	74	62.2	21	38.9	96	50.8
Good	17	14.3	31	37.4	58	30.7

n=number of individuals.

5.3 DEMOGRAPHICS

5.3.1 Estimation of sex

i) Blokhuizen

In all, there were 84 adult individuals in the Blokhuizen assemblage. The estimation of sex was possible in 68 cases: 35 were estimated to be male and 33 to be female. For 16 individuals sex could not be estimated due to the fragmentary nature and poor preservation of the remains. There is no significant difference between the observed male-female ratio and the expected ratio (1:1) (χ^2=0.059, df=1, p=0.808, n=84).

ii) Klaaskinderkerke

Of the 50 adult individuals, 33 were estimated to be male and 17 to be female. This is suggestive of a difference between the observed and expected male-female ratio which is confirmed by a chi-square goodness-of-fit test (χ^2=5.120, df=1, p=0.024, n=50). This suggests an imbalance in the number of male versus female burials. However, since a true prevalence is calculated for all analyses, this imbalance should not impact the results.

iii) Alkmaar

Of the 165 adults, sex could be estimated in the case of 149 individuals. The other 16 individuals were too incomplete or too ambiguous for sex estimation. In all, there were 83 females and 66 males in the Alkmaar assemblage. A chi-square goodness-of-fit test was run to determine if the observed male-female ratio is significantly different from the expected ratio (1:1). Even though there are more females than males, the difference is not statistically significantly (χ^2=1.940, df=1, p=0.164, n=149).

iv) Site comparisons

Figure 5.1 shows the sex distribution of the different sites combined. The comparison of the male-female ratio between different sites is performed in order to investigate possible differences that might be related to social and cultural change. The results of the ratio comparisons are shown in table 5.2. No statistical difference between the sex ratios is found when Alkmaar is compared with Blokhuizen, or Blokhuizen with Klaaskinderkerke. However, when the male-female ratio of Klaaskinderkerke is compared with that of Alkmaar, a significant difference appears.

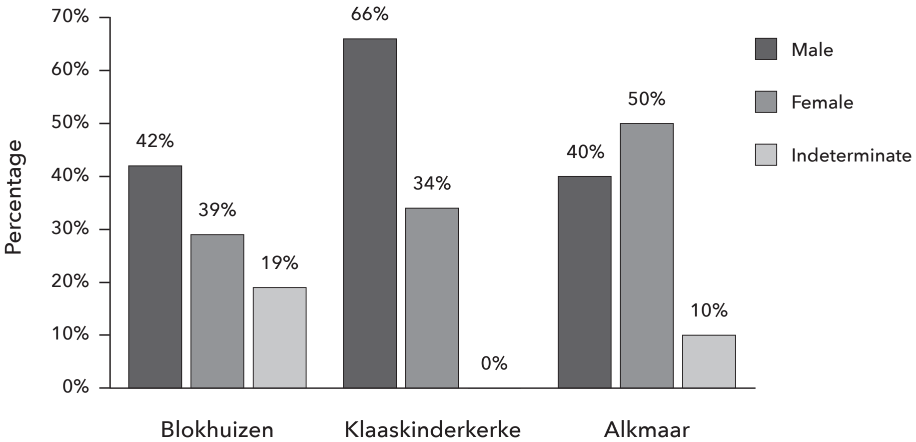


Figure 5.1: Sex distribution (%) in the collections of Alkmaar (n=165), Blokhuizen (n=84), and Klaaskinderkerke (n=50). Only adult individuals are included in this graph.

Table 5.2: Statistical comparison of the male-female ratios across the sites.

Site comparison	Sex ratios			
	χ^2	df	p	n
Alkmaar-Blokhuizen	0.966	1	0.326	271
Blokhuizen-Klaaskinderkerke	2.491	1	0.114	118
Klaaskinderkerke-Alkmaar	7.055	1	**0.008**	199

n=number of individuals included in the test; df=degrees of freedom.

5.3.2 Estimation of age-at-death

i) Blokhuizen

As noted in section 5.2, the preservation and degree of completeness of the Blokhuizen collection was not good. This limited estimation of age-at-death for many individuals. Of the 119 non-adult and adult individuals, only 65 could be placed in one of the age categories. The remaining 54 were estimated to be over 18 years at time of death, based on robusticity, size, and epiphyseal closure. Of these 54 individuals, 28 could be placed into larger age groups: 12 individuals were most likely under the age of 35 at time of death and 16 individuals are estimated to be older than 35 years at time of death. These larger age groups are used later in this study where age-at-death is a variable in the comparison.

In all, there were 84 adults and 35 non-adults in the Blokhuizen collection. Figure 5.2 shows the age-at-death distribution, including only those individuals who could be placed into one of the discrete age groups. The graph illustrates that most of the non-adults died between four and 12 years of age. Most of the adults appear to have died between the ages of 36 and 45 years. Figure 5.3 shows sex and age-at-death of the adult individuals. This graph shows that most of the females died between 36 and 45 years of age. The males are evenly spread over two age categories; 67% of the male individuals died between the ages of 26 and 45 years. There are no significant differences between males and females in relation to age-at-death (χ^2=2.226, df=3, p=0.527, n=29).

When the males and females are placed into the larger age groups of younger versus older than 35, the number in the different groups is similar. In all, there are 11 pre-35 males (37.9%) and 11 pre-35 females (47.8%), and 18 post-35 males (62.1%) and 12 post-35 females (52.2%), a difference which is not statistically significant (χ^2=0.515, df=1, p=0.473, n=52).

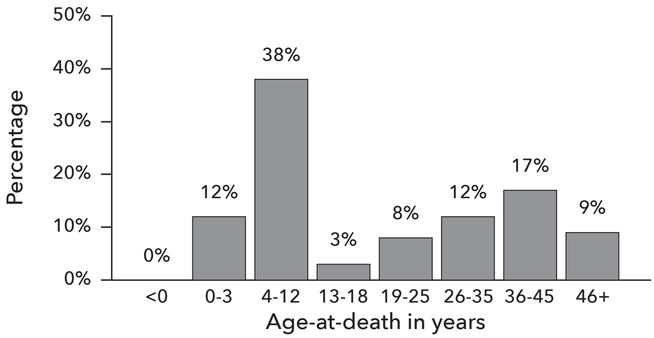


Figure 5.2: Age-at-death distribution of the individuals in the Blokhuizen collection (n=65).

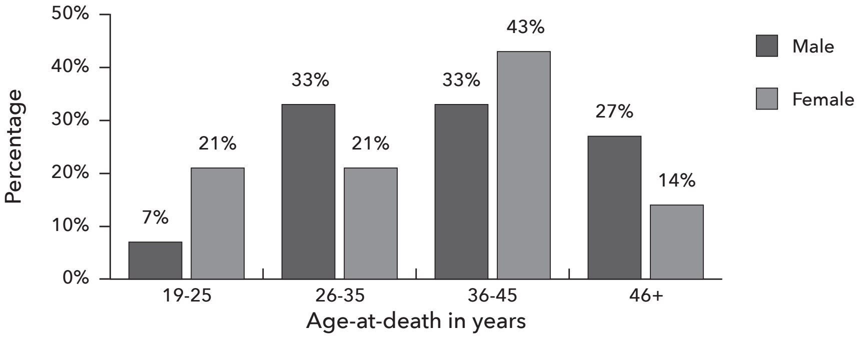


Figure 5.3: Combined age-at-death and sex distribution of the Blokhuizen collection. The graph only includes the adult individuals for whom both sex and age-at-death could be estimated (n=29: F=14, M=15).

ii) Klaaskinderkerke

In the Klaaskinderkerke collection, age-at-death could be estimated for 51 of 54 individuals. The remaining three individuals were estimated to be older than 18 years at time of death. In all, there were 50 adults (92.6%) and four non-adults (7.4%) in this collection. Figure 5.4 shows the age-at-death distribution in Klaaskinderkerke; the figure only includes the individuals who could be confidently placed into one of the age categories. This graph illustrates that most individuals died between 26 to 35 years of age. In addition, the number of non-adults in this collection is low. Figure 5.5 shows a combination of the age-at-death and sex estimates of the individuals. It appears that women generally died younger: the percentage of women in the younger age categories is higher. In the older age categories, the percentage of males is slightly higher. However, even though the percentages suggest varying patterns for males and females, there is no statistically significant difference in sex distribution across the age groups (χ^2=1.871, df=3, p=0.600, n=47). It is, however, important to note that the number of individuals in the different age groups is small and that this could have obscured differences.

To enlarge the sample size, the individuals are placed into two larger age groups, resulting in 15 males (50%) and 11 females (64.7%) in the younger age group (<35 years), and 15 males (50%) and six females (35.3%) in the older age group (>35 years). Clearly, there is no statistically significant difference between the numbers of younger and older males. While the number of females differs between the two age groups, the difference does not reach statistical significance (χ^2=1.471, df=1, p=0.225, n=17).

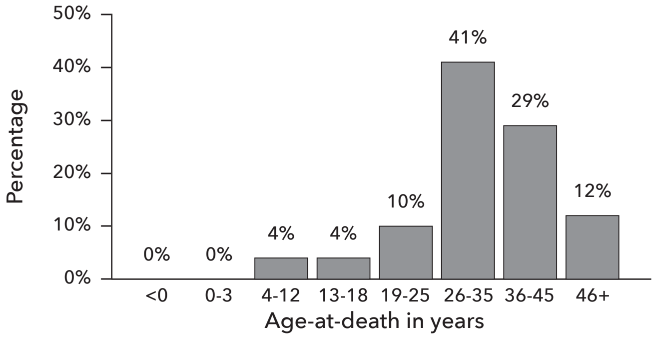


Figure 5.4: Age-at-death distribution of the individuals in the Klaaskinderkerke collection (n=51).

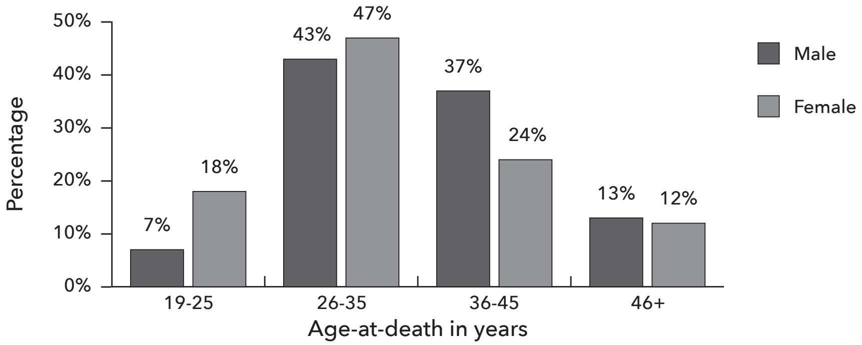


Figure 5.5: Combined age-at-death and sex distribution of the Klaaskinderkerke collection. The graph only includes the adult individuals for whom both sex and age-at-death could be estimated (n=47: F=17, M=30).

iii) Alkmaar

Age-at-death could be estimated in 154 out of 189 individuals. The remaining 35 individuals were estimated to be older than 18 years, based on size, robusticity, and epiphyseal closure, but assignment of a more specific age category was not possible. The Alkmaar collection contains of 24 non-adults (12.7%) and 165 adults (87.3%). Figure 5.6 shows the age distribution of the Alkmaar individuals. This graph demonstrates that most individuals died between 36 and 45 years of age. Figure 5.7 shows the adult individuals in combination with the sex distribution. Females appear to have died at a younger age than the males. This becomes most evident in the oldest age group; 20.3% of the men were estimated to have an age-at-death older than 46 years while only 5.6% of the women reached that age. However, overall there are no significant differences between the males and females in relation to age-at-death when the four age categories (19–25, 26–35, 36–45, and 46+ years) are used (χ^2=6.312, df=3, p=0.097, n=125). When the adults are placed in only two age-at-death categories, those younger versus older than 35 years, there is also no statistically significant difference in the number of males versus females in relation to age-at-death (χ^2=0.722, df=1, p=0.396, n=125).

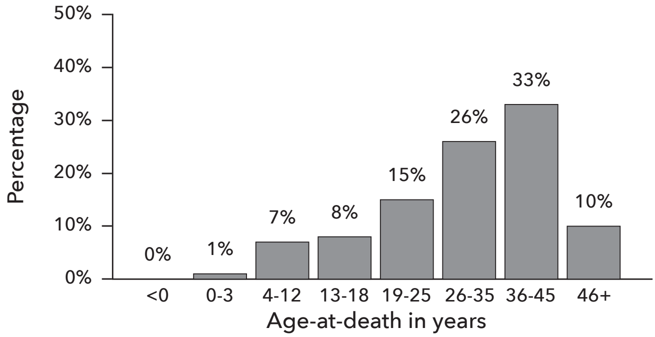


Figure 5.6: Age-at-death distribution of the individuals in the Alkmaar collection (n=154).

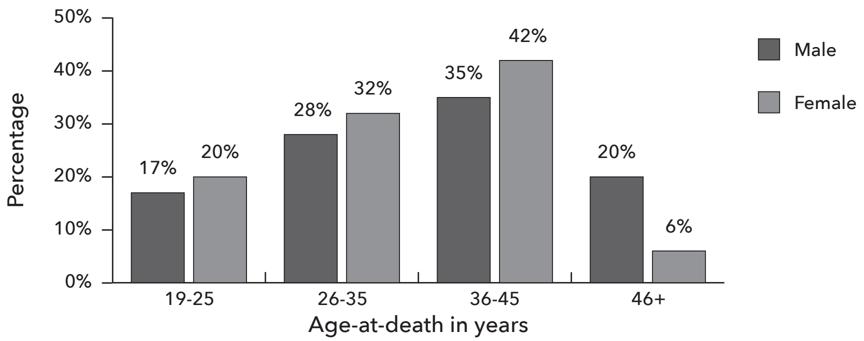


Figure 5.7: Combined age-at-death and sex distribution of the Alkmaar collection. The graph only includes the adult individuals for whom both sex and age-at-death could be estimated (n=125: F=71, M=54).

iv) Site comparisons

Table 5.3 presents an overview of the demographic data for all individuals in the three sites. What stands out is the difference in the number of non-adults among the different sites. In Alkmaar and Klaaskinderkerke, only 12.7% and 7.4%, respectively, consisted of non-adult individuals, while in the Blokhuizen collection 29.4% of the assemblage consisted of individuals under the age of 18 years. Figure 5.8 shows the non-adult age-at-death distribution in the three assemblages. This way, any patterns are less obscured by the adult individuals. Based on models developed for pre-industrial societies, a minimum of 30% of the individuals in a given cemetery should be non-adults. Although there has been some discussion recently about the 30% norm (Lewis 2007), it appears the non-adults were not buried, preserved, or excavated in Alkmaar and especially in Klaaskinderkerke. Therefore, the data are considered to be too unrepresentative of the real situation (only 17.4% non-adults) to be able to draw conclusions based on non-adult mortality patterns. Hence, further comparison and statistical analysis of age-at-death of non-adults in the different sites is not attempted. As a result of this, the conclusions in this research are mainly based on the adults.

Table 5.3: Overview of the demographic data for all individuals in the three sites.

Site	Age-at-death in years	Males		Females		Indet.		Total	
		n	%	n	%	n	%	n	%
Blokhuizen	<0	-	-	-	-	0	-	0	0.0
	0-3	-	-	-	-	8	-	8	6.7
	4-12	-	-	-	-	25	-	25	21.0
	13-18	-	-	-	-	2	-	2	1.7
	19-25	1	20.0	3	60.0	1	20.0	5	4.2
	26-35	5	62.5	3	37.5	0	0.0	8	6.7
	36-45	5	45.5	6	54.5	0	0.0	11	9.2
	46+	4	66.7	2	33.3	0	0.0	6	5.0
	<35	5	41.7	5	41.7	2	16.7	12	10.1
	>35	9	56.3	4	25.0	3	18.8	16	13.4
	Indet.	6	23.1	10	38.5	10	38.5	26	21.8
	Subtotal	35	29.4	33	27.7	51	42.9	119	100.0
Klaaskinderkerke	<0	-	-	-	-	0	-	0	0.0
	0-3	-	-	-	-	0	-	0	0.0
	4-12	-	-	-	-	2	-	2	3.7
	13-18	-	-	-	-	2	-	2	3.7
	19-25	2	40.0	3	60.0	0	0.0	5	9.3
	26-35	13	61.9	8	38.1	0	0.0	21	38.9
	36-45	11	73.3	4	26.7	0	0.0	15	27.8
	46+	4	66.7	2	33.3	0	0.0	6	11.1
	<35	0	0.0	0	0.0	0	0.0	0	0.0
	>35	0	0.0	0	0.0	0	0.0	0	0.0
	Indet.	3	100.0	0	0.0	0	0.0	3	5.6
	Subtotal	33	61.1	17	31.5	4	7.4	54	100.0
Alkmaar	<0	-	-	-	-	0	-	0	0.0
	0-3	-	-	-	-	2	-	2	1.1
	4-12	-	-	-	-	10	-	10	5.3
	13-18	-	-	-	-	12	-	12	6.3
	19-25	9	37.5	14	58.3	1	4.2	24	12.7
	26-35	15	38.5	23	59.0	1	2.6	39	20.6
	36-45	19	37.3	30	58.8	2	3.9	51	27.0
	46+	11	68.8	4	25.0	1	6.3	16	8.5
	<35	0	0.0	0	0.0	0	0.0	0	0.0
	>35	0	0.0	0	0.0	0	0.0	0	0.0
	Indet.	12	34.3	12	34.3	11	31.4	35	18.5
	Subtotal	66	34.9	83	43.9	40	21.2	189	100.0
Totals	Adults	134	44.8	133	44.5	32	10.7	299	82.6
	Non-adults	0	0.0	0	0.0	63	100.0	63	17.4
	Grand total	134	44.8	133	44.5	95	26.2	362	100.0

n=number of individuals.

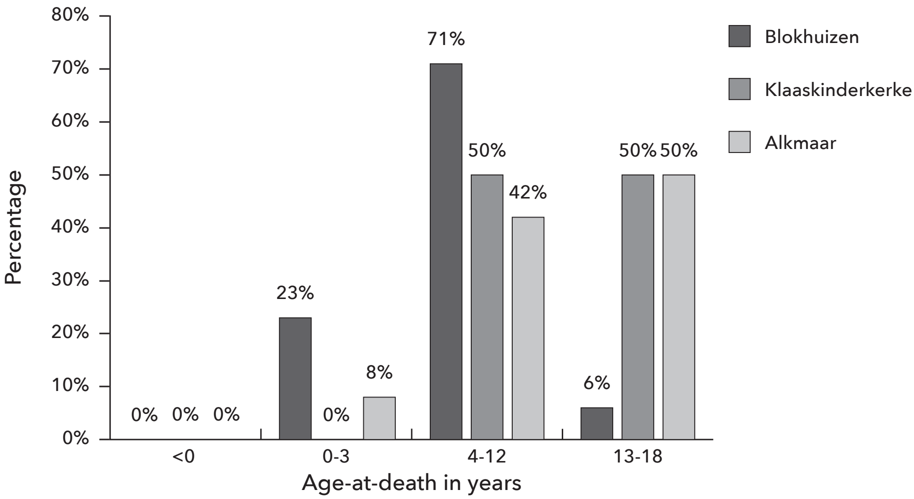


Figure 5.8: Non-adult age distribution in Blokhuizen (n=35), Klaaskinderkerke (n=4), and Alkmaar (n=24).

Figures 5.9 and 5.10 display the adult age-at-death distributions. Males and females are displayed separately to be able to study the differences between the sexes. Figure 5.9 shows that the percentage of males who died between the ages of 19 and 25 years is higher in Alkmaar than in the other sites. The percentages of males from Klaaskinderkerke who died between 26 and 35 years of age and between 35 and 46 years are higher in comparison with Alkmaar and Blokhuizen. Interestingly, the percentage of males from Klaaskinderkerke who were older than 46 years at time of death is lower than in the other sites. These differences, however, are not statistically significant (χ^2=4.470, df=6, p=0.613, n=99).

Figure 5.10 shows the age-at-death distribution of the adult females from the three sites. The percentages suggest that there exists a difference between the females of Klaaskinderkerke and the other females. A higher percentage of Klaaskinderkerke females died in the young middle adult category (26–35 years) than at Alkmaar and Blokhuizen. When studying the old middle adult age category (36–45 years), the distribution is the other way around: the percentage of females from Alkmaar and Blokhuizen in this age category is higher than that of Klaaskinderkerke. However, statistically there is no difference between the numbers of females in the different age categories (χ^2=4.429, df=6, p=0.619, n=102).

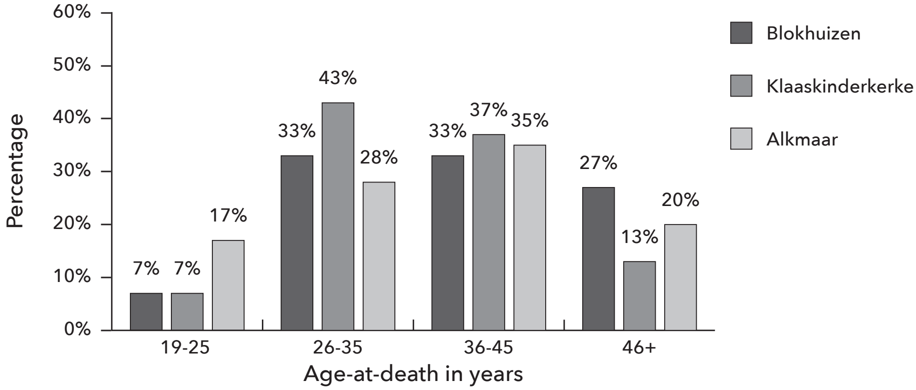


Figure 5.9: Adult male age distribution in Alkmaar (n=54), Blokhuizen (n=15), and Klaaskinderkerke (n=30). Only individuals for whom both sex and age could be estimated are included.

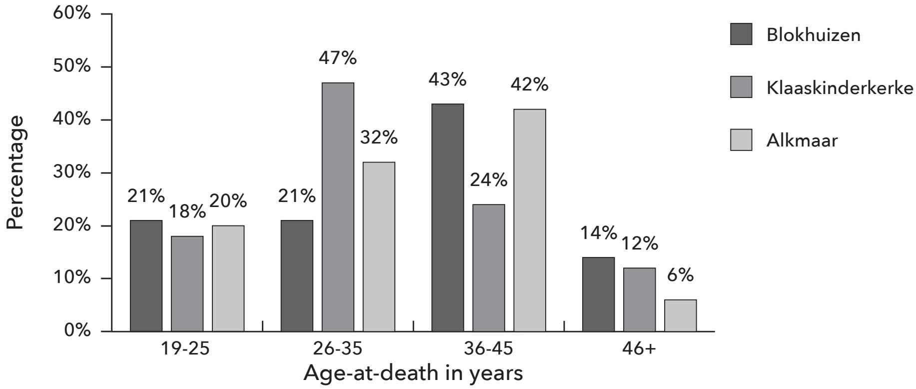


Figure 5.10: Adult female age distribution in Alkmaar (n=71), Blokhuizen (n=14), and Klaaskinderkerke (n=17). Only individuals for whom both sex and age could be estimated are included.

To enlarge the sample size for the purpose of statistical analysis, the larger age groups are considered (i.e., 19–35 and 36–46+ years). Table 5.4 shows the numbers of younger and older adults per site. In addition, it shows the total number of individuals in the different age groups. This indicates that in Alkmaar and Blokhuizen there are more older adults than younger adults. In Klaaskinderkerke more individuals died at a younger age.

Table 5.4: Number and percentages of younger adults (19-35 years) and number and percentages of older adults (36-46+ years) in the different sites.

Sites		Males		Females		Total	
		n	%	n	%	n	%
Blokhuizen	Younger adults	11	37.9	11	47.8	22	43.1
	Older adults	18	62.1	12	52.2	30	56.9
Klaaskinderkerke	Younger adults	15	50.0	11	64.7	27	56.2
	Older adults	15	50.0	6	35.3	21	43.8
Alkmaar	Younger adults	24	44.4	37	52.1	61	48.8
	Older adults	30	55.6	34	47.8	64	51.2

n=number of individuals.

Table 5.5 displays the results of a statistical comparison of the number of males and females in the larger age groups among the three sites. There are no statistically significant differences between the numbers of males and females in the different age groups across the sites. Even though the Blokhuizen collection is poorer preserved, the adult age distribution appears not to have been influenced by this

Table 5.5: Statistical comparison of the number of males and females in the two age groups between the sites.

Site comparison	Males				Females			
	χ2	df	p	n	χ2	df	p	n
Alkmaar-Blokhuizen	0.328	1	0.567	83	0.128	1	0.721	94
Blokhuizen-Klaaskinderkerke	0.871	1	0.351	59	1.125	1	0.289	40
Klaaskinderkerke-Alkmaar	0.239	1	0.625	84	0.877	1	0.349	88

n=number of individuals included in the test, df=degrees of freedom.

5.3.3 Summary demographics

In Alkmaar and Blokhuizen, the sex distribution is nicely balanced and, although Alkmaar has a slightly higher percentage of females, the difference is not statistically significant. In Klaaskinderkerke, however, the male-female ratio is skewed in favour of the males. The percentage of males (66%) is high in comparison with Alkmaar and Blokhuizen. In terms of the age-at-death distribution, Blokhuizen has significantly more non-adults than the other sites, possibly suggesting high childhood mortality (or greater fertility). However, considering the remarkably low number of non-adults found in Alkmaar and Klaaskinderkerke, it seems that the non-adults were not buried or preserved there. Therefore, no conclusions are drawn about childhood mortality at the studied sites. The adult age-at-death distribution does not reveal large differences between the sites. Females appear to have died at a younger age than males: all three sites have a higher percentage of younger females in comparison with males in the same age group. However, there are no statistically significant differences between the number of males and females in the age groups across the sites.

5.4 INDICATORS OF DISEASE

5.4.1 Infectious disease

i) Blokhuizen

In the Blokhuizen collection none of the specific infectious diseases studied in this research have been found. In addition, the characteristic lesions on the visceral surface of the ribs which could indicate a chronic respiratory infection have not been encountered.

ii) Klaaskinderkerke

In the Klaaskinderkerke collection, there are no definitive cases of any of the studied infectious diseases. There is one individual who has diffuse periosteal new bone on the visceral surface of the ribs. Although this could be linked to tuberculosis, the vertebrae of this individual show no lesions that can be associated with this disease. Therefore, this individual is considered to have possible tuberculosis (2.3%). Table 5.6 shows the demographic information of the individual.

Table 5.6: Demographic information of the individual with possible infectious disease in the Klaaskinderkerke collection.

Disease	Skeletal number	Sex	Age
Possible tuberculosis	K937V21	Male	36-45 years

iii) Alkmaar

Tuberculosis is the only specific infection found in the Alkmaar collection. Brucellosis was not encountered. Two individuals with a thorax present (2/147 individuals; 1.4%) displayed the characteristic spinal destructions associated with tuberculosis. One of the individuals (S290V812) showed multiple lytic lesions in both the thoracic and lumbar vertebrae. The fourth thoracic vertebrae is completely destroyed and collapsed. In addition, lytic lesions are present on the acromial end of the right clavicle, on the right scapula, and on the ilium of both ossa coxae. Figure 5.11 shows the vertebral destruction and the lesions on the clavicle. The other individual (S364V1017) with definitive tuberculosis has multiple lytic lesions in both the thoracic and lumbar vertebrae. In addition, this individual has patches of periosteal new bone on the visceral surface of the ribs.

Figure 5.11: Skeletal tuberculosis in Alkmaar individual S290V812. Left: right side of the body of thoracic vertebra eight, affected by multiple lytic lesions. Right: Inferior side of the right clavicle, showing multiple lytic lesions on the acromial end.

In addition to the two definitive cases, there are three individuals displaying characteristic rib lesions associated with tuberculosis. All three individuals show multiple patches of periosteal new bone on the visceral surface of the ribs. Therefore, these individuals are diagnosed with possible tuberculosis, although a different chronic lung infection cannot be ruled out. Figure 5.12 shows three examples of the rib lesions from one of the affected individuals (S418V949).

Figure 5.12: Rib lesions in Alkmaar individual S418V949. Patches of periosteal new bone on the visceral surface of the right ribs (five to seven).

Table 5.7 shows the demographic information of the individuals with both possible and definitive tuberculosis. It can be observed that both adults and non-adults show signs of the infection and that both males and females are affected. In addition, the table shows that the disease occurred in adults of all ages. Statistical analysis of the prevalence patterns has not been attempted considering the small number of affected individuals.

Table 5.7: Demographic information of the individuals with possible and definitive infectious diseases in the Alkmaar collection.

Disease	Skeletal number	Sex	Age
Possible tuberculosis	S197V705	Male?	26-35 years
	S211V760	Indeterminate	4-12 years
	S418V949	Indeterminate	18-25 years
Definitive tuberculosis	S290V812	Male	36-45 years
	S364V1017	Female	19-25 years

iv) Site comparisons

Definitive cases of infectious disease are only found in the Alkmaar collection, and exclusively tuberculosis was identified. The Blokhuizen individuals show no signs of the studied infectious diseases and in Klaaskinderkerke only one individual with rib lesions was found (suggestive of tuberculosis, but other chronic lung infections cannot be ruled out). It has to be taken into consideration that different numbers of individuals are available at the three sites. As is discussed in chapter three, since brucellosis and tuberculosis mainly affect the thorax, the majority of the ribs and vertebrae have to be present. For Alkmaar and Klaaskinderkerke this is the case in the majority of the individuals; 77.8% and 79.6% of the individuals, respectively, were available for study. In Blokhuizen, however, only 27.7% individuals had bones of the thorax which could be studied for the presence of diseases. This may have influenced the results.

5.4.2 Summary infectious disease

Tuberculosis is the only specific infectious disease noted amongst the studied skeletons. In Alkmaar, two definitive and three possible cases were encountered. In Klaaskinderkerke, one possible case was observed and in Blokhuizen no skeletal lesions suggestive of an infectious disease were noted. Poor preservation may influenced the results to some extent

5.5 INDICATORS OF ACTIVITY

5.5.1 *Osteoarthritis*

i) Blokhuizen

Osteoarthritis was found in only ten of the 84 adult individuals (11.9%). Three have osteoarthritis in multiple joints. Of the affected individuals, there are five females (15.2%) and four males (11.4%). For one of the individuals with osteoarthritis, the sex could not be estimated. The difference between the males and females is not statistically significant (χ^2=0.205, df=1, p=0.651, n=68). Figure 5.13 shows the prevalence of osteoarthritis in relation to age-at-death in the Blokhuizen collection. In this graph, the larger age groups, pre- and post-35 years, are used to enlarge sample size and make any differences more apparent. The percentages are in relation to the total numbers of individuals in particular age and sex groups. All individuals with osteoarthritis were older than 35 years at time of death.

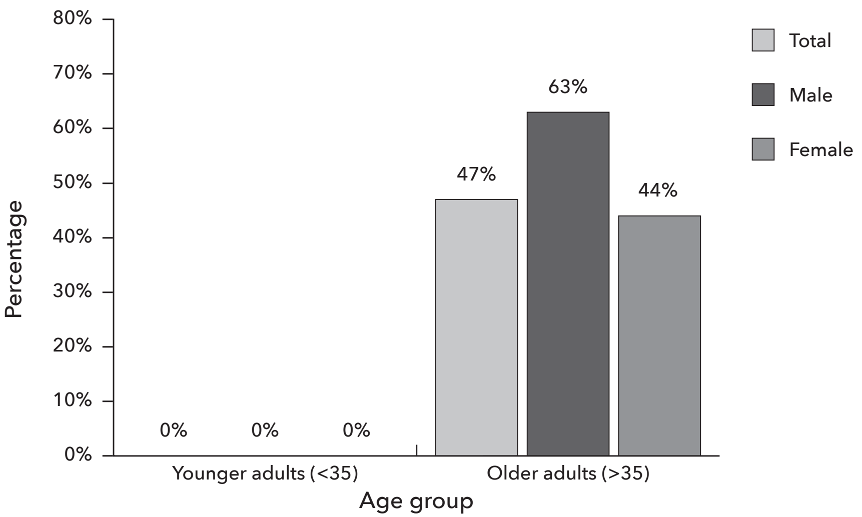


Figure 5.13: The prevalence of osteoarthritis in relation to age-at-death in the Blokhuizen collection.

Table 5.8 shows how many individuals have osteoarthritis in a particular joint in the Blokhuizen collection. For all affected individuals combined, the spine is the most common site for osteoarthritis: 16% of the adults in Blokhuizen show the diagnostic features of osteoarthritis on the vertebral facets. For the males separately, the spine is also the most commonly affected location (16.7%). For the females, the acromio-clavicular joint is most commonly affected by osteoarthritis (16.7%). There are other differences between the men and women from Blokhuizen. However, the number of affected individuals per joint site is very small, making statistical analysis of the differences unreliable.

Table 5.8: Number of individuals affected by osteoarthritis per joint type in the Blokhuizen collection.

Joints	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	0	0.0	1	2.1
ACJ	2	11.1	1	16.7	3	12.5
SCJ	0	0.0	0	0.0	0	0.0
Spine	3	16.7	1	14.3	4	16.0
Shoulder	1	4.5	2	9.1	3	6.7
Elbow	0	0.0	1	6.3	1	2.8
Wrist	0	0.0	0	0.0	0	0.0
Hand	0	0.0	1	10.0	1	4.3
Hip	1	3.8	2	7.1	3	5.4
Knee	0	0.0	2	8.7	2	4.4
Ankle	0	0.0	0	0.0	0	0.0
Foot	1	14.3	0	0.0	1	5.9

n=number of affected individuals, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, SCJ=sterno-clavicular joint.

To counter the influence of preservation, the total number of affected joints in relation to the number of observable joints is also considered here. This gives the true prevalence of osteoarthritis in the collection. In Blokhuizen, a total of 23 joints were affected by osteoarthritis (4.2%). The women appear to have more joints affected by osteoarthritis than men, 5.8% versus 3.2%. However, the difference between the sexes is not statistically significant (χ^2=2.195, df=1, p=0.138, n=526). Table 5.9 displays the number of joints that are affected in relation to the total number of observable joints. Some of the numbers are different from those in table 5.8 above since bilateral involvement and the exact number of present joints is taken into account here. Interestingly, the acromial-clavicular joint is the most commonly affected joint instead of the spine, for both males and females. The frequency of osteoarthritis of the shoulder appears high in the Blokhuizen collection.

Table 5.9: Number of joints affected by osteoarthritis per joint type in the Blokhuizen collection.

Joints	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	0	0.0	1	1.4
ACJ	3	14.3	2	25.0	5	17.2
SCJ	0	0.0	0	0.0	0	0.0
Spine	3	16.7	1	14.3	4	16.0
Shoulder	1	3.0	3	12.0	4	6.8
Elbow	0	0.0	2	8.0	2	3.8
Wrist	0	0.0	0	0.0	0	0.0
Hand	0	0.0	1	7.7	1	3.1
Hip	1	2.3	3	6.3	4	4.2
Knee	0	0.0	2	5.7	2	2.9
Ankle	0	0.0	0	0.0	0	0.0
Foot	1	9.1	0	0.0	1	4.2

n=number of affected joints, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, and SCJ=sterno-clavicular joint. Total includes individuals of indeterminate sex.

To study particular movements and activities, some of the joints are combined into two groups (table 5.10). The upper limb group includes the shoulder, elbow, wrist, and hand. The lower limb group includes the hip, knee, ankle and foot. This shows more pronounced differences between males and females. The sex differences in osteoarthritis frequency for the upper limbs is statistically significant (χ^2=5.168, df=1, p=0.023, n=166). The difference between males and females in osteoarthritis of the lower limbs is not statistically significant (χ^2=0.948, df=1, p=0.330, n=223).

Table 5.10: Number of joints affected by osteoarthritis per joint group in the Blokhuizen collection.

Joint groups	Males		Females		Total	
	n	%	n	%	n	%
Upper limb	1	1.2	6	8.2	7	4.2
Lower limb	2	1.9	5	4.2	7	3.0

n=number of affected joints, total includes individuals of indeterminate sex.

ii) Klaaskinderkerke

Osteoarthritis was identified in 14 of the 50 adult individuals (28.0%), of which 10 males (30.3%) and four females (23.5%) were found to be affected. It appears that men are more commonly affected by osteoarthritis than women, but this difference is not statistically significant (χ^2=0.255, df=1, p=0.613, n=50). Figure 5.14 shows the prevalence of osteoarthritis in relation to age-at-death in the Klaaskinderkerke collection. Again, almost all individuals with osteoarthritis are older than 35 years, which corresponds with the disease process.

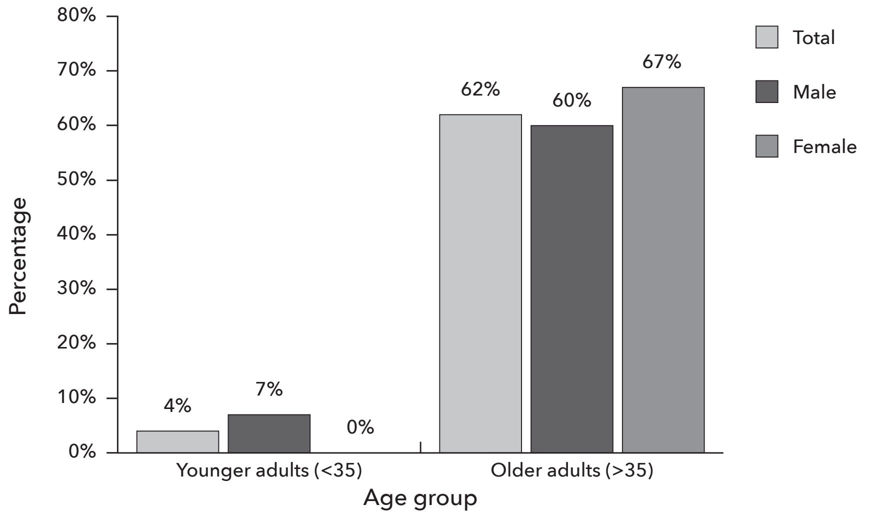


Figure 5.14: The prevalence of osteoarthritis in relation to age-at-death in the Klaaskinderkerke collection.

Table 5.11 displays the number of individuals with osteoarthritis in the Klaaskinderkerke collection per synovial joint. The spine is most commonly affected by osteoarthritis (31.4%), in both males and females. The differences between the males and females are not substantial, except for the fact that osteoarthritis of the hip appears to be more common in males.

Table 5.11: Number of individuals affected by osteoarthritis per joint type in the Klaaskinderkerke collection.

Joints	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	0	0.0	0	0.0
ACJ	2	8.7	1	9.1	3	8.8
SCJ	2	9.5	0	0.0	2	6.3
Spine	7	26.9	4	30.8	11	28.2
Shoulder	1	3.7	0	0.0	1	2.4
Elbow	0	0.0	0	0.0	0	0.0
Wrist	1	5.6	0	0.0	1	3.7
Hand	0	0.0	0	0.0	0	0.0
Hip	5	15.2	1	5.9	6	12.0
Knee	0	0.0	0	0.0	0	0.0
Ankle	0	0.0	0	0.0	0	0.0
Foot	0	0.0	1	100.0	1	8.3

n=number of affected individuals, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, and SCJ=sterno-clavicular joint. Total includes individuals of indeterminate sex.

To calculate a true prevalence of osteoarthritis for the Klaaskinderkerke collection, the number of affected joints was studied in relation to the observable joints. In all, there are 32 joints affected out of the 703 that were available for analysis (4.6%). The difference between males and females is small (4.9% versus 3.7%) and not statistically significant (χ^2=0.469, df=1, p=0.494, n=703). Table 5.12 displays the number and percentage of affected joints. The spine is clearly the most commonly affected joint. However, the hip joint is also often affected in both males and females.

Table 5.12: Number of joints affected by osteoarthritis per joint type in the Klaaskinderkerke collection.

Joints	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	0	0.0	0	0.0
ACJ	2	5.0	1	6.7	3	5.5
SCJ	3	8.6	0	0.0	3	5.7
Spine	7	26.9	4	30.8	11	28.2
Shoulder	1	2.0	0	0.0	1	1.4
Elbow	0	0.0	0	0.0	0	0.0
Wrist	2	5.3	0	0.0	2	3.9
Hand	0	0.0	0	0.0	0	0.0
Hip	9	14.3	2	6.5	11	11.7
Knee	0	0.0	0	0.0	0	0.0
Ankle	0	0.0	0	0.0	0	0.0
Foot	0	0.0	1	100.0	1	5.8

n=number of affected joints, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, SCJ=sterno-clavicular joint. Total includes individuals of indeterminate sex.

To study particular movements and activities, several of the joints have been divided into two groups (table 5.13). Clearly, the lower limbs, i.e., the weight bearing joints, are more commonly affected by osteoarthritis than the upper limbs in the Klaaskinderkerke collection. A comparison of osteoarthritis frequency in the upper and lower limbs, when the sexes are combined, gives a statistically significant result (χ^2=7.065, df=1, p=0.008, n=501). The same comparison for males and females separately does not provide statistically significant results, even though a similar trend is visible (males: χ^2=3.001, df=1, p=0.083, n=353, females: χ^2=2.941, df=1, p=0.086, n=149). Differences between males and females are not marked. Males have a slightly higher frequency of both upper and lower limb osteoarthritis in comparison to the females, but these differences are not statistically significant (upper: χ^2=1.267, df=1, p=0.260, n=248, lower: χ^2=0.145, df=1, p=0.703, n=254).

Table 5.13: Number of joints affected by osteoarthritis per joint group in the Klaaskinderkerke collection.

Joint groups	Males		Females		Total	
	n	%	n	%	n	%
Upper limb	3	1.7	0	0.0	3	1.2
Lower limb	9	5.1	3	3.9	12	4.7

n=number of affected joints, total includes individuals of indeterminate sex.

iii) Alkmaar

Osteoarthritis is present in 54 of the adult individuals (32.7%) of which there are 24 males (36.4%) and 28 females (33.7%). Sex could not be determined for two individuals with osteoarthritis. Slightly more men than women are affected by osteoarthritis, but this difference is not statistically significant (χ^2=0.112, df=1, p=0.738, n=149). Fifteen of the affected individuals had osteoarthritis in multiple joints (27.8%). Figure 5.15 shows the prevalence of osteoarthritis in relation to age-at-death. As expected, more older than younger adults were affected. In the older age group (35+), more than 50% of the adults show signs of osteoarthritis in the Alkmaar collection. There are no major differences between males and the females in the two age categories.

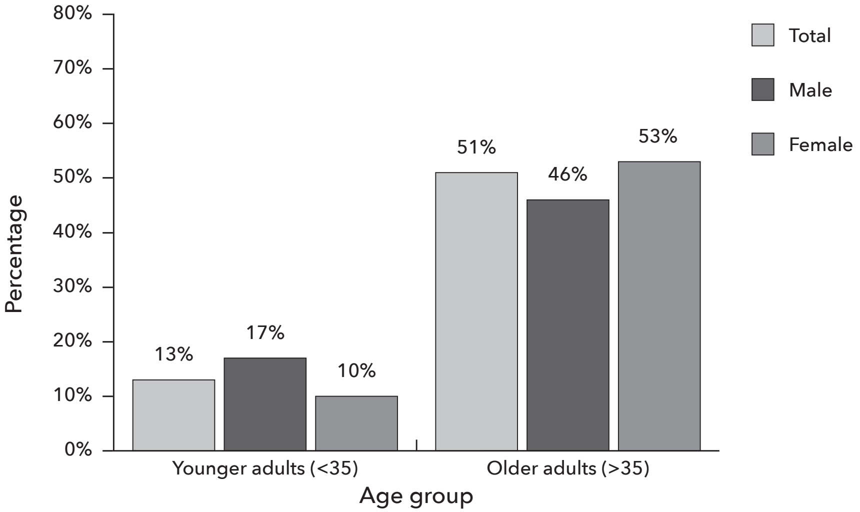


Figure 5.15: The prevalence of osteoarthritis in relation to age-at-death in the Alkmaar collection.

Table 5.14 displays the prevalence of osteoarthritis in adults per joint. Osteoarthritis in the spine is the most common in both males and females with 22% of the adults from Alkmaar affected. Males were more affected by osteoarthritis than females in almost every synovial joint, with the exception of the knee and the temporo-mandibular joint. However, the differences are small. The only large difference exists in the prevalence of osteoarthritis of the acromio-clavicular joint: 25% of the males were affected and only 10% of the females. This difference is statistically significant (χ^2=4.177, df=1, p=0.041, n=104), but it might be related to the fact that there are more mature males in the Alkmaar collection

Table 5.14: Number of individuals affected by osteoarthritis per joint type in the Alkmaar collection.

Joint	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	2	3.3	2	1.9
ACJ	11	25.0	6	10.0	17	15.9
SCJ	2	4.2	0	0.0	2	1.9
Spine	12	23.1	15	21.1	28	21.9
Shoulder	0	0.0	0	0.0	0	0.0
Elbow	2	3.6	1	1.3	3	2.2
Wrist	2	4.1	2	3.0	5	4.2
Hand	3	6.1	3	4.3	6	4.9
Hip	3	5.6	2	2.6	5	3.7
Knee	1	2.1	3	4.5	4	3.3
Ankle	0	0.0	1	1.5	1	0.9
Foot	2	5.6	1	1.8	3	3.1

n=number of affected individuals, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, SCJ=sterno-clavicular joint. Total includes individuals of indeterminate sex.

To counter possible effects of preservation, osteoarthritis prevalence is also calculated in relation to the total number of observable joints (2420). In Alkmaar, 95 joints are affected by osteoarthritis (3.9%). The difference between males and females is small when osteoarthritis prevalence is studied on an individual level. However, when the joints are analysed separately, males have clearly more joints affected than females (5.3% versus 3.1%). This difference between the sexes is statistically significant (χ^2=7.665, df=1, p=0.006, n=2334). Table 5.15 shows the numbers and percentages of affected joints per joint type. The spine is still a common site for osteoarthritis. However, males are more often affected by osteoarthritis in their acromial-clavicular joint. The difference in prevalence in this joint between males and females was already large when studied on an individual level. Here, the significance increased further (χ^2=7.631, df=1, p=0.006, n=187).

Table 5.15: Number of joints affected by osteoarthritis per joint type in the Alkmaar collection.

Joint	Males		Females		Total	
	n	%	n	%	n	%
TMJ	0	0.0	2	3.3	2	1.9
ACJ	18	23.6	10	9.0	28	14.7
SCJ	4	4.7	0	0.0	4	2.0
Spine	12	23.1	15	21.1	28	21.9
Shoulder	0	0.0	0	0.0	0	0.0
Elbow	2	2.1	1	0.8	3	1.3
Wrist	2	2.2	2	1.7	5	2.3
Hand	4	4.8	3	2.4	7	3.3
Hip	5	5.1	3	2.1	8	3.3
Knee	2	2.4	4	3.2	6	2.7
Ankle	0	0.0	1	0.9	1	0.5
Foot	2	3.5	1	1.1	3	1.9

n=number of affected joints, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, and SCJ=sterno-clavicular joint. Total includes individuals of indeterminate sex.

To study particular movements and activities, joints are divided into two groups, upper and lower limbs (table 5.16). Differences between the joint groups are small, both for the total number of joints analysed and for the separate analysis of males and females. Differences in frequency of osteoarthritis in the upper and lower limbs between males and females are also small and not statistically significant (upper: χ^2=1.504, df=1, p=0.220, n=853; lower: χ^2=0.646, df=1, p=0.422, n=804).

Table 5.16: Number of joints affected by osteoarthritis per joint group in the Alkmaar collection.

Joint groups	Males		Females		Total	
	n	%	n	%	n	%
Upper limb	8	2.3	6	1.2	15	1.7
Lower limb	9	2.8	9	1.9	18	2.2

n=number of affected joints, total includes individuals of indeterminate sex.

vi) Site comparisons

Table 5.17 shows an overview of the numbers and percentages of individuals with osteoarthritis (crude prevalence) in the three collections. This joint disease appears to have been most common in the Alkmaar collection. However, the difference with the Klaaskinderkerke collection is small. The individuals from the Blokhuizen collection showed the lowest amount of osteoarthritis (11.9%), but this might be related to the relatively low number of joints available for inspection. Table 5.18 displays the results of several statistical comparisons between the sites. It shows that there are significantly more individuals with osteoarthritis in the Alkmaar collection than in the Blokhuizen collection. This is apparent when the sexes are grouped, and remains when males and females are compared separately. Comparison of the Klaaskinderkerke collection with the individuals from Blokhuizen shows that males and combined numbers are statistically significantly different. However, comparison of the females reveals no significant difference. The differences between the Alkmaar and Klaaskinderkerke collections are not statistically significant.

Table 5.17: Number of individuals affected by osteoarthritis in the three collections.

Sites	Males		Females		Total	
	n	%	n	%	n	%
Blokhuizen	4	11.4	5	15.2	10	11.9
Klaaskinderkerke	10	30.3	4	23.5	14	28.0
Alkmaar	24	36.4	28	33.7	54	32.7

n=number of affected individuals, total includes individuals of indeterminate sex.

Table 5.18: Statistical comparison of the number of individuals affected by osteoarthritis in the three collections.

Site comparison	Sex	χ2	df	p	n
Alkmaar-Blokhuizen	C	12.638	1	**<0.001**	249
	M	7.097	1	**0.008**	101
	F	4.006	1	**0.045**	116
Blokhuizen-Klaaskinderkerke	C	5.523	1	**0.019**	134
	M	3.701	1	0.054	68
	F	0.534	1	0.465	50
Klaaskinderkerke-Alkmaar	C	0.397	1	0.529	215
	M	0.358	1	0.549	99
	F	0.675	1	0.411	100

C=all affected individuals combined, M=males, and F=females. n=number of individuals in the test.

Table 5.19 shows the numbers of individuals affected by osteoarthritis per joint for the three collections. Larger differences are found in the prevalence of osteoarthritis in the spine and hip. Klaaskinderkerke has a high percentage of both hip and spinal osteoarthritis in comparison with the other sites. The difference in the prevalence of hip osteoarthritis between Alkmaar and Klaaskinderkerke is statistically significant (χ^2=4.491, df=1, p=0.034, n=185). The difference in hip osteoarthritis between Blokhuizen and Klaaskinderkerke is not statistically significant (χ^2=1.500, df=1, p=0.221 n=106). The comparison of the prevalence of spinal osteoarthritis between the individuals from Alkmaar and Klaaskinderkerke does not reveal any statistically significant differences (χ^2=1.321, df=1, p=0.250, n=162). The same is true when Blokhuizen is compared with Klaaskinderkerke (χ^2=1.851, df=1, p=0.174, n=60).

Table 5.19: Number of individuals affected by osteoarthritis per joint type in the three collections.

Joint	Sex	Blokhuizen		Klaaskinderkerke		Alkmaar	
		n	%	n	%	n	%
TMJ	C	1	2.1	0	0.0	2	1.9
	M	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	2	3.3
ACJ	C	3	12.5	3	8.8	17	15.9
	M	2	11.1	2	8.7	11	25.0
	F	1	16.7	1	9.1	6	10.0
SCJ	C	0	0.0	2	6.3	2	1.9
	M	0	0.0	2	9.5	2	4.2
	F	0	0.0	0	0.0	0	0.0
Spine	C	4	16.0	11	28.2	28	21.9
	M	3	16.7	7	26.9	12	23.1
	F	1	14.3	4	30.8	15	21.1
Shoulder	C	3	6.7	1	2.4	0	0.0
	M	1	4.5	1	3.7	0	0.0
	F	2	9.1	0	0.0	0	0.0
Elbow	C	1	2.8	0	0.0	3	2.2
	M	0	0.0	0	0.0	2	3.6
	F	1	6.3	0	0.0	1	1.3
Wrist	C	0	0.0	1	3.7	5	4.2
	M	0	0.0	1	5.6	2	4.1
	F	0	0.0	0	0.0	2	3.0
Hand	C	1	4.3	0	0.0	6	4.9
	M	0	0.0	0	0.0	3	6.1
	F	1	10.0	0	0.0	3	4.3
Hip	C	3	5.4	6	12.0	5	3.7
	M	1	3.8	5	15.2	3	5.6
	F	2	7.1	1	5.9	2	2.6
Knee	C	2	4.4	0	0.0	4	3.3
	M	0	0.0	0	0.0	1	2.1
	F	2	8.7	0	0.0	3	4.5
Ankle	C	0	0.0	0	0.0	1	0.9
	M	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	1	1.5
Foot	C	1	5.9	1	8.3	3	3.1
	M	1	14.3	0	0.0	2	5.6
	F	0	0.0	1	100.0	1	1.8

n=number of affected individuals, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, SCJ=sterno-clavicular joint, C=all affected individuals combined, M=males, F=females.

Since the comparison of the crude prevalence of osteoarthritis between the sites may have been influenced by differential preservation, comparing the true prevalence may be more appropriate. Differences between the sites are much smaller when only the percentage of affected joints is taken into account (see table 5.20). Interestingly, Alkmaar now has the lowest overall percentage of osteoarthritis, although differences are small. Table 5.21 shows the results of the statistical comparison of the true prevalence. There are no statistically significant differences between the general true prevalence (males and females combined). There is a statistically significant difference between the females of Alkmaar and Blokhuizen.

Table 5.20: Number of joints affected by osteoarthritis in the three collections.

Sites	Males		Females		Total	
	n	%	n	%	n	%
Blokhuizen	9	3.2	14	5.8	24	4.4
Klaaskinderkerke	24	4.9	8	3.7	32	4.6
Alkmaar	51	5.3	42	3.1	95	3.9

n=number of affected joints, total includes individuals of indeterminate sex.

Table 5.21: Statistical comparison of number of joints affected by osteoarthritis in the three collections.

Site comparison	Sex	χ2	df	p	n
Alkmaar-Blokhuizen	C	0.305	1	0.581	2966
	M	2.252	1	0.133	1242
	F	4.673	1	**0.031**	1618
Blokhuizen-Klaaskinderkerke	C	0.018	1	0.895	1249
	M	1.351	1	0.245	774
	F	1.056	1	0.304	453
Klaaskinderkerke-Alkmaar	C	0.584	1	0.459	3123
	M	0.117	1	0.733	1446
	F	0.288	1	0.591	1591

The results for males and females are shown combined and separately. C=all affected joints combined, M=males, and F=females. n=number of joints included in the test.

Table 5.22 shows the numbers of affected joints per joint type for all three collections. The table indicates that most differences between the sites are small. The prevalence of osteoarthritis in the acromial-clavicular joint is relatively high in both Blokhuizen and Alkmaar. Additionally, the percentage of spinal and hip involvement is high in Klaaskinderkerke. The difference in frequency of hip osteoarthritis between Klaaskinderkerke and Alkmaar is statistically significant (χ^2=9.205, df=1, p=0.002, n=340).

Table 5.22: Number of joints affected by osteoarthritis per joint type in the three collections.

Joints	Sex	Blokhuizen		Klaaskinderkerke		Alkmaar	
		n	%	n	%	n	%
TMJ	C	1	2.1	0	0.0	2	1.9
	M	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	2	3.3
ACJ	C	5	17.2	3	5.5	28	14.7
	M	3	14.3	2	5.0	18	23.6
	F	2	25.0	1	6.7	10	9.0
SCJ	C	0	0.0	3	5.7	4	2.0
	M	0	0.0	3	8.6	4	4.7
	F	0	0.0	0	0.0	0	0.0
Spine	C	4	16.0	11	28.2	28	21.9
	M	3	16.7	7	26.9	12	23.1
	F	1	14.3	4	30.7	15	21.1
Shoulder	C	4	6.8	1	1.4	0	0.0
	M	1	3.0	1	2.0	0	0.0
	F	3	12.0	0	0.0	0	0.0
Elbow	C	2	3.8	0	0.0	3	1.3
	M	0	0.0	0	0.0	2	2.1
	F	2	8.0	0	0.0	1	0.8
Wrist	C	0	0.0	2	3.9	5	2.3
	M	0	0.0	2	5.3	2	2.2
	F	0	0.0	0	0.0	2	1.7
Hand	C	1	3.1	0	0.0	7	3.3
	M	0	0.0	0	0.0	4	4.8
	F	1	7.7	0	0.0	3	2.4
Hip	C	4	4.2	11	11.7	8	3.3
	M	1	2.3	9	14.3	5	5.1
	F	3	6.3	2	6.5	3	2.1
Knee	C	2	2.9	0	0.0	6	2.7
	M	0	0.0	0	0.0	2	2.4
	F	2	5.7	0	0.0	4	3.2
Ankle	C	0	0.0	0	0.0	1	0.5
	M	0	0.0	0	0.0	0	0.0
	F	0	0.0	0	0.0	1	0.9
Foot	C	1	4.2	1	5.8	3	1.9
	M	1	9.1	0	0.0	2	3.5
	F	0	0.0	1	100.0	1	1.1

n=number of affected joints, TMJ=temporo-mandibular joint, ACJ=acromio-clavicular joint, SCJ=sterno-clavicular joint, C=all affected individuals combined, M=males, F=females.

A comparison of the prevalence of osteoarthritis in the upper and lower limbs between the three skeletal collections shows some interesting differences (tables 5.23 and 5.24). In Blokhuizen, statistically significantly more females have osteoarthritis in comparison with the women in the other skeletal assemblages. Interestingly, osteoarthritis of the lower limbs is more common in Klaaskinderkerke in comparison with Alkmaar, although this difference disappears when males and females are studied separately.

Table 5.23: Number of joints affected by osteoarthritis per joint group in the three collections.

Sites	Joint group	Males		Females		Total	
		n	%	n	%	n	%
Blokhuizen	Upper	1	1.2	6	8.2	7	4.2
	Lower	2	1.9	5	4.2	7	3.0
Klaaskinderkerke	Upper	3	1.7	0	0.0	3	1.2
	Lower	9	5.1	3	3.9	12	4.7
Alkmaar	Upper	8	2.3	6	1.2	15	1.7
	Lower	9	2.8	9	1.9	18	2.2

n=number of affected joints, total includes individuals of indeterminate sex.

Table 5.24: Statistical comparison of the number of joints affected by osteoarthritis per joint group in the three collections.

Site comparison		Sex	χ2	df	p	n
Alkmaar-Blokhuizen	Upper limb	C	4.150	1	**0.042**	1047
		M	0.537	1	0.464	444
		F	15.388	1	**<0.001**	575
	Lower limb	C	0.544	1	0.461	1070
		M	0.250	1	0.617	423
		F	2.213	1	0.137	595
Blokhuizen-Klaaskinderkerke	Upper limb	C	3.733	1	0.053	416
		M	0.169	1	0.681	268
		F	6.257	1	**0.012**	146
	Lower limb	C	0.996	1	0.318	489
		M	1.719	1	0.190	282
		F	0.008	1	0.930	195
Klaaskinderkerke-Alkmaar	Upper limb	C	0.304	1	0.582	1127
		M	0.182	1	0.670	526
		F	0.882	1	0.348	575
	Lower limb	C	4.797	1	**0.029**	1089
		M	1.635	1	0.201	497
		F	1.373	1	0.241	561

The results for the males and females are shown combined and separately. C=all affected joints combined, M=males, F=females. n=number of joints included in the test.

5.5.2 Bone morphology

i) Blokhuizen

Table 5.25 shows the means and standard deviations of the platymeric index (the subtrochanteric shape of the femur) and platycnemic index (the shape of the tibia at the nutrient foramen) for both the left and right legs, and for both females and males. To assess if there are any shape differences between the left and right legs, the means are compared statistically. Since the indices are not normally distributed, non-parametric statistical tests are used. As can be observed in table 5.26, there are no statistically significant differences in shape between the left and right femora and tibiae. Therefore, to enlarge sample sizes, the left and right indices are grouped in subsequent comparisons.

Table 5.25: Platymeric and platycnemic indices in the Blokhuizen collection.

Indices	Side	Males			Females		
		M	SD	n	M	SD	n
Platymeric index	L	73.00	7.61	16	77.39	6.22	19
	R	73.77	8.50	15	75.15	3.36	14
Platycnemic index	L	69.25	5.36	10	74.23	4.65	15
	R	69.93	6.33	9	76.10	6.60	10

M=mean, SD=standard deviation, n=number of measured bones, L=left, and R=right.

Table 5.26: Statistical comparison of left and right leg means in the Blokhuizen assemblage.

Comparison	Males			Females		
	U	p	n	U	p	n
Femur left-right	114.0	0.830	31	101.0	0.255	33
Tibia left-right	44.5	0.968	19	63.0	0.531	25

n=number of individuals included in the test.

The results of the shape difference analysis between the males and females in the Blokhuizen collection can be observed in table 5.27. It is evident from the results that there are significant shape differences between the males and females.

Table 5.27: Statistical comparison of male and female means in the Blokhuizen assemblage.

Comparison	Platymeric index			Platycnemic index		
	U	p	n	U	p	n
Male-female	360.5	**0.042**	64	121	**0.006**	44

n=number of measured legs included in the test.

ii) Klaaskinderkerke

Table 5.28 shows the means and standard deviations of the platymeric and platycnemic index for both the left and right legs for both males and females. Table 5.29 shows that there are no statistically significant differences in shape between the left and the right legs (data are not normally distributed). Therefore, the left and the right indices are combined.

Table 5.28: Platymeric and platycnemic indices in the Klaaskinderkerke collection.

Indices	Side	Males			Females		
		M	SD	n	M	SD	n
Platymeric index	L	80.44	8.43	28	82.56	7.61	14
	R	80.05	7.58	30	80.91	8.69	13
Platycnemic index	L	74.36	6.75	24	74.32	4.88	10
	R	74.39	6.53	28	75.88	7.79	13

M=mean, SD=standard deviations, n=number of measured bones, L=left, and R=right.

Table 5.29: Statistical comparison of left and right leg means in the Klaaskinderkerke assemblage.

Comparison	Males			Females		
	U	p	n	U	p	n
Femur left-right	416.5	0.957	58	78.0	0.550	27
Tibia left-right	322.0	0.797	52	119.5	0.976	23

n=number of individuals included in the test.

The grouped sample is used to assess differences in leg shape between males and females in the Klaaskinderkerke collection. The results of the statistical analysis are shown in table 5.30 (data not normally distributed). The p-values indicate that there are no differences in shape between males and the females for both femur and tibia.

Table 5.30: Statistical comparison of femoral and tibial shapes between males and females from the Klaaskinderkerke collection.

Comparison	Playmeric index			Platycnemic index		
	U	P	n	U	p	n
Male-female	737.0	0.664	85	578.5	0.823	75

n=number of measured legs included in the test.

iii) Alkmaar

Table 5.31 shows the means and standard deviations for both left and right femora and tibiae of males and females from the Alkmaar collection. Except for the indices of the female tibiae, the indices are not normally distributed, which made it necessary to use non-parametric statistical tests for comparison. As can be observed from table 5.32, there are no statistically significant differences in shape between left and right femora and tibia for either sex. Therefore, left and right indices are grouped for subsequent analyses.

Table 5.31: Platymeric and platycnemic indices in the Alkmaar collection.

Indices	Side	Males			Females		
		M	SD	n	M	SD	n
Platymeric index	L	80.84	8.11	45	77.52	8.05	62
	R	84.02	5.93	41	77.23	7.51	59
Platycnemic index	L	75.71	5.12	41	77.91	6.27	63
	R	75.89	5.36	39	79.24	6.87	53

M=mean, SD=standard deviation, n=number of measured bones, L=left, R=right.

Table 5.32: Statistical comparison of femoral and tibial shapes between left and right legs of the Alkmaar collection.

Comparison	Males			Females		
	U	P	n	U	p	n
Femur left-right	757.5	0.154	86	1821.5	0.969	121
Tibia left-right	783.5	0.877	80	1483.0	0.301	116

n=number of measured legs.

Table 5.33 shows the results of a comparison of the platymeric and platycnemic indices between males and females in the Alkmaar collection (data not normally distributed). The table shows that the differences are highly statistically significant.

Table 5.33: Statistical comparison of femoral and tibial shapes between males and females in the Alkmaar collection.

Comparison	Platymeric index			Platycnemic index		
	U	P	n	U	p	n
Male-female	3203.5	**<0.001**	207	3203.5	**<0.001**	196

n=number measured legs included in the test.

iv) Site comparisons

Table 5.34 presents an overview of the means of the platymeric and platycnemic indices for both sexes in the three sites. The table shows that there are differences in the means for the femora and tibiae between the studied populations, indicating different femoral and tibial shapes and therefore possible differential use of the legs.

Table 5.34: Overview of the indices means for males (M) and females (F) in the Blokhuizen, Klaaskinderkerke, and Alkmaar collections.

Sites	**Sex**	**Platymeric index**			**Platycnemic index**		
		M	**SD**	**n**	**M**	**SD**	**n**
Blokhuizen	M	73.37	7.93	31	69.57	5.69	19
	F	76.44	5.25	33	74.98	5.46	25
Klaaskinderkerke	M	80.24	7.93	58	74.37	6.57	52
	F	81.77	8.04	27	75.21	6.59	23
Alkmaar	M	82.04	7.76	86	75.79	5.21	80
	F	77.37	7.78	121	78.52	6.56	116

n=number of measured legs (left and right are combined).

Table 5.35 displays the results of statistical testing in order to compare the means of the tibiae and femora across the sites. The comparison of the means from Alkmaar and Blokhuizen reveals highly significant differences. The males show differences in both femoral and tibial shape: the Alkmaar males have significantly rounder femora and tibiae. The females from Alkmaar and Blokhuizen only show a significant difference in the shape of the tibiae: the Blokhuizen tibiae are more medio-laterally flattened.

The comparison of Alkmaar and Klaaskinderkerke yields different results. Here, there are no significant differences for the femoral and tibial shapes between males of each site. In contrast, the femoral and tibial shapes of the females are significantly different: Alkmaar females have flatter femora and rounder tibiae than the Klaaskinderkerke females.

The comparison of Klaaskinderkerke and Blokhuizen reveals a different pattern. Both the femora and tibial shapes of the males are flatter in the Blokhuizen collection. A comparison of the females only results in a significant difference in femoral shape: the Blokhuizen females have flatter femora than the Klaaskinderkerke females.

Table 5.35: Statistical comparison of the shapes of the femora and tibiae of males (M) and females (F) across the studied sites.

Site comparison	**Sex**	**Platymeric index**			**Platycnemic index**		
		U	**p**	**n**	**U**	**p**	**n**
Alkmaar-Blokhuizen	M	543.5	**<0.001**	117	340.5	**<0.001**	99
	F	1944.0	0.817	154	926.0	**0.005**	141
Blokhuizen-Klaaskinderkerke	M	482.5	**<0.001**	89	285.0	**0.007**	71
	F	280.5	**0.014**	60	268.0	0.687	48
Klaaskinderkerke-Alkmaar	M	2143.0	0.153	144	1806.0	0.202	132
	F	1119.5	**0.011**	148	890.0	**0.012**	139

n=number of measured legs in the test (left and right are combined).

5.5.3 Summary activity markers

The intra- and inter site differences in activity patterns have been studied by looking at the prevalence of osteoarthritis and femoral and tibial shape differences. Osteoarthritis is most common in Alkmaar, although the difference with Klaaskinderkerke is small. Blokhuizen has a low prevalence of osteoarthritis. However, when the true prevalence is compared, there are no significant differences between the collections. In Alkmaar and Klaaskinderkerke, osteoarthritis is more common in females, although the differences between the sexes are not statistically significant. If the joints are studied separately, both the true and crude prevalence, the results do not point at radically different activities of men and women. However, some interesting differences in the prevalence of osteoarthritis in certain joints between the sites were apparent. Additionally, the comparison of upper and lower limb osteoarthritis revealed interesting differences between the studied collections. The data on bone morphology demonstrate differences between the sexes in the Alkmaar and Blokhuizen collections. In Klaaskinderkerke there are no statistically significant differences between sexes. The inter-site comparison demonstrates clear differences between the studied populations, indicating possible dissimilarities in activity patterns.

5.6 INDICATORS OF DIET

5.6.1 Dental caries

i) Blokhuizen

The Blokhuizen collection comprises 36 individuals with carious lesions (41.4%), of which 32 are older than 19 years of age (54.2%) and four younger than 19 years (14.3%). In addition to the calculation of individual caries prevalence, the caries frequency, which takes into account the number of observable teeth, has been studied. In Blokhuizen, there are 86 teeth with carious lesions out of 1197 observable teeth resulting in a caries frequency of 7.8%. With a frequency rate of only 1.7% (5/302 observable teeth), non-adults are the least affected by caries: the frequency for the adults is substantially higher at 9.1% (81/895 observable teeth). The frequency of ante-mortem tooth loss for adults is 11.7%.

Sex could be estimated in case of 30 of the 32 adults with caries. In all, there are 14 females (66.7%) and 16 males (57.1%) with carious lesions. The caries frequency of women is also higher than that of men in Blokhuizen, 13.6% versus 7.3% respectively. The difference in the caries frequency between males and females is statistically significantly (χ^2=8.605, df=1, p=0.003, n=817).

In Blokhuizen, there are differences between the adult age groups: 42.9% of the younger and 70.4% of the older adults are affected by caries. Statistically, there is a strong trend towards significance (χ^2=3.679, df=1, p=0.055, n=48). If the males and females are studied separately, the trend stays similar: younger males and females are less affected by caries than the older individuals (males: 40.0% versus 68.8%; females: 50.0% versus 87.5%). The differences are, however, not statistically significant (males: χ^2=2.084, df=1, p=0.149, n=26; females: χ^2=2.618, df=1, p=0.106, n=16).

The caries frequency in relation to age-at-death shows similar patterns: the younger individuals, both males and females, have a lower caries frequency than the older individuals. The younger individuals have a combined caries frequency of 5.3% (males: 4.7%, females: 6.9%), while the older individuals have a frequency of 14.2% (males: 9.6%, females: 28.9%). Statistically, the difference in frequency between the younger and older individuals is significant (χ^2=18.307, df=1, p<0.001, n=794). This suggests a clear correlation between age-at-death and the caries frequency. A separate comparison of the frequency for males and females shows a statistically significant difference between the younger and older males and females (males: χ^2=4.380, df=1, p=0.036, n=487, females: χ^2=21.927, df=1, p<0.001, n=249).

ii) Klaaskinderkerke

In total, there are 22 individuals (66.7%) with carious lesions in the Klaaskinderkerke collection of which there are 20 adults (40.0%) and two non-adults (66.7%). The non-adults appear to be more commonly affected than adult individuals, but the small number of non-adult individuals available for study may have resulted in a bias in the percentage of non-adult individuals with caries. The overall caries frequency (combining non-adults and adults) is 7.9%. The caries frequency of the adults is 8.3% and even though a higher percentage of non-adults than adults is affected by caries, the non-adults have a much lower frequency, only 4.0%. The frequency of ante-mortem tooth loss for adults is 8.4%.

Of the adult individuals with caries, there are five women (55.6%) and 15 men (71.4%) indicating a higher prevalence amongst the males in the Klaaskinderkerke collection. Statistical analysis shows, however, that this difference is not significant (χ^2=0.714, df=1, p=0.398, n=30). The caries frequency is lower among the females, 7.4% versus 8.8%, suggesting that fewer teeth in their dentition are affected by caries lesions. The difference in caries frequency between the sexes is not statistically significant (χ^2=0.281, df=1, p=0.596, n=494).

In the Klaaskinderkerke collection, there are no large differences in the number of individuals with caries between the younger and older adults. In the younger adult group, 61.1% of individuals are affected by caries and in the older age group 75.0%, which is not statistically significantly different (χ^2=0.625, df=1, p=0.429, n=30). If the younger and older males/

females are analysed by sex, similarly no statistically significant differences are found (males: χ^2=0.019, df=1, p=0.890, n=21; females: χ^2=2.057, df=1, p=0.151, n=9). The caries frequency, however, shows more marked differences between the two age groups: the younger individuals have a frequency of 6.2% and the older individuals a much higher one (12.3%). Statistically, this difference is significant (χ^2=5.446, df=1, p=0.020, n=494) suggesting that there is a clear correlation between age-at-death and caries frequency, which is supported by a correlation test (rs=0.105, p=0.020, n=494). When the males and females are studied separately, it becomes clear that the difference occurs mainly between the younger and older females. The difference in caries frequency means for the males between the adult age groups is not statistically different (χ^2=1.667, df=1, p=0.197, n=331). In case of the females, however, statistically more older adults are affected by caries (χ^2=5.502, df=1, p=0.019, n=163).

iii) Alkmaar

In the Alkmaar collection, there are 97 individuals with carious lesions (77.0%) of which ten are non-adults (58.8%) and 87 adults (79.1%). In total, 362 teeth show one or more carious lesions out of 2285 observable deciduous and permanent teeth. This results in an overall caries frequency of 15.8%. The caries frequency of the non-adult individuals is lower than for the adults: 10.9% versus 16.6%. The frequency of ante-mortem tooth loss for adults is 19.4%.

Of the adult individuals, there are 49 females (81.7%) and 36 males (80.0%) with carious lesions. This similarity is also seen in caries frequency: males have a caries frequency of 16.8%, and females of 16.7%. Clearly this difference is not statistically significant (χ^2=0.001, df=1, p=0.974, n=1915).

There are only minor differences in the number of affected individuals in the younger (<35 years) and older (>35 years) age categories. In the younger adult age group, 83.7% (41/49) are affected and in the older age group 77.4% (41/53) of the individuals have one or more carious lesions. Statistically, this difference is not significant (χ^2=0.644, df=1, p=0.422, n=102). The differences between males and females are also minor: in the younger adult age group 84.2% of the males and 86.2% of the females are affected by caries, which is not a significant difference (χ^2=0.037, df=1, p=0.848, n=48). In the older adult age group, 75.0% of the males and 81.5% of the females have carious lesions in their dentition. This difference is not statistically significant (χ^2=0.316, df=1, p=0.574, n=51).

The younger adult age group includes 1028 teeth of which there were 132 affected by caries, which gives a caries frequency of 12.8%. The older adult age group includes 881 teeth of which 181 were affected by caries resulting in a caries frequency of 20.5%. This suggests that age is related to caries frequency, which is supported by statistical analysis: a comparison of the caries frequency between the adult age groups gives a significant result (χ^2=20.543, df=1, p<0.001, n=1909).

The caries frequency of the Alkmaar men appears to relate more strongly to age-at-death than that of the females. Younger males have a caries frequency of 10.5%, while the older males have a frequency of 23.5%. The females show a smaller difference: the caries frequency is 14.8% in the younger age group and 18.8% in the older age group. A comparison of caries frequency between the younger and older males yields a clear statistically significant result (χ^2=22.813, df=1, p<0.001, n=744). The comparison of the caries frequency between the younger and older females is not statistically significant although there is a trend towards significance (χ^2=3.12, df=1, p=0.077, n=1120).

iv) Site comparisons

Firstly, the individual caries percentage and frequency of adults and non-adults are compared across the sites. Relations to specific age groups, both non-adults and adults, and sex are discussed below. Figure 5.16 shows the percentage of individuals with caries in the three studied collections. Clearly, the Alkmaar collection has the most adult individuals with one or more carious lesions. Klaaskinderkerke has the most non-adults with caries, but this is most likely by the small number of non-adults (n=2).

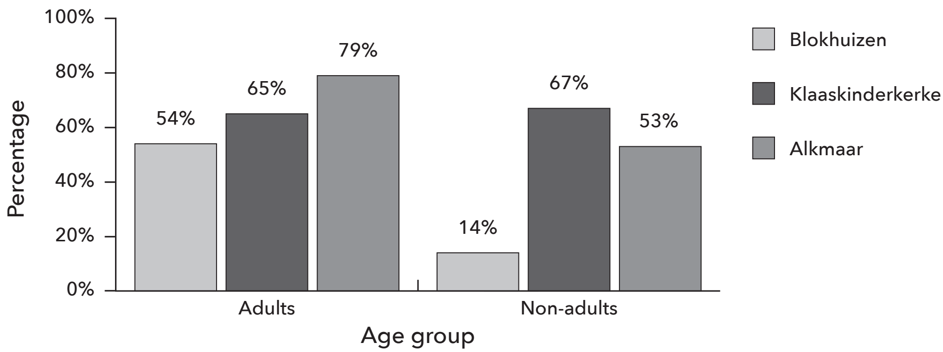


Figure 5.16: Percentages of individuals with caries in the studied sites.

Table 5.36 shows the results of the statistical analysis comparing the number of adult individuals with caries across sites. It is evident that there are significantly more adults and non-adults in the Alkmaar collection with caries than in the Blokhuizen collection. No significant differences exist between Klaaskinderkerke and Alkmaar. The comparison of Blokhuizen and Klaaskinderkerke reveals no statistically significant differences between the numbers of adults with caries. There are, however, significantly more non-adults with carious lesions in the Klaaskinderkerke collection, but sample size is very low making this difference unreliable.

Table 5.36: Statistical comparison of the caries prevalence the across studied sites.

Site comparison	Adults				Non-adults			
	$\chi 2$	df	p	n	$\chi 2$	df	p	n
Alkmaar-Blokhuizen	11.387	1	**0.001**	169	9.790	1	**0.002**	45
Blokhuizen-Klaaskinderkerke	1.265	1	0.261	89	4.763	1	**0.029**	31
Klaaskinderkerke-Alkmaar	2.020	1	0.155	140	0.065	1	0.798	20

n=number of individuals included in the test, df=degrees of freedom.

Figure 5.17 shows the caries frequency across the three sites. The individuals in the Alkmaar collection have the highest frequency. This is true for both adults and non-adults. Interestingly, the two rural sites, Blokhuizen and Klaaskinderkerke, do not differ substantially from each other; at both sites the caries frequencies of non-adults and adults are similar.

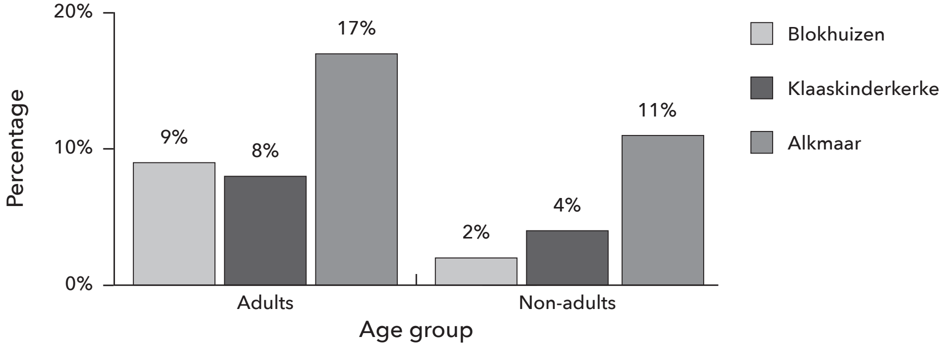


Figure 5.17: Caries frequency in the Alkmaar, Blokhuizen and Klaaskinderkerke collections. Adults and non-adults are displayed separately.

Since age may influence non-adult number and caries prevalence, the non-adults are divided in smaller age groups to make the inter-site comparisons more reliable. In table 5.37, the results for the infants (0–3 years), children (4–12 years) and adolescents (13–18 years) are shown separately. The non-adult caries frequency is not compared statistically considering the small number of available non-adults in Klaaskinderkerke.

Table 5.37: Non-adult caries percentage and frequency across the sites.

Sites		Caries prevalence			Caries frequency		
		%	n_{ai}	n_{oi}	%	n_{at}	n_{ot}
Blokhuizen	I	0.0	0	6	0.0	0	69
	C	19.0	4	21	2.4	5	211
	A	0.0	0	1	0.0	0	19
Klaaskinderkerke	I	0.0	0	0	0.0	0	0
	C	50.0	1	2	3.6	1	28
	A	100.0	1	1	4.3	1	23
Alkmaar	I	0.0	0	1	0.0	0	5
	C	44.4	4	9	10.0	12	120
	A	85.7	6	7	11.7	23	196

I=infant, C=child, A=adolescent, n_{ai}=number of affected individuals, n_{oi}=number of individuals with observable teeth, n_{at}=number of affected teeth, n_{ot}=number of observable teeth.

Table 5.38 shows the results of the statistical comparison of the caries frequency of the adult individuals amongst the studied sites. Clearly, in addition to the number of individuals with caries, the caries frequency in the Alkmaar collection is significantly higher than that in Blokhuizen and Klaaskinderkerke. No statistically significant difference exists between the rural sites Klaaskinderkerke and Blokhuizen.

Table 5.38: Statistical comparison of the adult caries frequency across the sites.

Site comparison	Adult		
	$\chi 2$	p	n
Alkmaar-Blokhuizen	29.023	**<0.001**	2859
Blokhuizen-Klaaskinderkerke	0.224	0.636	1389
Klaaskinderkerke-Alkmaar	21.619	**<0.001**	2458

n=number of teeth included in the test.

Table 5.39 shows the results of the analysis of caries prevalence and frequency for males and females at each site. When the sexes are studied separately, Alkmaar still has the highest caries prevalence and frequency for both males and females. The differences between Blokhuizen and Klaaskinderkerke are less marked. As can be observed in table 5.40, the Alkmaar males have a statistically significantly higher caries frequency in comparison with the males from Klaaskinderkerke and Blokhuizen, The statistical comparison of the female caries frequency and prevalence reveals significant differences between Alkmaar and Klaaskinderkerke and between Blokhuizen and Klaaskinderkerke: in Klaaskinderkerke the frequency is the lowest.

Table 5.39: Adult caries percentage and frequency across the sites.

Sites		Caries prevalence			Caries frequency		
		%	n_{ai}	n_{oi}	%	n_{at}	n_{ot}
Blokhuizen	M	57.1	16	28	7.3	37	507
	F	66.7	14	21	13.5	42	310
Klaaskinderkerke	M	71.4	15	21	8.8	29	331
	F	55.6	5	9	7.4	12	163
Alkmaar	M	80.0	36	45	16.8	130	774
	F	81.7	49	60	16.7	191	1141

M=male individuals, F=females individuals, n_{ai}=number of affected individuals, n_{oi}=number of individuals with observable teeth, n_{at}=number of affected teeth, n_{ot}=number of observable teeth.

Table 5.40: Statistical comparison of the adult caries percentage and frequency across the sites.

Site comparison		Caries prevalence				Caries frequency			
		χ2	df	p	n	χ2	df	p	n
Alkmaar-Blokhuizen	M	4.401	1	**0.036**	73	24.376	1	**<0.001**	1281
	F	2.025	1	0.155	81	1.842	1	0.175	1451
Blokhuizen-Klaaskinderkerke	M	1.054	1	0.305	49	0.591	1	0.442	838
	F	0.335	1	0.563	30	4.043	1	**0.044**	473
Klaaskinderkerke-Alkmaar	M	0.599	1	0.439	66	12.150	1	**<0.001**	1105
	F	3.136	1	0.077	69	9.543	1	**0.002**	1304

M=male individuals, F=female individuals, n=number of individuals/teeth included in test, df=degrees of freedom.

Table 5.41 presents the caries prevalence and frequency of the younger (<35 years) and older (>35 years) adult individuals. It shows that the main differences in caries prevalence between the sites are in the younger adult group. In the two rural sites, the younger individuals are less often affected by caries than older individuals. In Alkmaar, the percentage of affected individuals is much higher for the younger individuals. This is, however, not the case for caries frequency, which is also lower for the younger Alkmaar individuals. Statistically, there are significant differences between the younger individuals at the three sites, both in caries prevalence and caries frequency, confirming that significantly more younger Alkmaar individuals are affected by caries (table 5.42). The comparison of the two rural sites does not reveal any statistically significant results. The caries prevalence of the older adults is not significantly different between the sites. In contrast, the caries frequency gives significantly different results: in Alkmaar the older adults have significantly more teeth affected by caries than at the other two sites.

Table 5.41: Adult caries percentage and frequency across the sites.

Sites		Caries prevalence			Caries frequency		
		%	n_{ai}	n_{oi}	%	n_{at}	n_{ot}
Blokhuizen	Y	42.9	9	21	5.3	23	434
	O	70.4	19	27	14.2	51	360
Klaaskinderkerke	Y	61.1	11	18	6.2	20	323
	O	75.0	9	12	12.3	21	171
Alkmaar	Y	83.7	41	49	12.8	132	1028
	O	77.4	41	53	20.5	181	872

Y=younger individuals (<35 years), O=older individuals (>35 years), n_{ai}=number of affected individuals, n_{oi}=number of individuals with observable teeth, n_{at}=number of affected teeth, n_{ot}=number of observable teeth.

Table 5.42: Statistical comparison of the adult caries percentage and frequency across the sites.

Site comparison		Caries prevalence				Caries frequency			
		χ2	df	p	n	χ2	df	p	n
Alkmaar-Blokhuizen	Y	12.000	1	**0.001**	70	18.309	1	**<0.001**	1462
	O	0.466	1	0.495	80	6.840	1	**0.009**	1241
Blokhuizen-Klaaskinderkerke	Y	1.293	1	0.256	39	0.275	1	0.600	757
	O	0.088	1	0.767	39	0.352	1	0.553	531
Klaaskinderkerke-Alkmaar	Y	3.857	1	**0.050**	67	10.880	1	**0.001**	1351
	O	0.084	1	0.771	64	6.304	1	**0.012**	1052

Y=younger individuals (<35 years), O=older individuals (>35 years), n=number of individuals/teeth included in test, df=degrees of freedom.

Table 5.43 shows the caries prevalence and frequency divided by sex and age. In Alkmaar and Blokhuizen both the younger and older females have a higher caries prevalence than the males In Blokhuizen, this is also true for the caries frequency. In Alkmaar, however, the older males have a higher caries frequency. In Klaaskinderkerke, more younger males are affected by caries, but females in the older adult age group are more commonly affected. The caries frequency is higher for both the older males and females in comparison with the younger adults in Klaaskinderkerke. The comparison of the sites shows that in Alkmaar both younger males and females have a higher caries prevalence and frequency than those in the other collections. In the older age category (both males and females), the differences are smaller, although in the caries frequency some large differences still exist between the sites.

Table 5.44 displays the results of the statistical comparison of the caries prevalence and frequency divided by age and sex across the sites. The table shows that there are statistically significantly more younger females with caries in Alkmaar than in the other sites. The caries frequency of the younger females in Alkmaar is also significantly higher than in Blokhuizen and Klaaskinderkerke. The high caries frequency of the older males in Blokhuizen in comparison with the other sites is striking. Between the Blokhuizen and Klaaskinderkerke, the two rural sites, there are no statistically significant differences suggesting similar dietary patterns for males and females of all ages.

Table 5.43: Adult caries percentage and frequency divided by age and sex across the sites.

Sites		Caries prevalence			Caries frequency		
		%	n_{ai}	n_{oi}	%	n_{at}	n_{ot}
Blokhuizen	YM	40.0	4	10	4.7	11	236
	YF	50.0	4	8	6.9	11	159
	OM	68.8	11	16	9.6	24	251
	OF	87.5	7	8	28.9	26	90
Klaaskinderkerke	YM	72.7	8	11	7.1	14	197
	YF	42.9	3	7	4.8	6	126
	OM	70.0	7	10	11.2	15	134
	OF	100.0	2	2	16.2	6	37
Alkmaar	YM	84.2	16	19	10.5	42	400
	YF	86.2	25	29	14.8	90	608
	OM	75.0	18	24	23.5	81	344
	OF	81.5	22	27	18.8	96	512

YM=younger male individuals (<35 years), YF=younger female individuals (<35 years), OM=older male individuals (>35 years), OF=older female individuals (>35 years), n_{ai}=number of affected individuals, n_{oi}=number of individuals with observable teeth, n_{at}=number of affected teeth, n_{ot}=number of observable teeth.

Table 5.44: Statistical comparison of the adult caries percentage and frequency divided by age and sex across the sites.

Site comparison		Caries prevalence				Caries frequency			
		χ2	df	p	n	χ2	df	p	n
Alkmaar-Blokhuizen	YM	5.983	1	**0.014**	29	6.625	1	**0.010**	636
	YF	4.850	1	**0.028**	37	6.852	1	**0.009**	767
	OM	0.188	1	0.665	40	19.529	1	**<0.001**	595
	OF	0.157	1	0.692	35	4.870	1	**0.027**	602
Blokhuizen-Klaaskinderkerke	YM	2.291	1	0.130	21	1.180	1	0.277	433
	YF	0.077	1	0.782	15	0.583	1	0.445	285
	OM	0.005	1	0.946	26	0.256	1	0.613	385
	OF	0.278	1	0.598	10	2.234	1	0.135	127
Klaaskinderkerke-Alkmaar	YM	0.574	1	0.449	30	1.788	1	0.181	597
	YF	6.131	1	**0.013**	36	9.256	1	**0.002**	734
	OM	0.091	1	0.763	34	9.618	1	**0.002**	478
	OF	0.448	1	0.504	29	0.146	1	0.702	549

YM=younger male individuals (<35 years), YF=younger female individuals (<35 years), OM=older male individuals (>35 years), OF=older female individuals (>35 years), n=number of individuals/teeth included in test.

Interestingly, while it is clear that the caries frequency and prevalence is higher in Alkmaar, so is the percentage of ante mortem tooth loss. Blokhuizen and Klaaskinderkerke have similar frequencies (11.7% and 8.4%, respectively), but Alkmaar has a much higher percentage at 19.4%. Considering that ante mortem tooth loss is commonly the result of caries, these differences frequency support the results that the Alkmaar collection was more affected by caries.

5.6.2 Nutritional deficiencies

i) Blokhuizen

None of the diagnostic features associated with the studied metabolic disorders were encountered in the Blokhuizen collection, suggesting that vitamin D and C deficiencies were not present, or did not alter the bone.

ii) Klaaskinderkerke

The skeletal indicators associated with scurvy are not observed in the Klaaskinderkerke collection. The diagnostic features associated with a vitamin D deficiency, on the other hand, are present in several individuals. Three of the adults in Klaaskinderkerke show the typical bilateral bending of both the femora and tibiae associated with residual rickets (see figure 5.18). One individual with bending deformities also has slight scoliosis in their upper thoracic vertebrae. Another individual show bending of the right femur. This is most likely the result of a vitamin D deficiency in childhood as well. However, since it is unilateral, this individual is diagnosed with possible residual rickets.

Figure 5.18: Residual rickets in individual K927V9A. Image shows bending deformity of the right tibia. The proximal end is visible on the left and the anterior surface of the bone shown.

Table 5.45 presents the demographic information about the individuals affected by residual rickets. It shows that only females definitively show the results of vitamin D deficiency in childhood (17.6%). Considering the different age-at-death of the females with residual rickets, childhood vitamin D deficiency does not appear to influence longevity.

Table 5.45: Demographic information on the individuals with possible and definitive metabolic diseases in the Klaaskinderkerke collection.

Disease	Skeletal number	Sex	Age
Possible residual rickets	K943V33	Male	36-45 years
Definitive residual rickets	K927V9A	Female?	26-35 years
	K931V13	Female	46+ years
	K944V34	Female	36-45 years

iii) Alkmaar

One individual in the Alkmaar collection shows skeletal indicators of vitamin C deficiency: scurvy. As discussed in chapter three, scurvy is difficult to diagnose in the skeleton, since many of the skeletal indicators are non-specific. This individual, between the age of 16 and 18 years, shows porosity of the eye orbits and sphenoid bone. In addition, the individual has a substantial amount of alveolar bone loss, which is unusual in an individual of this age. However, since only a few of the diagnostic criteria are observed, this individual is diagnosed with possible scurvy. The skeletal indicators of a vitamin D deficiency are not encountered.

iv) Site comparisons

Few cases of metabolic diseases are found in the studied skeletal collections. Scurvy is only possibly present in the Alkmaar collection and vitamin D deficiency is only observed in Klaaskinderkerke. None of the relevant metabolic diseases are noted in the Blokhuizen collection. There is no point in attempting statistical analysis of the observed differences between the studied sites, due to the low number of affected individuals.

5.6.3 Summary diet

Only the study of the carious lesions showed clear intra- and inter site differences. In Alkmaar and Blokhuizen, more adults than non-adults are affected by dental caries. This is different in Klaaskinderkerke, although it is most likely due to the small number of observable non-adults. The site comparisons show statistically significant differences, mainly between the younger adults, of which those from Alkmaar have a much higher caries prevalence and frequency. This suggests a higher consumption of foods that accelerated tooth decay in the Alkmaar collection. The study of metabolic diseases was not able to point to large differences in nutritional status, since almost no cases were observed. However, the fact that the bone features associated with vitamin D were only observed in Klaaskinderkerke is interesting and may point to differences in nutritional stress or living conditions (exposure to sunlight).

5.7 INDICATORS OF NON-SPECIFIC STRESS

5.7.1 Stature

i) Blokhuizen

Stature could be estimated for 22 individuals, of which there were 14 males and eight females. The mean male stature is 172.30 ± 5.7 cm. The females are substantially shorter, with a mean stature of 163.53 ± 4.4 cm. As expected, this difference is statistically significant (t=3.736, df=20, p=0.001, n=22).

The differences in height between the adult age groups and the correlation between stature and age-at-death are studied for Blokhuizen. As mentioned in section 5.3.2, not all adult individuals could be placed into discrete age categories due to poor preservation and low completeness. However, in some cases it was possible to estimate if the individual was younger or older than 35 years. These individuals are included in this analysis since only two larger age groups are used, bringing the total number of individuals to 21. Considering the sexually dimorphic nature of stature in Blokhuizen, the males and females are examined separately. A comparison of the mean stature of the younger males (M=170.05 cm, SD=7.29, n=6) with the mean stature of the older males (M=173.99, SD=4.0 cm, n=8) shows a difference of almost 4 cm. In particular, there are two younger males that are quite a bit shorter than the rest of the males (figure 5.19). However, the difference is not statistically significant (t=−1.303, df=12, p=0.217, n=14).

To study the correlation between age-at-death and height in the Blokhuizen assemblage, the results for the male individuals are plotted in figure 5.19. The graph shows that the younger males are shorter than the older adults. To test if this observed pattern holds up, a Spearman's coefficient of rank correlation is executed. The test shows that there is no statistically significant correlation between age-at-death and stature (rs=0.286, p=0.321, n=14).

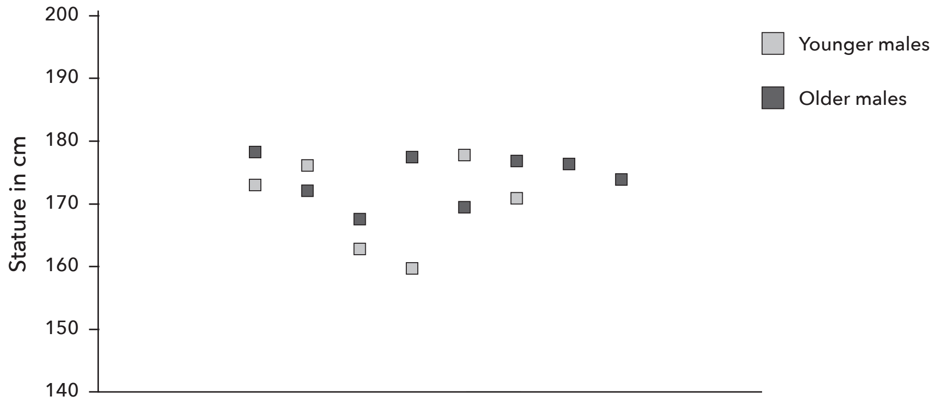


Figure 5.19: Correlation of stature with age-at-death of the adult male individuals from Blokhuizen (n=14; younger adults (<35 years): n=6, older adults (>35 years): n=8). Only individuals for whom sex, age, and stature could be estimated are included in this graph.

As mentioned, the number of individuals available for study is substantially influenced by the poor condition of the skeletal material. Sex, age, and stature could be estimated for only seven female individuals. A comparison of the mean stature of the younger females (M=165.41 cm, SD=2.7, n=4) with the mean stature of the older females (M=161.26 cm, SD=6.4 cm, n=3) shows a difference of more than 4 cm. The younger individuals were taller at time of death. However, as with the male individuals, this difference is not statistically significant (t=1.196, df=5, p=0.285, n=7). The difference between the age groups is also visible when the results are plotted (Figure 5.20). However, no statistically significant correlation is found between age and height is found (rs=-0.289, p=0.530, n=7).

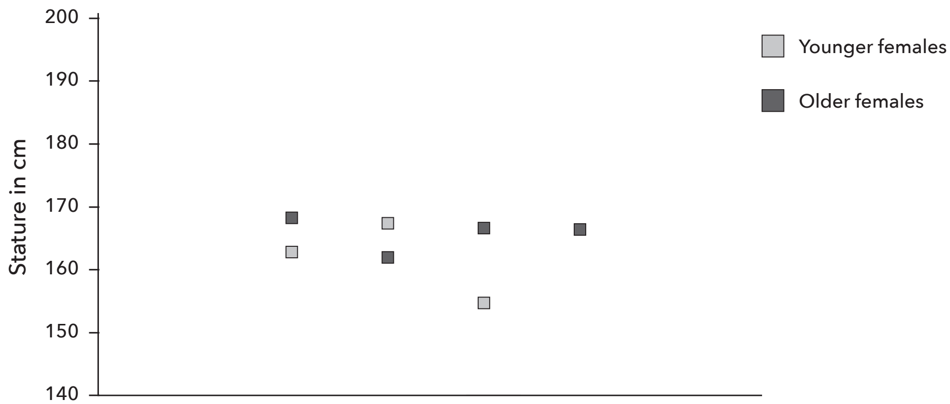


Figure 5.20: Correlation of stature with age-at-death of the adult female individuals from Blokhuizen (n=7; younger adults (<35 years): n=4, older adults (>35 years): n=3). Only individuals for whom sex, age and stature could be estimated are included in this graph.

ii) Klaaskinderkerke

Stature could be estimated for 47 adult individuals, of which there were 32 males and 15 females. The mean female stature is 163.52 ± 4.6 cm. This mean stature of the males is 173.79 ± 6.6 cm. These suggest strong sexual dimorphism in stature in the Klaaskinderkerke collection. An independent samples t-test confirms the highly significant difference between the male and female stature means (t=4.532, df=45, p<0.001, n=47).

The differences in mean height between the age groups and the correlation between stature and age-at-death have been studied for the Klaaskinderkerke assemblage. Firstly, the males of Klaaskinderkerke collection are discussed. Two male individuals were excluded as age could not be estimated. When the means for the younger adults males (M=173.76 cm, SD=7.9, n=15) and the older adult males (M=174.68 cm, SD=5.1, n=15) are calculated, it is apparent that the difference in stature means is only 0.92 cm. Clearly, this difference is not statistically significant (t=−0.376, df=28, p=0.709, n=30).

To illustrate the lack of patterning, the correlation between age-at-death and height is plotted in figure 5.21. There is no statistically significant correlation between age-at-death and height with respect to the Klaaskinderkerke male individuals. This is as confirmed by a Spearman's coefficient of rank correlation test (rs=0.089, p=0.641, n=30).

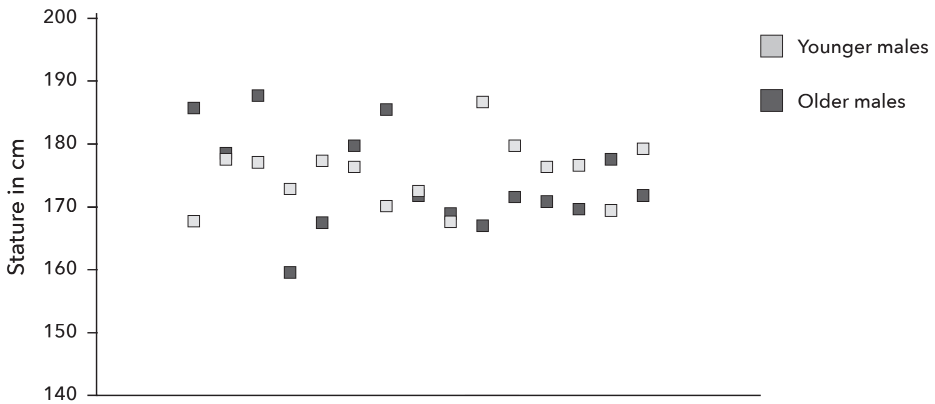


Figure 5.21: Correlation of stature with age-at-death of the adult male individuals from Klaaskinderkerke (n=30; younger adults (<35 years): n=15, older adults (>35 years): n=15). Only individuals for whom sex, age and stature could be estimated are included in this graph.

As with mean male stature, there appears to be no difference between the female heights in the different age groups. The younger adult females (n=11) have a mean stature of 163.77 ± 5.3 cm; the older adult females (n=4) one of 162.84 ± 2.3 cm. An independent samples t-test shows no statistically significant difference (t=0.336, df=13, p=0.645, n=15). The correlation between age-at-death and height is plotted in figure 5.22 where no patterning is observed. This is statistically confirmed (rs=-0.105, p=0.710 n=15). It is, however, important to note that the sample size for the older female adults is small (n=4).

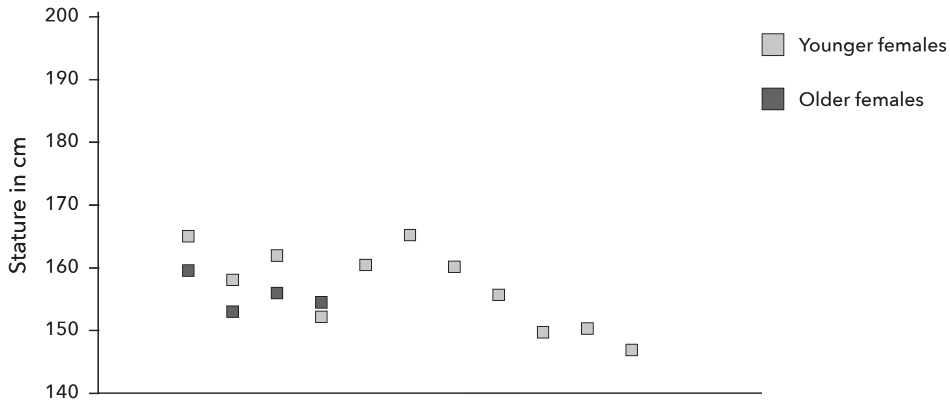


Figure 5.22: Correlation of stature with age-at-death of the adult female individuals from Klaaskinderkerke (n=15; younger adults (<35 years): n=11, older adults (>35 years): n=4). Only individuals for whom sex, age and stature could be estimated are included in this graph.

iii) Alkmaar

Stature could be estimated for 123 individuals, of which there are 54 males and 69 females. The mean stature of the males is 174.75 ± 6.3 cm; that of the females is 162.15 ± 5.7 cm. The average difference between males and females is 12.6 cm indicating the sexually dimorphic character of stature in the Alkmaar assemblage. As expected, the difference between the mean stature of the males and females is highly statistically significant (t=11.560, df=121, p<0.001, n=123).

Differences in height between the age groups have been researched in order to determine if a shorter stature is associated with a younger age-at-death. For this purpose, only two age groups were used (19–35 years and 36–46+ years) to enlarge sample size per age group and make the different sites comparable. This analysis only includes individuals for whom sex, age, and stature could be estimated.

Firstly, the mean stature of the males in the younger adult age group (M=174.52 cm, SD=6.9 cm, n=21) is compared with the mean stature in the older adult age group (M=174.93 cm, SD=6.3 cm, n=24) using an independent samples t-test. This test determined that there is no statistical difference between groups (t=–0.014, df=59, p=0.989, n=61). In addition to comparing the means, the correlation of age-at-death and height is studied. Figure 5.23 shows the correlation of height in cm with the age-at-death of the male adult individuals. The graph shows no correlation between the variables; the stature of younger adults is dispersed evenly among the stature of older adults. A Spearman's coefficient of rank correlation confirmed that there is no statistically significant correlation between stature and age-at-death (rs=0.39, p=0.797, n=45).

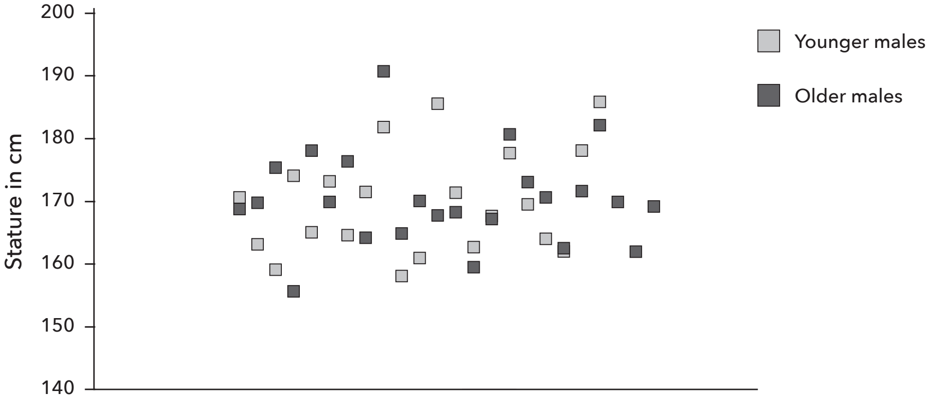


Figure 5.23: Correlation of stature with age-at-death of the adult male individuals from Alkmaar (n=45; younger adults (<35 years): n=21, older adults (>35 years): n=24). Only individuals for whom sex, age and stature could be estimated are included in this graph.

Subsequently, the difference in the stature means between the two age groups and the correlation between age-at-death and stature of the adult females has been studied. A comparison of the mean stature of the younger females (M=162.33 cm, SD=6.3 cm, n=33) to the mean stature of the older females (M=162.35 cm, SD=5.5 cm, n=28) indicates that there is no statistically significant difference (t=–0.014, df=59, p=0.989, n=61). To study the correlation between age-at-death and stature, the data are plotted in a scatterplot. Figure 5.24 displays the younger (n=33) and the older females (n=28), and their height in cm. As with the Alkmaar males, there is no correlation between stature and age-at-death. A Spearman's coefficient of rank supports this finding (rs=–0.041, p=0.753, n=61).

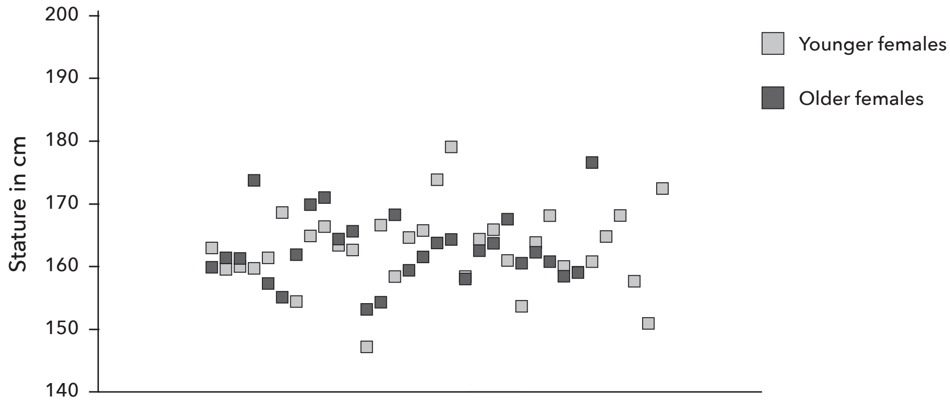


Figure 5.24: Correlation of stature with age-at-death of the adult female individuals from Alkmaar (n=61; younger adults (<35 years): n=33, older adults (>35 years): n=28). Only individuals for whom sex, age and stature could be estimated are included in this graph.

iv) Site comparisons

The stature means with standard deviations per site are shown in table 5.46 shows. The males and females are shown separately. The table shows that the differences in stature mean are small between the studied sites. This is true for both the mean male statures and the mean female statures. The apparent lack of difference is confirmed statistically, which determined that there are no significant differences between sites for both the males and females (see table 5.47).

Table 5.46: Overview of the stature means for the males and females of the three sites.

Sites	Males			Females			Mean difference
	M	SD	n	M	SD	n	
Blokhuizen	172.30	5.7	14	163.53	4.4	8	8.77
Klaaskinderkerke	173.79	6.6	32	163.52	4.6	15	10.27
Alkmaar	174.75	6.3	54	162.15	5.7	69	12.60

The stature means (M) and the standard deviation (SD) are in centimetres. n=number of individuals used to calculate the means, MD=mean difference in cm between male and female stature.

Table 5.47: Statistical comparison of the male and female stature means between sites.

Site comparison	Males				Females			
	t	df	p	n	t	df	p	n
Alkmaar –Blokhuizen	1.311	66	0.195	68	-0.656	75	0.514	77
Blokhuizen-Klaaskinderkerke	-0.731	44	0.468	46	0.001	21	0.999	23
Klaaskinderkerke-Alkmaar	0.670	84	0.505	86	-0.868	82	0.388	84

n=number of individuals, df=degrees of freedom.

A comparison between the stature means in the age groups and the different sites is performed as well. Table 5.48 presents the male and female stature means per age group and per site. The table shows that the differences between the sites are very small for both the males and females. To test if there are indeed no significant differences between the age group specific stature means among the sites, several t-tests are conducted of which the results of the tests are displayed in table 5.49. No statistically significant differences have been found.

Table 5.48: Overview of the stature means per age group for the individuals from the Alkmaar, Blokhuizen, and Klaaskinderkerke collections.

Sites		Males			Females		
		M	SD	n	M	SD	n
Blokhuizen	Y	170.05	7.3	6	165.40	2.7	4
	O	173.99	4.0	8	161.26	6.4	3
Klaaskinderkerke	Y	173.77	7.9	15	163.77	5.3	11
	O	174.68	5.1	15	162.84	2.3	4
Alkmaar	Y	174.52	6.9	21	162.33	6.3	33
	O	174.93	6.3	24	162.35	5.5	28

The stature means (M) and the standard deviation (SD) are in centimetres. n=number of individuals.

Table 5.49: Statistical comparison of the mean male and female statures in a specific age group between the three different sites.

Site comparison		Males				Females			
		t	df	p	n	t	df	P	n
Alkmaar- Blokhuizen	Y	1.381	25	0.180	27	−0.957	35	0.345	37
	O	0.393	30	0.697	32	0.321	29	0.751	31
Blokhuizen-Klaaskinderkerke	Y	−0.991	19	0.334	21	0.585	13	0.569	15
	O	−0.331	21	0.744	23	−0.467	5	0.660	7
Klaaskinderkerke-Alkmaar	Y	0.304	34	0.763	36	−0.681	42	0.499	44
	O	0.130	37	0.898	39	−0.172	30	0.865	32

Y=younger individuals (<35 years), O=older individuals (>35 years), n=number of individuals, df=degrees of freedom.

5.7.2 Dental enamel hypoplasia

i) Blokhuizen

Due to poor preservation of the dentitions, only 51 individuals (12 non-adults and 39 adults) from the Blokhuizen collection could be assessed (i.e., had at least three anterior teeth available and were not mature adults) for the presence of enamel hypoplasia. Table 5.50 shows the number and percentages of teeth per tooth type available for study. The percentages indicate the proportion of available tooth types in relation to the total number of studied teeth. In a complete adult dentition (32 teeth), 25.0% should be incisors (8/32), 12.5% canines (4/32), 25.0% premolars (8/32), and 37.5% molars. The incisors appear to be somewhat underrepresented in the sample, which is, considering the preservation of the skeletal material, most likely the result of post-mortem tooth loss. The calculated percentages for the other tooth types are very close to the expected numbers. The non-adult data are influenced by the ages of the individuals; the percentages are solely an indication of the studied teeth.

Table 5.50: Number of studied teeth per tooth type for enamel hypoplasia from Blokhuizen.

Tooth types	Non-adult		Adult		Total	
	n	%	n	%	n	%
Incisors	32	36.0	168	21.6	200	23.1
Canines	6	6.7	104	13.4	110	12.7
Premolars	11	12.4	219	28.2	230	26.6
Molars	40	44.9	286	36.8	326	36.6
Total	89	100.0	777	100.0	866	100.0

n=number of teeth available for study. Percentage is in relation to total number of present teeth.

In the Blokhuizen assemblage, 27 individuals (52.9%) had enamel hypoplasia. Of these, 21 are adults (53.8%) and six are non-adults (50.0%). Four of the non-adults died between the age of four and twelve years; one individual was between the age of 12 and 18 years, and one was estimated to be an infant (0–3 years), who showed a single horizontal line on the unerupted first permanent upper molars. Considering the small sample size for the non-adults, no statistical analysis has been attempted.

Of the adult individuals with enamel hypoplasia, 12 are males, eight are females, and one adult is of indeterminate sex. When studied in relation to the total number of analysed males and females in the Blokhuizen collection, 52.2% of the males and 61.5% of the females are affected by enamel hypoplasia. This difference is not statistically significant (χ^2=0.295, df=1, p=0.587, n=36). The lack of difference is most likely not related to different numbers of observable teeth: the percentage of total expected teeth as well as the percentage of the expected anterior teeth for males and females are very similar (64.9% versus 63.0%, and 58.9% versus 61.6%, respectively).

Approximate age-at-death could be estimated for 35 of the adult individuals with observable teeth, of which 19 could be placed into the younger adult age group and 16 into the older adult age group. The younger age group includes 12 individuals with enamel hypoplasia (63.2%), the older age group eight individuals (50.0%). Based on these percentages, there appear to be slightly more younger adults than older adults with enamel hypoplasia in the Blokhuizen collection. However, no statistically significant difference was found (χ^2=0.614, df=1, p=0.433, n=35).

To study possible differences in enamel hypoplasia in relation to sex and age-at-death, males and females are discussed separately. Table 5.51 shows the total number of affected individuals and the number of affected males and females. Interestingly, there is a significant difference between the age groups in the males: more younger males are affected by enamel hypoplasia (χ^2=4.791, df=1, p=0.029, n=22). More older females are affected by enamel hypoplasia, but this is not statistically significant (χ^2=1.837, df=1, p=0.175, n=10). Although the difference appears large, the sample size is very small for the females with estimated age, making the statistical analysis unreliable. Moreover, as noted above, there is a difference in number of observable teeth between the younger and the older adults, which could have influenced the results discussed here.

Table 5.51: Number of individuals with enamel hypoplasia in the different age groups in relation to total number of individuals in the specific age groups in the Blokhuizen collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	8	80.0	4	57.1	12	63.2
Older adults	4	33.3	3	100.0	8	50.0

n=number of affected individuals. The total includes individuals with indeterminate sex.

ii) Klaaskinderkerke

The collection of Klaaskinderkerke comprises 26 individuals (24 adults and 2 non-adults) with enough observable teeth to score for enamel hypoplasia. Table 6.52 shows the number and percentages of teeth per tooth type available for study. If the adult calculated percentages are compared with the expected percentages listed above, it becomes clear that the incisors are underrepresented in the sample, most likely as a result of post-mortem tooth loss. It is important to note that this could have influenced the enamel hypoplasia prevalence, since the anterior teeth are the most prone to developing dental defects. The incisors are well represented in the non-adult sample.

Table 5.52: Number of studied teeth per tooth type for enamel hypoplasia from Klaaskinderkerke.

Tooth types	Non-adults		Adults		Total	
	n	%	n	%	n	%
Incisors	11	36.7	84	18.4	95	19.5
Canines	2	6.6	62	13.6	64	13.2
Premolars	6	20.0	134	29.4	140	28.8
Molars	11	36.7	176	38.6	187	38.5
Total	30	100.0	456	100.0	486	100.0

n=number of teeth available for study.

In total, 14 of the studied individuals are affected by enamel hypoplasia (53.8%). None of them are non-adults. Since the sample size of the non-adults is very small (only two non-adults), it should be noted that an assessment of non-adult prevalence of enamel hypoplasia is unreliable and, consequently, has not been attempted.

Sex could be estimated for all the affected adults: in total there were six females (75.0%) and eight males (50.0%) with enamel hypoplasia. The percentages show that there is a difference between numbers of affected males and females. Statistically, however, it is not significant (χ^2=1.371, df=1, p=0.242, n=24).

The age-at-death could be estimated for all the affected individuals: in total, there are nine younger adults (60.0%) and five older individuals (55.6%) with enamel hypoplasia. The difference between the percentages of younger and older adults with enamel hypoplasia is statistically insignificant (χ^2=0.046, df=1, p=0.831, n=24). The percentages of anterior teeth are similar between the two age groups: the younger adults have 49.0% and the older adults 48.1% of the expected number of anterior teeth (χ^2=0.018, df=1, p=0.893, n=300).

To study the possible age differences in relation to enamel hypoplasia between the sexes, males and females are discussed separately. The results are shown in table 5.53. There appear to be more younger than older females with enamel hypoplasia. Of the six younger adult females, five are affected by enamel hypoplasia (83.3%). Of the two females older than 35 years, one (50%) had hypoplastic bands on her teeth. Considering the small sample size, statistical testing is not attempted. The difference between the percentages of younger and older affected males is small. The table shows that there are more older males with enamel hypoplasia. Considering the small sample size, no statistical analysis is performed. The difference between the younger males and younger females appears substantial, but may be influenced by small sample size.

Table 5.53: Number of individuals with enamel hypoplasia in the different age groups in relation to total number of individuals in the specific age groups in the Klaaskinderkerke collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	4	44.4	5	83.3	9	60.0
Older adults	4	57.1	1	50.0	5	55.6

n=the number of affected individuals. The total includes individuals with indeterminate sex.

iii) Alkmaar

The Alkmaar collection comprises 98 individuals (86 adults and 12 non-adults) with teeth meeting the criteria. Table 5.54 presents the number of teeth per tooth type available for study. The table shows that the actual percentages are similar to the expected percentages. There is a slight underrepresentation of molars, most likely as a result of ante-mortem tooth loss, or congenital absence, which is common for the 3rd molar (Hillson 2005). For non-adults, the expected percentages are very difficult to calculate, since the number of tooth types present depends on the age composition of the non-adult group. Therefore, the percentages shown below are solely an indication of what was available.

Table 5.54: Number of studied teeth per tooth type for enamel hypoplasia from Alkmaar.

Tooth types	Non-adults		Adults		Total	
	n	%	n	%	n	%
Incisors	76	31.8	451	26.1	527	26.8
Canines	27	11.3	246	14.2	273	13.9
Premolars	52	21.8	484	28.0	536	27.2
Molars	84	35.1	548	31.7	632	32.1
Total	239	100.0	1729	100.0	1968	100.0

n=number of teeth available for study.

Of the 98 individuals that could be studied for the presence of enamel hypoplasia, 64 individuals (65.3%) are affected, of which eight are non-adults (66.7%) and 56 adults (65.1%). The affected non-adults include six adolescents between the age of 12 and 18 years and two children between the age of four and seven years of age. All the non-adult individuals have multiple types of permanent teeth affected. Figure 5.25 shows linear enamel hypoplasia in an adolescent. The image displays the multiple linear lines on the incisors and canines. In addition, the hypoplasia (plane-form defect type) on the top part of the crowns of the incisors and canines is noteworthy.

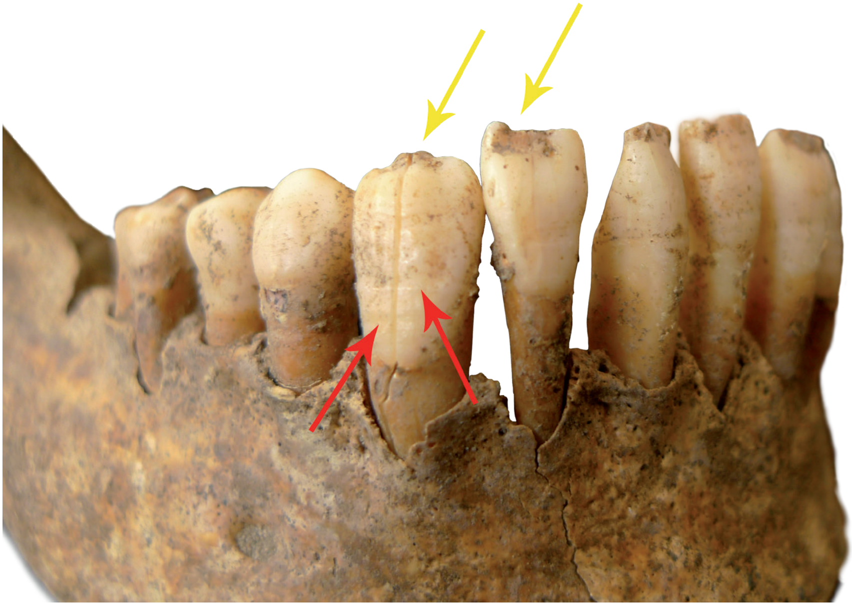


Figure 5.25: Enamel hypoplasia in an adolescent individual from Alkmaar (S442V1039). Note the multiple horizontal lines on the incisors and canines (red arrows), and the partial destruction of the top part of the crowns (yellow arrows).

Of the adult individuals with enamel hypoplasia, 18 are male and 37 are female; sex could not be estimated for one of the affected adult individual. The percentages of males and females with enamel hypoplasia are 56.3% and 72.5%, respectively. Even though more females are affected, the difference is not statistically significant (χ^2=2.337, df=1, p=0.126, n=83). Since the numbers of observable teeth are similar between males and females (62.6% versus 63.9%) and not statistically significant different (χ^2=0.467, df=1, p=0.495, n=2656), the lack of observed differences in enamel hypoplasia prevalence are not related to differences in number of observable teeth.

Age-at-death could be estimated for 54 of the affected adult individuals, of which 35 were younger than 35 years of age and 19 were older than 35 years. As discussed in paragraph 2.8.2, the mature adults are not included in the sample. Table 5.55 presents the total number of affected individuals in relation to the total observable number of individuals in that particular age group. The table shows that the percentage of affected individuals in the younger age group is higher in comparison with the older age group. This difference is statistically highly significant (χ^2=7.189, df=1, p=0.007, n=81). This difference may have been caused by differential preservation of the dentitions. The younger adults have 71.4% of their expected teeth and the older adults 58.7%. This difference is statistically significant (χ^2=45.020, df=1, p<0.001, n=2556). However, the difference in number of observable teeth is mainly caused by a decrease in the number of molars as a result of ante-mortem tooth loss.

If just the percentages of observable anterior teeth are compared, the difference disappears. The younger adults have 68.8% and older adults have 68.7% of the expected number of anterior teeth available for study. Therefore, the difference in enamel hypoplasia between the age groups can be considered to be real.

If the sexes are analysed separately according to age groups, similar patterns are visible (see table 5.55). The percentage of younger males with enamel hypoplasia is higher than that of older males with enamel hypoplasia. However, this difference is not statistically significant (χ^2=0.362, df=1, p=0.547, n=30). The females show a much larger difference: more younger females are affected by enamel hypoplasia than older females. This difference is statistically significant (χ^2=6.941, df=1, p=0.008, n=48). In addition, the difference between the affected younger males and younger females appears large but does not reach statistical significance, although a strong trend is suggested (χ^2=3.505, df=1, p=0.061, n=43). In contrast, there is no difference between the number of older males and females with enamel hypoplasia (χ^2=0.002, df=1, p=0.968, n=35).

Table 5.55: Number of individuals with enamel hypoplasia in the different age groups in relation to total number of individuals in the age groups in the Alkmaar collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	11	64.7	23	88.5	35	79.5
Older adults	7	53.8	12	54.5	19	51.4

n=number of affected individuals. The total includes individuals with indeterminate sex.

iv) Site comparisons

Table 5.56 displays the combined data on the number of the different teeth available for all three sites. With respect to non-adults, it is difficult to make a comparison with expected numbers. A total of 32 teeth can be expected for adults. As discussed above, all sites reasonably match the expected numbers. There is a slight underrepresentation of molars in Alkmaar and an underrepresentation of incisors in Blokhuizen and Klaaskinderkerke. To check if similar numbers of tooth types have been studied across the sites, statistical analysis has been performed on the total numbers of available teeth. The results are shown in table 5.57. The table shows that in the Alkmaar sample there are significantly less molars in comparison with Blokhuizen and Klaaskinderkerke. Additionally, the individuals from Blokhuizen and Klaaskinderkerke have significantly fewer incisors than the Alkmaar individuals. This is most likely related to post-mortem tooth loss. Although most of the statistical comparisons were not significant, the different numbers of molars and especially incisors may have influenced the enamel hypoplasia prevalence results.

Table 5.56: Total number of studied teeth per tooth type for enamel hypoplasia from the three sites.

Tooth type	Blokhuizen		Klaaskinderkerke		Alkmaar	
	n	%	n	%	n	%
	Total					
Incisors	200	23.1	95	19.5	527	26.8
Canines	110	12.7	64	13.2	273	13.9
Premolars	230	26.6	140	28.8	536	27.2
Molars	326	36.6	187	38.5	632	32.1
Total	866	100.0	486	100.0	1968	100.0
	Adults					
Incisors	168	21.6	84	18.4	451	26.1
Canines	104	13.4	62	13.6	246	14.2
Premolars	219	28.2	134	29.4	484	28.0
Molars	286	36.8	176	38.6	548	31.7
Total	777	100.0	456	100.0	1729	100.0
	Non-adults					
Incisors	32	36.0	11	36.7	76	31.8
Canines	6	6.7	2	6.6	27	11.3
Premolars	11	12.4	6	20.0	52	21.8
Molars	40	44.9	11	36.7	84	35.1
Total	89	100.0	30	100.0	239	100.0

n=number of studied teeth.

Table 5.57: Statistical comparison of the percentages of teeth per tooth type across the three sites.

Site comparison		Percentages of teeth per tooth type			
		χ2	df	p	n
Alkmaar-Blokhuizen	Incisors	4.279	1	**0.039**	2834
	Canines	0.704	1	0.401	2834
	Premolars	0.104	1	0.709	2834
	Molars	8.220	1	**0.004**	2834
Blokhuizen- Klaaskinderkerke	Incisors	2.296	1	0.130	1352
	Canines	0.060	1	0.806	1352
	Premolars	0.791	1	0.374	1352
	Molars	0.092	1	0.762	1352
Klaaskinderkerke-Alkmaar	Incisors	10.770	1	**0.001**	2454
	Canines	0.163	1	0.687	2454
	Premolars	0.482	1	0.488	2454
	Molars	0.7098	1	**0.008**	2454

n=the number of affected individuals.

Table 5.58 shows the numbers and the percentages of individuals affected by enamel hypoplasia in the three studied sites. The adults and non-adults are displayed separately. The table shows that there are fewer non-adults than adults with enamel hypoplasia in Blokhuizen and Klaaskinderkerke. In Alkmaar, however, the percentage of non-adults with dental defects is slightly higher. It has to be taken into account that the sample size for the non-adults is very small at all three sites. For Alkmaar and Blokhuizen, 12 non-adults were studied; in Klaaskinderkerke only two non-adults had enough teeth to be included in the sample. From the table it is clear that Alkmaar has the highest percentage of enamel hypoplasia for both non-adults and the adults.

Table 5.58: Number and percentage of individuals (adults and non-adults) with enamel hypoplasia in the three sites.

Sites	Adults		Non-adults		Total	
	n	%	n	%	n	%
Blokhuizen	21	53.8	6	50.0	27	52.9
Klaaskinderkerke	14	58.3	0	0.0	14	53.3
Alkmaar	56	65.1	8	66.7	64	65.3

n=number of affected individuals.

Table 5.59 shows the results of the statistical comparison of the prevalence of enamel hypoplasia between the sites. The analysis has been executed for the adult individuals only, considering the small sample size of non-adults: statistical testing would be unreliable. As becomes clear from the table, there are no statistical differences in adult enamel hypoplasia prevalence between the sites.

Table 5.59: Statistical comparison of the adult prevalence of enamel hypoplasia across the studied sites.

Site comparison	Adults			
	$\chi 2$	df	p	n
Alkmaar-Blokhuizen	1.441	1	0.230	125
Blokhuizen-Klaaskinderkerke	0.121	1	0.728	63
Klaaskinderkerke-Alkmaar	0.373	1	0.541	110

n=number of individuals included in the test, df=degrees of freedom.

Before showing the results of enamel hypoplasia prevalence divided by sex, the available number of teeth for males and females per site are displayed to be able to correctly interpret the prevalence data. Table 5.60 shows the expected number of teeth (i.e., if the dentition would be complete: 32 teeth) and observed numbers of teeth per age group. Additionally, the table shows the numbers of expected (12 per individual) and observed anterior teeth, since these are most prone to developing enamel defects.

Table 5.60: Numbers and percentages of expected teeth versus observed number of teeth separated by sex across the three sites.

Sites		Males				Females			
		n_e	n_o	%	n	n_e	n_o	%	n
Blokhuizen	AT	276	170	61.6	23	156	92	59.0	13
	T	736	464	63.0	23	416	270	64.9	13
Klaaskinderkerke	AT	192	94	49.0	16	96	52	54.2	8
	T	512	269	57.8	16	256	160	62.5	8
Alkmaar	AT	384	267	69.5	32	612	410	67.0	51
	T	1024	641	62.6	32	1632	1043	63.9	51

AT= anterior teeth (incisors and canines), T=total (all tooth types combined), n_e=number of expected teeth, n_o=number of observed teeth, n=number of individuals.

Table 5.61 presents the results of the statistical comparison of the numbers of available teeth in the different sites. The table shows that there are statistically significant differences, especially between the males of the studied sites. The females of the different sites appear to have more similar numbers of teeth available. These differences may have affected the enamel hypoplasia prevalence results and are therefore taken into account when the prevalence data are interpreted.

Table 5.61: Statistical comparison of the percentages of anterior teeth and percentages of all teeth combined separated by sex across the three sites.

Site comparison		Males				Females			
		χ2	df	p	n	χ2	df	p	n
Alkmaar-Blokhuizen	AT	4.522	1	**0.033**	660	3.531	1	0.060	768
	T	0.036	1	0.849	1760	0.143	1	0.706	2048
Blokhuizen-Klaaskinderkerke	AT	7.352	1	**0.007**	468	0.561	1	0.454	252
	T	13.747	1	**<0.001**	1248	0.397	1	0.528	672
Klaaskinderkerke-Alkmaar	AT	23.158	1	**<0.001**	576	6.022	1	**0.014**	708
	T	14.303	1	**<0.001**	1536	0.190	1	0.663	1888

AT= anterior teeth (incisors and canines), T=total (all tooth types combined).

Table 5.62 shows the numbers and the percentages of affected individuals separated by sex. Females consistently have a higher prevalence of enamel hypoplasia at all three sites. However, as has been shown above, the differences between the number of affected males and females within the sites is not significantly different. Additionally, the percentages suggest that there are no differences in the number of affected males and females between the sites. Table 5.63 shows the results of the statistical analysis testing for these differences. As expected, there are no statistically significant differences, indicating that across the sites males and females are equally as likely to develop dental defects. It is important to note, however, that the indicated differences in number of available teeth between the sexes could have influenced the results.

Table 5.62: Number and percentage of males and females with enamel hypoplasia in the three sites.

Sites	Males		Females		Total	
	n	%	n	%	n	%
Blokhuizen	12	52.2	8	61.5	21	53.8
Klaaskinderkerke	8	50.0	6	75.0	14	58.3
Alkmaar	18	56.3	37	72.5	56	65.1

n=number of individuals affected individuals. The total includes individuals with indeterminate sex.

Table 5.63: Statistical comparison of male and female prevalence of enamel hypoplasia across the studied sites.

Site comparison		Enamel hypoplasia prevalence			
		χ2	df	p	n
Alkmaar-Blokhuizen	M	0.090	1	0.765	55
	F	0.602	1	0.438	64
Blokhuizen-Klaaskinderkerke	M	0.018	1	0.894	39
	F	0.404	1	0.525	21
Klaaskinderkerke-Alkmaar	M	0.168	1	0.682	48
	F	0.021	1	0.885	59

M=male, F=female, n=number of individuals included in the test, df=degrees of freedom.

Before showing the results of the enamel hypoplasia prevalence per age group, the available numbers of teeth for the younger and older adults per site are compared in order to be able to correctly interpret the prevalence data. Table 5.64 shows the expected number of teeth (i.e., if the dentition would be complete: 32 teeth) and the observed number of teeth per age group. Additionally, the table shows the number of expected and observed anterior teeth. From the table it becomes clear that there are some differences between the sites in the percentages of both the anterior teeth as well as all teeth combined.

This is confirmed by a statistical analysis of the percentages of available teeth. The results can be found in table 5.65. It is clear that there are several statistically significant differences between the percentages. Especially, the difference in teeth numbers between Alkmaar and Klaaskinderkerke is large. These differences may have influenced the enamel hypoplasia prevalence results in the age groups and they have to be taken into account.

Table 5.64: Numbers and percentages of expected teeth versus observed number of teeth separated by age across in the three sites.

Sites		Younger adults				Older adults			
		n_e	n_o	%	n	n_e	n_o	%	n
Blokhuizen	AT	228	145	63.6	19	192	105	54.7	16
	T	608	424	69.7	19	512	281	54.9	16
Klaaskinderkerke	AT	192	94	49.0	15	108	52	48.1	9
	T	480	310	64.6	15	288	146	50.7	9
Alkmaar	AT	528	363	68.8	44	444	305	68.7	37
	T	1408	1005	71.4	44	1148	674	56.9	37

AT= anterior teeth (incisors and canines), T=total (all tooth types combined), n_e=number of expected teeth, n_o=number of observed teeth, n=number of individuals.

Table 5.65: Statistical comparison of the percentages of anterior teeth and percentages of all teeth combined per age group across the three sites.

Site comparison		Younger adults				Older adults			
		$\chi2$	df	p	n	$\chi2$	df	p	n
Alkmaar-Blokhuizen	AT	1.919	1	0.166	756	11.479	1	**0.001**	636
	T	0.554	1	0.457	2016	2.124	1	0.145	1660
Blokhuizen-Klaaskinderkerke	AT	9.107	1	**0.003**	420	1.185	1	0.276	300
	T	3.245	1	0.072	1088	1.229	1	0.254	800
Klaaskinderkerke-Alkmaar	AT	23.788	1	**<0.001**	720	16.050	1	**<0.001**	552
	T	7.818	1	**0.005**	1888	6.040	1	0.014	1436

AT= anterior teeth (incisors and canines), T=total (all tooth types combined).144

Table 5.66 shows the numbers and percentages of individuals affected by enamel hypoplasia separated by age. The younger adults consistently have a higher prevalence of enamel hypoplasia than the older adults. However, as was shown above, they also had a higher percentage of the expected teeth available for study.

Table 5.66: Numbers and percentages of younger and older adults with enamel hypoplasia in the three sites.

Sites	Younger adults		Older adults		Total	
	n	%	n	%	n	%
Blokhuizen	12	63.2	8	50.0	21	53.8
Klaaskinderkerke	9	60.0	5	55.6	14	58.3
Alkmaar	35	79.5	19	51.4	56	65.1

n=number of affected individuals. The total includes individuals with indeterminate age.

Table 5.67 presents the statistical comparison of the prevalence of enamel hypoplasia in the two age groups. The table shows that there are no statistically significant differences in prevalence between the younger and older adults at the three sites. It has to be kept in mind, though, that there are differences in numbers of available teeth, which possibly influenced the results. However, considering the similarities in prevalence, it is unlikely that the differences in teeth number are solely responsible for the insignificant results.

Table 5.67: Statistical comparison of enamel hypoplasia prevalence between younger and older adults across the sites.

Site comparison		Enamel hypoplasia prevalence			
		χ^2	df	p	n
Alkmaar-Blokhuizen	Younger adults	1.881	1	0.170	63
	Older adults	0.008	1	0.928	53
Blokhuizen-Klaaskinderkerke	Younger adults	0.035	1	0.851	34
	Older adults	0.071	1	0.790	25
Klaaskinderkerke-Alkmaar	Younger adults	2.254	1	0.133	59
	Older adults	0.051	1	0.821	46

M=male, F=female, n=number of individuals included in the test, df=degrees of freedom.

Table 5.68 combines the data on enamel hypoplasia prevalence with the estimations of sex and age-at-death. In Alkmaar and Klaaskinderkerke, the percentage of young females with enamel hypoplasia is higher than that of older females with enamel hypoplasia, suggesting that the presence of the pathology was influencing female longevity. The difference between the numbers of younger and older females with enamel hypoplasia is only significant in Alkmaar, as was shown above. In Blokhuizen, more younger males are affected by enamel hypoplasia. It is important to note here that differences in available number of teeth may have influenced the results.

Table 5.68: Numbers and percentages of individuals with enamel hypoplasia separated by sex and age-at-death in the Alkmaar, Blokhuizen and Klaaskinderkerke collections.

Sites		Males		Females		Total	
		n	%	n	%	n	%
Blokhuizen	Younger adults	8	80.0	4	57.1	12	63.2
	Older adults	4	33.3	3	100.0	8	50.0
Klaaskinderkerke	Younger adults	4	44.4	5	83.3	9	60.0
	Older adults	4	57.1	1	50.0	5	55.6
Alkmaar	Younger adults	11	64.7	23	88.5	35	79.5
	Older adults	7	53.8	12	54.5	19	51.4

n=the number of affected individuals.

5.7.3 Cribra orbitalia and porotic hyperostosis

i) Blokhuizen

The Blokhuizen collection comprises 56 individuals with eye orbits to assess for cribra orbitalia and 64 crania for the study of porotic hyperostosis. Cribra orbitalia was found in 13 individuals (23.2%).The lesions were healed in all the affected individuals. More non-adults than adults are affected by cribra orbitalia: 53.3% of the non-adults show the lesions while only 12.2% of the adults are affected. The difference in prevalence between adults and non-adults is statistically significant (χ^2=10.472, df=1, p=0.001, n=56). Porotic hyperostosis was not found in the Blokhuizen collection.

Eight non-adults are affected by cribra orbitalia (53.3%). Children between four and 12 years of age appear to be the most affected: six of the eleven children with orbits show healed cribra orbitalia (54.5%). Of the four infants with orbits available for study, two are affected by cribra orbitalia (50.0%). The difference between the two age groups is not statistically significant (χ^2=0.227, df=1, p=0.643, n=15). The two adolescents in the Blokhuizen collection had no orbits available for study.

Of the five adults with cribra orbitalia, three are male (15.0%) and two are female (10.5%). The difference in the percentages of affected males and females is not statistically significant (χ^2=0.174, df=1, p=0.676, n=39).

Age-at-death could be estimated for all of the affected adult individuals: two younger adults (14.3%) and three older adults (13.6%) were found to have cribra orbitalia. Table 5.69 combines the age-at-death estimates with the estimated sex for the affected individuals. The table shows that there are more young females than males affected by cribra orbitalia: none of the males with cribra orbitalia died before the age of 35 years. Interestingly, the females show the opposite pattern: none of the affected women died after reaching the age of 35 years.

Table 5.69: Number of individuals with cribra orbitalia in the different age groups in relation to total number of individuals in the specific age groups in the Blokhuizen collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	0	0.0	2	28.6	2	14.3
Older adults	3	25.0	0	0.0	3	13.6

n=number of affected individuals.

ii) Klaaskinderkerke

In total, there are 27 individuals with eye orbits available for the study of cribra orbitalia. In addition, 31 crania are present to assess porotic hyperostosis. Cribra orbitalia is present in seven individuals (25.9%), all of whom are adults (29.2%). Porotic hyperostosis is present in two adult individuals (6.5%).

Sex could be estimated for all individuals with cribra orbitalia: four are males (26.7%) and three are females (33.3%). The difference in the number of affected males and females is not statistically significant (χ^2=0.121, df=1, p=0.728, n=24), suggesting that the sexes were equally affected by cribra orbitalia. The two individuals with porotic hyperostosis are both female (20.0%). Interestingly, these two women are not affected by cribra orbitalia.

For all individuals with cribra orbitalia, age-at-death could be estimated. Three of the individuals are estimated to be younger adults (23.1%) and four are older adults (36.4%). The difference in the percentage of cribra orbitalia between the younger and older adults is not statistically significant (χ^2=0.509, df=1, p=0.476, n=24), suggesting that the younger and older adults are equally affected by this stress marker. Table 5.70 shows the age-at-death of the affected individuals in relation to their estimated sex. It suggests that more younger females than younger males are affected by cribra orbitalia. This is, however, not confirmed by a statistical test (χ^2=0.660, df=1, p=0.461, n=13).

Table 5.70: Number of individuals with cribra orbitalia in the different age groups in relation to total number of individuals in the specific age groups in the Klaaskinderkerke collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	1	14.3	2	33.3	3	23.1
Older adults	3	37.5	1	33.3	4	36.4

n=number of affected individuals.

The two females affected by porotic hyperostosis in the Klaaskinderkerke collection both died before the age of 35 years (28.6%). Since none of the three older female crania present in this assemblage show this stress marker, it suggests that more younger females than older females are affected by porotic hyperostosis.

iii) Alkmaar

Cribra orbitalia was documented in 17 of the 94 individuals (18.1%) of whom one or both eye orbits were available for study. Only healed cases of cribra orbitalia were found. Porotic hyperostosis was only noted in one individual (0.8%) and it was healing at time of death. Interestingly, none of the individuals, of whom both the orbits and the cranial vault could be studied, show both cribra orbitalia and porotic hyperostosis. Figure 5.26 shows an example of healed cribra orbitalia in an adult female and a non-adult cranial fragment with healing porotic hyperostosis.

In total, six of the non-adults are affected by cribra orbitalia (54.5%); three of them are children between four and 12 years of age (50.0%) and the other three are adolescents between 13 and 18 years of age (50.0%). The individual with porotic hyperostosis was a child aged between four and 12 years of age.

Figure 5.26: Healed cribra orbitalia in an adult female (S278V802) and healing porotic hyperostosis on the parietal bone of a child (S045V534). (Photo: R. Schats, Laboratory for Human Osteoarchaeology).

The adult individuals from Alkmaar are only affected by cribra orbitalia. Of the 83 adults with orbits available for study, 11 individuals are affected (13.3%). Two of these are males (6.1%), eight are females (17.0%), while the sex of one affected individual could not be estimated. Statistical testing shows that the difference in cribra orbitalia prevalence between males and females is not significant (χ^2=2.130, df=1, p=0.144, n=80).

Age-at-death could be estimated for 80 of the adult individuals with orbits. In total, four younger adults (11.1%) and seven older adults (15.9%) are affected by cribra orbitalia. The difference in the percentage of affected individuals between the age groups is not statistically significant (χ^2=0.384, df=1, p=0.535, n=80). However, when the age-at-death of the affected individuals is linked with sex, differences appear to be present. Table 5.71 shows the number of affected individuals split by age-at-death and sex. None of the affected males died before the age of 35 years, while four of the affected females died in that age group. However, this difference is not statistically significant (χ^2=2.669, df=1, p=0.102, n=35). It appears that in general, there are relatively more older than younger adults with cribra orbitalia.

Table 5.71: Number of individuals with cribra orbitalia in the different age groups in relation to total number of individuals in the specific age groups in the Alkmaar collection.

Age groups	Males		Females		Total	
	n	%	n	%	n	%
Younger adults	0	0.0	4	18.2	4	11.1
Older adults	2	10.5	4	16.7	7	15.9

n=number of affected individuals. Total includes individuals with indeterminate sex.

iv) Site comparisons

Table 5.72 combines the data from the three sites to show the differences in cribra orbitalia prevalence among them. From the table it appears that there is a large difference between the adults of Alkmaar and Klaaskinderkerke. The differences between the other sites are not as marked. A large percentage of non-adults are affected in the Blokhuizen collection; in Alkmaar and especially in Klaaskinderkerke, the non-adults are less often affected. If the adults and non-adults are combined, there are statistically more individuals with cribra orbitalia in Blokhuizen than in Alkmaar (χ^2=5.896, df=1, p=0.014, n=126).

Table 5.72: Numbers and percentages of individuals with cribra orbitalia in the studied collections.

Sites	Adults		Non-adults		Total	
	n	%	n	%	n	%
Blokhuizen	5	12.2	8	53.3	13	23.2
Klaaskinderkerke	7	29.2	0	0.0	7	25.9
Alkmaar	11	13.4	6	54.5	17	18.1

n=number of affected individuals.

Table 5.73 shows the results of the statistical comparison between the three sites for the number of adults and non-adults with cribra orbitalia. While there are some larger differences between Klaaskinderkerke and the other two sites for both the adults and non-adults, there are no statistically significant differences found.

Table 5.73: Statistical comparison of the prevalence of cribra orbitalia across the sites.

Site comparison	Adults				Non-adults			
	χ2	df	p	n	χ2	df	P	n
Alkmaar-Blokhuizen	0.027	1	0.869	124	0.004	1	0.951	26
Blokhuizen-Klaaskinderkerke	2.897	1	0.089	65	2.880	1	0.090	12
Klaaskinderkerke-Alkmaar	3.369	1	0.066	102	2.864	1	0.091	18

n=number of individuals included in the test, df=the degrees of freedom.

Table 5.74 shows the numbers of affected individuals in the different age groups to assess if differences in the prevalence of cribra orbitalia between the younger and older adults in the studied sites exist. When comparing the total number of affected individuals in the different age groups, there are no substantial differences. A statistical comparison of the prevalence of cribra orbitalia by age group across the sites, as was done for the prevalence of enamel hypoplasia, has not been attempted considering the small sample sizes.

Table 5.74: Numbers and percentages of adult individuals with cribra orbitalia in the different age groups in the three sites.

Sites		Males		Females		Total	
		n	%	n	%	n	%
Blokhuizen	Younger adults	0	0.0	2	28.6	2	14.3
	Older adults	3	25.5	0	0.0	3	13.6
Klaaskinderkerke	Younger adults	1	14.3	2	33.3	3	23.1
	Older adults	3	37.5	1	33.3	4	36.4
Alkmaar	Younger adults	0	0.0	4	18.2	4	11.1
	Older adults	2	10.5	4	16.7	7	15.9

n=number of affected individuals.

Table 5.75 shows the number of individuals with porotic hyperostosis at the studied sites. Very few individuals were affected by this stress marker: only a child in Alkmaar and two younger females in Klaaskinderkerke. Considering the limited number of individuals affected by this stress indicator, further statistical comparisons and analyses have not been performed.

Table 5.75: Numbers and percentages of individuals with porotic hyperostosis at the three sites.

Sites	Adults		Non-adult	
	n	%	n	%
Blokhuizen	0	0.0	0	0.0
Klaaskinderkerke	2	6.5	0	0.0
Alkmaar	0	0.0	1	7.1

n=number of affected individuals.

5.7.4 Summary non-specific stress markers

Intra- and inter-site differences in non-specific stress markers have been assessed in order to study variations in systemic stress levels between sex and age groups and between the three sites. Overall, the prevalence of the stress markers was relatively similar between the collections. An inter site comparison of stature reveals no statistically significant differences, indicating either similar stress levels or that differences in stress did not influence adult height. The same pattern is observed for dental enamel hypoplasia, cribra orbitalia, and porotic hyperostosis: there are small intra-site variations, but no large statistically significant differences between the sites suggesting similar stress levels or differences that did not result in a higher or lower prevalence of the studied non-specific stress markers.

6

Discussion

6.1 INTRODUCTION

The primary objective of this research was to study the consequences of socioeconomic developments during the medieval period in Holland and Zeeland using an osteoarchaeological approach. As discussed in chapter one, historical literature can give information on general trends and developments such as broad changes in subsistence patterns, environmental circumstances, and living conditions. However, how these changes influenced people at an individual physical level is difficult to assess using exclusively historical data. The analysis of human skeletal remains from different archaeological sites provides a new, uniquely direct, perspective on the impact of socioeconomic developments on urban and rural populations of the Middle Ages.

This study has demonstrated that medieval socioeconomic developments had physical consequences for the citizens of Holland and Zeeland. Although not all aspects of medieval life are reflected in the human remains, the comparison of early rural Blokhuizen with later rural Klaaskinderkerke and urban Alkmaar has shown differences as well as similarities between the prevalence and expression of skeletal indicators of disease, activity, and diet. Several of the observed patterns could be related to the medieval socioeconomic changes, thereby improving our understanding of the physical impact of these developments for the people.

While there are small differences between the rural and urban collections, one of the main findings of this research is the absence of a clear-cut division between the two living environments in terms of disease, activity, and diet. Not surprisingly, the lives of the medieval citizens seem to have been influenced by many factors, with living environment perhaps being a smaller aspect than previously assumed. Based on the skeletal data, there is no marked rural-urban divide in medieval Holland and Zeeland, in contrast to data from other places in medieval Europe (Woods 2003). The negative association between health and urban living ingrained in our perception of past societies is not supported by this research.

This chapter discusses the results of the osteoarchaeological analyses in relation to the historical contextual information. This discussion demonstrates the importance of local research into physical consequences of medieval socioeconomic changes on the lives of rural and urban people.

6.2 DISEASE AND MEDIEVAL DEVELOPMENTS

An important objective of this research was to assess if late medieval socioeconomic developments influenced disease patterns and general stress levels. This was done through comparison of the prevalence of certain infectious diseases and indicators of non-specific stress among three skeletal assemblages: Blokhuizen, Klaaskinderkerke, and Alkmaar

6.2.1 Rural comparisons

Specific infections: respiratory diseases

Skeletal lesions associated with specific infectious diseases were not encountered in the rural skeletal collection of Blokhuizen. It has to be noted that the poor preservation of the Blokhuizen remains could have influenced the results: only 28% of individuals had a thorax available for inspection. However, air-borne infections, which include lung diseases such as tuberculosis, are likely to have been less common in areas with more fresh air and less crowded living conditions. Considering that the inhabitants of Blokhuizen would likely have lived in small dispersed farm houses, the absence of signs of these types of infections falls within expectations. Similarly, no evidence of respiratory infections was encountered in the comparative rural skeletal collection of Vronen (Alders and van der Linde 2011). Interestingly, however, data from England present a different image. The skeletal remains from Raunds Furnells, a rural settlement in England (AD 850–1100), showed indications of a possible tuberculosis infection, although only one individual appears to have been affected (Powell 1996). Lewis (1999) also notes that respiratory infections were common in the rural skeletons she analysed. Additionally, Mays and colleagues (2001) encountered *M. tuberculosis* in several individuals from the rural village of Wharram Percy, England (AD 950-1500). Using ancient DNA research, they confirmed that the individuals were affected by the human (and not bovine) form of tuberculosis. Considering that the population density in Wharram Percy was probably low, Mays *et al.* (2001) link the occurrence of the disease to contact with the urban centre of York. Several larger towns already existed in England during the central medieval period. Although incidental interaction with more distant towns cannot be ruled out, the potential exposure to tuberculosis for the inhabitants of Blokhuizen and Vronen was limited considering the fact that there were no urban centres in Holland during the central medieval period.

The second rural collection, from Klaaskinderkerke, did not provide definitive cases of infectious disease. There is only one individual who showed new bone formation on the visceral surface of the ribs which suggests a chronic lung infection. Similarly, in the contemporary rural skeletal collection from Cruyskerke, no evidence of specific infections or chronic lung diseases was encountered (Sannen 2010). This indicates that there is no discernible increase in the prevalence of these types of diseases in the later rural settlements in comparison with the earlier ones such as Blokhuizen and Vronen. Even though population size increased in Holland and Zeeland in this period, population densities in rural villages appear to have remained too low to sustain crowd-dependent diseases such as tuberculosis.

An important change from the central to late medieval period in Holland and Zeeland was increased contact with more densely populated areas. As discussed in chapter one, many urban centres came into existence during this period. This, in combination with greater market dependence, would have increased interaction and contact between the rural areas and towns. This could have promoted the spread of air-borne diseases to the rural hinterland, as appears to have been the case for the individuals in Wharram Percy (Mays *et al.* 2001). Klaaskinderkerke, and especially Cruyskerke, are close to urban centres such as Dordrecht and Zierikzee, which had relatively high population densities in this period. The absence of skeletal lesions suggest that the assumed increased contact with nearby towns did not result in a higher prevalence of respiratory infections in Klaaskinderkerke and Cruyskerke which could indicate that these types of diseases were absent in the towns the rural inhabitants were in contact with. However, considering the fact that diseases like tuberculosis need a relatively high population density to sustain themselves, the limited population size and density in rural villages likely resulted in rapid dissolution of bacteria (Dobson and Carper 1996; Mays *et al.* 2001). Lewis (1999, 2002) came to similar conclusions in her research, when studying the process of urbanisation and industrialisation by comparing the non-adults of different English sites. She found no significant differences in the prevalence of infectious diseases between the early and later medieval rural non-adults. Even though her focus on non-adults may have resulted in different patterns, Lewis' data concur with the results from the present research, indicating that the socioeconomic developments in the late medieval period did not visibly impact the prevalence of certain infectious diseases in the countryside.

Specific infections: animal-borne diseases

While the human form of tuberculosis is unlikely to have been present in the early rural settlements, the bovine form is likely to have been common in Holland in the central medieval period given the expected regular contact with cattle. Although it is not possible to distinguish between the two types of tuberculosis on the basis of skeletal remains, the absence of characteristic lesions for either form in Blokhuizen and Vronen (Alders and van der Linde 2011) suggests that the *M. bovis* was not present in the villages. Other specific animal-borne diseases such as brucellosis were also not encountered in the skeletal remains from Blokhuizen and Vronen. The absence of skeletal lesions associated with bovine tuberculosis and brucellosis suggests that these diseases were uncommon in the countryside in the period between AD 1000 and 1200. Similar results were obtained in English research: in addition to human bone samples, Mays and colleagues (2001) tested some bovine remains from the site of Wharram Percy for the presence of *M. bovis* and found no evidence for the disease, even though the authors expected this disease to have been common. Moreover, the scholars were unable to find the *Brucella* bacteria in any of the analysed humans (Mays *et al.* 2001). The absence of skeletal evidence and negative DNA results suggest that animal diseases were of lesser importance in the medieval period than previously assumed.

While there is no direct evidence for specific animal diseases, close contact with animals could have resulted in several other afflictions. The use of faeces as fertilisers exposed villagers to parasites such as roundworms and hookworms (Lewis 1999), which may have resulted in anaemia. Microscopic analyses of samples from cesspits used in medieval towns indeed indicate the occurrence of intestinal parasites. Research on material from the late medieval Dutch city of Kampen demonstrated the presence of roundworms and whipworms (Haaster *et al.* 2000). Anthrax, another virulent bacterial infection, was most likely also a common disease in the medieval period for people working with animals on a regular basis. In addition to being fatal for livestock, humans can become infected with this disease by touching the hides of the affected animals, resulting in a characteristic black lesion on the skin, or by eating meat contaminated with the bacterium (Sternbach 2003; Lewis 1999). Archaeological and historical evidence suggest that these diseases and parasitic infections played an important role in medieval society. However, as they do not result in specific skeletal lesions, their prevalence cannot be directly studied from an osteoarchaeological perspective. Nonetheless, these animal related afflictions may have been responsible for non-specific stress markers, which are addressed below.

The comparison of the early rural skeletal assemblages with later medieval ones demonstrated no osteoarchaeologically visible increase in animal-borne infections. No indications for brucellosis or bovine tuberculosis have been found in the human skeletal remains from Klaaskinderkerke. Even though pastoral farming was less common in Zeeland in comparison with Holland (van Steensel 2012b), the inhabitants of Klaaskinderkerke would have owned animals for private use. Taking into account that animals and humans presumably lived in the same dwelling, diseases such as brucellosis or bovine tuberculosis could have been common in the late medieval period as well. DNA evidence from a pit with cattle remains dating to the late medieval period has shown that brucellosis was present in The Netherlands in late medieval times (de Jong and Houwers 2008), but the extent of the disease is currently unknown. It is possible that the prevalence of bovine tuberculosis and brucellosis are grossly underestimated in the archaeological record due to the limited skeletal involvement of both diseases (Waldron 2009). However, the skeletal absence of specific animal diseases in both Dutch and English rural skeletal collections points to a low significance of these infections in the medieval period.

Non-specific stress markers

To investigate the presence of other diseases or deficiencies which do not leave any specific lesions in the skeleton, non-specific skeletal stress markers were studied. Stunting of growth is considered to be an important indicator of childhood stress, even though catch-up growth could obscure some differences (Goodman and Armelagos 1989). Average adult stature for males is 172 cm in the Blokhuizen collection. This is equal to the average stature of the males from Vronen (Alders and van der Linde 2011). In Blokhuizen, the females had an average height of 164 cm. This is only slightly shorter than in Vronen, where the females had an average stature of 165 cm (Alders and van der Linde 2011). Even though only a small number of individuals from both sites could be assessed, the average stature for males from Blokhuizen and Vronen is comparable with the average height of other skeletal collections from the same time period (Maat 2005; Steckel 2004). Table 6.1 displays the male stature trend in northern Europe based on skeletal collections from Scandinavia, The Netherlands, and Britain through time. The average stature for the central medieval period is 173.4 cm, which is only slightly higher than what was found for the Blokhuizen and Vronen males.

The table shows that stature decreased through time, mainly in the post-medieval period, most likely as a result of processes associated with industrialisation. However, some loss of height is also apparent from central to late medieval times. This slight trend is, however, not reflected in the skeletal remains in the present study. Mean stature of the males and females in Klaaskinderkerke is 174 cm and 164 cm, respectively. Statistically, the average Klaaskinderkerke statures do not differ significantly from those of Blokhuizen. The lack of difference between the stature means of both males and females suggests that stress levels did not markedly increase (or decrease) in the countryside as a result of socioeconomic developments in the late medieval period.

Table 6.1: Adult male stature trends in northern Europe (after Steckel 2004, table 2, p. 216).

Time period	Average stature (cm)
9^{th}–11^{th} centuries	173.4
12^{th}–14^{th} centuries	171.5
17^{th}–18^{th} centuries	167.5
18^{th} century	166.2
Late 19^{th} century	169.7

The comparison of the other non-specific skeletal stress markers gave similar results. In Blokhuizen, 53% of the sample had enamel hypoplasia and in Klaaskinderkerke 54% of studied individuals were affected. Unfortunately, the enamel hypoplasia prevalence is difficult to compare with Cruyskerke and Vronen, as different methods were used. Considering that there were no statistically significant differences in the number of teeth for each tooth type between Blokhuizen and Klaaskinderkerke, the lack of difference in enamel hypoplasia prevalence suggests that stress remained at a similar level through time. The data on enamel hypoplasia are preferred over stature data since the former is a permanent marker while growth stunting as a result of childhood stress can be obscured in adult height due to catch-up-growth. Enamel hypoplasia prevalence can be lost due to dental wear, which was addressed by excluding old adults from the sample. Given the lack of significant differences between the sites with regards to age, this should have been of minimal effect in this research. Therefore, the lack of difference in enamel hypoplasia prevalence between Blokhuizen and Klaaskinderkerke is a strong indication of the lack of difference in non-adult stress.

The same trends can be observed through the comparison of the prevalence of cribra orbitalia. Cribra orbitalia (in active and healed states) was found in 23.2% of the Blokhuizen individuals. As expected based on the differences in the location of red blood cell production (Walker *et al.* 2009), more non-adults than adults were affected by cribra orbitalia (53.3% of the non-adults and only 12.2% of the adults). The orbital lesions were found in 25.9% of the Klaaskinderkerke individuals, all of whom were adults. In comparison with Blokhuizen, the Klaaskinderkerke prevalence is very comparable.

Conservative comparisons with the comparative sites, bearing in mind methodological issues, demonstrate differences in prevalence of cribra orbitalia, with Blokhuizen and Klaaskinderkerke having higher rates. In Vronen and Cruyskerke, only 16.6% and 1.9%, respectively, of individuals are reported to have been affected by cribra orbitalia. Although this may suggest that general stress was higher in Blokhuizen and Klaaskinderkerke, considering that there were no differences in average height, a different explanation is more likely. The occurrence of endemic malaria in the area around Blokhuizen and Klaaskinderkerke may have been responsible for the high prevalence of cribra orbitalia. As discussed in chapter three, malaria can cause chronic anaemia in turn often causing cribra orbitalia (Gowland and Western 2012). Considering the fact that both Blokhuizen and Klaaskinderkerke were located in areas with numerous marshes (Schats 2015b), the endemic presence of malaria mosquitoes could be a major factor contributing to the high prevalence of cribra orbitalia. Cruyskerke appears to have been in an area with low malaria endemicity (Schats 2015b), possibly explaining its very low cribra orbitalia prevalence. Vronen, located in a region where malaria mosquitoes were common, the cribra orbitalia prevalence is higher than in Cruyskerke. An explanantion for the difference between Blokhuizen and Vronen was that the latter was not located on peat, but on geest lands (soils composed of mixture of peat, clay, and sand from sand dunes which are slightly elevated in the landscape). Although the area surrounding the village would have still been relatively wet, the slight elevation may have resulted in a drier area directly surrounding Vronen which was less suited for malaria mosquitoes hence causing a lower cribra orbitalia prevalence.

In summary, the inter-site comparisons for each non-specific stress marker gave similar results: there are no statistically significant differences between central medieval rural Blokhuizen and late medieval rural Klaaskinderkerke, suggesting no marked increase or decrease in stress levels. Similar results have been found in other studies. Lewis (1999, 2002) also found no differences in stress markers between early and later medieval rural non-adults. It is important to note that the comparison of non-specific stress markers cannot reveal if the source(s) of stress changed. However, the lack of difference indicates that even though socioeconomic circumstances changed as a result of medieval developments, this did not result in a major increase or decrease of general stress levels.

Changes in life ≠ changes in disease

As discussed in the chapter one, the socioeconomic developments in the late medieval period influenced several aspects of rural life. Changes in agricultural practices, shifts in occupation, interaction with urban centres, and the reduction of self-sufficiency all impacted the rural residents. Yet, the lack of difference in prevalence of infectious disease and non-specific stress markers between Blokhuizen and Klaaskinderkerke and the other contemporary rural collections suggests that these changes did not visibly impact disease frequency. These results suggest that the individuals of Blokhuizen and Klaaskinderkerke were able to adequately adapt to changes in socioeconomic circumstances.

6.2.2 Rural-urban comparisons

Specific infections: respiratory diseases

The urban skeletal remains do show a change in disease patterns: tuberculosis and other signs of chronic lung disease were only encountered in Alkmaar, indicating that the transformation to urban living indeed impacted infectious disease prevalence. The Alkmaar collection yielded two individuals with skeletal lesions pathognomonic for tuberculosis: clear spinal lytic lesions and collapse of the vertebral column. In addition, three individuals displayed the characteristic lesions on the visceral surface of the ribs associated with a chronic respiratory infection, possibly also tuberculosis.

The fact that tuberculosis, infamous as a disease of overcrowding and poor living, is found in Alkmaar and not in any of the rural sites suggests that living in the urban environment had an effect on infectious disease prevalence. The higher population density in comparison with the rural areas may have been responsible for this. However, there are other Dutch urban skeletal collections from the same time period which do not show evidence for this disease.

In the skeletal remains from the Franciscan friary in Dordrecht (Maat *et al.* 1998) and in the collection from Koningsveld in Delft (Groen, forthcoming), both towns with higher population densities than Alkmaar, tuberculosis or other lung diseases are not encountered. This may suggest that not all urban centres were plagued by the same diseases. Most likely, this is the result of local differences in living conditions and hygienic measures. Additionally, the presence of infirmaries with their own graveyard could have influenced the data: diseased individuals would be buried there and not in the regular cemeteries. In Alkmaar, however, even though infirmaries were present in the late medieval period (Vis 1991, 2007), none had their own cemeteries. People who died in the infirmaries were buried in one of the Alkmaar regular cemeteries (Bitter 2015, pers. comm.). This is also shown by the list of individuals buried at the Franciscan friary (appendix 1): for example, Anna Jansdochter appears to have come from the infirmary, as it is noted in the archival sources as '*uittet gasthuis*' meaning 'from the infirmary'.

To date, there are no known rural skeletal collections from Holland and Zeeland with osteological indications of tuberculosis, pointing to the more urban profile of this disease. In contrast to this, Lewis (1999, 2002), found a higher prevalence of respiratory disease in the rural compared to the urban skeletons she studied. Lewis relates this higher prevalence to allergic reactions as a result of close contacts with animals and exposure to soil pollutants (Lewis 1999, 2002). While the villagers in the countryside of Holland and Zeeland could have been exposed to similar pollutants, this appears not to have been sufficiently chronic or severe to cause a visible impact on the skeleton.

Specific infections: animal-borne diseases

As in the rural collections of Blokhuizen and Klaaskinderkerke, no confirmed cases of specific infections transmitted by animals were found in the Alkmaar collection. There are no skeletal signs of brucellosis. Similarly, in Delft and Dordrecht, no specific animal diseases were encountered in the skeletons. It is, however, possible that the individuals diagnosed with tuberculosis in Alkmaar could in fact have been suffering from the bovine instead of the human form. Since the skeletal consequences of the two diseases is the same (Mays *et al.* 2001; Waldron 2009), it is not possible to distinguish *M. bovis* from *M. tuberculosis* on the basis of osteological criteria alone; ancient DNA testing would be necessary. However, as was argued by Mays and colleagues (2001), it is expected that the human form of tuberculosis is more common in urban environments considering the more densely populated living conditions. Moreover, the majority of the urban population of Alkmaar probably had less direct contact with animals. Yet, it has to be noted that infection through the ingestion of contaminated cattle products, primarily milk, would have been a risk for both rural and urban residents. However, this would most likely have resulted in a primary lesion in the alimentary tract or cervical lymph nodes (Aufderheide and Rodríguez-Martín 1998; Mays *et al.* 2001), and is therefore less likely to result in the spinal deformities associated with tuberculosis such as observed in Alkmaar.

Non-specific stress markers

While specific infectious diseases are only observed in the Alkmaar collection, the non-specific stress markers did not increase in comparison with Klaaskinderkerke and Blokhuizen. Average male stature is 175 cm and average female stature is 162 cm in Alkmaar. These average male and female statures are comparable to those of Blokhuizen (M=172 cm and F=164 cm) and the Klaaskinderkerke skeletons (M=174 cm and F=164 cm); the observed differences are not statistically significant. These stature means are also comparable to the average stature of the individuals in the Koningsveld collection (Delft) (M=176 cm and F=162 cm) (Groen, forthcoming) and in the Dordrecht collection (M=173 cm and F=161 cm) (Maat *et al.* 1998), indicating only minor differences between the urban centres in the county of Holland. The fact that there are only slight variations in stature means between the rural and urban skeletal collections suggest that stress levels did not markedly change as a result of the socioeconomic developments.

A similar trend is demonstrated by the comparison of enamel hypoplasia prevalence. While there were slightly more individuals with enamel defects in the Alkmaar collection (65.3%) than in Blokhuizen (52.9%) and Klaaskinderkerke (53.8%), the number of affected individuals in the urban collection is not significantly higher than at the rural sites. There are some differences in the types of teeth that were available for study between the collections, but considering that the sample includes only individuals with three or more anterior teeth and no old adults, this should not have influenced the results to any great extent. Therefore, the lack of difference in enamel hypoplasia prevalence between the three skeletal populations is a clear indication of an absence of differences in childhood stress.

Comparing the prevalence of cribra orbitalia between the three collections reveals slightly higher rates of this stress marker in the rural settlements. Both Blokhuizen and Klaaskinderkerke have a higher percentage of individuals affected (23.2% and 25.9%, respectively) while in Alkmaar 18.1% of individuals were affected. These differences between the sites do not reach statistical significance. In comparison with the Dordrecht skeletons, the prevalence of cribra orbitalia in Alkmaar is high: in Dordrecht only three percent of the individuals had the orbital lesions (Maat *et al.* 1998). The fact that the prevalence of cribra orbitalia is high in the collections from the present study can be explained by the possible malaria endemicity in the areas surrounding the studied sites. Both Holland and Zeeland were favoured by malaria mosquitoes due to the presence of brackish water. Dordrecht, although in the county of Holland, is considered to be an area with less malaria mosquitoes, at least in the post-medieval period (Schats 2015b; Seventer 1969).

If malaria was indeed responsible for at least some of the observed cribra orbitalia, the small differences between the urban and rural environments may be explained by the fact that malaria mosquitoes were most likely more prevalent in the countryside. Modern research suggests that urban environments are typically less suitable for malaria mosquito vectors (Brieger 2011; Hay *et al.* 2005) which may have been the case for Alkmaar as well, even though the town was in a marshy area.

With regard to the non-specific stress markers, Lewis (1999, 2002) found a similar pattern: enamel hypoplasia and cribra orbitalia prevalence were not increased in the English medieval urban collection in comparison with the earlier and later rural collections. In addition, although the urban sample she studied might have had a higher socioeconomic status, she found similar growth profiles for the rural and urban skeletal assemblages (Lewis 1999, 2002). This study suggests that migration to towns in England was not responsible for a rise in stress levels. Betsinger (2007), who compared urban individuals through time, did not encounter any differences in stress markers between the collections she studied in Poznań, Poland. The results of her study likewise suggest that increased urbanisation did not visibly impact stress levels. Quintelier (2013) found similar results when studying the urban population of Tongeren, Belgium, through time. She also did not observe an increase in stress levels as urbanisation intensified (Quintelier 2013). In contrast to these studies, Kjellström (2005), who compared individuals dating to different phases of urban development from the Swedish medieval city of Sigtuna, noticed an increase in non-specific stress markers in the later phases. Mean stature of the women dating to the later period also decreased. She links this deterioration of health to the establishment of a true urban settlement, which in Sigtuna appeared to be associated with poorer living conditions and large scale immigration which increased population density (Kjellström 2005; Kjellström *et al.* 2005).

The unhealthy city?

These regional comparisons show that different patterns in response to urbanisation are encountered, most likely due to local differences in living conditions and hygiene. An important observation, however, is that, most researchers support the finding of this study: the lack of marked differences in stress markers between town and country. These results express the need for a reconsideration of the common view of medieval towns as dirty and unhealthy. Woods, discussing early modern European cities, writes: *"Cities were graveyards, demographic sinks, and there was a clear penalty in terms of life chances to being or becoming a resident"* (2003:30). Since he based his argument on mortality data from 15th-century Italian cities, this remark is probably not far off. However, this image does not seem to apply to the medieval towns of Holland and Zeeland. Even though infectious disease prevalence was higher in Alkmaar, the comparison of non-specific stress markers between the rural and urban collections does not support the idea of disease-riddled towns and the stress-free countryside. Stature and prevalence of enamel hypoplasia and cribra orbitalia were similar.

The fact that the prevalence of non-specific stress markers was not higher in urban individuals may point to more hygienic living circumstances than previously assumed for medieval towns in Holland and Zeeland. While large cities such as Paris or Florence are known to have had major problems with waste disposal (Pitchel 2005; Roberts and Cox 2003), this appears to have been rather well organised in the towns of Holland and Zeeland (Bitter 2007b; van Oosten 2014). Van Oosten, who researched the cesspit system in Alkmaar, noted that keeping the important waterways free from waste was most likely economically motivated: clean water was necessary for making beer and cloth. While probably not the main concern of the citizens, the waste-free canals had a clear health benefit as well. Additionally, houses in Alkmaar were generally made out of wood (Bitter 2007b) which would have ensured better ventilation than stone buildings. The relatively 'healthy' character of Alkmaar is also noted by the famous medieval physician Pieter van Foreest, who mentions that the sea breeze, the spacious streets, and the good flow of water in the broad canals guaranteed the health of the town (Vis 2007).

6.2.3 Summary: influence of medieval developments on disease

The prevalence of stress markers indicate that the late medieval developments had no marked influence on the rural populations: prevalence remained similar through time. Interesting, the skeletal data also suggest that the image of the town as a disease-riddled demographic sink is not applicable to Holland and Zeeland in the medieval period. While tuberculosis was present in Alkmaar citizens, this disease has not been found in skeletal collections of contemporary towns in Holland and Zeeland such as Dordrecht and Delft. Furthermore, although respiratory infections were more common in Alkmaar, there are no differences in stress markers between the rural and urban collections. This suggests that health disruptions were present in both living environments the Middle Ages. An important observation here is that the skeletal data from Holland and Zeeland studied in this research suggest that the living conditions in towns were not necessarily worse than those in the country. Both living environments appear to have had their own threats with regard to disease which resulted in the presence of skeletal stress markers and certain diseases.

6.3 ACTIVITY AND MEDIEVAL DEVELOPMENTS

A second aim of this research was to assess if specific socioeconomic developments in the medieval period influenced activity patterns. This was done through the comparison of the prevalence of osteoarthritis and bone morphology between three skeletal assemblages. Specific attention is given to differences in the gendered division of labour between villages and town. Unfortunately, limited data on osteoarthritis (only crude prevalence is known) and no data on bone morphology are available for the comparative skeletal collections.

6.3.1 Rural comparisons

Osteoarthritis and activity

The overall or crude prevalence of osteoarthritis (i.e., the number of adults with one or more affected joints) is low in the Blokhuizen collection, at 11.9%. The crude percentage is higher in the contemporary rural skeletal collection of Vronen (29%). The age distribution in the collections is similar which ensures that the observed differences are not the result of variations in the age compositions. A possible explanation for the low crude osteoarthritis prevalence in Blokhuizen is the relatively poor preservation of joint surfaces. Therefore, the analysis of the true osteoarthritis prevalence, which takes into account how many joints are present, gives a more realistic image. The true osteoarthritis prevalence in the Blokhuizen collection is 4.4%.

In Klaaskinderkerke, the crude osteoarthritis prevalence is much higher than in Blokhuizen (28%). This difference can most likely be explained by the better preservation of the Klaaskinderkerke skeletons. This is supported by the fact that there is only a small difference in true prevalence between the two skeletal assemblages: the Klaaskinderkerke individuals have 4.7% of their joints affected by osteoarthritis. The small difference in true osteoarthritis prevalence between Blokhuizen and Klaaskinderkerke points to similar activity patterns for both groups of villagers. In Holland agricultural activities, specifically arable farming, were reduced as a result of subsidence of the peat soils during the late medieval periods (Hoppenbrouwers 2001; van der Linden 1982), but this was not the case in Zeeland. The clay rich soils were not affected as much by subsidence and arable farming could continue into the late medieval period. Even though pastoral farming became important in Holland, in Zeeland, the emphasis remained on crop cultivation (van Steensel 2012b). The fact that both the Blokhuizen and Klaaskinderkerke individuals were mainly occupied with arable farming and were therefore engaged in similar levels of physical activity, may explain the lack of difference in the overall true osteoarthritis prevalence.

However, if the joints are studied separately, some differences are noticeable which may point to variation in the types of activities that were carried out in the two villages. Although the observed difference does not reach statistical significance at the 0.05 level, the Klaaskinderkerke individuals had a higher prevalence of spinal and especially hip osteoarthritis in comparison with individuals from Blokhuizen. It is likely that the Klaaskinderkerke individuals placed more strain on their backs and hips in comparison with the earlier rural peoples of Blokhuizen. Additionally, in Klaaskinderkerke, osteoarthritis was significantly more common in the lower limbs, while in Blokhuizen the differences between the two joint groups were much smaller. Thus, even though overall true osteoarthritis prevalence does not reveal any differences between the two rural sites, the separate comparison of the joints and joint groups does demonstrate variation. Changes in physical labour are deemed to be the most likely cause of the significant differences in osteoarthritis.

The variations in osteoarthritis prevalence between joint groups and specific joints may have been related to the emergence of a market economy and the reduction of self-sufficiency in the late medieval period. While the inhabitants of Blokhuizen were most likely only producing crops for their own use, the late medieval villagers of Klaaskinderkerke were engaged in more market-oriented commercial arable farming resulting in a surplus that could be sold on the market. Moreover, agriculture in the late medieval countryside was not only focused on food production. The cultivation of certain crops used in the urban industries became important in the late medieval period. The production of madder was of great commercial significance in Zeeland. The red dye, extracted from the roots of the plant, was used to colour cloth and other textiles (van Steensel 2012b).

However, the introduction of other activities besides arable farming in the late medieval period most likely had a more direct impact on activity patterns, and may be responsible for the differences between these two rural communities. In addition to agriculture, the extraction of peat (*moernering*) from underneath the clay was one of the main activities in the countryside of Zeeland (Dekker 1996; Leenders 1999, 2004; van Steensel 2012b). Although damaging to the landscape, the salty peat (*darink*) was necessary for the production of salt and, to a lesser extent, for fuel. Particularly the demand for salt as a means of food preservation increased in the late medieval period, especially due to the development of the herring fishery (Dekker 1996; van Dam 2006; van Steensel 2012b). The on-board gutting and salting of herring ensured that the fish would not rot during transport. This sea fishing, for herring and other fish, became another significant activity for villagers in Zeeland from the 13th century onwards (Bennema and Rijnsdorp 2015; van Steensel 2012b; Unger 1978). This commercialisation of labour in the countryside in the late medieval period may account for the variation in osteoarthritis between the joint groups observed between Blokhuizen and Klaaskinderkerke. While arable farming was a main activity in both villages, the more market-oriented production and the increase of non-agrarian activities in the late medieval period most likely resulted in variations in mechanical loading and therefore in the differences in patterns of osteoarthritis.

Osteoarthritis and male-female differences
No significant differences in the true prevalence of osteoarthritis were found between the males and females in Blokhuizen. This suggests that the activities that were carried out in the village resulted in a similar overall amount of mechanical loading on the joints of both sexes. However, a separate analysis of the upper and lower limbs does reveal differences between the males and females of Blokhuizen. Women have significantly more osteoarthritis in their upper limbs than men. This results points to differences between male and female occupation in rural Blokhuizen.

Historical data on male and female rural activities indeed suggest differences in tasks. Women in agrarian communities in Holland were involved in several activities associated with food production such as baking bread and brewing beer. Another common task of rural women was the spinning of wool and linen. Men are expected to have performed more of the jobs related to arable farming (Kaptein 2007). Historical research on labour in the English medieval countryside presents a similar image. Village women were occupied with a wide range of agricultural activities such as sowing, weeding, reaping, and gleaning, while the men were commonly tasked with activities such as ploughing, an exercise commonly seen as more strenuous (Jewell 1996). Additionally, women were often responsible for taking care of the children and animals, as well as the household, which included tasks such as washing and cleaning (Jewell 1996). The osteoarthritis results suggest that female activities placed more mechanical loading on the upper limbs, while the forces exerted during the male tasks are more equally distributed throughout the body. This pattern of osteoarthritis seems to fit historical information about the activities which were common for women in an agricultural village. Indeed, female tasks may have placed a heavy burden on the upper limbs. For example, the washing of clothes, viewed as a woman's job, required manual beating and pounding of the fabric (Rawcliffe 2009). Other common female activities such as milking cows, churning of butter, and caring for animals (Mate 1999) may have required more from the upper limbs in comparison with the lower limbs.

In Klaaskinderkerke, there were also no significant differences in overall true osteoarthritis prevalence between males and females. In addition, the comparison of the osteoarthritis prevalence in upper and lower limbs revealed no significant sex differences. What does stand out is the high prevalence of hip osteoarthritis in the male individuals of Klaaskinderkerke. Fourteen percent of the studied male hip joints demonstrate signs of osteoarthritis while only 6.5% of the females were affected. Even though this is not clear from the other comparisons, it suggests that the males and females in Klaaskinderkerke were involved in different tasks which predisposed the men to developing hip osteoarthritis. Physical activities that, according to modern clinical research, are associated with hip osteoarthritis include long periods of standing, walking long distances, excessive bending and kneeling, lifting, climbing, and/or moving heavy objects (Felson 1994:65), all of which can be associated with a wide range of activities.

The comparison of true osteoarthritis prevalence between the sexes in Blokhuizen and Klaaskinderkerke reveals no significant differences in the total number of affected joints. Males and females had a similar overall prevalence through time. However, significant differences become apparent when the upper and lower limbs are compared separately. The Blokhuizen women had a significantly higher prevalence of osteoarthritis in the upper limbs, particularly the shoulder, in comparison with the Klaaskinderkerke women. A different trend is visible for the men: the Klaaskinderkerke males had a higher percentage of lower limb osteoarthritis, especially in the hip, although this difference does not meet statistical significance. These variations between the males and females of Blokhuizen and Klaaskinderkerke point to differences in the rural activities and may suggest that the socioeconomic developments in the medieval period resulted in changes in occupation for both men and women. As discussed above, the more market-oriented crop cultivation and the increase in non-agrarian activities in the late medieval period may have altered mechanical loading and therefore the risk for osteoarthritis. The comparison of male and female osteoarthritis between Blokhuizen and Klaaskinderkerke points to activity changes through time.

Additionally, the separate comparison of the different joint sites reveals clear differences between the males and females of Klaaskinderkerke and Blokhuizen. The Klaaskinderkerke men and women have a higher prevalence of spinal osteoarthritis in comparison to Blokhuizen. Differences in spinal osteoarthritis are difficult to interpret. While a higher prevalence could suggest increased mechanical loading on the vertebral column, there is some controversy over the relationship between spinal osteoarthritis and activity (Weiss and Jurmain 2007). Knüsel *et al.* (1997) found that spinal degeneration was a poor indicator for occupational stress. Moreover, these authors noted that differences in osteoarthritis prevalence were more likely to reflect differences in the curvature of the spine rather than occupational variations (Knüsel *et al.* 1997). Considering this, the observed differences in spinal osteoarthritis between Blokhuizen and Klaaskinderkerke are difficult to interpret and might be the result of other, more morphological, differences between the two groups of people. In contrast, the clear difference in the prevalence of hip osteoarthritis between the males of the two sites does suggest a change in mechanical loading on that joint. Possibly, the increase in distances travelled by foot as a result of regular visits to the newly formed urban centres can be related to the higher prevalence of hip osteoarthritis for the Klaaskinderkerke men. Additionally, the increase in non-agrarian activities such as herring fishing and commercial peat extraction for salt may have altered the daily work, and thereby mechanical loading, of the late medieval male villagers.

Bone morphology and activity

Another possible way to detect differences in activity patterns is the study of lower limb bone morphology. As outlined in chapter three, individuals with a flat bone shape, indicating directional muscle pull, are more likely to have been more mobile and physically active than individuals with rounder bone morphology. In Blokhuizen, both the femoral and tibial shapes are relatively flat indicating high activity levels. In contrast, the Klaaskinderkerke individuals had, on average, rounder bone shapes. This is most apparent when the males from Blokhuizen and Klaaskinderkerke are compared: both the femoral and tibial shapes are significantly different. The rounder leg shape of the males in Klaaskinderkerke indicates less directional muscle pull, which could be related to a change in activity patterns. Interestingly, the Klaaskinderkerke men had a higher prevalence of osteoarthritis in their lower limbs, especially in their hip joints. Thus, both skeletal markers point to a change in male activity patterns through time. Possibly, the increase in commercial activities, such as peat extraction which would increase mechanical loading while reducing mobility, can be responsible for this shift in male activity patterns. Additionally, commercial fishing may have required more mechanical loading on the lower limbs, and can be another explanation for the differences between the Blokhuizen and Klaaskinderkerke men.

The differences between the females of the two rural populations are less clear. The Klaaskinderkerke women have significantly rounder femora in comparison with the females from Blokhuizen. However, the comparison of tibial shape reveals no significant difference, which makes it difficult to comment on whether or not the activities of the women changed through time on the basis of bone morphology data. Interestingly, however, a shift in female activities is suggested by the osteoarthritis data. Since the main osteoarthritis difference is visible in the comparison of the upper limbs, this may explain why the comparison of female morphology of the lower leg bones does not reveal a similar pattern. Directional muscle pull as well as mechanical loading of the lower limbs seem to have remained similar, while mechanical loading of the upper limbs appears to have decreased through time for the late medieval women.

Changes in male-female differences through time

In addition to the clear differences between the men of Blokhuizen and Klaaskinderkerke, there appears to be a shift in the skeletal expression of the sexual labour division through time. Although some differences in shape between males and females are expected as a consequence of anatomical variation, the males from Blokhuizen have significantly flatter tibiae and femora than the females, indicating more directional muscle pull for men. This may point to a more pronounced sexual division of labour in the Blokhuizen people. In particular, this finding is suggestive of higher mobility in the men. This is consistent with historical information that notes that men were more commonly worked in the agricultural fields (Jewell 1996; Kaptein

2007). This did not necessarily require them to walk long distances, but activities such as ploughing may have resulted in substantial muscle pull on the lower limbs. The women appear to have been less mobile which may fit with the idea that they were more concerned with tasks in and around the house (Jewell 1996; Kaptein 2007), with the osteoarthritis data indicating that their activities were strenuous for their upper limbs.

Interestingly, there are no significant differences in bone morphology between the men and women of Klaaskinderkerke. This does not necessarily mean that men and women were performing similar tasks, but it does suggest that the activities they were carrying out required equal levels of muscle pull, possibly that there was less of a difference in their average cumulative mobility. A similar image is presented by the comparison of osteoarthritis prevalence between men and women. Only the prevalence of hip osteoarthritis is suggestive of differences in mechanical loading. This lack of variation in both muscle pull and osteoarthritis between men and women from Klaaskinderkerke could be related to the commercialisation and diversification of labour in the countryside in the late medieval period. With the addition of other occupations besides agriculture, there were more variable activities that may have been more equitably distributed amongst males and females. A possible result of this could be that male and female muscle pull and mechanical loading would have become more similar. The variety of activities may have obscured male-female activity differences as visible in the skeleton. Additionally, sea fishing, so important in Zeeland in the late medieval period, resulted in men being away for extended periods of time, possibly requiring the women to take over some of the tasks previously executed by the men. This may have lowered the mobility of the men and increased the mobility of the females, such that the final outcome was similar, explaining the lack of difference between the sexes.

Shifting activities through time?

Based on the skeletal data, differences in the activity patterns of the rural individuals are visible when the two villages are compared. It has to be noted that there might have been certain local differences between Blokhuizen and Klaaskinderkerke which may explain some of the variations in activity patterns irrespective of the developments in the late medieval period. Differences in environment, soil type, and consequently types of agriculture are likely to have influenced patterns of osteoarthritis and bone morphology. It is to be expected that some of the smaller variations in the type of joints affected by osteoarthritis are due to local variation. However, several of the observed differences cannot be fully explained by intrinsic factors alone. The comparison upper versus lower limb osteoarthritis between Blokhuizen and Klaaskinderkerke demonstrated highly significant differences, which strongly suggests a shift in activity. The comparison of morphology of the lower limbs also reflects shifts in activity patterns. The males from Klaaskinderkerke experienced significantly less directional muscle pull than those from Blokhuizen, which points to a transformation in activity. Additionally, the Klaaskinderkerke men have a higher prevalence of lower limb osteoarthritis. These observations are congruent with an increased focus on market production and commercial activities, and especially a decrease in agricultural work. Tasks like fishing and peat extraction may increase mechanical loading and reduce mobility. Moreover, the disappearance of strong sexual dimorphism in bone shape in Klaaskinderkerke is also consistent with the commercialisation of activity and the greater variability of occupation resulting in more similar muscle pull for men and women. In sum, the skeletal data on osteoarthritis and bone morphology are suggestive of changes in activity patterns, pointing to increased diversification of physical tasks as a result of the socioeconomic developments in the late medieval period.

6.3.2 Rural-urban comparisons

Osteoarthritis and urban activity

Only 3.9% of the studied joints in the Alkmaar collection showed signs of osteoarthritis. While this prevalence is lower than that of the rural sites, the comparison of the total number of affected joints among the three studied collections revealed no significant differences suggesting that the overall levels of mechanical loading remained similar through time. The intra-site comparison of osteoarthritis prevalence between males and females in the Alkmaar collection revealed significant differences. The men had more joints affected by osteoarthritis than the women. While on average the men were more commonly affected, there were no differences in prevalence in upper and lower limbs between males and females: men just have a higher osteoarthritis prevalence in most joints, suggesting generally higher mechanical loading for the Alkmaar males in comparison with the females. As might be expected, the data suggest that men were involved in more physically demanding tasks.

The separate comparison of the male and female osteoarthritis prevalence between the sites reveals interesting patterns. The comparison of overall prevalence and prevalence in upper and lower limbs of male osteoarthritis between the three skeletal assemblages demonstrates no significant differences indicating that mechanical loading for the men is comparable through time and living environment. Even though the historical data point to increased economic specialisation and a marked decrease in agricultural activities in the towns of Holland and Zeeland, the osteoarthritis data indicate that urban activity patterns did not significantly lower or raise the prevalence of joint disease in men. While it might have been expected that agricultural tasks would result in more mechanical loading on the joints, these results suggest that the urban activities, although different, were responsible for similar levels of physical stress.

The occupations in Alkmaar were quite varied in the late medieval period. While the large scale textile companies decreased in Alkmaar in the 16th century, an increase was noted in traders/craftsmen such as bakers, tailors, shoemakers, smiths, but also weavers and shipbuilders who were organised in guilds (Kaptein 2007). In addition, individuals within Alkmaar commonly owned land outside of the town, the products of which were sold on the local market, but also exported abroad (Kaptein 2007). Although it is difficult to argue what the occupations of the men in this skeletal sample were, the osteoarthritis prevalence data suggests that a substantial amount manual labour was present in their daily tasks.

The separate comparison of female osteoarthritis prevalence, however, does reveal significant differences. The Alkmaar women have significantly fewer joints affected by osteoarthritis in comparison with the Blokhuizen women, specifically in the upper limbs, indicating that the earlier medieval females experienced higher degrees of mechanical loading on their joints. This suggests that the tasks performed by the rural Blokhuizen women involved more mechanical loading than the activities of the women in the town of Alkmaar. The rural women of Blokhuizen are expected to have been occupied with tasks mainly focusing on agriculture. In an urban context, female tasks were most likely different. The list of individuals buried in the Franciscan cemetery in Alkmaar shows that several women were housewives (appendix 1). Other occupations are unfortunately not mentioned. From Dordrecht, however, there is some information on female occupations within the town. A survey of 492 individuals in AD 1555 found 41 women employed outside the household (Unger 1915). Women worked in the textile business as bleachers, fur processors, spinsters, and seamstresses. In the food industries, women were employed as bakers, brewers, and butchers. Additionally, the Dordrecht survey notes that several women were involved in trade, commonly selling or buying products (Unger 1915). Considering the low number of women included in the survey, it is likely that a large part of the female population was not independently employed. Instead, many women were probably working from home where they were responsible for the household and other tasks associated with the occupation of their husband, as is suggested by English historical literature (Jewell 2007). While this is not indicated in the survey from Dordrecht, Jewell (2007) notes that in English towns, many women, irrespective of marital status, entered household service. Based on the osteoarthritis comparison, it is clear that the Alkmaar females experienced substantially less mechanical loading on their joints which suggests that female rural agricultural activities in the central medieval period were more strenuous than female urban industrial activities. The marked reduction of agricultural tasks replaced by more commercial or household activities for the urban women may have caused mechanical loading to decrease substantially

Interestingly however, there is no difference in osteoarthritis prevalence between the women of Alkmaar and Klaaskinderkerke, while significant variations were observed between the females of Klaaskinderkerke and Blokhuizen. This indicates that urban living is not the only factor influencing activity patterns of the women. The results suggest that the socioeconomic developments in the late medieval period impacted both rural and urban female activities.

The osteoarthritis prevalence suggests that activities with similar levels of mechanical loading were carried out in both town and county. Even though this comparable prevalence of joint disease does not directly imply that they were performing similar tasks, historical literature suggests that late medieval rural and urban activities overlapped. The types of activities were similar (Hoppenbrouwers 2001), even though agriculture would still be important in the countryside, especially in Zeeland (van Steensel 2012b). In the late medieval period, both town and country were highly commercialised and heavily focused on production for the market (Hoppenbrouwers 2001). While the level of specialisation was different, townspeople being more specialised, the fact that they worked in comparable industries may have resulted in similar levels of mechanical loading.

Bone morphology and urban activity

The results of the analysis of bone shape suggest that the Blokhuizen males were experiencing more directional muscle pull than the Alkmaar males: both femoral and tibial shapes are significantly different. However, since there are no differences in muscle pull between the males of Klaaskinderkerke and Alkmaar, which points to similar mobility levels, it is not just the distinction between a rural and urban environment that can explain the marked variation between Blokhuizen and the other populations. As was suggested by the osteoarthritis data, the results from the bone morphology comparisons support the idea that the socioeconomic developments in the late medieval period impacted the activity patterns of both rural and urban individuals. As discussed above, the activities between the late medieval rural and urban populations overlapped. Both the osteoarthritis and bone morphology data indicate that in the case of the men, urban living did not impact significantly on activity patterns. It appears that the transition from the central to the late medieval period had a more substantial effect on activity patterns.

There is a decrease in female muscle pull levels as a result of living in an urban environment. While femoral shapes are similar between Blokhuizen and Alkmaar, the tibial shape is significantly different. Since the tibia is more reliable for studying activity (Pomeroy and Zakrzewski 2009), the differences in the tibial shape tentatively point to reduced muscle pull for the Alkmaar women in comparison with those of Blokhuizen. The comparison between the females of Klaaskinderkerke and Alkmaar gives highly significant results for both the femur and the tibia. The results, however, are somewhat contradictory: the Klaaskinderkerke women have rounder femora and flatter tibia than the women in Alkmaar. Since the tibia, as was noted above, is considered to be more reliable for studying activity, these results hint at higher female muscle pull levels in Klaaskinderkerke in comparison with Alkmaar. This suggests that, while no change was noted in the men, the change from a rural to an urban environment transformed female activities: mobility was lowered, possibly as a result of more work taking place in and around the house.

6.3.3 Summary: influence of medieval developments on activity

The data on osteoarthritis and bone morphology suggest that socioeconomic developments of the medieval period impacted activity patterns. General levels of osteoarthritis remained similar through time, but differences in prevalence in specific joints or joint groups point to a transformation in activity. The bone morphology data has demonstrated marked differences between the populations suggesting a shift in activity patterns. The most important conclusion is that the largest differences are not between the rural and urban collections, but between those from the central medieval and late medieval periods. Both men and women from Blokhuizen experienced higher degrees of muscle pull than the individuals from Klaaskinderkerke and Alkmaar. Additionally, the prevalence of osteoarthritis in the upper limbs of the Blokhuizen women is significantly higher than that among the Klaaskinderkerke and Alkmaar women. Another important finding is that the female activity pattern seems to be more influenced by urban living than that of the men. The Alkmaar women experienced lower degrees of muscle pull than the Blokhuizen and Klaaskinderkerke women. These results suggest that the socioeconomic developments in the late medieval period, including the commercialisation of rural industries, more market-oriented production, and the increase in non-agrarian activities in both town and country, may have been responsible for an impact on activity patterns of the late medieval people.

6.4 DIET AND MEDIEVAL DEVELOPMENTS

A third objective of this research was to assess if the socioeconomic developments in the medieval period influenced dietary patterns. This was done through a comparison of the prevalence and frequency of carious lesions and the prevalence of indicators of nutritional stress among the three skeletal assemblages.

6.4.1 Rural comparisons

Caries and diet

By studying caries prevalence, it is possible to gain insight into the type of foods (i.e., proteins or carbohydrates) that were consumed. Populations more dependent on foods rich in carbohydrates often have a higher caries prevalence and frequency. A diet mainly composed of proteins will result in lower caries rates (Hillson 2008). In Blokhuizen, caries prevalence (i.e., the number of individuals with one or more caries lesions) is 41.4%. The overall caries frequency (i.e., the number of teeth showing caries in relation to the total number of observed teeth), which gives a more reliable picture of the amount of carious lesions since it takes into account factors such as differential preservation and post-mortem and ante-mortem tooth loss, is 7.8%. This pattern is comparable to that of the contemporary village of Vronen where 7.1% of the studied teeth were affected by caries (Alders and van der Linde 2011), suggesting that similar types/proportions of foods were consumed in the two villages.

Caries prevalence in Klaaskinderkerke is significantly higher than in Blokhuizen. Since similar percentages of teeth and tooth types survived at both sites, the caries prevalence data are presumably not an artefact of differential preservation or variations in the amount of ante-mortem tooth loss. Historical, archaeozoological, and archaeobotanical data indicate that the central medieval diet was most likely relatively simple, mainly consisting of cereals and meat (Bakels *et al.* 2000; Ettema 2005). Bread made from the available grains, mainly wheat and barley, appears to have been an important food product (Burema 1953; Jansen-Sieben and van Winter 1989). Fruits and vegetables, on the other hand, were considered lesser food products, beans and cabbage-like vegetables were seen as the least '*kwaadaardig*' (evil) (Baudet 1904; Burema 1953). Moreover, milk products such as cheese and butter, although representing more luxury products, were most likely also consumed. Meat and fish are considered to have been consumed on a regular basis. Although fish bones are not commonly encountered in the central medieval village sites in Holland and Zeeland (Kok 1999), fish was most likely a common meat replacement in combination with eggs (Rawcliffe 2013; van Dam 2009). Since the caries prevalence in Klaaskinderkerke is higher than in Blokhuizen, a dietary shift is suggested by the data, in this case the ingestion of more carbohydrates.

Local variations in preference or availability of certain crops may have been responsible for a different diet causing the observed increase in carbohydrate consumption. In addition, changes in and diversification of agricultural practices as well as intensification of international trade in the late medieval period could have expanded and diversified diet (Woolgar *et al.* 2006). This hypothesis is supported by archaeobotanical and archaeozoological research which shows a greater diversity of fruits and vegetables, and more types of animals in the countryside during later medieval times (van Haaster *et al.* 2001). Indeed, an increase in fruit consumption or the intake of more sugar and honey may have been responsible for the higher prevalence of caries in Klaaskinderkerke. It is, however, difficult to assess if everyone would have had access to these products. Both Baudet (1904) and Burema (1953) state that sweets and cakes were available in late medieval society, but that not everyone could afford them.

Another explanation for the higher caries prevalence may be an increase in alcohol consumption. Studies performed on animals in a laboratory setting show that a higher intake of alcoholic drinks promotes bacterial growth in the oral cavity (Kantorski 2007). During the central medieval period in Holland, beer production on a commercial scale was still in its infancy (Unger 2004). Although small quantities may have been produced at home, only after AD 1300 did commercial beer production became important (Unger 2004). Therefore, it is possible that beer was consumed on a more regular basis in Klaaskinderkerke causing carious lesions to increase.

However, this potential shift in food consumption did not result in an increase in the number of teeth affected by caries: the overall caries frequency (non-adults and adults combined) in Blokhuizen (7.8%) is comparable to that in Klaaskinderkerke (7.9%). A separate analysis of the adult caries frequency shows similar results. The adults of Klaaskinderkerke had a caries frequency of 8.7% and in Blokhuizen this was 9.1%. The similarity in frequency and dissimilarity in prevalence can be explained by the fact that in Blokhuizen the individuals with caries had many teeth affected.

The women in Blokhuizen had twice as many teeth affected by caries in comparison with the men. The females had a caries frequency of 13.5% while the men only had a frequency of only 7.3%. The trend of women having a higher caries frequency is observed in many skeletal collections from different cultures with different dietary practices (for an overview see Lukacs and Thompson 2008). Dietary differences between men and women are a common explanation for this variation which is frequently related to the notion that women have easier access to food and snack during meal preparation (Lukacs and Largaespada 2006). Another often noted cause of the sexual division is that teeth erupt earlier in girls than in boys, hence increasing exposure time (Lukacs and Largaespada 2006). Lately, a physiological explanation has received attention. Recent research by Lukacs and Thompson (2008) has shown that the hormonal changes associated with pregnancy, and also with puberty and menstruation, result in modifications in saliva composition making the oral environment more cariogenic in women than in men (Lukacs and Largaespada 2006; Lukacs and Thompson 2008). Although dietary differences between males and females cannot be ruled out, the fact that sexual differences in caries prevalence and frequency are commonly present in prehistory and history (e.g., Hemphill 2008; Lukacs and Thompson 2008; Olson and Sagne 1976) makes the physiological explanation highly plausible.

Interestingly, there are no significant differences in caries frequency between males (8.8%) and females (7.4%) in Klaaskinderkerke. If the hormonal explanation is valid, then the actual lack of difference may point to a difference in diet between males and females in this village. These data suggest that the women were eating fewer carbohydrates, since their caries frequency is significantly lower in comparison with the Blokhuizen women. The females from Klaaskinderkerke appear to have been consuming more protein, possibly in the form of meat, milk products, or eggs. More milk products in the diet, especially cheese, would lower caries rates since these food items have protective effects against caries (Hillson 2008). In addition, increased fish consumption may have contributed to the observed decrease in caries. As was discussed in chapter three, fish-eaters have on average lower caries rates (Littleton and Frolich 1993). Since commercial fishing became an important activity in late medieval Zeeland (van Steensel 2012b), it is possible that the consumption of fish also increased. These hypotheses, however, do not explain why only the caries rates among the women decreased. The caries frequency for the Klaaskinderkerke males actually increased, suggesting greater carbohydrate consumption.

Changes in rural diet?

The caries data suggest that there was a shift in diet from the central to late medieval periods for the females. The caries frequency decreased substantially, suggesting more or different proteins and fewer carbohydrates in the diet. Considering that milk products and fish have a protective effect against caries, this could suggest that women in Klaaskinderkerke were more regularly consuming these food stuffs than the women in Blokhuizen. As commercial fishing became more important in the late medieval period, fish might have been more readily available in Klaaskinderkerke. The men from Klaaskinderkerke, on the other hand, do not seem to have benefitted from the greater availability of fish. The caries frequency of the males is slightly higher in comparison with the males from Blokhuizen, but this difference is not statistically significant. A possible explanation can be that men were consuming more protein in addition to more carbohydrates, maybe in the form of beer, resulting in an overall similar caries frequency in comparison with Blokhuizen. If this is indeed the case, the caries data point to a dietary shift for both males and females in the late medieval period.

Nutritional stress

An evaluation of the skeletal indications for specific nutritional deficiencies suggests that the diet consumed by the Blokhuizen individuals was sufficient in certain nutrients. The characteristic bending of the lower legs associated with vitamin D deficiency was not observed in the Blokhuizen collection, suggesting a healthy intake of food products with vitamin D, most likely meat, fish, and eggs, as well as sufficient exposure to sunlight. Similarly, scurvy was also not encountered in Blokhuizen. While the identification of scurvy in skeletal remains is difficult, the complete absence of the disease suggests that the Blokhuizen diet was most likely sufficient in vitamin C. Citrus fruits are an important source of vitamin C, but several vegetables, especially certain types of cabbage, contain it as well. Archaeologically, fruit remains are rarely encountered in villages dating to central medieval times, especially those on the peat soils. This is most likely the result of the inability of fruit trees to grow on the peat (Bakels *et al.* 2000). Vegetables would then be the most likely source of vitamin C, but these are also hardly ever found during archaeobotanical research, which presumably results from the poor preservation of vegetable remains in archaeological contexts (Bakels *et al.* 2000). Possibly, the villagers supplemented their diet by gathering wild fruits such as blackberries and blackcurrants (Bakels *et al.* 2000; van Haaster *et al.* 1997).

While none of the studied nutritional diseases were encountered in Blokhuizen, there are three pathognomonic cases of residual rickets in Klaaskinderkerke. These cases may point to increased nutritional stress in the late medieval period. However, since there are no significant differences in the prevalence of non-specific stress markers between Blokhuizen and Klaaskinderkerke, and because the Klaaskinderkerke caries frequencies suggest a large component of vitamin D-rich foodstuffs such as fish, it is possible that the increased rickets prevalence has a more behavioural explanation. Considering that sunlight is the most important source of vitamin D, the cases of residual rickets may suggest that the children in Klaaskinderkerke spent more of their time indoors or wore more occlusive clothing than the children of Blokhuizen. Interestingly, all of the individuals with residual rickets were females, suggesting that they were possibly more at risk for developing vitamin D deficiency.

The changes in the activity patterns of the late medieval villagers indicated by the differences in osteoarthritis and bone morphology could have played a role in the observed increase in vitamin D deficiency. Although changes in clothing cannot be ruled out, the late medieval intensification of commercial activities in the rural settlements may have resulted in more tasks being performed indoors, while previously most activities would have taken place on the land. It is possibly that an increase in indoor activities such as spinning and weaving was responsible for the higher prevalence of vitamin D deficiency in the Klaaskinderkerke girls/women. A similar pattern was observed in the English skeletal collections studied by Lewis (1999). She also noted a slight increase in nutritional deficiencies in the later rural assemblage. Considering a similar absence of differences in stress markers between her collections, a behavioural explanation, clothing or more time indoors, was deemed more likely by Lewis as well.

Evidence for late medieval famine?

The fact that no differences in nutritional status are observed between Blokhuizen and Klaaskinderkerke is interesting considering the occurrence of periods of food scarcity in the late medieval period, which could have negatively influenced the nutritional value of the consumed diet. Three back-to-back crop failures as a result of extreme weather conditions throughout Europe in the years AD 1315 to 1317 strongly diminished the availability of agricultural products. Moreover, damp conditions on many of the agricultural fields allowed plant diseases such as mould, mildew, and rust to flourish (Jordan 1996; Blockmans and Hoppenbrouwers 2009). Additionally, the poor weather laid the foundations for the outbreak of deadly animal diseases, affecting predominantly cattle and to a lesser degree sheep (Jordan 1996; Newfield 2009; Slavin 2012). The crop failures and animal mortality resulted in a catastrophic subsistence crisis affecting the entire continent of Europe, including Holland and Zeeland (Jordan 1996). Jordan (1996) estimates that 10% of the population died as a result of the famine which is more than twice the expected mortality rate for the late medieval period. However, evidence of this ‘Great Famine’ is not visible in the skeletal remains studied in this research. The prevalence of non-specific stress markers and stature means between Blokhuizen and Klaaskinderkerke collections are similar and large differences in nutritional deficiencies are not observed. Historical sources focusing on this period in time in Zeeland seem to fail to mention the famine (Dekker and Kruisheer 1967). These results could suggest that the famine did not impact the individuals from Klaaskinderkerke to a great extent. However, if the famine was indeed as deadly as Jordan (1996) suggests, several of the Klaaskinderkerke individuals could have died as a result of it without having the time to develop skeletal lesions. This could explain why no increase in stress markers or differences in stature means are noted. Considering the fatality of the famine, it is plausible that some individuals of Klaaskinderkerke died as a result of it without demonstrating an increase in non-specific stress markers.

6.4.2 Rural-urban comparisons

While the difference in caries between Blokhuizen and Klaaskinderkerke is difficult to interpret, the Alkmaar caries results indicate a marked dietary shift. Although variations do not meet statistical significance, the urban individuals had a higher caries prevalence than the inhabitants of both Blokhuizen and Klaaskinderkerke. Moreover, the individuals from Alkmaar had a significantly higher caries frequency than the individuals from the rural populations which suggests a clear increase in carbohydrate consumption by the urban people. This apparent dietary shift is further corroborated by the early onset of caries in Alkmaar. The younger adults in the urban collection have significantly more teeth affected by caries than those from Klaaskinderkerke and Blokhuizen pointing to a clear increase in cariogenic food consumption. These caries data indicate that there is both a dietary shift through time as well as a shift associated with urban living. In the late medieval period a broad variety of foods must have been available in the urban centres as a result of the increase in international trade (van Bavel 2011). However, since both rural and urban people in the late medieval period would have had access to urban markets, the influx of new and different products alone cannot explain the large difference in caries prevalence and frequency between Alkmaar and Klaaskinderkerke. One aspect of urban living that might be responsible for the increase in carious lesions is that townspeople would have had more access to and have been more dependent on the market for food. Although some citizens may have had access to small gardens (Bitter 2007b; Dijkman 2010), agriculture was not a common task for urban people. Even though commercialisation of the countryside in the late medieval period also made villagers more market dependent, they most likely still produced some products and kept animals for their own use, thereby possibly limiting their carbohydrate intake. The more regular market access for the urban citizens would have increased their opportunity to buy products which contained sugar.

A separate analysis of the sexes shows that the Alkmaar men had a significantly higher caries frequency than the men from the two rural collections indicating that they were consuming different kinds of food products, mainly more carbohydrates. In addition, while the females from Blokhuizen and Alkmaar had a similar caries frequency, the difference between the Alkmaar and Klaaskinderkerke females is much larger, pointing to more starches and sugars in the urban female diet in comparison with village women from the same time period. What the separate analysis of the sexes also reveals is the lack of variation between males and females in caries frequency (16.8% versus 16.7%). As discussed above, throughout history women have commonly had higher caries rates, which suggests that this lack of difference in caries frequency actually points to dietary variation. It suggests that the men in Alkmaar were consuming more cariogenic foods than women, as appeared to be the case in Klaaskinderkerke. Overall, the caries data suggest a clear increase in carbohydrate consumption for the urban inhabitants, especially for the males.

Isotopic case study: Blokhuizen and Alkmaar compared

Stable isotope ratios of carbon and nitrogen from the bone collagen of 50 individuals from Blokhuizen and Alkmaar were analysed in the context of the Master's research of IJk van Hattum (2014) in order to gain insight into their diet. Isotopic ratios differ in different classes of food which are then incorporated into the skeleton (DeNiro and Epstein 1978, 1981; Schoeninger and DeNiro 1984). The analysis of these ratios allows for an estimation of the types of consumed foods and in certain cases the rough proportions of different foods. Generally, a difference can be made between the consumption of marine and terrestrial food products, and between C3 (most European crops) and C4 (tropical and subtropical) plants (figure 6.1) (DeNiro and Epstein 1978, 1981; Schoeninger and DeNiro 1984).

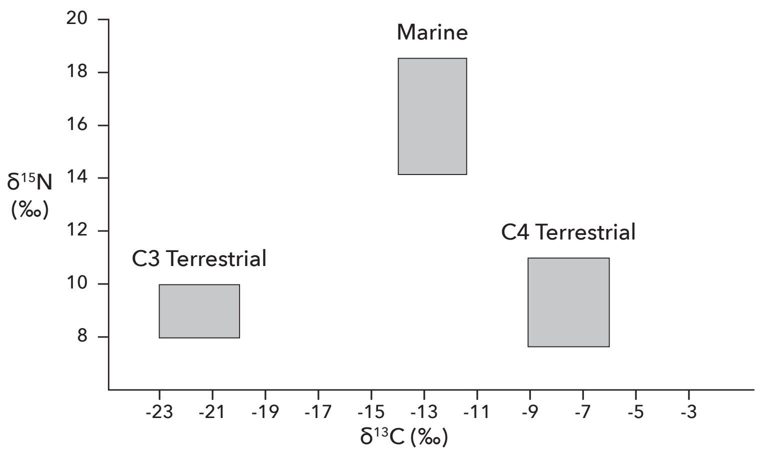


Figure 6.1: Approximate stable isotope ratios when consuming pure C3, C4, and marine diets (after Mays 2010, figure 10.2, p. 270).

The comparison of the isotopic signatures of people of Blokhuizen and Alkmaar suggests a dietary shift. While the caries data point to increased consumption of carbohydrates by the urban population, especially for the males, the isotopic data indicate that the Alkmaar people, both the men and women, were also consuming different protein types (van Hattum 2014, figure 6.2). These data indicate that the urban citizens consumed products higher up on the food chain, most likely marine or freshwater fish, but also increased intake of omnivores such as chickens (and their eggs) and pigs should be considered. Cesspit research from Alkmaar has shown that a wide variety of proteins were available (Esser *et al.* 2001). Meat consumption appears to have been focused primarily on cattle, pig, and sheep or goat. Birds, mainly chicken and duck, have also been encountered in the Alkmaar deposits, although to a lesser extent (Esser *et al.* 2001). Fish and shell fish were commonly found in the deposits indicating that they were indeed a significant source of food. Especially mussels appear to have been favoured in Alkmaar (Zeiler and Brinkhuizen 2010).

Based on the isotopic data, the diet of the Blokhuizen individuals appears to have been mainly composed of terrestrial food products, most likely cereals and protein from herbivores such as cows (van Hattum 2014). Fish was of less importance in the Blokhuizen diet. As noted above, fish bones are not commonly encountered at the rural wetland village sites (Kok 1999) while they are regularly found in urban contexts (Esser 2003). This may in part be due to differential preservation and excavation techniques, yet, the lack of fish bones in combination with the isotopic data from Blokhuizen suggests that fish consumption was indeed limited in the central medieval villages.

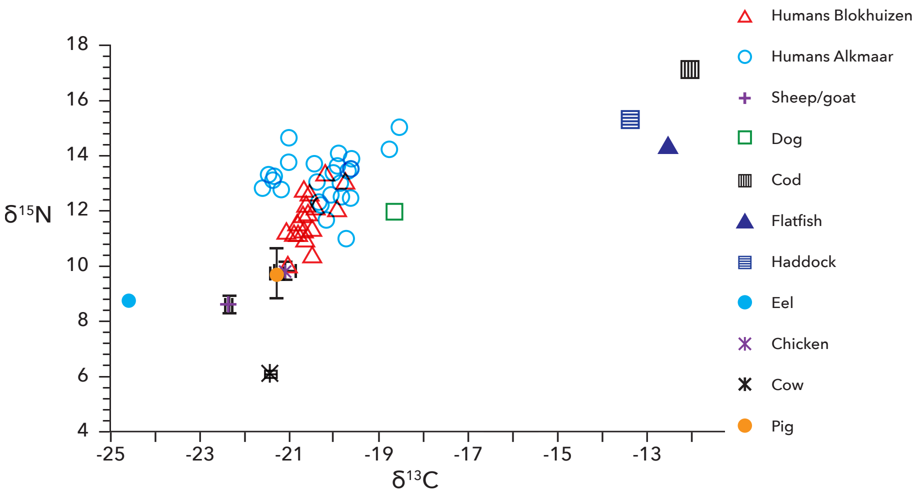


Figure 6.2: Stable carbon and nitrogen isotope ratios of the individuals from Blokhuizen and Alkmaar compared to the average stable isotope ratios from fauna specimens from Alkmaar and the stable carbon and nitrogen isotope ratios from fish samples from Oldenzaal. Error bars are one standard deviation (after van Hattum 2014, figure 10, p. 109).

This observation is consistent with the clear increase in commercial fishing activities during the late medieval period. As mentioned, herring fishing became a significant industry in Zeeland and parts of Holland and herring became an important export product making its way up to England, and even being transported as far as Basel (Unger 1978). Especially the new preservation technique of curing herring on board of the ship (kaken) allowed for export and import over large distances. According to Unger (1978:338), *"From 1439 to 1441 about 375 lasts of herring went from the province of Holland alone to Germany"*. Since a last is approximately 1000 kilograms, vast amounts of herring were caught in the late medieval period of which a good portion was exported. However, a large portion also made it to the markets in Holland and Zeeland (Unger 1978). In addition to locally procured fish, stable isotope research on fish bones dating to the late medieval period indicate that fish was also imported from distant waters such as arctic Norway, Iceland, and/or the northern isles of Scotland (Barret *et al.* 2011).

As a result of increased water management, especially the creation of dikes and sluices, eel fishing became important in the late medieval period (van Dam 1997). The associated expansion of fresh water resulted in an increase of eels in Holland. Eels are comfortable in the peat environment of Holland, with its shallow water. Furthermore, the fact that eels migrate from fresh to salt water at some point in their lifetime made them travel to the sluices where they could be caught by fishermen (van Dam 1997). While this development could have expanded the availability of eel on the markets, the isotopic data do not suggest a marked increase in eel consumption in the late medieval period, suggesting that this fish may have been a more minor part of the diet. This is further supported by van Dam (2003) who notes that large portions of eel are exported to oversee ports which might explain the apparent lack of local consumption.

The isotope data also demonstrate that the individuals from Alkmaar had a more heterogeneous diet than the people of Blokhuizen. Most inhabitants of Blokhuizen appear to have been consuming similar food products. Male and female isotopic ratios were similar, suggesting that there were no marked sex-based differences in diet (van Hattum 2014). This also supports the hypothesis that the difference in caries frequency between the Blokhuizen males and females had a hormonal origin and was not the result of large dietary differences. In Alkmaar, however, there were differences in the stable isotope values of males versus females suggesting a more marked difference in diet (van Hattum 2014). The increase in the type of products that were available as a result of the expansion of the market, and thereby the likely diversification of the diet in the late medieval period may have contributed to this. The decreased reliance on home grown foods could have resulted in larger differences in diet within the urban population.

Nutritional stress

The skeletal remains from Alkmaar do not provide any evidence for a change in nutritional stress. Only one individual shows signs of a possible vitamin C deficiency. Skeletal lesions associated with vitamin D deficiency were not encountered. As noted above, none of the skeletal indicators for nutritional disease were found in Blokhuizen. Three cases of vitamin D deficiency were documented in Klaaskinderkerke, but it is argued that this increase in prevalence has a sociocultural explanation. Considering the similarities in the prevalence of enamel hypoplasia, and the lack of difference in stature means, large differences in nutritional status are unlikely.

6.4.3 Summary: influence of medieval developments on diet

The comparison of the caries rates tentatively shows the late medieval diet contained more cariogenic products than that of previous times. In Klaaskinderkerke more individuals were affected by carious lesions than in Blokhuizen suggesting increased consumption of carbohydrates. However, the comparison of the caries frequency does not follow the same pattern. The comparison of the urban and rural individuals gives stronger results: a clear increase in caries prevalence and frequency is observed, suggesting higher consumption of cariogenic products. Increased consumption of sugar-rich fruits could have contributed to the higher caries rates in the urban collection. It is possible that higher market dependence was responsible for the increased consumption of cariogenic foods. Furthermore, an isotopic case study of a small sample of individuals from Blokhuizen and Alkmaar demonstrated that in addition to the increase in carbohydrates, the Alkmaar townspeople were consuming different types of protein, most likely more marine or freshwater fish which is in line with the increase in commercial fishing and the greater availability of fish in the late medieval period. Furthermore, the isotopic data indicate increased dietary heterogeneity in the Alkmaar population, which can be linked to their greater dependence on the market for food.

The analyses of caries and stable isotopes indicate that the urban diet in the medieval town of Alkmaar was different from that of Blokhuizen and Klaaskinderkerke. Lewis (1999, 2002) also reported a statistically significant increase in carious lesions in the dentitions of urban non-adults, a pattern which she also links to greater access to imported and refined foods. Moreover, Kjellström (2005) notes an increase in the prevalence of carious lesions when the urban settlement of Sigtuna became more established. Although she does not relate this specifically to a larger component of imported foods, she notes it was most likely related to increased carbohydrate consumption. Interestingly, Betsinger (2007) noted no differences in caries prevalence between the three consecutive urban Polish collections she studied, indicating that the diet, or at least the proportions of proteins to carbohydrate, remained similar throughout urban development (Betsinger 2007). Since Betsinger studied collections dating from AD 950 to 1250, it is possible that international trade and market exchange in that period were not yet at the level of late medieval England and Holland, therefore limiting the availability of imported and refined foods.

With regards to nutritional stress, no significant differences are visible between the collections. This is consistent with the lack of difference in the non-specific stress markers. Nutritional deficiencies were not found in Blokhuizen and Alkmaar. The presence of residual rickets in Klaaskinderkerke is considered to have a behavioural explanation, considering the similar prevalence of non-specific stress markers and comparable stature means. Although the Great Famine between AD 1315 and 1317 could have influenced mortality rates and stress marker prevalence, this is not visible in the excavated population of Klaaskinderkerke. Although this may suggest that the famine was not as influential in Zeeland as it was in other areas in Northern Europe, it is necessary to consider the possibility that some of the Klaaskinderkerke individuals may have died as a result of the famine before developing any signs of a pathological stress response.

6.5 OSTEOARCHAEOLOGY AND MEDIEVAL SOCIOECONOMIC DEVELOPMENT

The main goal of this research was to osteoarchaeologically study the socioeconomic developments of the medieval period and associated life consequences. This bottom-up approach aimed at increasing our understanding of the physical impacts of medieval socioeconomic changes. Historical data show that the medieval period in Holland and Zeeland can be characterised as a period of substantial change and development during which the foundations were laid for the prosperous Golden Age of the 17th century. Large scale urbanisation, optimisation of rural and urban industries, and the development of extensive international trade networks in the late medieval period triggered a blossoming Dutch economy. This study has provided new and unique perspectives on these historical developments, by adding physical information on individuals to the existing body of historical data.

The comparison of the skeletal remains from Blokhuizen, Klaaskinderkerke, and Alkmaar has demonstrated that the developments in the late medieval period were not limited to socioeconomic consequences but also impacted the medieval citizens physically. Changes in disease, activity, and diet are indicated by several of the skeletal markers studied in this research.

However, although the opposite might have been expected on the basis of other research (e.g., Woods 2003), marked differences between town and country appear to be absent, especially in the late medieval period. The largest differences are found between central medieval Blokhuizen and the two late medieval skeletal collections, especially in terms of activity, which indicates that socioeconomic developments in the late medieval period not only influenced the citizens of the newly formed towns, but simultaneously left their mark on the rural villages from the same time period. While there are small variations suggesting that rural and urban living environments were different, also in the late medieval period, generally speaking, this research does not uphold a marked rural-urban dichotomy, rather supporting the idea of a relatively fluid and interdependent relationship between town and country in the late medieval period.

Another important observation that can be made on the basis of the data presented in this chapter is that comparable research carried out in other places in Europe has found both similar and different skeletal patterns. This reinforces the unique contribution of the current research, yet also expresses the need for more local osteoarchaeological analyses focusing on similar topics in Europe to achieve a nuanced and accurate view of the changing European society in this dynamic era. Extrapolating what is known about the consequences of urbanisation and other developments in the medieval period from certain regions to other areas might result in incorrect conclusions. As this research has shown, it is vital to have a good understanding of local factors influencing populations to be able to draw refined and informed conclusions about the physical consequences of medieval socioeconomic developments.

7

Life in Transition

7.1 INTRODUCTION

This research investigated the physical consequences of the socioeconomic developments in the medieval period for the inhabitants of Holland and Zeeland. The central focus was how human skeletal remains can reflect the life alterations associated with medieval developments and how skeletal analyses can contribute to a better understanding of the impact of these changes. To answer the central question, three key aspects of medieval life were studied: disease and stress, activity, and diet. By comparing three different skeletal collections, two rural and one urban, and through the incorporation of historical information, this study presents a new perspective on socioeconomic development in the medieval period and the repercussions on the daily lives of people during these transitional times. This chapter presents the conclusions of this research in a structured way by providing answers to the subquestions and main research question outlined in chapter one. The chapter ends with a discussion on directions for future research.

7.2 SUBQUESTIONS

7.2.1 Subquestion 1: patterns of disease

- Which changes in patterns of disease and stress levels can be observed? Are there differences between the rural skeletal remains from earlier and later medieval times? In which ways do the rural collections differ from the urban collection?

The skeletal analysis of the three collections revealed that there are changes in the patterns of disease. Infections associated with high population densities such as tuberculosis or other lung diseases were not found in the collection of Blokhuizen, dating to the central medieval period before large-scale urbanisation took place. Considering that these villagers lived in farms with large distances between the houses, this finding is consistent with the expected palaeopathological framework. In the late medieval rural collection of Klaaskinderkerke, diseases such as tuberculosis and other respiratory infections were also not encountered. Even though population numbers within Holland and Zeeland increased, population densities appear to have remained low enough for crowd dependent diseases such as tuberculosis to be unsustainable. In addition, the comparison of Blokhuizen and Klaaskinderkerke shows that stress levels were not visibly increased or decreased in the rural areas through time. These results suggest that socioeconomic developments in medieval Holland and Zeeland did not have any profound skeletally visible impact on the people living in the countryside with regards to disease and systemic stress.

In contrast, the comparison of disease prevalence between the rural and urban collections did reveal differences. Tuberculosis and evidence for non-specific lung infections were solely found in the urban skeletal remains suggesting that townspeople had a higher risk of developing these kinds of diseases than villagers. The relatively high population densities could have contributed to the apparent increase in respiratory disorders. Interestingly, however, the indicators of non-specific stress do not demonstrate a significant increase in comparison with the rural collections. In fact, cribra orbitalia prevalence is even slightly higher in the countryside. Taking into account the environmental factors in Blokhuizen and Klaaskinderkerke, it is hypothesised that the higher cribra orbitalia prevalence might be associated with a greater presence of malaria in the rural areas.

Direct skeletal evidence for the occurrence of animal diseases such as brucellosis or bovine tuberculosis have not been found in any of the skeletal assemblages. Although osteoarchaeological visibility is possibly a factor, the skeletal data suggest that animal diseases which may have posed a risk for people were of lesser significance in medieval society.

The comparison of disease and stress patterns between the rural and urban skeletal collections has demonstrated that episodes of stress were common in both town and country. These results suggest that both rural and urban inhabitants were faced with threats which physically impacted their lives. While the risks appear to have been different, one living environment cannot be considered better or 'healthier' than the other.

7.2.2 Subquestion 2: patterns of activity

- In which way did changes to physical activity patterns during the medieval period and especially during urbanisation impact the bodies of the citizens? Which differences can be observed between inhabitants of villages and towns? Is it possible to observe differences in the division of labour?

The differences in osteoarthritis prevalence and bone morphology suggest that activity patterns changed during the medieval period. Overall levels of mechanical loading seem to have stayed roughly the same through time. However, the separate comparison of men and women as well as that of specific joint groups reveal significant differences indicating that types of physical activity for both men and women changed through time. Hip osteoarthritis was very prevalent in the men from Klaaskinderkerke pointing to specific activities in this village. In addition, differences in the prevalence of osteoarthritis in upper and lower limbs indicate that activities changed over time. Osteoarthritis prevalence is substantially lower among the females of Alkmaar, suggesting that the shift to urban living had the most profound effect on the daily lives of women.

The data on bone morphology also suggest shifts in activity patterns. The most marked difference is between the collections from the Central and Late Middle Ages, and not between the town and country. Both the men and women from Blokhuizen experienced higher degrees of muscle pull than those from Klaaskinderkerke and Alkmaar. The fact that activities were reorganised in the late medieval period and that occupations for villagers and townspeople overlapped during that time, may account for the lack of difference between the late medieval rural and urban individuals. This suggests that socioeconomic developments in the late medieval period influenced the activity patterns of society as a whole, both in rural and urban areas.

The division of labour between men and women appears to have changed as well. A significant difference in bone shape between males and females existed in Blokhuizen, indicating that the activities they carried out required markedly different levels of muscle pull. This clear distinction in bone shape between men and women disappeared in Klaaskinderkerke. This does not necessarily mean that males and females carried out the same tasks, but it does suggest that their respective activities required similar levels of muscle pull. This can be related to the idea that the late medieval people living in the countryside were occupied with a broad range of activities, which could blur skeletal differences. Interestingly, the skeletal remains of Alkmaar demonstrate clear shape differences between men and women, indicating a more pronounced distinction between gender-related activity levels in the town.

The data on activity suggest that the medieval socioeconomic developments, which include more market-oriented production, the commercialisation of rural industries, and the increase in non-agrarian activities in both town and country, can be linked to skeletally recognisable changes in activity patterns of the late medieval people. The osteoarchaeological analyses demonstrated a clear shift in patterns of physical activities through time, with the lives of women being more profoundly altered by the transition to an urban environment.

7.2.3 Subquestion 3: patterns of diet

- Which evidence exists for a change in dietary patterns? Are there differences in consumed food types between the earlier and later medieval rural collections? In which respect does the rural diet differ from the urban diet? Is there evidence for a change in nutritional stress levels through time or as a result of urban living?

The caries data point to a change in dietary patterns. The comparison of Blokhuizen and Klaaskinderkerke shows changes in both caries prevalence and frequency, suggesting variations in the spectrum of consumed foods. The availability of protein, possibly fish, appears to have increased in the late medieval period. This is particularly evident in the caries frequency of the women in Klaaskinderkerke. For the men, on the other hand, the comparison of the caries frequency suggests an increase in carbohydrate consumption as well.

The comparison of the rural skeletal collections with the Alkmaar assemblage revealed significant differences in caries prevalence and frequency. The townspeople appear to have been consuming more cariogenic products than the inhabitants of Blokhuizen and Klaaskinderkerke. In addition, the fact that the younger adults in Alkmaar have significantly more teeth affected by caries than those in the other collections points to an earlier onset of caries and therefore to a high starch and sugar intake for the urban population. Isotopic data point to a shift in diet for the inhabitants of Alkmaar as well. The carbon and nitrogen isotopes suggest that the urban individuals were consuming different types of protein, most likely freshwater or marine fish. Additionally, the isotopic data indicate increased dietary heterogeneity in the urban population. From these data, it can be concluded that the town residents were consuming more cariogenic products and different types of protein than their rural counterparts. Since the populations under study are assumed to have had a similar socioeconomic status, this indicates that urban living influenced diet. Increased dependence on and access to the market, where a wide variety of products could have been obtained, may have been responsible for the observed dietary shift.

The analysis of vitamin deficiencies in combination with the indicators of non-specific stress does not point to a change in nutritional stress. Evidence for a vitamin D deficiency is found only in Klaaskinderkerke. However, considering the similar prevalence of other stress markers between the sites, it is hypothesised that this higher prevalence is related to shielding from the sun by spending more time indoors or wearing occlusive clothing. The apparent increase in residual rickets may be associated with the changes in activity patterns in the late medieval period: the decrease of agricultural activities and increase in commercial activities may have resulted in more tasks carried out within the house.

The combination of caries and stable isotopes clearly points to a dietary shift. With regards to diet, there appears to be a relatively strong differentiation between town and country. This is most likely related to differences the availability of market products. The urban diet appears to have been more diverse, composed of more sugars and starches as well as different types of proteins in comparison with the rural diet. Once more, as was suggested by the discussion on disease and stress, the dietary data suggest that the rural living environment is not better than the urban one or vice-versa. Clearly, different food products in different proportions were consumed, but both diets appear to have been able to meet nutritional needs.

7.3 MAIN RESEARCH QUESTION

- In which ways do human skeletal remains reflect key socioeconomic developments in the medieval period in Holland and Zeeland, and how do the results contribute to a better understanding of the impact of these developments?

The human skeletal remains offered unique direct data on the physical effects of the socioeconomic developments in the medieval period. Differences in disease, activity, and diet which can be linked to social or economic processes in the medieval period are clearly discernible when the skeletal collections are compared. However, although there are differences, what stands out in this research is the absence of a marked distinction between town and country. The variations that were observed in disease, activity, and diet were not so outspoken that they fully support the idea that on the eve of modernity, towns and villages in Holland and Zeeland had become worlds apart. Especially in terms of disease, this research has shown that a more nuanced image is necessary. The popular image of the town as a horrible place compared to the idyllic countryside is not reflected by the people from Blokhuizen, Klaaskinderkerke, and Alkmaar. The rural environment appears to have created challenges to physical well-being, just like the urban environment, though slightly different in nature.

The combination of osteoarchaeological information with historical contextual data has provided a more detailed, accurate image of the influence of change and development on populations. In doing this, this study has clearly demonstrated the power of multidisciplinary research. In sum, this research has provided new data on individual residents in medieval Holland and Zeeland and used this information to assess the physical impact of socioeconomic developments in this period, thereby providing multifaceted high-resolution data for a more complete understanding of lives in transition.

7.4 FUTURE RESEARCH DIRECTIONS

This research has demonstrated the effectiveness of osteoarchaeological methods for evaluating the impact of socioeconomic developments in the medieval period. However, some individual aspects of this research raised new questions that merit a more detailed analysis and the application of different methods. Furthermore, to extend this type of research in the future to gain even more insight in this period, additional questions should be asked and more collections consulted. First, a discussion on how the current results can be enhanced is presented, after which suggestions for expansion of this research are discussed.

7.4.1 Boosting the current results

The high cribra orbitalia prevalence in the skeletal collections from the countryside is hypothesised to have been due to malaria. However, since the orbital lesions are not pathognomonic for malaria infection, this hypothesis cannot be confirmed on the basis of macroscopic analysis alone. Therefore, it would be particularly useful to study this topic using biomolecular methods such as ancient DNA or proteomics. Some studies focusing on detecting malaria in skeletal remains using DNA techniques have been performed, unfortunately with limited success (e.g., Pinello 2008; Salares *et al.* 2004). This may be due to the methods that were used in the past. Recently, new DNA techniques have been developed which may improve the detectability of the ancient pathogen in human bones (Kobolt *et al.* 2013). Additionally, analysis of human dental calculus has shown to have great potential for the analysis of disease in past populations (Warinner *et al.* 2015), which may also be of use in the search for malaria parasites. The development of these new techniques to allow the detection of malaria in ancient remains can provide solid evidence for the hypothesis formulated here, and would contribute to a better understanding of this disease and its impact on past populations around the world.

Similar techniques could be used to diagnose tuberculosis, bovine and human, and brucellosis in skeletal remains. As was briefly touched upon in chapter three and six, ancient DNA research into these diseases has proven to be extremely valuable in archaeology (e.g., Mays *et al.* 2001). In this dissertation, diseases were diagnosed on the basis of macroscopic evidence alone, and, consequently, most likely present an underestimation of the true prevalence. Future research could benefit from the inclusion of biomolecular methods for the identification of disease in the skeletal collections.

This current research has chosen to focus on osteoarthritis and lower limb morphology in order to study activity patterns. While this approach revealed interesting patterns, more methods and techniques could be employed for further study to expand and further solidify data on activity in medieval populations. The bone morphology of the other limbs, such as the arms and clavicle, could be included in the future studies to gain broader insights into the activity patterns of the rural and urban individuals (e.g., Inskip 2013; Wanner *et al.* 2007), possibly with the help of CT imaging (Stock and Pfeiffer 2001). Additionally, the study of entheseal changes could help understanding the type of activities and level of muscle strain in a better way (e.g., Henderson *et al.* 2013; Vilotte and Knüsel 2013).

7.4.2 Thinking big: future questions and ideas

This research could benefit a great deal from the inclusion of more skeletal collections. Although this study included three collections representative of the period, more data could enhance the results. For example, comparisons with larger and more densely populated towns could increase the understanding of life in the urban environment. Furthermore, comparisons outside Holland and Zeeland, with, for example, towns in the south and east of The Netherlands, may provide new insights into the consequences of socioeconomic developments in the medieval period in the whole of the country.

While this research focused on the medieval period, broadening of the time frame to create a wide diachronic sample could give very interesting results. By including skeletal collections from later and earlier time periods, a more chronologically complete and detailed image can be gained. In England, Lewis (1999) compared skeletons from the industrial period with those from earlier periods in order to study the impact of industrialisation on people. Since this research has demonstrated differences between the present study and research form the UK, this line of investigation is necessary in Dutch research as well.

This research has shown the effectiveness of using osteoarchaeology to study large developments in society. An increase of this type research in Europe could substantially enhance the image we have of life through the ages, both on a region specific as well as on differences between areas. The combination of historical data with skeletal information has proven to be instrumental in obtaining a better understanding of these medieval transitions, marking this approach as essential for future research.

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APPENDIX 1: LIST OF INDIVIDUALS BURIED AT THE FRANCISCAN FRIARY (AD 1540-1560)

Year	Name	Occupation	Remarks
1540	Jan Wouters		
	Aryaen Jansz moeder		
1541	Guert Jansz		
	Jan Beyersz wijff		
	Reyer Mollers weduwe		
	Reyer de soon van Brechte Reyers		
	Claes Cuypers wijff		
	Ariaan Zeylmaecker	Sail maker	
	Huysvrouvan Heerman uit die Kanisstraet	House wife	
	Reyer Nannen		
	Geryt Jacobs brouwer	Brewer	
	Arijntge Backer op Ritsevoert sijn wijf		
	Clara Diericx		
	Jan Cornelis	Baker	
	Jacop Claesz dochter		
	Reyer Jacopsz	Beggar	
	Dierick Huygen wijf		
	Neeltgen, vrouw van Cornelis Cogsz		
1542	IJff Pelzer		
	Coman Bancraesdochter		
	Marytgen Foreestes		
	de man zijn wijff uit Texel		
	Comen Jan Harmen		
1543	Diever Cossen		
	Willem Zael		
	Jan Golen		
	Haesgen Jan Symonsdochter		
	Heyndrick Sloetmaker	Locksmith	
1544	Aelbers up 't Afterdam		
	Cornelis Harmens wijf		
	Dieuwer Stoopren		
	Aerjan van Forest		In church
	Pieter Comans wijf Reynou		
	Garbrant Matthijs		
	Heyndrick int varcken		In church
	Cornelis Brantgen wijf		In church
	Piter Halfvastendochter		In church
1545	Neel Jans (Louwers?)		Cemetery
	Catrijn Jansz., moeder van Jan Matthijsz	Wood buyer	
	Willem Coster		
	Pieternelle Frans		
	Pieter Comans		

Year	Name	Occupation	Remarks
1545	Jonge Pieter Gerritsz		
	Baert Gielisz		Child
	Harman Goecoop		
	Jan Cornelis zijn broer		
	Yeff Trements		
	Wendelmoet int Heilige Geeststeegje		
	Rem Olyslagers weduwe		
1546	Claes Jansz Cuyper	Cooper	
	Gherbrich Hiernonymus Pouwelsz wijf		
	Engel Claesz		Child
	Alijdt Symons, Cornelis Garbrandsz wijf		
	Cornelys Keyser	Fish buyer	
	Griet Jordaens		
	Cornelis Thijsz.		Child
	Dierick opte Conynxweg tot Scaegen		
	Neeltge Symon Jans		
	Gerrytge Jan Croonendochter		
	Ijff Pelser		In church
	Jan Heeckelaers wijf		
	Hereman de wever	Weaver	
1547	Jan Nannicksz wijf	House wife	
	Duyff Wouter brouwers weduwe	Brewers' widow	
	Hillegont Comans Maertensdochter		
	Symen Sa(v)entaer wijff		
	Maritgen Paawiller		
	de moeder van Piter Zayen		
1548	Jonge Pieter Gerrytsz weduwe		
	Pieter Jacop Steyer		
	Dirck Jansz		
	Jacob Willemsz brouwers zoen	Brouwer	
	Claes de Walen huysvrou Aeff	House wife	
1549	Geertruyt Maerten van Foreesten dochter		
	Alijt Jan Brunz(en)	House wife	
	Lysbet Piters		
	Neel Jans		
	heer Willem Claes		
1550	Clemens van Foreest		
	Marytgen Comen Jacob Coelen weduwe		
	Coman Nyel of Daniël Matthyszoon		
1551	Willem Diericsz		
1552	Dierick Aerntszoon		
1553	Willem Jacobsz Gort		
1556	een vrouw van Opmeer		
	Marytgen Ijsbrantsz, de weduwe van Pieter Bartolmeus		
	Jacob Dircksz zoontje		Child

Year	Name	Occupation	Remarks
1557	Jacob Thaemsz		
	Claes Thaemsz		
	Nan Jansz`		
	Dirck Claesz		
	Lysbet Harmens		
	Frans		
	Walich Jansz		
	Anna Jansdochter		uittet gasthuis (infirmary)
	Trijn Piet Vechters		
	Zeger Jans Gorter		
	mr. Gijsbert Ewijk		
	Aefge, dienstmaecht van Aef Claes Eellen		
	Jan Nanninckszoon		
	Zil, een maecht		
	Neel Jans dochter		
	Trijn Claes van Ruyven		
	Jordaen van Foreest		
1559	Cornelis Thamsson		
	Marytgen Wyntgen Pieter Nomen dochter		
	Fij Jan Splinters		
1560	Lysbet Cornelis		

APPENDIX 2: ADULT SKELETAL RECORDING FORM

Site:	
Site code:	
Feature number:	
Find number:	
Observer(s):	
Date:	

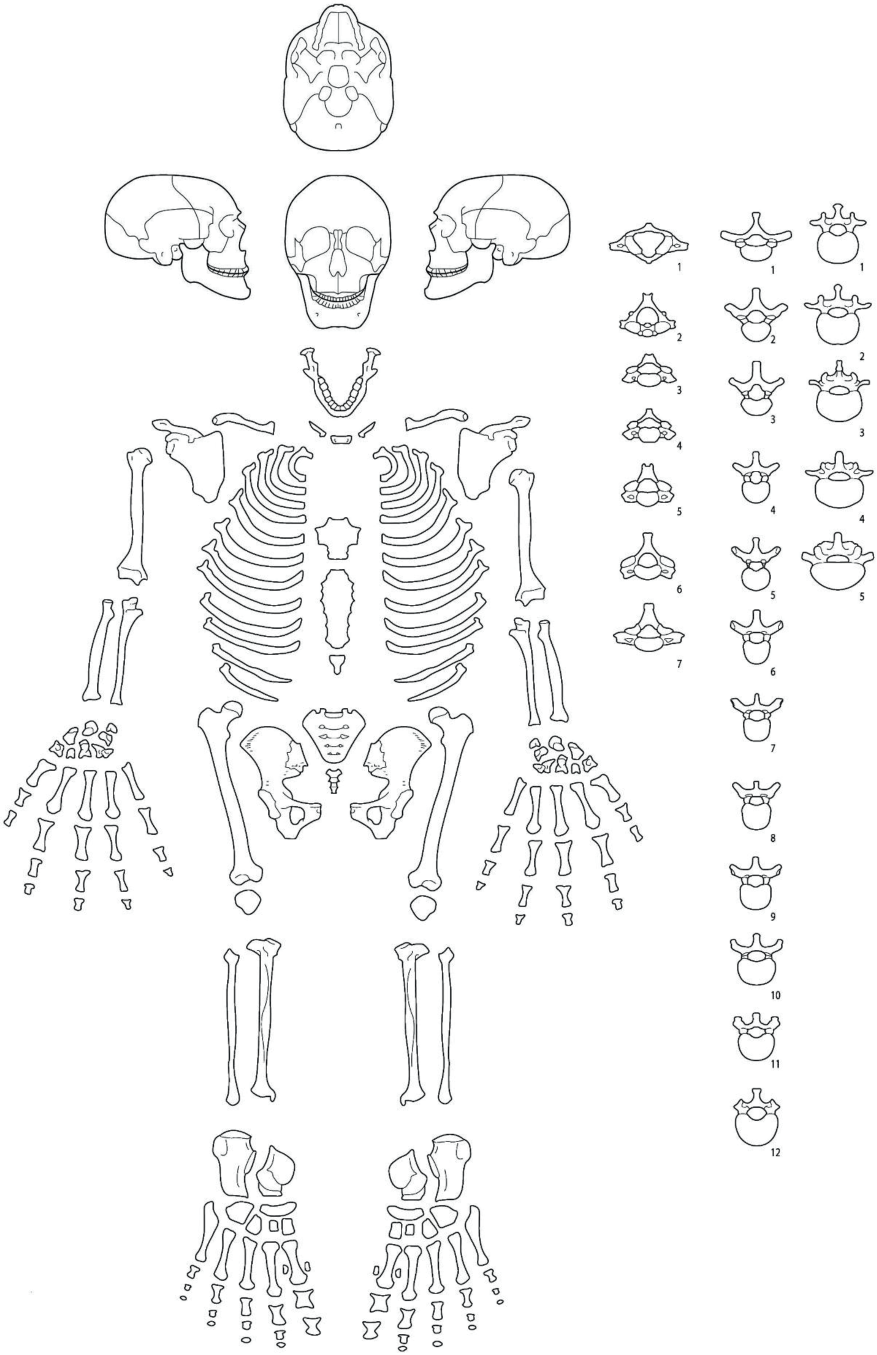
Burial type:	
Preservation:	
Completeness:	
Associated materials:	

Summary

Age:		
Sex:		
Stature:	Trotter	
	Breitinger	
Pathology:		

Remarks:

SKELETAL INVENTORY (COLOUR ABSENT BONES/SEGMENTS)



Skull	Left	Right
Frontal		
Occipital		
Sphenoid		
Ethmoid		
Vomer		
Hyoid		
Parietal		
Temporal squama		
Petrous part		
Maxilla		
Zygomatic		
Nasal		
Lacrimal		
Palatine		
Nasal Concha		
Malleus		
Stapes		
Incus		
Mandibular body		
Mandibular ramus		

Sternum	
Manubrium	
Body	
Xiphoid	

Clavicles	Left	Right
Medial 1/3		
Diaphyseal 1/3		
Lateral 1/3		

Scapula	Left	Right
Body		
Glenoid		
Acromion		

Innominate	Left	Right
Ilium		
Ischium		
Pubis		

Unidentified	Body	Neural Arch
Unidentified C (#)		
Unidentified T (#)		
Unidentified L (#)		
Unidentified S (#)		
Unidentified Vertebrae		

Vertebrae	Body	Neural arch
C1		
C2		
C3		
C4		
C5		
C6		
C7		
T1		
T2		
T3		
T4		
T5		
T6		
T7		
T8		
T9		
T10		
T11		
T12		
L1		
L2		
L3		
L4		
L5		
Supernumerary		
S1		
S2		
S3		
S4		
S5		
Coccyx		

Ribs	Left		Right	
	Head 1/2	Body 1/2	Head 1/2	Body 1/2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
Supernumerary				
Ribs 3-10 (#)				

Humerus	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Radius	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Ulna	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Carpals	Left	Right
Scaphoid		
Lunate		
Triquetral		
Pisiform		
Trapezium		
Trapezoid		
Capitate		
Hamate		
Sesamoid		

Metacarpals	Left	Right
Metacarpal 1		
Metacarpal 2		
Metacarpal 3		
Metacarpal 4		
Metacarpal 5		

Hand Phalanges	Proximal	Inter-mediate	Distal
1 (#)			
2-5 (#)			

Femur	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Patella	Left	Right
Patella		

Tibia	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Fibula	Left	Right
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Tarsals	Left	Right
Calcaneus		
Talus		
Navicular		
Cuboid		
Medial cuneiform		
Intermediate cuneiform		
Lateral cuneiform		
Sesamoid (#)		

Metatarsals	Left	Right
Metatarsal 1		
Metatarsal 2		
Metatarsal 3		
Metatarsal 4		
Metatarsal 5		

Foot Phalanges	Proximal	Inter-mediate	Distal
1 (#)			
2-5 (#)			

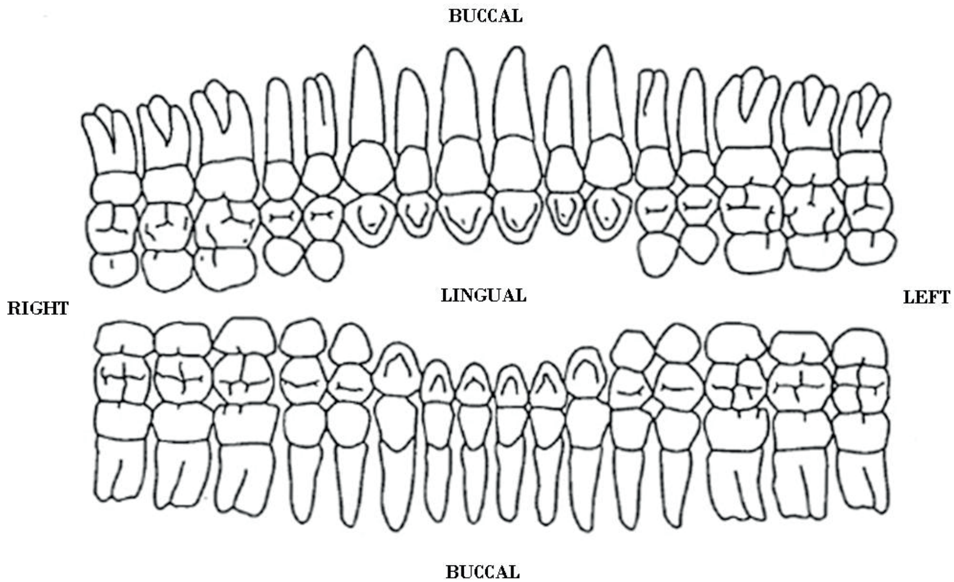
A	**Bone/segment absent**
C	**Complete: >75%**
P	**Partial: 25-75%**
F	**Fragment: <25%**

Completeness	

DENTAL INVENTORY

Element	Status	Calculus	Aveolar athrophy	Caries
1.1				
1.2				
1.3				
1.4				
1.5				
1.6				
1.7				
1.8				

Element	Status	Calculus	Aveolar athrophy	Caries
2.1				
2.2				
2.3				
2.4				
2.5				
2.6				
2.7				
2.8				



Element	Status	Calculus	Aveolar athrophy	Caries
4.1				
4.2				
4.3				
4.4				
4.5				
4.6				
4.7				
4.8				

Element	Status	Calculus	Aveolar athrophy	Caries
3.1				
3.2				
3.3				
3.4				
3.5				
3.6				
3.7				
3.8				

P	**Present**
M	**Missing**
PML	**Post-mortem loss**
AML	**Ante-mortem loss**
UE	**Unerupted**
CA	**Congenital absence**

Metrics

Cranial measurements (mm): Midline	Measurement
Maximum length (g-op)	
Maximum breadth (eu-eu)	

Post-cranial measurements (mm)		Right	Left
Clavicle	Max Length		
	Circumference		
Scapula	Glenoid Cavity Height		
	Height		
	Breadth		
Humerus	Max Length		
	Projective Length (males only)		
	Epicondylar Breadth		
	Vertical Head Diameter		
	Deltoid Circumference		
Radius	Max Length		
	Parallel Length (males only)		
	Max Head Diameter		
Ulna	Max Length		
Femur	Max Length (ML)		
	Bicondylar Length (BL)		
	Max Head Diameter (MHD)		
	Epicondylar Breadth (EB)		
	Subtroch Ant-Post Diameter (SAPD)		
	Subtroch Med-Lat Diameter (SMLD)		
Tibia	Length (L)		
	Total Length (males only)		
	Max. Proximal Epiphyseal Breadth (MPEB)		
	Max. Distal Epiphyseal Breadth (MDEB)		
	Sagittal (A-P) diam. at nutrient foramen (APD)		
	Transv. (M-L) diam. at nutrient foramen (MLD)		
Fibula	Max Length		

Indices

Cranial indices	Value	Category
Cranial Index		

Post-cranial indices	Value left	Value right	Category
Platymeria			
Platycnemia			

Stature

Trotter 1970:

Bone used?	Side used	Measurement

Calculation:

Coefficient		Measurement		Constant		Stature		SD
	x		+		=		±	

Breitinger 1953 (males and right bones only): in cm

Bone	Coeff.		Measurement		Constant		Stature		SD (cm)
Humerus	**2.715**	x		+	**83.21**	=		±	**4.9**
Radius	**2.968**	x		+	**97.09**	=		±	**5.4**
Femur	**1.645**	x		+	**94.31**	=		±	**4.8**
Tibia	**1.988**	x		+	**95.59**	=		±	**4.7**
					Average stature			±	

NON-METRIC TRAITS

Cranial traits

Midline traits	Score	Comments
Metopic suture		
Ossicle at bregma		
Ossicle at lambda		
Inca bone		
Palatine torus		

Bilateral traits		Score right	Score left	Comments
Lambdoid ossicle	Number			
Maxillary torus				
Mandibular torus				

Post-cranial traits

Midline traits	Score	Comments
Sternal foramen		
Sacralisation (L5/L6)		

Bilateral traits	Score right	Score left	Comments
Os acromiale			
Septal aperture			
Supracondylar process			
Allen's fossa			
Poirier's facet			
Third trochanter			
Vastus notch			
Tibial squatting facets			
Cervical ribs			

SEX ESTIMATION

Cranial trait (midline)	Score	Score WEA	Weight
Glabella			3
Nuchal plane/crest			3
Parietal and frontal tuberosity's			2
External occipital protuberance			2
Frontal inclination			1

Cranial trait (bilateral)	LEFT		RIGHT		Weight WEA
	Score	Score WEA	Score	Score WEA	
Mastoid process					3
Zygomatic process					3
Superciliary arch					2
Zygomatic bone					2
Orbit (form and margin)					1

Mandible trait (midline)	Score	Score WEA	Weight
Total aspect			3
Mental eminence			2

Mandible trait (bilateral)	LEFT		RIGHT		Weight WEA
	Score	Score WEA	Score	Score WEA	
Gonial angle					1
Inferior margin					1

Pelvic Trait	LEFT		RIGHT		Weight WEA
	Score	Score WEA	Score	Score WEA	
Pre-auricular sulcus					3
Greater sciatic notch					3
Pubic arc/angle					2
Arc composé					2
Innominate bone					2
Obturator foramen					2
Ischial body					2
Iliac crest					1
Iliac fossa					1
Pelvic inlet (midline)					1

Pelvic trait	Score left	Score right
Ventral arch		
Subpubic concavity		
Ischiopubic ramus ridge		
Shape of pubic bone		
Acetabulum size		
Dorsal pitting		
Sacral morphology		

SEX ESTIMATION (CONTINUED)

Measurements

	Left	Right	Sex left	Sex right
Max Glenoid Length (M>36mm, F<34)				
Max Clavicle Length (M >160mm, F < 130mm				
Max Clavicle Circumference (M> 41 mm, F< 28 mm)				
Max Scapula Length (M > 151mm, M? >149mm) (F< 140mm, F? <144mm)				
Humeral Head Diameter (M > 46.04 mm F< 46.04 mm)				
Humeral Epicondylar Breadth (M> 60.06 mm, F< 60.06 mm				
Humeral Deltoid Circumference (M> 68.30 mm, F< 68.30 mm				
Femoral Head Diameter (M > 47.5mmF < 42.5mm				

WEA degree of sexualisation- cranium $\frac{\Sigma Wx}{\Sigma W}$ ________ = ☐

WEA degree of sexualisation-mandible $\frac{\Sigma Wx}{\Sigma W}$ ________ = ☐

WEA degree of sexualisation-pelvis $\frac{\Sigma Wx}{\Sigma W}$ ________ = ☐

ESTIMATED SEX:

M M? I F? F

AGE-AT-DEATH ESTIMATION

Pubic symphysis males-Todd (1970)

Stage left	Age range	Stage right
1	19-18	1
2	20-21	2
3	22-24	3
4	25-26	4
5	27-30	5
6	30-35	6
7	35-39	7
8	39-44	8
9	44-50	9
10	50+	10

Dental attrition-Maat (2001)

Element	Score	Age range
1.6		
1.7		
1.8		
2.6		
2.7		
2.8		
3.6		
3.7		
3.8		
4.6		
4.7		
4.8		

Auricular surface-Buckberry and Chamberlain (2002)

Score Left	Trait	Score Right
	Transverse organisation	
	Surface texture	
	Microporosity	
	Macroporosity	
	Apical changes	
	Composite score	
	Age range	

Auricular surface-Lovejoy *et al* (1985)

Stage left	Age Range	Stage right
1	20-24	1
2	25-29	2
3	30-34	3
4	35-39	4
5	40-44	5
6	45-49	6
7	50-59	7
8	60+	8

Suture closure – Meidl and Lovejoy (1985)

Vault sites	Score
Midlambdoid (1)	
Lambda (2)	
Obelion (3)	
Anterior saggital (4)	
Bregma (5)	
Midcoronal (6)	
Pterion (7)	
Composite score	
Age range	

Lateral-Anterior sites	Score
Midcoronal (6)	
Pterion (7)	
Sphenofrontal (8)	
Inferior sphenotemporal (9)	
Superior sphenotemporal (10)	
Composite score	
Age Range	

Pubic symphysis-Males

Phase left	Age range	Phase right
1	18.5 ± 2.1	1
2	23.4 ± 3.6	2
3	28.7 ± 6.5	3
4	35.2 ± 9.4	4
5	45.6 ± 10.4	5
6	61.2 ± 12.2	6

Suchey and Brooks 1990

Pubic symphysis-Females

Phase left	Age range	Phase right
1	19.4 ± 2.6	1
2	25.0 ± 4.9	2
3	30.7 ± 8.1	3
4	38.2 ± 10.9	4
5	48.1 ± 14.6	5
6	60.0 ± 12.4	6

Suchey and Brooks 1990

AGE-AT-DEATH ESTIMATION (CONTINUED)

Epiphyseal fusion

Bone		**Open**	**Partial**	**Closed**
Clavicle: Medial epiphysis		<23	17-30	>21
Sacral Vertebrae (S1-S2)		<27	14-30	>21
Innominate	Iliac crest	<20	14-22	>18
	Ischial epi.	<18	14-20	>16
Sternum	B1-B2	<25	15-25	>15
	B2-B3	<20	11-20	>11
	B3-B4	<15	4-15	>4
	B4- Xiphoid	<40	-	>35

Sternal rib end-Males

Stage left	**Age range**	**Stage right**
0	< 17	0
1	17-19	1
2	20-23	2
3	24-28	3
4	26-32	4
5	33-42	5
6	43-55	6
7	54-64	7
8	> 64	8
Rib:		Rib:

Iscan *et al.* 1986

Sternal rib end-Females

Stage left	**Age range**	**Stage right**
0	< 14	0
1	14-15	1
2	16-19	2
3	20-24	3
4	24-32	4
5	33-46	5
6	43-58	6
7	59-71	7
8	> 69	8
Rib:		Rib:

Iscan *et al.* 1987

ESTIMATED AGE:

Adult: 18+

Young Adult: 19-25 Young

Middle Adult: 26-35

Old Middle Adult: 35-46

Mature Adult: 46+

PATHOLOGY

APPENDIX 3: ADOLESCENT SKELETAL RECORDING FORM

Site:	
Site code:	
Feature number:	
Find number:	
Observer(s):	
Date:	

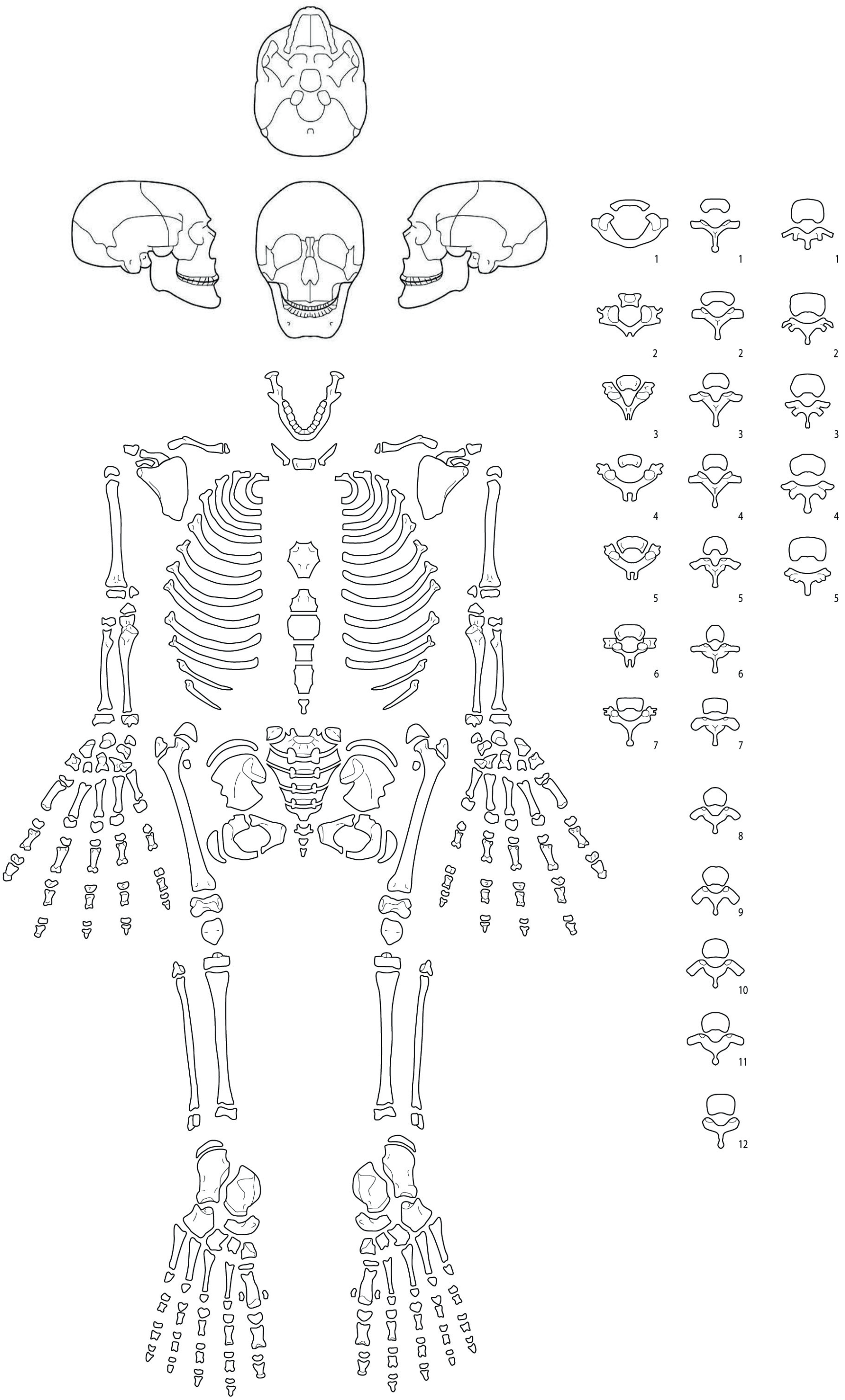
Burial type:	
Preservation:	
Completeness:	
Associated materials:	

Summary

Age:	
Pathology:	

Remarks:

Skeletal inventory (colour absent bones/segments)



Skull	Left	Right
Frontal		
Occipital		
Sphenoid		
Ethmoid		
Vomer		
Hyoid		
Parietal		
Temporal squama		
Petrous part		
Maxilla		
Zygomatic		
Nasal		
Lacrimal		
Palatine		
Nasal Concha		
Malleus		
Stapes		
Incus		
Mandibular body		
Mandibular ramus		

Sternum	
Manubrium	
Body	
Xiphoid	

Clavicles	Left	Right
Medial epiphysis		
Diaphyseal 1/3		
Lateral 1/3		

Scapula	Left	Right
Body		
Glenoid		
Acromion		
Coracoid		

Innominate	Left	Right
Ilium		
Ischium		
Pubis		
Iliac crest		
Ischial tuberosity		

Unidentified	Body	Arch
Unidentified C (#)		
Unidentified T (#)		
Unidentified L (#)		
Unidentified S (#)		
Unidentified Vertebrae		

Vertebrae	Body	Neural arch
C1		
C2		
C3		
C4		
C5		
C6		
C7		
T1		
T2		
T3		
T4		
T5		
T6		
T7		
T8		
T9		
T10		
T11		
T12		
L1		
L2		
L3		
L4		
L5		
Annular rings (#)		
S1		
S2		
S3		
S4		
S5		
Coccyx		

Ribs	Left		Right	
	Head 1/2	Body 1/2	Head 1/2	Body 1/2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
Supernumerary				
Ribs 3-10 (#)				
Epiph. head (#)				
Epiph. tub (#)				

Humerus	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Medial condyle		
Distal compound epiphysis		

Radius	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Ulna	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Carpals	Left	Right
Scaphoid		
Lunate		
Triquetral		
Pisiform		
Trapezium		
Trapezoid		
Capitate		
Hamate		

Metacarpals	Left	Right
Metacarpal 1		
Base epiphysis MC1		
Metacarpal 2		
Metacarpal 3		
Metacarpal 4		
Metacarpal 5		
Distal epiphyses (#)		

Hand Phalanges	Proximal	Inter-mediate	Distal
1 (#)			
2-5 (#)			
Base epiphyses (#)			

Femur	Left	Right
Femoral head		
Greater trochanter		
Lesser trochanter		
Diaphyseal 1/3		
Distal epiphysis		

Patella	Left	Right
Patella		

Tibia	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Fibula	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Tarsals	Left	Right
Calcaneus		
Talus		
Navicular		
Cuboid		
Medial cuneiform		
Intermediate cuneiform		
Lateral cuneiform		
Sesamoid		

Metatarsals	Left	Right
Metatarsal 1		
Base epiphysis MT1		
Metatarsal 2		
Metatarsal 3		
Metatarsal 4		
Metatarsal 5		
Distal epiphyses (#)		

Foot Phalanges	Proximal	Inter-mediate	Distal
1 (#)			
2-5 (#)			
Base epiphyses (#)			

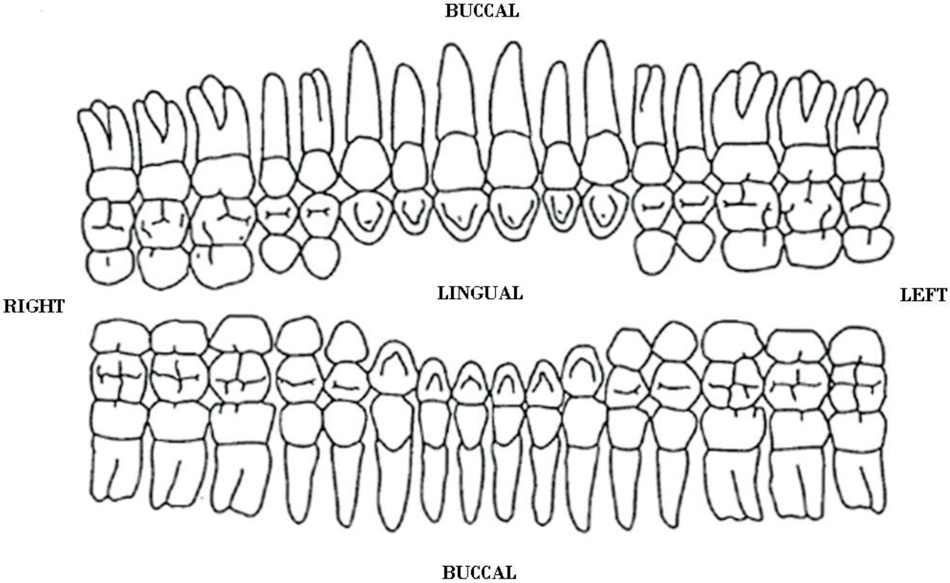
A	**Bone/segment absent**
C	**Complete: >75%**
P	**Partial: 25-75%**
F	**Fragment: <25%**

Completeness	

DENTAL INVENTORY

Element		Calculus	Aveolar athrophy	Caries
	Status			
1.1				
1.2				
1.3				
1.4				
1.5				
1.6				
1.7				
1.8				

Element		Calculus	Aveolar athrophy	Caries
	Status			
2.1				
2.2				
2.3				
2.4				
2.5				
2.6				
2.7				
2.8				



Element		Calculus	Aveolar athrophy	Caries
	Status			
4.1				
4.2				
4.3				
4.4				
4.5				
4.6				
4.7				
4.8				

Element		Calculus	Aveolar athrophy	Caries
	Status			
3.1				
3.2				
3.3				
3.4				
3.5				
3.6				
3.7				
3.8				

P	**Present**
M	**Missing**
PML	**Post-mortem loss**
AML	**Ante-mortem loss**
CA	**Congenital absence**
UE	**Unerupted**

METRICS

Cranial measurements (mm): Midline	Measurement
Maximum length (g-op)	
Maximum breadth (eu-eu)	

Post-cranial measurements (mm)		Right	Left	With epiphysis?
Clavicle	Max Length			
Scapula	Glenoid Cavity Height			
	Height			
	Breadth			
Humerus	Max Length			
	Epicondylar Breadth			
	Vertical Head Diameter			
	Max Diameter at Midshaft			
Radius	Max Length			
Ulna	Max Length			
Femur	Max Length (ML)			
	Max Head Diameter (MHD)			
	Epicondylar Breadth (EB)			
Tibia	Max Length (L)			
Fibula	Max Length			

AGE-AT-DEATH ESTIMATION

Epiphyseal fusion		Open	Partial	Closed
Vertebrae	Annular rings	<21	14-23	>18
Sacrum	Auricular surface	<21	15-21	>17
	S1-S2 bodies	<27	14-30	>21
	S1-S2 Alae	<20	11-27	>14
	S2-5 bodies	<20	12-28	>19
	S2-5 Alae	<16	10-21	>13
Sternum	1st costal notch	<23	18-25	>21
	B1-B2	<25	15-25	>15
	B2-B3	<20	11-20	>11
	B3-B4	<15	4-15	>4
Ribs	Head	<21	17-22	>19
	Tubercle	<20	18-20	>18
Scapula	Coracoid-Glenoid	<16	14-18	>16
	Acromion	<20	15-20	>15
	Inferior Angle	<21	17-22	>17
	Medial Border	<21	18-22	>18
Clavicle	Sternal end	<23	17-30	>21
Humerus	Proximal	<20	14-21	>16
	Distal	<15	11-18	>12
	Medial epicondyle	<18	13-18	>13
Radius	Proximal	<18	12-18	>13
	Distal	<19	14-20	>15
Ulna	Proximal	<16	12-18	>12
	Distal	<20	15-20	>15
Hand	Metacarpals	<17	11-18	>12
	Phalanges	<17	11-18	>12
Os Coxae	Iliac crest	<20	14-22	>18
	Ischial tuberosity	<18	14-20	>16
	Tri-radiate complex	<16	11-18	>14
Femur	Head	<18	14-19	>14
	Greater trochanter	<18	14-19	>14
	Lesser trochanter	<18	14-19	>14
	Distal	<19	14-20	>17
Tibia	Proximal	<18	14-20	>17
	Distal	<18	14-18	>15
Fibula	Proximal	<19	14-20	>15
	Distal	<18	14-20	>15
Foot	Calcaneus tuberosity	<16	10-20	>14
	Metatasals	<17	11-16	>11
	Phalanges	<17	11-16	>11
BOBBS		<18	11-18	>11

Bone length

Bone	Length (mm)	Age Range (Maresh 1955)
Humerus		
Radius		
Ulna		
Femur		
Tibia		
Fibula		

Dental development (Morees *et al.* 1963)

Element	Developemental stage	Age range

Ubelaker 1978	

<u>ESTIMATED AGE:</u>

Young Adolescent: 13-15

Older Adolescent: 16-18

PATHOLOGY

APPENDIX 4: CHILD SKELETAL RECORDING FORM

Site:	
Site code:	
Archis no.:	
Feature number:	
Find number:	
Observer(s):	
Date:	

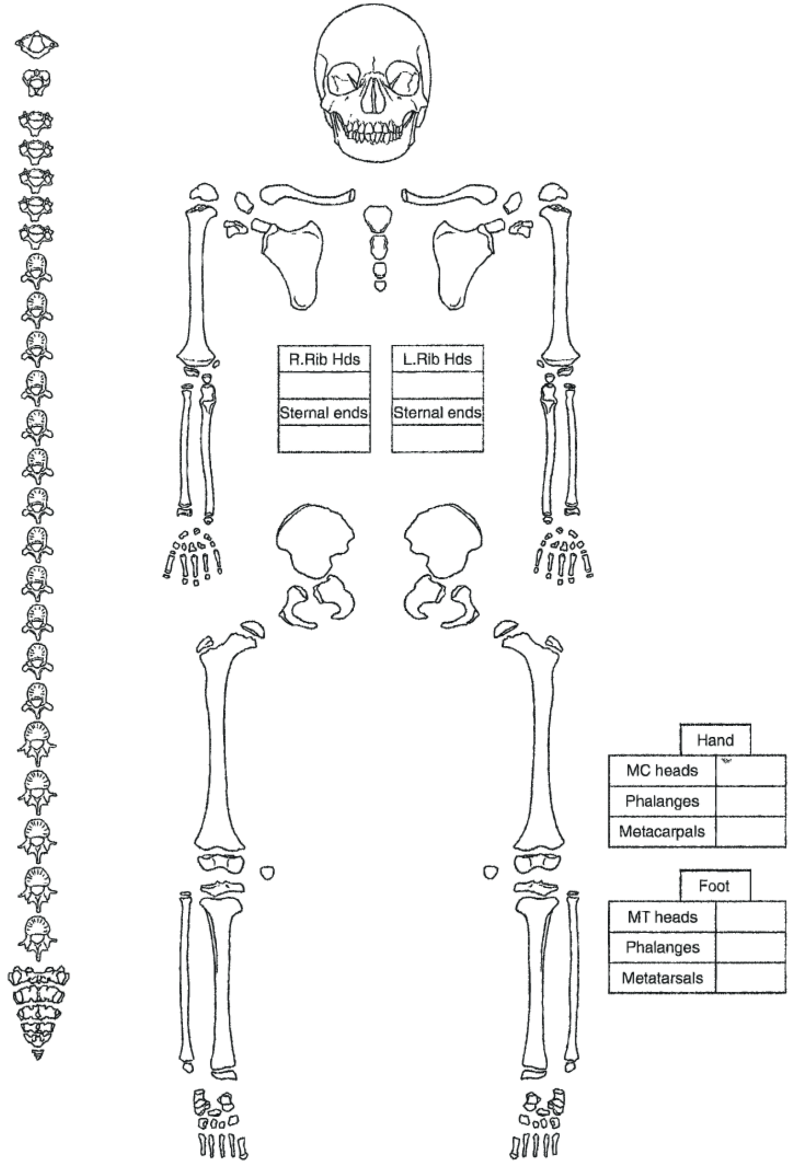
Burial type:	
Preservation:	
Completeness:	
Associated materials:	

Summary

Age:	
Pathology:	

Remarks:

Skeletal inventory (colour absent bones/segments)



Skull	Left	Right
Frontal		
Occipital		
Sphenoid		
Ethmoid		
Vomer		
Hyoid		
Parietal		
Temporal squama		
Petrous part		
Maxilla		
Zygomatic		
Nasal		
Lacrimal		
Palatine		
Nasal Concha		
Malleus		
Stapes		
Incus		
Mandibular body		
Mandibular ramus		

Sternum	
Manubrium	
Body (#)	

Clavicles	Left	Right
Medial 1/3		
Diaphyseal 1/3		
Lateral 1/3		

Scapula	Left	Right
Body		
Glenoid		
Acromion		
Coracoid		

Innominate	Left	Right
Ilium		
Ischium		
Pubis		

Vertebrae	Body	Neural arch
C1		
C2		
C3		
C4		
C5		
C6		
C7		
T1		
T2		
T3		
T4		
T5		
T6		
T7		
T8		
T9		
T10		
T11		
T12		
L1		
L2		
L3		
L4		
L5		
S1		
S2		
S3		
S4		
S5		
Coccyx		

Ribs	Left		Right	
	Head 1/2	Body 1/2	Head 1/2	Body 1/2
Number (#)				

Unidentified	Body	Arch
Unidentified C (#)		
Unidentified T (#)		
Unidentified L (#)		
Unidentified S (#)		
Unidentified Vertebrae		

Humerus	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Medial condyle		
Distal epiphysis		

Radius	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Ulna	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Hand	#
Carpals(#)	
Metacarpal heads (#)	
Metacarpals (#)	
Phalanges (#)	

Femur	Left	Right
Femoral head		
Greater trochanter		
Diaphyseal 1/3		
Distal epiphysis		

Patella	Left	Right
Patella		

Tibia	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Fibula	Left	Right
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Tarsals	Left	Right
Calcaneus		
Talus		
Navicular		
Cuboid		
Medial cuneiform		
Intermediate cuneiform		
Lateral cuneiform		

Metatarsals	
Metatarsal heads (#)	
Metatarsals (#)	
Phalanges (#)	

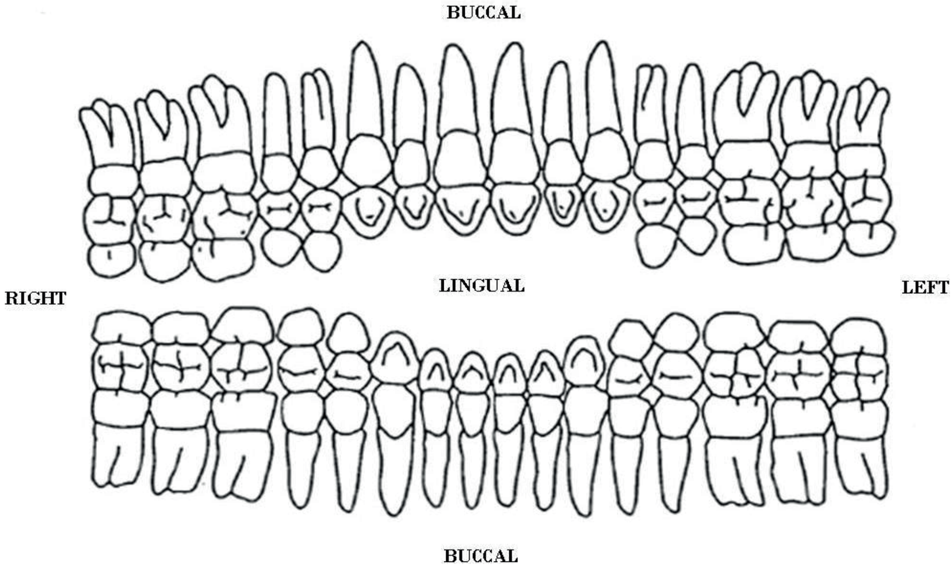
A	Bone/segment absent
C	Complete: >75%
P	Partial: 25-75%
F	Fragment: <25%

Completeness	

DENTAL INVENTORY (PERMANENT)

Element	Status	Calculus	Aveolar athrophy	Caries
1.1				
1.2				
1.3				
1.4				
1.5				
1.6				
1.7				
1.8				

Element	Status	Calculus	Aveolar athrophy	Caries
2.1				
2.2				
2.3				
2.4				
2.5				
2.6				
2.7				
2.8				



Element	Status	Calculus	Aveolar athrophy	Caries
4.1				
4.2				
4.3				
4.4				
4.5				
4.6				
4.7				
4.8				

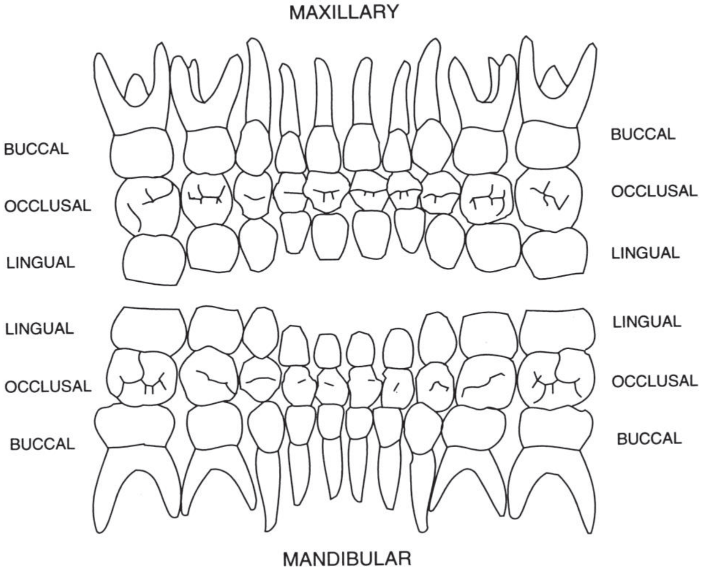
Element	Status	Calculus	Aveolar athrophy	Caries
3.1				
3.2				
3.3				
3.4				
3.5				
3.6				
3.7				
3.8				

P	Present
M	Missing
PML	Post-mortem loss
AML	Ante-mortem loss
CA	Congenital absence
UE	Unerupted

DENTAL INVENTORY (DECIDUOUS)

Element	Status	Calculus	Aveolar athrophy	Caries
5.1				
5.2				
5.3				
5.4				
5.5				

Element	Status	Calculus	Aveolar athrophy	Caries
6.1				
6.2				
6.3				
6.4				
6.5				



Element	Status	Calculus	Aveolar athrophy	Caries
8.1				
8.2				
8.3				
8.4				
8.5				

Element	Status	Calculus	Aveolar athrophy	Caries
7.1				
7.2				
7.3				
7.4				
7.5				

P	Present
M	Missing
PML	Post-mortem loss
AML	Ante-mortem loss
CA	Congenital absence
UE	Unerupted

METRICS

Bone	Measurement	Right	Left
Clavicle	Max Length		
	Max Diameter at midshaft		
Scapula	Length (height)		
	Width		
	Length of spine		
Humerus	Max Length		
	Distal width		
	Max Diameter at midshaft		
Radius	Max Length		
	Max Diameter at midshaft		
Ulna	Max Length		
	Max Diameter at midshaft		
Femur	Max Length		
	Distal Width		
	Max Diameter at midshaft		
Tibia	Max Length		
	Max Diameter at midshaft		
Fibula	Max Length		
	Max Diameter at midshaft		

AGE-AT-DEATH DETERMINATION

Epiphyseal fusion	Degree of fusion	Age range
Atlas – anterior arch		
Atlas – posterior synchondrosis		
Atlas – neurocentral junction		
Axis – dentoneural junction		
Axis – dentocentral junction		
Axis – posterior arch		
Axis – dens		
Cervical Vertebrae – neural arches to each other		
Cervical Vertebrae – neural arches to centrum		
Thoracic Vertebrae – neural arches to each other		
Thoracic Vertebrae – neural arches to centrum		
Lumbar Vertebrae – neural arches to each other		
Lumbar Vertebrae – neural arches to centrum		
Sacrum – S1 – lateral element to neural arch		
Sacrum – S1 – alae to centrum		
Sacrum – S1 – neural arch		
Sacral Vertebra – S2-S3		
Sacral Vertebra – S3-S4		
Sacral Vertebra – S4-S5		
Sacrum – superior-inferior alae		
Sternum		
Humerus – capitulum, trochlea, lateral epicondyle		
Humerus – distal epiphysis		
Radius – proximal epiphysis		
Ulna – proximal epiphysis		
Os Coxae – ilium-pubis		
Os Coxae – ischium-pubis		
Os Coxae – ischium-ilium		
Occipital – lateral part to squama		
Occipital – basilar part to lateral part		
Spheno-occipital synchondrosis		

Bone length

Bone	Length (mm)	Age Range (Maresh 1955)
Clavicle		
Humerus		
Femur		
Radius		
Ulna		
Tibia		
Fibula		

Dental development (Morees et al 1963)

Element	Developemental stage	Age range

Ubelaker 1978	

ESTIMATED AGE:

Young child (juvenile): 4-7

Old child: 8-12

Pathology

APPENDIX 5: INFANT SKELETAL RECORDING FORM

Site:	
Site code:	
Archis no.:	
Feature number:	
Find number:	
Observer(s):	
Date:	

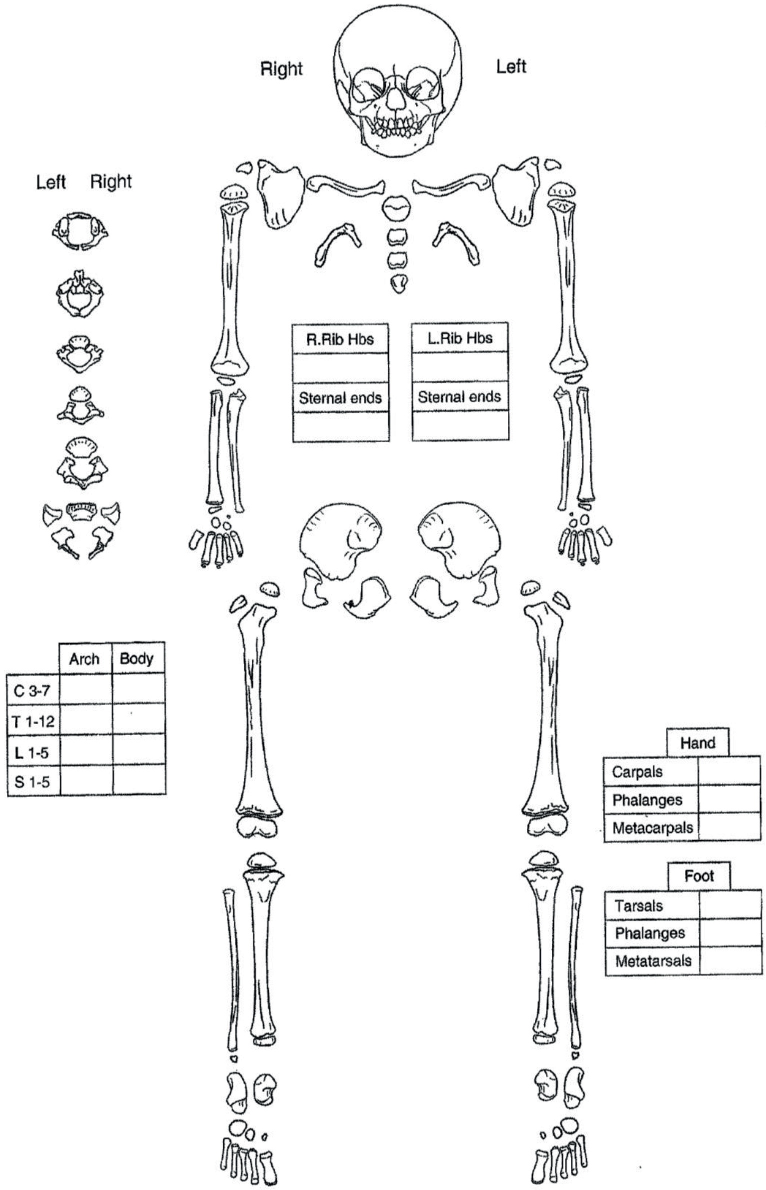
Burial type:	
Preservation:	
Completeness:	
Associated materials:	

Summary

Age:	
Pathology:	

Remarks:

SKELETAL INVENTORY (COLOUR ABSENT BONES/SEGMENTS)



	Arch	Body
C 3-7		
T 1-12		
L 1-5		
S 1-5		

	Hand
Carpals	
Phalanges	
Metacarpals	

	Foot
Tarsals	
Phalanges	
Metatarsals	

Skull	**Left**	**Right**
Frontal		
Occipital-pars squama		
Occipital-pars lateralis		
Occipital-pars basilaris		
Sphenoid-body		
Sphenoid-lesser wing		
Sphenoid-greater wing		
Ethmoid		
Vomer		
Hyoid		
Parietal		
Temporal-pars squama		
Temporal-pars tymapani		
Temporal-pars petrosa		
Maxilla		
Zygomatic		
Nasal		
Lacrimal		
Palatine		
Nasal Concha		
Malleus		
Stapes		
Incus		
Mandibular body		
Mandibular ramus		
Unidentified fragments		

Humerus	**Left**	**Right**
Proximal epiphysis		
Diaphyseal 1/3		
Medial condyle		
Distal epiphysis		

Radius	**Left**	**Right**
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Ulna	**Left**	**Right**
Proximal epiphysis		
Diaphyseal 1/3		
Distal epiphysis		

Hand/Foot	**Hand**	**Foot**
Carpals/tarsals (#)		
Metacarpals/metatarsals(#)		
Phalanges		

Completeness	

Vertebrae	**Body**	**Neural arch**	
		Left	**Right**
C1			
C2			
C3-C7 (#)			
T1-T12 (#)			
L1-L5 (#)			
S1-S5			

Ribs	**Left**		**Right**	
	Heads	Ends	Heads	Ends
Rib 1				
Rib 2				
Rib 3-12 #				

Innominate	**Left**	**Right**
Ilium		
Ischium		
Pubis		

Sternum	
Manubrium	
Body (#)	

Clavicles	**Left**	**Right**
Medial 1/3		
Diaphyseal 1/3		
Lateral 1/3		

Scapula	**Left**	**Right**
Body		
Acromion		

Femur	**Left**	**Right**
Femoral head		
Greater trochanter		
Diaphyseal 1/3		
Distal epiphysis		

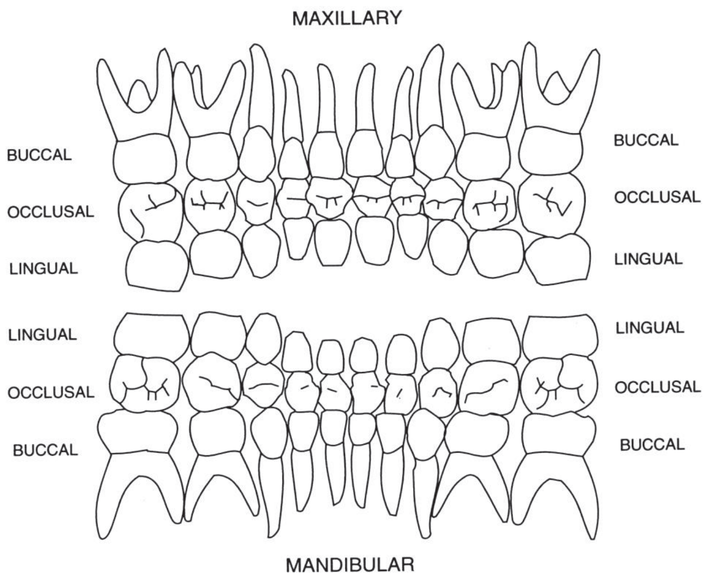
Patella	**Left**	**Right**
Patella		

Tibia	**Left**	**Right**
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Fibula	**Left**	**Right**
Proximal 1/3		
Diaphyseal 1/3		
Distal 1/3		

Element		Calculus	Aveolar athrophy	Caries
	Status			
5.1				
5.2				
5.3				
5.4				
5.5				

Element		Calculus	Aveolar athrophy	Caries
	Status			
6.1				
6.2				
6.3				
6.4				
6.5				



Element		Calculus	Aveolar athrophy	Caries
	Status			
8.1				
8.2				
8.3				
8.4				
8.5				

Element		Calculus	Aveolar athrophy	Caries
	Status			
7.1				
7.2				
7.3				
7.4				
7.5				

P	**Present**
M	**Missing**
PML	**Post-mortem loss**
AML	**Ante-mortem loss**
CA	**Congenital absence**
UE	**Unerupted**

METRICS

Bone	Measurement	Right	Left
	Pars basilaris of Occipital – max. length		
	Pars basilaris of Occipital – width		
	Pars basilaris of Occipital – sagittal length		
	Occipital – squama lenght		
	Occipital – squama width		
	Occipital – pars lateralis height		
	Occipital – pars lateralis width		
	Temporal – pars petrosa length		
	Sphenoid body length		
	Sphenoid body width		
	Mandibular length of body		
	Width of mandibular arc		
Clavicle	Max Length		
Scapula	Length (height)		
	Width		
	Length of spine		
Humerus	Max Length		
	Distal width		
	Max Diameter at midshaft		
Radius	Max Length		
	Max Diameter at midshaft		
Ulna	Max Length		
	Max Diameter at midshaft		
Femur	Max Length		
	Distal Width		
	Max Diameter at midshaft		
Tibia	Max Length		
	Max Diameter at midshaft		
Fibula	Max Length		
	Max Diameter at midshaft		

AGE-AT-DEATH DETERMINATION

Epiphyseal fusion	Degree of fusion	Age range
Occipital – pars lateralis to squama		
Occipital – pars lateralis to pars basilaris		
Occipital – posterior fontanelle		
Sphenoid – pre and post-sphenoid parts		
Sphenoid – greater wings to body		
Frontal – metopic suture		
Frontal – anterior fontanelle		
Temporal – tympanic ring to squama		
Temporal – petrous portion to squamous portion		
Atlas – anterior arch		
Axis – dens		
Cervical Vertebrae – neural arches to each other		
Thoracic Vertebrae – neural arches to each other		
Lumbar Vertebrae – neural arches to each other		
Lumbar Vertebrae – neural arches to centrum		
Mandible		

Bone measurements

Bone	Measurements (mm)	Age Range
Pars basilaris of Occipital – max. length		
Pars basilaris of Occipital – width		
Pars basilaris of Occipital – sagittal length		
Clavicle		
Humerus		
Femur		
Radius		
Ulna		
Tibia		
Fibula		

Dental development (Moorees et al 1963)

Element	Developemental stage	Age range

Ubelaker 1978	

<u>ESTIMATED AGE:</u>

Young infant: 0-1

Older infant: 2-3

PATHOLOGY

Summary

Life in transition. An osteoarchaeological perspective of the consequences of medieval socioeconomic developments in Holland and Zeeland (AD 1000-1600)

This research investigates the impact of socioeconomic developments on the physical condition of medieval populations in Holland and Zeeland between AD 1000 and 1600 through the analysis of human skeletal remains from three archaeological sites. In a relatively brief period of time, this region went from being scarcely populated to an area characterised by expanding urban centres and flourishing trade systems. These large scale developments had an impact on the daily lives of medieval people. Living environment and social conditions changed drastically for both rural communities and the residents of the new towns. While these socioeconomic developments of the medieval period in Holland and Zeeland, such as higher population density in the town, commercialisation of agriculture, and the expansion of international trade, have been studied in detail from a broad historical perspective, there is a paucity of data concerning the impact of these developments on the people themselves. Hence, this research proposes a different approach to this subject which allows a detailed examination of the physical consequences of medieval developments in Holland and Zeeland by investigating the process from an osteoarchaeological perspective on the level of the individual human body. The potential physical influences of socioeconomic changes to lifeways are studied on the basis of three themes, disease, activity, and diet.

Individuals from two rural and one urban skeletal collections are analysed. Since the land reclamation village of Blokhuizen (AD 1000-1200) in Holland predates urban development in the area, its inhabitants can serve as a rural baseline to which the other skeletal assemblages can be compared. This small farming village on the peat was mainly engaged with arable faming and to a lesser extent with pastoral farming. A total of 119 individuals from the Blokhuizen site were included in this research. The second skeletal assemblage is associated with the rural village of Klaaskinderkerke in Zeeland, dating to the late medieval period (AD 1286-1573), when urbanisation was well on its way. This collection of 54 individuals

provides the rural perspective during this time. The 189 individuals excavated at the Franciscan friary in the town of Alkmaar (AD 1448-1572) provide the urban perspective. This medium-sized town in the county of Holland had about 9,000 inhabitants in the late medieval period with a fairly high population density, allowing for a proper investigation into the effects of urban life. By comparing the osteoarchaeological data from these three rural and urban populations, it is possible to gain a better understanding of the potential physical consequences of the socioeconomic developments for medieval people.

Several skeletal indicators reflecting aspects of past disease, activity, and diet are studied to investigate possible physical changes. Firstly, the prevalence of two specific infectious diseases affecting the skeleton, brucellosis and tuberculosis, is researched. Tuberculosis, a chronic lung infection, is a disease commonly associated with poverty, malnutrition, and overcrowding, and therefore often related to urbanisation. Research focused on other medieval European towns has shown that the prevalence of this disease tends to increase as a result of urban living conditions. Brucellosis, on the other hand, is a chronic infection that is spread by infected animals through the inhalation of infected aerosols, handling of infected blood, or consumption of infected raw meat or milk. It is therefore more likely to occur in a rural area where residents proportionately had more direct contact with cattle.

Changes in the medieval activity patterns are examined through osteoarthritis prevalence and differences in bone morphology. Osteoarthritis is a joint disease that causes a decrease of cartilage, with different bony responses as a result. Although many factors may contribute to this disease, such as genetics, body weight, and living conditions, mechanical stress is one of the most important determinants. Alterations in bone morphology can also be seen in response to certain changes to activity patterns. This study examined the femur and tibia, with flatter bones suggesting higher activity and especially higher mobility levels. By comparing bone morphology and the prevalence and location of osteoarthritis between the skeleton populations, it is possible to determine whether the activity patterns have changed over the time, potentially as a result of urban living.

Shifts in the diet of medieval communities are studied by analysing the prevalence of carious lesions and certain skeletal markers of nutritional deficiencies. Caries, or tooth decay, is often related to diet in archaeological studies. In many areas of the world, an increase in caries prevalence was noted when diet became more carbohydrate rich. This is related to the fact that the oral bacteria which cause dental caries flourish in the presence of carbohydrates. Therefore, a higher percentage of caries points to an increased intake of products containing sugars and/or starches. In addition, the signs of specific vitamin deficiencies, such as the skeletal changes caused by vitamin C and D, can provide a better understanding of the nutritional value of the diet. The comparison of the frequency of dental caries as well as the prevalence of vitamin deficiencies between the three skeletal collections offers the opportunity to investigate changes in dietary patterns.

Additionally, non-specific skeletal stress indicators are studied. These are bony reactions which suggest that the individual experienced some form of stress, such as episodes of disease or malnutrition, at some point during their life. However, the exact cause of this stressor cannot be determined. In the current study, growth delays, enamel hypoplasia, and cribra orbitalia/porotic hyperostosis are analysed. Health problems in childhood can lead to growth stunting, which can result in a shorter adult stature. Therefore, the average adult body height of the populations is compared to determine whether the developments in the Middle Ages impacted growth. Enamel hypoplasia, small localised bands/pits with less enamel on the teeth, indicate that there was a period of stress at the time when that particular tooth was formed. Cribra orbitalia and porotic hyperostosis, porosity in the eye sockets and on the cranial vault respectively, are often related to anaemia, but also vitamin deficiencies may be responsible for this. By comparing the prevalence of enamel hypoplasia and cribra orbitalia/porotic hyperostosis between populations, the level of systemic stress can be studied and it can be assessed whether the socioeconomic developments have impacted the levels of stress in the daily levels of medieval people.

The results of the skeletal analysis of the three collections revealed that there are differences between the populations. With regards to disease it is striking that tuberculosis and evidence for other, non-specific, lung infections were solely found in the urban skeletal remains suggesting that townspeople had a higher risk of developing these kinds of diseases than villagers. The relatively high population densities could have been an important factor in the apparent increase in respiratory disorders. Interestingly, however, the indicators of non-specific stress are not significantly increased in the urban skeletal collection. In fact, cribra orbitalia prevalence is slightly higher in the countryside. Taking into account the environmental factors in Blokhuizen and Klaaskinderkerke, it is hypothesised that the higher cribra orbitalia prevalence might be associated with a greater presence of malaria in the rural areas. The comparison of disease and stress patterns between the rural and urban skeletal collections has demonstrated that episodes of stress were common in both town and country. These results suggest that both rural and urban inhabitants were faced with threats which physically impacted their lives. While the risks appear to have been different, one living environment cannot be considered better or 'healthier' than the other.

The differences in osteoarthritis prevalence and bone morphology suggest that activity patterns changed during the medieval period. Overall levels of mechanical loading seem to have stayed roughly the same through time. However, the separate comparisons of men and women as well as that of specific joint groups reveal significant differences indicating a shift in the types of physical activity for both men and women. The women from Blokhuizen exhibit significantly more osteoarthritis in the joints of the upper extremity (shoulder, elbow, wrist and hand) than women from the other populations. The urban women in particular have a significantly lower prevalence of osteoarthritis. Although less pronounced, differences are also apparent when the men from the different populations are compared with each other. The observed variations in mechanical loading can be the result of the decline in agriculture in the late medieval period. During this period rural populations were strongly focused on production for the market, which resulted in decreased agricultural activities. In contrast, employment grew in the commercial fishery, textile trade, and breweries. For urban individuals agricultural activities were unusual. Both men and women worked in the urban industries and performed specialised activities. Significant changes were also observed with regards to bone morphology suggesting changes to mobility levels. Both the men and women from Blokhuizen experienced higher degrees of muscle pull than those from Klaaskinderkerke and Alkmaar. The fact that activities were reorganised in the late medieval period and that occupations for villagers and townspeople overlapped during that time, may account for the lack of difference between the late medieval rural and urban individuals. This suggests that socioeconomic developments in the late medieval period influenced the activity patterns of society as a whole, both in rural and urban areas.

Dietary patterns also appear to have changed over time and as a result of urban living. The individuals in Alkmaar have a higher prevalence of dental caries, suggesting that the urban diet contained larger amounts of sugars and starches. This difference can be explained by the diversification and expansion of the market in the late medieval period. Residents of Alkmaar were more dependent on the market than the villagers. Although the late medieval rural populations had access to the market as well, they were still able to grow products for own use which may have limited there consumption of market products. This may explain the large differences between Klaaskinderkerke and Alkmaar. Although the diet was clearly different, the lack of evidence for nutritional deficiencies suggest that the rural and urban diet were adequate in terms of nutritional value. The complementary master study of Hattum focusing on the differences in food pattern between Blokhuizen and Alkmaar based on stable isotopes (carbon and nitrogen) shows interesting results. While the caries frequency indicates a marked increase in carbohydrates for the urban dwellers, the isotopic research suggests that the inhabitants of Alkmaar consumed other proteins than the villagers. The higher $\delta 15N$ values of the urban citizens show that they probably ate more fish than the people of Blokhuizen. This increase in fish consumption can be related to the commercialisation of fishing in Holland and Zeeland during the late medieval period. In addition, the isotopic study shows that the diet of urban residents was more diverse than the diet of the rural population which is consistent with the idea that people in the town were dependent on the market for food.

Although differences are observed between the different skeletal collections, the key finding of this research is the absence of a marked distinction between town and country. The variations that were observed in disease, activity, and diet do not fully support the traditional idea that on the eve of modernity, towns and villages in Holland and Zeeland had become worlds apart. Especially in terms of disease, this research has shown that a more nuanced view is necessary. The popular image of the town as a horrible place compared to the idyllic countryside is not reflected by the people from Blokhuizen, Klaaskinderkerke, and Alkmaar. The rural and urban environment each created challenges to the physical well-being of individuals, albeit slightly different in nature. The combination of osteoarchaeological information with historical contextual data has provided a more detailed, accurate image of the influence of change and development on populations. In doing this, this study has clearly demonstrated the power of multidisciplinary research. In sum, this research has provided new data on individual residents in medieval Holland and Zeeland and used this information to assess the physical impact of socioeconomic developments in this period, thereby providing multifaceted high-resolution data for a more complete understanding of lives in transition.

Samenvatting

Levens in transitie. Een osteoarcheologische kijk op de gevolgen van de middeleeuwse sociaaleconomische ontwikkeling in Holland en Zeeland (1000-1600 na Chr.)

Deze studie onderzoekt de gevolgen voor de bevolking van de sociaaleconomische ontwikkeling in de middeleeuwse graafschappen Holland en Zeeland vanuit osteoarcheologisch perspectief. In slechts enkele eeuwen ontpopte deze regio zich in de late middeleeuwen tot een gecommercialiseerd en geürbaniseerd landschap met een centrale positie binnen de internationale markt. Deze ontwikkeling had grote invloed op verschillende aspecten van het middeleeuwse leven: leefomgeving en sociale omstandigheden veranderden drastisch zowel voor de mensen op het platteland als voor de bewoners van de nieuwe steden. Hogere bevolkingsdichtheid in de stad, commercialisering van de landbouw en het door de uitbreiding van de internationale handel ontstaan van nieuwe contacten en beschikbaar komen van voordien onbekende producten hebben het dagelijks leven van de middeleeuwse mens diepgaand beïnvloed. Echter, gedetailleerde informatie over de impact van deze sociaaleconomische veranderingen op de lichamelijke gesteldheid van de middeleeuwer is schaars. Bijgevolg had dit osteoarcheologisch onderzoek als doel meer inzicht te krijgen in de geschiedenis van deze periode en de gevolgen van de plaatsgevonden sociaaleconomische veranderingen door de mens zelf als studieobject te nemen. Aan de hand van drie thema's, namelijk ziekte, activiteit en dieet, worden de mogelijke gevolgen van de laatmiddeleeuwse sociaaleconomische ontwikkeling in Holland en Zeeland onderzocht en in kaart gebracht.

In de context van dit onderzoek zijn drie skeletcollecties geanalyseerd die door hun datering en context geacht worden een representatief beeld te geven van de fysieke consequenties van de ontwikkelingen in de late middeleeuwen. De bewoners van ruraal Blokhuizen (1000-1200 na Chr.) in het graafschap Holland dienen als beginpunt, omdat er in deze periode nog geen sprake was van commercialisering en/of verstedelijking. Naar alle waarschijnlijkheid hield dit kleine boerendorpje op het veen zich voornamelijk bezig met de akkerbouw en in mindere mate met veeteelt. In totaal zijn 119 individuen van de vindplaats

Blokhuizen onderzocht. De tweede skeletcollectie die tijdens dit onderzoek bestudeerd werd, is opgegraven in het voormalige dorp Klaaskinderkerke in Zeeland. Aangezien deze rurale collectie met 54 individuen dateert uit de late middeleeuwen (1286-1573), geven deze skeletten een beeld van de gevolgen van de sociaaleconomische ontwikkeling in deze periode voor een plattelandspopulatie. De laatste skeletcollectie bestaat uit 189 individuen opgegraven uit een begraafplaats bij het Minderbroedersklooster in Alkmaar, te dateren tussen 1448 en 1572. Deze middelgrote stad in het graafschap Holland telde ongeveer 9000 inwoners in de late middeleeuwen en had een redelijk hoge populatiedichtheid waardoor de gevolgen van het stadsleven goed onderzocht konden worden. Door de osteoarcheologische gegevens van deze drie rurale en urbane populaties met elkaar te vergelijken, krijgen we een goed inzicht in de mogelijke consequenties van de plaatsgevonden sociaaleconomische ontwikkelingen voor de lichamelijke gesteldheid van de middeleeuwse mens.

Om de eventuele gevolgen van de sociaaleconomische veranderingen in beeld te brengen, is gekeken naar verschillende skeletindicatoren binnen de thema's ziekte, activiteit en dieet. Allereerst is onderzoek gedaan naar het voorkomen van twee specifieke infectieziekten. Tuberculose, een chronische longaandoening, wordt veelal geassocieerd met gebrekkige leefomstandigheden, slechte hygiëne en armoede. Bovendien is in andere Europese landen als gevolg van urbanisatie een toename van deze ziekte geconstateerd. Brucellose is de tweede infectieziekte die is bestudeerd. Deze aandoening wordt verspreid door geïnfecteerde dieren. Het ligt daarom voor de hand dat zij speciaal voorkomt in een rurale omgeving waar de bewoners verhoudingsgewijs meer direct contact hebben met vee.

Veranderingen in de middeleeuwse activiteitspatronen zijn onderzocht aan de hand van het voorkomen van artrose en op basis van verschillen in botvorm. Artrose is een gewrichtsaandoening resulterend in een afname van kraakbeen, met verschillende botreacties tot gevolg. Hoewel vele factoren kunnen bijdragen aan het veroorzaken van deze ziekte, zoals erfelijkheid, lichaamsgewicht en leefomstandigheden, is mechanische stress een van de belangrijkste. De morfologie van de botten in het skelet toont veranderingen als gevolg van wijzigingen in de bewegingspatronen. In deze studie zijn specifiek bovenbeen en scheenbeen onderzocht, waar plattere botten hogere activiteit en met name hogere mobiliteit veronderstellen. Door deze botvormen en de prevalentie en locatie van artrose tussen de skeletpopulaties te vergelijken, is het mogelijk om te achterhalen of de activiteitspatronen door de tijd heen zijn veranderd, al dan niet als gevolg van het leven in een stad.

Verschuivingen in het dieet zijn bestudeerd door cariës en bepaalde voedseldeficiënties te analyseren. Cariës, oftewel tandbederf, wordt in de archeologie vaak gerelateerd aan het dieet. In verschillende regio's in de wereld nam het percentage cariës toe wanneer de betreffende populaties in hogere mate afhankelijk werden van de inname van koolhydraten.

Dit is het gevolg van het feit dat de bacteriën die verantwoordelijk zijn voor het ontstaan van cariës goed gedijen in de aanwezigheid van sachariden. Derhalve wijst een hoger percentage aan cariës op een toegenomen inname van producten die suikers en/of zetmeel bevatten. Daarnaast kan de aanwezigheid van specifieke vitaminetekorten, zoals die aan vitamine C en D, een beeld geven van de voedingswaarde van het gevolgde dieet. De vergelijking van de cariësfrequentie alsmede de prevalentie van vitaminetekorten biedt de mogelijkheid om eventuele veranderingen in dieetpatronen te onderzoeken.

Ten slotte is gekeken naar aspecifieke stressindicatoren. Deze veranderingen in het skelet geven aan dat op een bepaald moment in het leven van de betreffende persoon het lichaam sterk beïnvloed werd zonder dat de exacte oorzaak hiervan te achterhalen valt. Binnen het huidige onderzoek zijn groeiachterstanden, glazuurhypoplasie en cribra orbitalia geanalyseerd. Gezondheidsproblemen in de kindertijd kunnen leiden tot een vertraagde groei, die nog zichtbaar is in de volwassen lichaamslengte. In deze studie worden de gemiddelde lichaamslengtes van de onderzochte populaties vergeleken om zo vast te stellen of de ontwikkelingen in de middeleeuwen effect hadden op de groei. Glazuurhypoplasie, d.w.z. kleine gebieden met minder glazuur op de tanden, geven aan dat er een periode van stress was op het moment dat die specifieke tand werd aangelegd. Cribra orbitalia, porositeit in de oogkassen, wordt veelal gerelateerd aan bloedarmoede, maar ook vitaminetekorten kunnen hiervoor verantwoordelijk zijn. Door de prevalentie van glazuurhypoplasie en cribra orbitalia tussen de populaties te vergelijken, kan een goed beeld worden verkregen van de hoeveelheid systemische stress en kan worden onderzocht of de sociaaleconomische ontwikkelingen in de middeleeuwen hierop van invloed zijn geweest.

De resultaten laten duidelijke verschillen zien tussen de verschillende skeletpopulaties. Met betrekking tot het voorkomen van ziekten valt op dat tuberculose alleen voorkwam in de stadspopulatie van Alkmaar. Deze ziekte wordt vaak geassocieerd met een hoge populatiedichtheid waardoor de tuberkelbacillen zich makkelijk kunnen verspreiden. Aangezien de dorpen veel dunner bevolkt waren dan de steden, is het niet verwonderlijk dat tuberculose alleen in Alkmaar is aangetroffen. Echter, omdat de drie skeletcollecties in vergelijkbare mate aspecifieke stress vertonen, is het onwaarschijnlijk dat de algehele gezondheidstoestand in de stad slechter was. Opvallend is dat cribra orbitalia iets meer voorkwam op het platteland. Dit kan mogelijk te maken hebben met het voorkomen van malaria. De muggen die malaria overbrengen, zijn dol op gebieden met veel brak water en houden minder van een stadsomgeving. Wat uit de analyse duidelijk naar voren komt, is dat zowel de rurale als urbane inwoners van Holland en Zeeland stress ervoeren. Dit leidt tot de conclusie dat in de middeleeuwen het platteland niet per se een gezondere leefomgeving was dan de stad. Stad en platteland zijn verschillend voor wat betreft de typen ziektes die er voorkwamen, maar de ene leefomgeving was niet beter dan de andere.

Met betrekking tot de menselijke activiteiten zijn enkele verschillen waargenomen. Hoewel de algemene prevalentie van artrose geen duidelijke veranderingen laat zien, zijn wel verschillen waargenomen bij de vergelijking van specifieke gewrichten en gewrichtsgroepen. De vrouwen van Blokhuizen vertonen significant meer artrose in de gewrichten van de bovenste extremiteit (schouder, elleboog, pols en hand) dan de vrouwen van de andere populaties. Vooral de urbane vrouwen hebben een beduidend lagere prevalentie. Hoewel minder uitgesproken, zijn ook verschillen te zien als de mannen met elkaar worden vergeleken. De geconstateerde variaties in mechanische belasting kunnen het gevolg zijn van de afname van landbouwactiviteiten in de late middeleeuwen. De rurale populaties waren in deze periode sterk gericht op productie voor de markt, wat tot gevolg had dat de landbouwactiviteiten afnamen. Daarentegen groeide de werkgelegenheid in de commerciële visserij, lakenhandel en bierbrouwerij. Voor de stadsbewoners was landbouw een ongewone bezigheid. Zowel mannen als vrouwen werkten in de urbane industrieën en verrichtten over het algemeen zeer gespecialiseerde activiteiten. Ook zijn duidelijke veranderingen in het mobiliteitsniveau geconstateerd. De inwoners van Blokhuizen maakten intensiever gebruik van hun benen dan de latere rurale populatie van Klaaskinderkerke en de stadsbevolking van Alkmaar. Tussen Klaaskinderkerke en Alkmaar zijn de verschillen klein, wat mogelijk wijst op een vergelijkbaar activiteitenpatroon. Dit lijkt te passen binnen de veronderstelling dat men zich zowel in de stad als op het platteland met gelijksoortige werkzaamheden bezighield en beide sterk op de markt gericht waren.

Ook het voedselpatroon lijkt te zijn veranderd. Op basis van het cariëspercentage is het duidelijk dat de inname van koolhydraten toenam. De individuen in Alkmaar tonen een hogere prevalentie aan cariës, hetgeen suggereert dat het stadsdieet grotere hoeveelheden suikers en zetmeel bevatte. Mogelijk is dit verschil veroorzaakt door de diversificatie en uitbreiding van de markt in de late middeleeuwen. De ingezetenen van Alkmaar waren meer afhankelijk van de markt dan de dorpsbewoners. Hoewel de laatmiddeleeuwse plattelandspopulaties ook toegang hadden tot de markt, verbouwden zij nog wel producten voor eigen gebruik. Dit kan de grote verschillen tussen Klaaskinderkerke en Alkmaar verklaren. Hoewel het dieet duidelijk anders was, laat het gebrek aan aanwijzingen voor voedingstekorten zien dat zowel de rurale als de urbane populaties genoeg voedingsstoffen uit hun eten konden halen.

Het complementaire Master-onderzoek van IJk van Hattum naar de verschillen in voedselpatroon tussen Blokhuizen en Alkmaar op basis van stabiele isotopen (stikstof en koolstof) laat interessante resultaten zien. Waar de cariësfrequentie een duidelijke toename van koolhydraten aangeeft in het dieet van de stadsbewoners, komt uit het isotopenonderzoek naar voren dat de bewoners van Alkmaar ook andere eiwitten tot zich namen dan de dorpsbewoners. De hogere $\delta 15N$ waarden van de stedelingen tonen aan dat zij waarschijnlijk meer vis aten dan de inwoners van Blokhuizen. Deze toename in de visconsumptie is bijzonder goed te relateren aan de commercialisering van de visserij in Holland en Zeeland gedurende de late middeleeuwen. Daarnaast komt uit het isotopenonderzoek naar voren dat het dieet van de stadsbewoners meer divers was dan het dieet van de plattelandsbevolking wat aansluit bij het idee dat de mensen in de stad afhankelijk waren van de markt voor voeding.

Een belangrijke conclusie van deze studie is dat hoewel duidelijk verschillen aan te tonen zijn die gerelateerd kunnen worden aan de middeleeuwse sociaaleconomische processen, de stedelingen niet slechter af waren dan de plattelandsbevolking. Vooral met betrekking tot het voorkomen van ziekten wordt algemeen aangenomen dat de stad slecht was voor de gezondheid, iets dat niet wordt bevestigd door het huidige onderzoek. Hoewel er duidelijke verschillen zijn tussen Blokhuizen en de bevolking van de twee andere plaatsen, toont deze studie aan dat er vooral overeenkomsten zijn tussen de rurale en urbane populaties in de late middeleeuwen met betrekking tot menselijke activiteiten. Ook hier lijkt de veronderstelde sterke tegenstelling tussen stad en platteland niet op te gaan. Het grootste verschil tussen beide is te vinden in de vergelijking van de dieetpatronen. De stadsbewoners namen duidelijk andere voedselproducten tot zich dan de plattelanders, maar het ontbreken van aanwijzingen voor vitaminetekorten en verschillen in aspecifieke stress suggereert dat beide dieetpatronen genoeg voedingstoffen bevatten. Samenvattend kan gesteld worden dat dit osteoarcheologisch onderzoek een vernieuwend perspectief biedt op de turbulente middeleeuwen. De combinatie van de studie van de historische documentaire gegevens met de analyse van directe en unieke osteoarcheologische data heeft geleid tot een beter beeld van de gevolgen van de sociaaleconomische ontwikkelingen op de lichamelijke gesteldheid van de middeleeuwse mens.

Curriculum vitae

Rachel Schats was born in 1987 in the city of Voorburg, The Netherlands. From 1999 to 2005, she attended the *Haags Montessori Lyceum*. In 2005, Rachel started her undergraduate studies at Leiden University where she received her BA in 2008 with a major in Caribbean archaeology and a minor in archaeological sciences. During her undergraduate, Rachel participated in several excavations in the Caribbean. For her graduate studies, Rachel remained at Leiden University where she was accepted into the research master programme Religion and Society specialising in Caribbean osteoarchaeology. To expand her knowledge in skeletal anatomy and palaeopathology, Rachel studied under prof. Simon Hillson and prof. Tony Waldron at University College London as an Erasmus Exchange student. After obtaining her research master degree in 2010, Rachel started working at the Faculty of Archaeology, Leiden University as a teaching/research assistant supporting the osteoarchaeological education while simultaneously working on her PhD project. During this time, she developed her education skills by teaching several of undergraduate and graduate course at Leiden University, VU University Amsterdam, University of Groningen, and Saxion School for Applied Sciences. Additionally, Rachel wrote several physical anthropological reports and presented at national and international conferences. As of January 2016, she is appointed as a lecturer in Human Osteoarchaeology at the Faculty of Archaeology, Leiden University.

LIFE IN TRANSITION

Life in Transition investigates the impact of socioeconomic developments on the physical condition of medieval populations in Holland and Zeeland between AD 1000 and 1600 through the analysis of human skeletal remains from three archaeological sites. Focusing on several skeletal indicators of disease, activity, and diet, this research studies the physical consequences of these developments from a hitherto unexplored perspective. The combination of osteoarchaeological information with historical contextual data provides a more detailed image of the influence of change and development on medieval populations, thereby gaining a more complete understanding of lives in transition.