THE LATE MEDIEVAL AGRARIAN CRISIS AND BLACK DEATH PLAGUE EPIDEMIC IN MEDIEVAL DENMARK: A PALEOPATHOLOGICAL AND PALEODIETARY PERSPECTIVE

A Dissertation

by

CASSADY J. YODER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2006

Major Subject: Anthropology

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Approved by:

Chair of Committee, Lori E. Wright
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ABSTRACT

The Late Medieval Agrarian Crisis and Black Death Plague Epidemic in Medieval Denmark: A Paleopathological and Paleodietary Perspective. (August 2006)

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Chair of Advisory Committee: Dr. Lori Wright

The medieval period of Denmark (11^{th}-16^{th} centuries) witnessed two of the worst demographic, health, and dietary catastrophes in history: the Late Medieval Agrarian Crisis (LMAC) and the Black Death plague epidemic. Historians have argued that these events resulted in a change in subsistence from a cereal grain to a more pastorally-focused diet, and that the population decimation resulted in improved living conditions. This dissertation bioarchaeologically examines the impact of these historically described events on the diet and health of the population from Jutland, Denmark. I examine the stable isotopic ratios of carbon and nitrogen, dental caries, cribra orbitalia, porotic hyperostosis, periosteal reactions, and femur length to examine the samples for dietary and health differences due to sex, time period, site and social status.

The results suggest that there are few chronological differences in diet or health in these samples. There are greater disparities among the sites, as peasants from the rural site had a more terrestrially-based diet and poorer health than the urban sites. While there is little difference in diet by sex, there is a disparity in health between the sexes. However, the direction of difference varies by site, suggesting that the relative treatment of the sexes was not universal in Denmark. While the results indicate there is little difference in health by status, there are dietary differences, as elites had a more marine-based diet than peasants.

This research indicates the importance of bioarchaeological analysis in the interpretation of historical events. The recording of history is dependent on the viewpoint of the recorder and may not accurately reflect the importance of events on the the population itself. Bioarchaeological techniques examine skeletal material from the individuals in question and may provide a better understanding of the consequences of historic events on the population, such as the effects of the LMAC and Black Death on the population of Denmark. This research reveals that, contrary to historical expectation, these events did not have a measurable impact on Danish diet or health. Thus, the use of historical documentation and bioarchaeological analyses provides a richer understanding of these historical events.

DEDICATION

For my family, both by blood and by love

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CHAPTER I

INTRODUCTION

> And behold a pale horse: and his name that sat upon him was Death, and Hell followed with him. And power was given unto them over the fourth part of the earth, to kill with sword, and with hunger, and with death, and with the beasts of the earth
>
> Rev. 6.8 RSV

Although this quote speaks of the biblical apocalypse when famine, war, plague and death would descend upon the people, it is equally applicable to life in late medieval Europe, especially the 14th century. This period in Europe witnessed several famines, many wars, and the Black Death plague epidemic. The Middle Ages in Europe spanned from the 5th century to the 16th century. Prior to the 14th century the population of Europe grew as the stable climate of the Medieval Warm Period resulted in the expansion of available fertile land for farming. In the 14th century this period of prosperity came to an abrupt halt with worsening weather conditions, severe famines, the Hundred Years War, and the Black Death plague epidemic, which arrived in Europe in the mid-14th century. The population of Europe reeled from crisis to crisis for most of this century. The medieval people must have felt as if their God was punishing them. A poem from 1327 A.D. states of the famines of the day: "when God saw that the world was so over proud, He sent a dearth on earth, and made it full hard…And then they turned pale who had laughed so loud, And they became all docile who before were so proud" (Aberth, 2001).

This dissertation follows the style of The American Journal of Physical Anthropology.

The world of medieval Europe was falling apart, prompting the people to see signs of the apocalypse alongside the actual events of the day,

> a great mortality and pestilence began…in a certain province, terrible events and unheard of tempests overwhelmed that whole province for three days. On the first day it rained frogs, serpents, lizards, scorpions and many venomous beasts…On the second day thunder was heard, and lightning flashes...On the third day there fell fire together with stinking smoke from the heavens, which consumed all the rest of men and beasts, and burned up all the cities and castles of those parts
>
> *Chronicle de Flandre*, 1348 A.D. (Aberth, 2001).

The medieval period of Denmark covered a much shorter time period than what is normally referred to as medieval in the rest of Europe. Defined as beginning with the end of the Viking Age 1050 A.D. and ending in the mid 16^{th} century, almost the entire medieval period of Denmark was influenced by these catastrophic events. The medieval period opened with the campaign of King Canute to reclaim England for Denmark, which resulted in King Canute's death at the hands of his own people in 1086 A.D. In this period, the Danes also faced periodic raids by the Slavic Wends, and territorial disputes over Slesvig in southern Jutland, and Scania in what is now Sweden. The period ended with a battle for succession between Count Christopher of Oldenburg and Duke Christian of Gottorf that engulfed the entire nation in war and that is now referred to as the Count's War (Lauring, 1963). In the midst of this period came several famines, notably the Great Famine of 1315 A.D. (Jordan, 1996) which was the worst famine of the Middle Ages, and the Black Death, which entered Denmark in 1350 A.D. The Black Death alone has been estimated to have killed half of the population of Denmark (Benedictow, 2004; Gottfried, 1983).

Historians have suggested that these catastrophic events resulted in a dramatic reduction in the population, a change in subsistence and, at least initially, an improvement of the living conditions of peasants and an alteration in the relationships between members of different social classes (Dyer, 1989; Dyer, 1994a; Dyer, 1994b; Dyer, 2002; Jager, 1981; Orrman, 2003; Vahtola, 2003). However, no matter how well researched, historical documentation can only illuminate what the people living at the time saw fit to record. This information is often limited to the actions of important people or important events and may gloss over the everyday lives of the common people. This is especially true for medieval Denmark, as written sources concerning medieval Scandinavia are rare and those that do exist typically only deal with economic relations or the affairs of the elite. Overall, very few historical documents for the life of the common peasants and laborers exist (Boldsen, 1996; Dyer, 1989).

The research presented in this dissertation seeks to test the historical supposition that there was a change in diet and health with the calamitous events of the mid 14th century by examining the health status and diet of a wide variety of people from the Jutland peninsula of Denmark. In addition, this research aims to understand differences in health and diet among different segments of Danish society: between the sexes, over time, among three different sites and by social class. I address these research questions through paleopathological and bone chemistry analyses of human skeletal remains from the sites of Øm Kloster, St. Mikkel and Ribe. This research can thus provide information concerning the actual activities of groups of people often overlooked in historical documents. Øm Kloster was a rural monastic sit that yielded the skeletal remains of peasant, elite and monastic skeletons. The site of St. Mikkel is a parish cemetery located just outside the city wall of the town of Viborg, and the skeletal sample from Ribe site is from a cemetery located in the middle of Ribe, one of the largest and most active trade cities in medieval Denmark.

I examine the health status of these skeletal samples through the analysis of paleopathological indicators of ancient health. The indicators used here are cribra orbitalia and porotic hyperostosis, periosteal reactions and femur length. Cribra orbitalia and porotic hyperostosis are the result of severe childhood anemia (Stuart-Macadam, 1987). A periosteal reaction is considered to be a measure of infectious disease and is a lesion that is formed when a new layer of reactive bone is deposited on the original bone surface as the result of infection. While it is often not possible to determine the infectious agent that caused the periosteal reaction, the presence of this lesion indicates that some episode of ill health occurred (Cook, 1976; Ortner, 2003). I use femur length as a proxy measure for adult stature, which is considered to be a good indicator of childhood and adolescent health (Goodman and Martin, 2002).

I use stable isotopic ratios of nitrogen and carbon as well as the analysis of dental caries to examine medieval diet. The isotopic study of diet rests on the premise that the relative abundance of the isotopes of these elements is determined by their relative proportion in the diet of the individual. In northern Europe, the ratio of carbon 12 and 13, referred to as $\delta^{13}C$, in the human skeleton can provide information on the relative contribution of terrestrial and marine resources, whereas the ratio of nitrogen 14 and 15, referred to as $\delta^{15}N$, is used to determine the relative amount of animal and plant resources in the diet (DeNiro and Epstein, 1978a; Schoeninger and Deniro, 1984; Schoeninger et al., 1983a; Schoeninger et al., 1983b). Dental caries are the result of the acidic waste products of bacteria in the mouth. Diets high in sugar and carbohydrates are more cariogenic than diets high in protein and fats (Hillson, 1996). There is a synergistic relationship between diet and health, and thus, the use of both health and dietary indicators allows a more complete understanding of both the health status and the nutritional quality of the medieval diet (Larsen, 1997; Mensforth et al., 1978).

In the pages that follow, I first provide the historical background upon which this research rests. I begin this discussion with an overview of medieval European history in general and medieval Danish history specifically, to the extent that historical documentation allows (Chapter II). I continue this historical review with a presentation of both historical and bioarchaeological literature on the parameters of medieval diet and health (Chapter III). Following this discussion of the historical foundations of this research, I describe the sites analyzed in this study, theoretical issues in bioarchaeological research and the research hypotheses analyzed in this dissertation (Chapter IV).

Next, I discuss the theoretical framework for the stable isotopic analysis of diet, the results of the samples analyzed in this dissertation and I discuss the implications of these results (Chapter V). I continue the discussion of medieval Danish diet with the analysis of the abundance of carious lesions in Chapter VI. Chapter VII presents the abundance of cribra orbitalia and porotic hyperostosis with respect to each research question. The results of the analysis of periosteal reactions comparing the sexes, over time, among the sites or by social status are presented in Chapter VIII. The results of the analysis of femur length are presented and discussed in Chapter IX. In the final chapter (Chapter X), I examine the relationship among the dietary and health indicators and integrate the results of all of these analyses together with respect to each research question. Implications of this research for our understanding of medieval diet and health and suggestions for future research are also presented in the final chapter.

The goal of this dissertation is to obtain a more holistic understanding of the medieval period in the Jutland peninsula of Denmark by using bioarchaeological techniques in concert with known information about the period provided by historical documents. Although the 14^{th} century must have felt like the coming of the apocalypse to the medieval people, my research asks what life was actually like for the people who lived in this period and seeks to address the gaps in the historical data by examining segments of the population often overlooked in the historical literature. At the same time, I will use information from this literature in order to interpret the skeletal data and to more accurately reconstruct life in the medieval period.

CHAPTER II

A BRIEF HISTORY OF MEDIEVAL DENMARK

The medieval period in Denmark spanned the time between the end of the Viking Age (1050 A.D.) and the middle of the 16th century. This was a dynamic period that witnessed marked population growth (Becher, 2000), and the consolidation of both the Danish royal kingdom and the Catholic Church. By 1000 A.D., Denmark was a developed state with towns, royal fortresses, manors, highroads and taxation (Randsborg, 1989). From the 11th century onwards Danish society was increasingly divided into lords and peasants. However, nobility in Denmark, unlike the nobility of many other medieval European countries, was still very much tied to the land. The King, the Catholic Church and nobles owned large tracts of land. Throughout the period there were also increasingly more freeholders, who were free individuals not of noble birth, who owned farms, especially following the rapid expansion of arable land before 1300 A.D. Finally, there was growth in the number of semi-free tenants, called *landboer*, who were tenant-farmers on the large estates of the wealthy. This class ultimately became the largest group in rural society by the end of the period (Poulsen, 1997).

However, the Danish medieval period was not a time of uninterrupted prosperity, it was instead marked by two of the largest health and demographic crises known in history: the Late Medieval Agrarian Crisis (LMAC) and the Black Death plague epidemic. In order to examine the effect of these crises on the health and diet of the Danish people, it is first necessary to provide a brief historical review of this time period. In this chapter, I will refer to the time from the beginning of the Danish medieval period

(1050 A.D.) until the start of the LMAC (1300 A.D.) as the "early" Danish medieval period, and the period from the start of the LMAC until the close of the medieval period as the "late" medieval period. In this chapter I first discuss the treatment of women and the types of activities that women engaged in medieval Scandinavia. I then introduce the climate, agriculture in the countryside, life in towns and life in Cistercian monasteries in the early period. Next, I detail the Little Ice Age, Late Medieval Agrarian Crisis and Black Death plague epidemic in medieval Europe and Denmark. Last, I present aspects of life in medieval Denmark in the late period.

WOMEN IN SCANDINAVIA

Women in medieval Scandinavia were not completely independent from men, however, they enjoyed a better position in society than was typically found elsewhere in medieval Europe (Bennett, 1987; Jewell, 1996; Sawyer and Sawyer, 1993). Kinship in Scandinavia was organized bilaterally, that is, kinship was reckoned on both the father and the mother's side. Women were also allowed to inherit property after the death of a parent or spouse. Married and unmarried women were entitled to half of the "brother's lot" or half of the share her brother would inherit. A widow inherited a share of her husband's property equal to her son's and took her share of the estate first (Sawyer and Sawyer, 1993). A widow could continue her husband's business or work the farm after her husband's death (Orrman, 2003 #11896; Hanson, 1992 #11874). Although widows did enjoy a good deal of freedom, they were not completely independent, as they had to have the permission of their family before remarrying and they had to have a male guardian. However, widows did, choose their own guardians. A married woman was always under her husband's guardianship, but in practice they often had a great deal of freedom. Not only could Scandinavian women own, inherit and manage property independently from men, they also typically had an equal right as men to divorce (Hanson, 1992; Orrman, 2003).

In addition to working alongside their husbands, many married women also had their own businesses. Whereas men were more often involved in crafts like stone, wood or iron working, women were more often engaged in producing cloth, food, or brewing beer (Jewell, 1996). Rural women often worked alongside their husbands in the agricultural field (Sawyer and Sawyer, 1993). In the countryside, women's work typically included the preparation of food, textiles, child care, laundry and care of the livestock (including milking). Men typically worked in the fields, hunted, and fished. However, women helped the men mow the hay and during harvest times (Orrman, 2003). Unmarried daughters in the countryside who were not needed at home often left home to work on a different farm or moved to a nearby city to earn their living. Women living in towns could dispose of property on their own. In towns women often worked as brewers, bakers, spinners, and weavers. Working women did not have their own guilds in Denmark, but they could join some male guilds; however, women never earned as much as their male counterparts (Sawyer and Sawyer, 1993).

THE EARLY MEDIEVAL PERIOD OF DENMARK

Climate, agriculture and the countryside

From the 10th to the mid-13th century, Europe experienced an extended period of unusually mild and stable weather. This period is called the Medieval Warm period and it was the warmest period of the previous 8,000 years. The warmer air and sea surface temperature led to a reduction in the ice-pack, which resulted in much more favorable conditions for sea travel. This warm weather expanded the growing season, and thus, the land available for cultivation. The weather was so pleasant that until the 12th century, Icelandic farmers could grow barley, something they were unable to do again until the 1900s. Vineyards were started in England 300-500 km north of their 20th century limits. In fact, so much wine was produced in England that the French tried to block the English trade of wine on the continent. Average summer temperatures for most of Europe were between .7^{o} and 1^{o} C above 20th century averages and May frosts were a rarity (Fagan, 2000). The average temperature for Scandinavia was one degree higher than it is now, which had a measurable impact on the amount of land that could be cultivated. Rural and urban settlements were founded on land that had never been cleared before, well above the level at which cultivated plants can be grown today. For example, forest clearance and settlement spread 100-200 meters higher in elevation than in present day Norway. Wheat was grown as far north as Trondheim, and oats were grown even further north (Fagan, 2000). The expansion in settlement was partly driven by a demand for land due to the partible inheritance system, as land holdings were broken down into smaller and smaller pieces with each successive generation (Platt, 1978).

The majority of settlements in the Middle Ages in Denmark were small villages and hamlets. While some of these villages may have had up to 30 or 40 farms the majority consisted only of about 10 farms. Before the 12th century most farms in Denmark practiced continuous cropping which resulted in the need for these villages to move fairly regularly to new sites in the village territory in order to maximize their harvest. After the 12th century Danish farmers shifted to a crop rotation system and would then let one field lie fallow each year. This system maximized production and villages moved less often after it was adopted. The fields were parceled into long parallel strips and doled out to the villagers (Orrman, 2003). Some areas of Denmark continuously exported grain throughout the medieval period. Barley and winter rye were the main cereal grains grown. Wheat was a luxury crop and was grown sparingly. Cereal farming required fertilization, and therefore, most farms also practiced limited animal husbandry (Orrman, 2003). As cereal grains were the main component of the early medieval diet, the expansion of agricultural zones and the higher productivity of the land in turn resulted in conditions favoring population growth (Dyer, 1989; Platt, 1978). The population of England grew from 1.4 million people in the 11th century to 5 million people by 1300 A.D. (Fagan, 2000). The population size of Denmark has been estimated at 750,000 people in 900 A.D. and between one and one and a half million in 1300 A.D. (Becher, 2000; Boldsen, 1997; Cipolla, 1993; Jordan, 1996), the vast majority of whom were peasants (Benedictow, 2003). One consequence of the sharp rise in population was an increase in urbanization, as some people chose to leave the land and make their living in the growing urban centers.

Life in medieval towns

Urbanization came late to Scandinavia relative to other areas in Europe. In fact it has been estimated that only 4% of Danish parishes were urban in 1200 A.D. (Boldsen, 1996). However, beginning at the end of the 10th century the number of towns grew rapidly. The urban population continued to expand throughout the medieval period and doubled between 1200 A.D. and the close of the medieval period in the 1530s. At its height only about 10% of the population of Denmark lived in an urban environment. Thus, Denmark was largely an agrarian society for much of this period, with the larger towns only dotting the landscape. Unfortunately very few rural medieval parish cemeteries have been excavated. One of the cemetery samples analyzed in this dissertation is from the rural monastery of Øm Kloster, and a large portion of the burials at this site are from the rural lay population. The other two cemetery sites presented in the current study are from urban settings.

Medieval Scandinavian towns were small, relatively densely populated areas, often functioning as administrative districts, and typically included between 100-1000 people. These towns were very important in that they served as markets where imported items were distributed and surplus goods were gathered and redistributed (Sawyer and Sawyer, 1993). These early towns typically developed as unwalled harbors and were frequented by farmers, merchants and traders. They developed in a number of different ways, such that no single Scandinavian town provides a typical example. The very earliest towns developed as market centers, such as Hedeby and Ribe in Denmark and Birka in Sweden (Cohen, 1977). Hedeby was extremely important for trade and maritime activity in the Viking and early medieval period (Jacobsen, 1986). It was located on a natural route for merchants in the Jutland peninsula and was known for its textiles and leather goods (Cohen, 1977). The city moved to the north side of the fjord after it was burned down about 1050 A.D. and renamed Slesvig (also written Schleswig), (Crumlin-Pedersen, 1997; Jacobsen, 1986). This was such an important town that the whole of south Jutland was often referred to as Slesvig.

Not all towns were founded as provincial markets like Hedeby and Ribe; others started as ecclesiastical and administrative centers, like the town of Viborg, or as harbor towns, like Copenhagen (Cohen, 1977). The inhabitants of medieval towns were not wholly concerned with agrarian pursuits like their rural counterparts but instead focused more on trade and commerce (Lilley, 2002). Many cottage industries were established in these towns, finishing the raw materials that were produced elsewhere. Smaller medieval towns typically produced most of their own food, from either their garden plots or from the fields immediately surrounding the town. However, individuals in larger towns often had to rely on food from the rural hinterlands (Dyer, 1989). Many towns, especially the larger ones, also did not replace their own population but instead relied on immigration from rural areas to keep up the town population (Boldsen, 1984; Hanawalt, 1993).

Many of these towns were later walled for protection from foreign raiders as they grew in importance. Although this added to the safety of the townspeople, it also meant that they lived in very tight quarters. Most shop-owners lived above, or below, their shop (Hanawalt, 1993). Houses were built much more closer together than they were in the villages. In fact, the population density of medieval Winchester, England exceeded that of many modern English cities (Dyer, 1989). The greater population density resulted in increased sewage problems, making medieval towns, at least in England, much less hygienic places to live than rural communities (Hanawalt, 1993). Privies often ran into drains, which often leaked into the street and soil. Most waste from households eventually found its way into the streets, where the children played and commerce activity occurred (Dyer, 1989; Hanawalt, 1993). The poor hygiene and cramped quarters of medieval towns meant that epidemic diseases were far more common than they were in the surrounding countryside (Dyer, 1989). The daily routine in town and the countryside was set by the canonical hours so that the work day was longer in summer and shorter in winter. As work was not permitted on holy days, such as a saint's feast day, a town person's day-to-day life was dictated by religious observances (Lilley, 2002).

Social stratification was marked in these towns, with the merchant class being at the top of the hierarchy. They were followed by master craftsmen, journeymen and apprentices. Further down were the laborers, servants and finally marginalized people such as beggars, vagrants and prostitutes. Merchants and craftsman were often wealthy and are reported to have enjoyed a better diet and a large household with servants. Laborers led a precarious existence, with often long periods of time between jobs (Dyer, 1989). However, the rich and poor often lived on the same street, or even the same property (Hanawalt, 1993)

Denmark was never as urbanized as England but it was by far the most urbanized country in Scandinavia, with over seventy towns by 1300 A.D. (Benedictow, 2004; Boldsen, 1996). These towns continued to grow until the mid-fourteenth century. This growth was due to the immigration of peasants from the crowded countryside into the emerging towns (Dyer, 1994a). Although this was period of great urban expansion, many were making a precarious living as wage earners and occasional traders. Life was also becoming increasingly difficult for those who remained in the countryside, as much of the newly cultivated lands was in marginal areas that produced increasingly poor cereal yields. Many of these new farms were abandoned by the late 13th century. The abandonment of these settlements was very difficult for the already overpopulated and stressed society, and served to widen the growing gap between production and demand.

In addition to the poor yields, the Danish crown and church also levied increasingly high taxes on the peasant population beginning in the mid 12^{th} century. These taxes were so onerous that there were several armed peasant revolts from the mid 12^{th} century until 1350 A.D (Orrman, 2003). Many communities were already surviving at near subsistence levels when the catastrophes of the 14^{th} century struck (Dyer, 1989; Orrman, 2003).

Monastic life

As mentioned above, not everyone in the medieval period lived in towns or in rural communities; some instead lived in secluded monastic communities. The main monastic order in medieval Denmark by the 12^{th} was the Cistercian order. One of the samples for this research is the Cistercian monastery of Øm Kloster (Øm). One of the main tenets of Cistercian monastic life was seclusion from the world. The Cistercians achieved this goal by situating their monasteries in harsh environments ("deserts") far from other human habitation (Knowles, 1969; McGuire, 1982).

The Rule of St. Benedict and the Cistercian constitution were the guiding forces of Cistercian life. They instructed the monks on their monastic structures, their daily activities, what they were allowed to eat, and when they were to eat it. The three main features of the Cistercian order were their strict seclusion from the world, the demand that they survive off of the fruits of their own labor, their rejection of the customary feudal and ecclesiastical revenues, and the institution of the lay brotherhood (Lekai, 1978). These ideals came from the Cistercians interpretation of the Rule of St. Benedict that defined three governing rules for monasteries: 1. prayer (opus dei) 2. reading or study and 3. manual labor (France, 1992). It was the emphasis on manual labor that set the Cistercians apart from the other Benedictine orders. The rule on manual labor became one of the primary features of Cistercian life and required that they make fairly large changes in their social structure in order to carry out their interpretation of the rule. Monks were supposed to do three hours of work in the fields a day, except during harvest time when they were to do five hours of work.

Cistercian monasteries were to be self-supporting and the monks soon realized that because of other strictures on their day (time spent in prayer and study) they could not do enough field work and other manual labor to be completely self sufficient. Therefore, they instituted the lay-brotherhood or *conversi* (France, 1992). The lay-brothers were usually drawn from the peasant class and mostly did agricultural work, but they also did some masonry, carpentry, blacksmithing, weaving and tailoring, and were millers, cobblers, brewers, gardeners and fisherman. The monks were to be secluded and so could not leave the monastery to go into to town to sell surplus goods or to communicate with the outside world, and therefore, the lay-brothers would often be sent off the monastery to trade or take messages (France, 1992). There was no formal living quarters for the lay-brothers at Øm Kloster, as the west range, the traditional location for the lay-brothers was not built at this site until near the close of the medieval period. However, *conversi* were present at Øm Kloster and are mentioned as having responsibility for tending to the animals, working at the agricultural granges and taking care of monastery business in the secular world (France, 2003). Although the lay-brothers were instrumental in the functioning of the monastery, the monks were still very active members of the community.

THE LITTLE ICE AGE AND LATE MEDIEVAL AGRARIAN CRISIS

The unprecedented population growth and generally favorable conditions of the early period did not last. The late 13th century began a five hundred year period of colder and more unstable weather known as the “Little Ice Age”. The climate fluctuated between warm, cool, wet and dry. In this period the population suffered from arctic winters, very hot summers, serious droughts or extreme flooding (Fagan, 2000). Years of great harvests were followed by extremely poor yields, long periods of mild winters and warm summers followed by incredible cold (Fagan, 2000). At first the colder temperatures in the north made it more pleasant for the rest of Europe, but the severe nature of the cooling trend soon became apparent. The first hints of cooler weather were felt in Greenland and Iceland in the early part of the 13th century. Early frosts and bad harvests struck Poland and central the Russian plains in 1215 A.D. (Fagan, 2000). The winter of 1309-1310 A.D. was so cold that the Thames actually froze over, and trade was disrupted between the Baltic and the English Channel (Fagan, 2000).

The spring rains of 1315 A.D. were so severe that they stopped the military campaigns of the One Hundred Year War in their tracks, as all of northern Europe became mired in mud. Crop yields plummeted as thousands of hectares of cereals never ripened. The fall plantings of wheat and rye could not be planted and failed completely. Hay could not be cured properly, leading to famine in the animal populations as well (Fagan, 2000; Jordan, 1996). 1316 A.D. was the worst year for cereal crops in the entire Middle Ages. Wine and salt productions were also affected as vines never ripened and salt mines became un-navigable (Fagan, 2000). Diseases of cattle were also rampant, resulting in even higher mortality. This resulted in a shortage of meat and also of the manure used to fertilize the fields, further reducing agricultural productivity. The bad harvests finally ended in 1322 A.D. (Fagan, 2000; Jordan, 1996), and the late 1320s and 1330s had warmer and drier summers, but this was the exception and not the rule. The ocean was also much stormier, making shipping increasingly difficult and hampering trade (Fagan, 2000). The generalized unstable weather, which lasted to some extent or another until about 1800 A.D. resulted in routine crop failures or poor crop yields, has been named the Late Medieval Agrarian Crisis.

THE BLACK DEATH

On the heel of the famines of the early 14th century came another catastrophic event, the Black Death. The plague entered Jutland in Denmark in the late autumn of 1349 (Benedictow, 2004), possibly from Norway or England. The height of the plague in Denmark was during the summer and autumn of 1350 A.D. The plague killed 50% of the population of Scandinavia (Benedictow, 2004; Gottfried, 1983). In northern Europe, virtually all cities lost between a fourth and a half of their population in the first wave of the plague. The population of Europe lost 25 million people in a span of two years (Cipolla, 1993). The first tentative signs of recovery were not seen in Denmark until 1450 A.D., and it wasn't until well into the 16th century that there were clear signs of settlement and population growth in the country (Benedictow, 2004; Vahtola, 2003).

The conventional understanding of the Black Death is that it was caused by the bubonic plague bacillus, *Yersinia pestis*. In October of 1347 A.D., a Genoese fleet sailing from the Orient docked at the Messina harbor. On these ships were rats and fleas carrying *Yersinia pestis*. *Yersinia pestis* lives in the digestive tract of fleas and can be transferred to another host during feeding. In Europe, the most common host was the black rat (*Rattus rattus*). An important feature about the bacterium is that it can survive in the rodent's burrow long after the infected rodent is dead. Thus the plague can reoccur after the original epidemic dies down (Gottfried, 1983). *Yersinia pestis* is found in rat fleas (*Xenopsylla cheopis)*, but not in human fleas (*Pulex irritans)*. As rat fleas prefer a rat host to any other animal, they only bite humans when the rat population is decimated (Benedictow, 2004).

Yersinia pestis can cause different types of plague. The primary form, called primary bubonic plague, occurs when an infected rat flea bites a human victim, and in the process regurgitates plague bacteria into the wound. The bacteria drain along the lymphatic tract to the nearest lymph node. The node swells into the bubo, a pea or egg, sized lump that is very tender to the touch. This is the basic and most common form of plague and typically has a six day incubation period. If the flea bites directly into a vein then the plague bacteria may be directly injected into the blood stream, typically overwhelming the lymph system. This type of plague is called primary bacteraemic plague and is the most lethal and fastest moving type of plague.

In 50-60% of primary bubonic plague cases the lymphatic system eventually becomes overwhelmed and the plague bacteria enter the blood stream. This is called secondary bacteraemic plague and is also very lethal. In some cases of secondary bacteraemic plague the bacteria are transported with the blood into the lungs, resulting in pneumonic inflammation. When individuals with the secondary pneumonic form cough they can spread the plague by droplet infection, infections resulting from this are called primary pneumonic plague (Benedictow, 2004). However, primary pneumonic plague is fairly rare because the plague bacterium is so large that it is only found in large droplets. These droplets are not spread far and rarely make it into the lungs; instead they typically become stuck in the upper respiratory tract. If an infection does result, it starts in the pharynx and then moves onto the bloodstream and is then known as the primary bacteraemic type. Studies of modern plague outbreaks indicate that the mortality rate of the plague increases as population size decreases. This finding is consistent with the spread of plague throughout rural medieval Europe. This inverse relationship between mortality rates and population size is because the plague is not spread by cross-infection between humans, but instead by rat fleas. In the countryside, generally each household is co-resident with one rat colony, whereas in the more crowded cities, one rat colony is co-resident with several households (Benedictow, 1987).

In recent years, the causal agent of the Black Death has been called into question (Twigg, 2003; Wood and De Witte-Avina, 2003; Wood et al., 2003). Examination of well-documented modern outbreaks of the bubonic plague, such as that in China during the 18th and 19th centuries and India in the 20th century, reveals some differences from the medieval plague. This research has led some to question whether the medieval plague outbreak was in fact the bubonic plague caused by the *Yersinia pestis* bacilli. The medieval Black Death swept through Europe extremely rapidly. In fact, in less than four years it swept through all of Europe (Wood et al., 2003). The more recent epidemic of bubonic plague in China took more than a hundred years to travel a similar distance (Bennedict, 1996). In addition, the bubonic plague is a zoonosis, and thus first must be established in a local rodent population before it can spread to human populations. As rodent species do not move long distances on their own, they are not very efficient at transmitting diseases across large areas. In addition, some scholars argue that the Black Death was present in Iceland even though the black rat is not present in that country (Karlsson, 1996). Therefore, they argue that it is unlikely that the Black Death was a rodent-based zoonosis (Wood and De Witte-Avina, 2003; Wood et al., 2003). In addition, modern bubonic plague show an overall mortality rate of 1% and most mortality estimates from the Black Death are between 20-50% of the population (Twigg, 2003). Taken together this research suggests that the epidemic we refer to as the Black Death may not have been due to *Yersinia pestis*, unless it was an ancestral form that had a sufficiently different transmission pattern.

Researchers have tried identifying *Yersinia pestis* DNA in medieval plague victims with mixed success. Only one research group has identified bubonic plague DNA in medieval material (Raoult et al., 2000; Raoult and Drancourt, 2002). However, their results have been met with a great deal of skepticism as their laboratory had used *Y. pestis* as a control in an earlier study, possibly introducing modern *Y. pestis* DNA into the analysis and contaminating the results (Wood and De Witte-Avina, 2003). Another group of researchers tried replicating these results on a different group of medieval plague victims, in a lab that had never analyzed modern *Y. pestis* DNA, without success (Gilbert et al., 2004). Thus, the use of ancient DNA has not resolved the debate over the cause of the Black Death, indeed, it may have further muddied the waters. However, although the causal agent of the Black Death is not definitively known, the effects of this disease are well known and documented.

THE LATE MEDIEVAL PERIOD OF DENMARK

The catastrophic events of the first half of the 14^{th} century led to a sharp decline in population in Denmark. This diminished the workforce tremendously and so the price of labor rose. At the same time, there was more land available which resulted in a devaluing of the land and a reduction in rent prices between landlords and peasant tenants. In many cases the inhabitants of these villages were living at the limits of subsistence due to the village location in marginalized areas and the increasingly small size of individual holdings before the climate change. The bad weather acted to exacerbate these problems, and these small villages were abandoned (Vahtola, 2003). Some of these desertions started prior to the 14^{th} century, but they become more widespread after the mid-14^{th} century (Dyer, 1989; Dyer, 1994a; Dyer, 2002). Land prices dramatically fell in Denmark around 1330 A.D. which resulted in a reduction in rent prices as well. There was a decline in most regions in Denmark from 1330-1360 A.D. Some scholars argue that this decline provides evidence that the agrarian crisis was present in Denmark by 1350 A.D. However, others have argued that the decline was due to a variety of other reasons: farmer's riots due to higher taxes, the particularly cold weather from 1330-1390 A.D., war during the 1330s and 1340s, and, of course, the Black Death in 1350 A.D. (Vahtola, 2003).

There were regional differences in the effect of these calamitous events, for instance, declines in cereal production were worse in the middle of Zealand, than in the northwest part of Zealand. Southwest Jutland suffered more than other areas of Jutland, in part due to the disastrous weather in 1362 A.D. By 1600 A.D. a total of 143 medieval churches had been abandoned, 85% of which were in Jutland. Half of the farms close to the city of Ribe in western Jutland were deserted. The desertions were less dramatic in the more fertile northern Jutland, perhaps as little as 10-20% of the farms. The drift of the population away from the land continued throughout the period to some extent and was aggravated by the continuing population losses due to repeated plague epidemics and wars. Land desertion was at its height between 1350 and 1420 A.D. (Vahtola, 2003). Much of the former agricultural land began to be converted into pasture (Jager, 1981). However, the instability did not last the same length of time everywhere as there were some signs of stabilization in rent prices by 1370 A.D. on the islands of Denmark (Gissel, 1981).

The demographic and climatic crises of the 14th century resulted in a reduction in grain production in the Jutland peninsula of Denmark. The catastrophic population loss of the 14th century resulted in a general lessening of commerce and industry, and thus to a period of urban decline as well. This was due to the generally lower population size of the towns, coupled with the lower rates of immigration from the countryside. Many smaller towns also declined to the point that they could no longer be considered urban (Dyer, 1989). After the Black Death, and with the generalized unstable weather conditions, there was wide-scale migration from inland towns and villages to the coastal centers in all parts of Denmark. This was in part due to the importance of fishing and commerce. The desertions of towns and markets was not just limited to Denmark, they also occurred in England and the rest of Europe. The number of markets in England had severely declined by 1500 A.D.; of the 45 early medieval markets in Staffordshire, only 20 survived into the Late Middle Ages (Rowley, 1986).

However, not all of the desertions were due to agricultural troubles. In Denmark, a number of towns were deserted in southern Jutland from 1410-1432 due to wars and political turmoil with Germany over the control of Slesvig and southern Jutland. For towns that were founded on poor soils, like Herderslev, the desertion was permanent, in towns on richer soils, like Aabenraa, the desertion was typically not permanent (Gissel, 1981). In addition, towns that supplied the larger cities of northern Germany with trade or served as links on the trade network generally prospered, whereas those that were not part of this network were abandoned permanently. Scandinavia produced a great deal of raw materials for the rest of Europe. In the late period some areas of Denmark continued to be large exporters of grain, but also began exporting butter, dried and salted meat, hides and live cattle. Denmark imported spices, salt, cloth, wine, and beer (Dahlback, 2003). It has been estimated that by the end of the medieval period 5% of the population of Denmark lived in towns (Benedictow, 2003).

Many areas of Denmark became almost completely reliant on trade of cereals from other regions in Denmark and the Hanseatic markets in Germany (Gissel, 1981). However, there was still substantial agricultural cereal production in eastern Jutland, which was typically brought to the coast for trade and redistribution. As mentioned above, cattle rearing became important in western Jutland by 1400 A.D., and cattle production became increasingly important in the country throughout the late medieval period (Orrman, 2003). After 1450 A.D. both lords and peasants raised and shipped cattle to the Dutch and the Hansa towns in northern Germany. Dairy herds larger than four or five cows were rare on Danish farms in the 13th and 14th centuries. However, in the beginning of the 15th century the normal size of a dairy herd on a Danish farm was 20 cows. The number of meat cattle raised also rose for lords and peasants alike. In 1485 A.D., 13,020 oxen were sold at one Danish custom post to other European countries. In 1501 A.D., 28,300 oxen were exported from Denmark and in 1540 A.D., 35,000 animals were exported (Poulsen, 1997). Part of the change in production was due to the fact that it was easier and more economical for many areas to raise livestock than cereal grains and it was harder to transport cereals to the harbors than it was to drive cattle or carry smaller goods like butter (Gissel, 1981). Another factor influencing the shift to a more pastoral economy is the greater demand for cattle in European markets. At the end of the 14^{th} century the price of cattle and butter was much higher in Europe than at the start of the 14^{th} century. This has led some historians to argue that the Danes took advantage of this demand and increased their cattle farming (Sawyer and Sawyer, 1993).

The economic strength of the church, crown and nobility were not affected in the long term by the catastrophic 14^{th} century. However, these changes were extremely hard at first on the rural lower classes, particularly in Jutland in the beginning of the 14^{th} century, as the generally unfavorable weather conditions, combined with Jutland's thin, sandy soils made cereal grain yields even poorer. However, the fall in land prices eventually worked in the favor of the rural population. After the disastrous mid-14^{th} century, there was a general homogenization of the Danish peasantry. The peasants could work large tracts of land, 15 hectares or more, under the three crop rotation system. This system easily supported them and their family. The growing demand for beef cattle in the Netherlands and Germany in the 15^{th} century encouraged the shift from cereal cultivation to animal husbandry. The general desertion of the land made grazing lands and field for hay production more easily attainable for the Danish peasant (Orrman, 2003). In addition to migration to the coasts, there was also a fair amount of migration of Jutlanders to Eastern Denmark and to Sweden in the 14th century. Peasant revolts were more severe in Jutland than in the Danish islands (Gissel, 1981), in part because of the generally harsher conditions suffered by the Jutlanders.

The decline in population also resulted in a general improvement of the living conditions for the urban peasant population after 1350 A.D., as they had cheaper food, reduced rents and higher wages in the late period. The aristocrats were not as fortunate; they received less for their grain and their income from rents were lower (Orrman, 2003). Different social groups were repositioned; some were less successful now, others were more successful. Rural housing improved. Wage earners in towns gained more freedom to choose jobs. A skilled artisan might make more as a harvest worker, and was free to change jobs if he so choose. Ploughmen might switch and become carpenters or mariners if they felt it was more profitable. Women in towns had greater job opportunities and earning power after the Black Death. Women could work better jobs such as weaving, whereas earlier they had been limited to spinning thread. Also, many were able to take over the job of their deceased husband or father (Dyer, 2002; Winet et al., 1998).

The social attitude towards the poor changed dramatically throughout the medieval period. Before the 14th century, the poor were seen as a natural part of society, people to be pitied and given alms. In the 11th century, wealthy individuals often founded hospitals for the "deserving poor." However, during the labor shortages of the mid-14th century the poor began to be seen in a harsher, more unforgiving light (Dyer, 1989). Soon after the Black Death it became illegal to demand or offer higher rates than before the Black Death, it was now also illegal to quit a job before the contract expired and to refuse work if one were able bodied. It was also illegal to give alms to those who were able to work. All of these new laws were enacted to defend the interests of the employers. In 1363 A.D., it became illegal for agricultural workers to wear clothing that cost more than 12d a yard. The visible symbols of social rank were losing their meaning which made the upper classes very uncomfortable.

Peasants and wage earners also began paying more in taxes and fines because lords, whose income from rents and produce had declined, now looked for any breach of manorial discipline and charged the offender a fine in order to increase his own wealth (Dyer, 2002). Wealthy landowners also began charging their tenants additional fees by the start of the 16th century. Eventually these fees amounted to half of the payments made from tenants to landowners. Landowners also began restricting access to the forest and meadows on their land, which tenants had earlier used for raising their farm animals. By the end of the medieval period the agrarian way of life was once again becoming difficult for the majority of the peasant farming population, although, it was still better than it had been before 1350 A.D. (Orrman, 2003).

After the mid-fourteenth century, many could afford better constructed homes. The local elite could now afford a well built hall, with several outbuildings, and many could afford agricultural servants (if they could find them). Land was more plentiful for rural laborers as well and some could afford to own property (Mate, 1998). Some rural peasants were able to purchase more land and were thus economically more secure. In England, new terminology was used to describe the peasant; they were no longer just free and in servitude, but were categorized based on economic stratification. Yeomen were individuals who had 80 acres of land or more, whereas husbandmen and laborers had a few acres of land but still worked for wages (Dyer, 2002). Due to the population loss it was difficult to find laborers who were available to work the land in the late period, another factor that encouraged many to convert their fields from cereal production to pasture lands (Dyer, 2002).

The 14th century also witnessed changes in the organization of Cistercian monasteries. The practice of the lay-brotherhood for instance began to decline and was disbanded all together during the 15th century (Lekai, 1953). After the abandonment of the lay-brother system many monasteries rented out some of their land to peasants for money or agricultural products. In addition, the dietary restrictions for Cistercian monks were relaxed, and monks were increasingly allowed to eat terrestrial animal products. Despite these changes however, the core features of Cistercian life were maintained.

SUMMARY

The early Danish medieval period was characterized by an incredible period of warm and stable weather that allowed farming in previously uncultivable areas and encouraged tremendous population growth. This growth and prosperity came to an end starting around 1300 A.D. with the beginning of the Little Ice Age and the Late Medieval Agrarian Crisis. The deteriorating climate meant that many newly cultivated fields no longer produced sufficiently high enough yields to sustain the communities that worked them. Famines were widespread and people abandoned these marginal lands. In 1350 A.D. conditions became even harsher with the introduction of the Black Death plague into Denmark. The famines and Black Death decimated the population of Denmark. The decreased population is argued by historians to have resulted in a labor shortage that in effect increased wages and improved the living conditions for the survivors. Historians also argue that the crises of the 14th century resulted in a subsistence shift for the medieval peasant population. Before the crises, the diet of peasants largely consisted of cereal grain, often cooked as bread, but the increasingly unstable weather conditions resulted in a shift to a more pastoral diet. Thus, historical evidence suggests that although the crises in the mid-14th century resulted in widespread death and famine in the short-term, in the long-term they actually improved the living conditions of the peasant population of Europe. However, the historical record admittedly is vague on dietary and health issues and does not indicate how dramatic this shift may have been (White 1976), or to what extent it was shared across the social spectrum of Danish society. This dissertation seeks to examine these issues in greater detail using human bone chemistry and bone indicators of health and diet.

CHAPTER III

MEDIEVAL DIET AND HEALTH

Two of the most fundamental features of any skeletal investigation of a past population are the examination of diet and health. Dietary and health information on historical groups can be gathered from both historical texts and bioarchaeological analysis. Historical texts are important as they often provide first hand accounts about aspects of life that may be difficult to determine archaeologically, and they provide a baseline of information for more specific inquiry about certain features of life in the population in question. Bioarchaeological analysis is of crucial importance in the study of historic populations because it can be used not only to verify the historical documents, but can also provide information on groups of people or aspects of daily life that have not been discussed in the historical texts. Used in concert, these tools provide a powerful way of investigating past populations. This chapter presents the historical and bioarchaeological evidence of medieval diet and health.

DIET IN MEDIEVAL EUROPE

Due to the wealth of historical documentation and the comparative ease of gathering information from historical texts, much of our knowledge of medieval diet in medieval Europe comes from historical sources. However, there is a great deal of debate among historians as to the composition and nutritional value of the medieval diet. Many scholars argue that the diet was deficient in vitamins, minerals and protein (Fossier, 1988). Others argue that it was more nutritionally sound (Britton, 1977; Pearson, 1997;

Rosener, 1992), and that certain classes of individuals in fact enjoyed a very plentiful diet. Historical and isotopic sources indicate that social class had a large impact on diet (Dyer, 1989; Mays, 1997). Overall, historical texts suggest that the medieval diet was heavily composed of cereal grains and that, due to expense, meat was a much rarer component of diet for the majority of the population.

Fasting rules

The Danish diet was not only proscribed by availability of foodstuffs and cost, but also by religion. In the medieval period, Denmark was a Catholic nation and thus fell under the Catholic fasting rules. The fasting rules prohibited the eating of meat on Fridays and Saturdays, and on some Wednesdays, on the eve of important holidays, and everyday during the forty days of Lent. Lent is the religious period from Ash Wednesday until Easter Sunday. Dispensations from fasting were prevalent throughout medieval Europe. For example, children, old people, and pregnant and lactating women were exempted from the Lenten fast. In Norway and likely much of medieval Scandinavia, women were prohibited from breastfeeding for longer than 22-34 months. Some argue this rule was in place to reduce the number of women who might continue to breastfeed in order to be exempt from fasting (Benedictow, 1988; Benedictow, 2003). For the majority of individuals without special dispensations, between one-third and one-half of the days of the year were covered by some type of fasting rule. This potentially had a serious affect on the nutrition and health of the population, as fasting not only entailed a significant decrease in total calories consumed, but also dramatically limited the amount of animal protein eaten, and thus reduced the overall nutritional value of the diet

(Benedictow, 1988). However, it is not clear how faithfully the Danish people followed the fasting rules, and hence, the actual impact of fasting on the diet. One isotopic study that examined diet in England found significant differences in the consumption of marine resources in medieval individuals as compared with earlier Romano-British and Anglo-Saxon burials and they tentatively attribute this difference to the adherence to the medieval fasting regulations (Muldner and Richards, 2005).

Diet before 1350 A.D.

Before the 15th century Europeans usually ate two meals a day: one substantial meal at noon, and a lighter supper in the evening. However, peasants and craftsmen often ate a meal in the morning as well. Children, the elderly, and the sick were also allowed a morning meal, usually composed of bread (Adamson, 2004). Cereal grains were the most important dietary resource for the majority of people in the medieval period (Dyer, 1983). Cultivation of cereal grains increased in early medieval Denmark due to the introduction of new agricultural technology, such as the wheel plough, and became the main food source for all of Europe after the 11th century (Rosener, 1992). The grains were cooked either as bread, porridge, or pottages (similar to stew). Barley (*Hordeum vulgare*) was the main cereal crop in the beginning of the medieval period, although winter rye was also routinely grown. Bread was either leavened or unleavened and was typically made from rye or barley. Barley was used to make both bread and malt, whereas rye (*Secale cereale*) was for used to make bread alone (Orrman, 2003). Wheat (*Triticum*) was the primary cereal grain used in the bread of the upper class, whereas it was used to feed the peasant class only on special occasions. Peasants mostly subsisted on dark bread and porridge made from barley or oats (*Avena sativa*) (Adamson, 2004; Arcini, 1999). Paleobotanical studies in medieval Lund, which was part of Denmark in the medieval period (although it is now part of Sweden), have found remains of oats, barley, wheat, and rye. Cereal grains comprised about half of the food consumed at each meal in medieval Lund (Arcini, 1999).

Historical sources indicate that dairy products, meat, and large amounts of fresh fruits and vegetables were available on a limited basis for the majority of the population (Dyer, 1983; Gregersen and Jensen, 2003). Regardless of class, most individuals had access to some sort of garden, allowing them to supplement their diet with a limited supply of fruit and vegetables. Historical documentation suggests that garden produce was more commonly eaten by peasants than by aristocrats, although this may be an artifact of historical record keeping and not an actual lack of vegetables in the upper class diet. Kale was likely the main vegetable eaten and the primary source of vitamin C. Other important vegetables in the early medieval diet were onion, turnip, swede (*Brassica napobrassica*), white-beet, mustard, and hops. Cabbage and other root crops were also commonly grown (Arcini, 1999; Orrman, 2003). Legumes, especially broad beans, were an important protein source for peasants (Adamson, 2004). Eggs were available on a limited basis year around, whereas milk was available only on a seasonal basis (Arcini, 1999).

Fish were readily available to most of the Danish people, if they could afford it, due either to their close proximity to the ocean or to the abundance of dried and salted fish sold at markets (Enghoff, 1996; Lauring, 1963). The four main fishes eaten were herring (*Clupea harengus*), cod (*Gadidae sp.*), eel (*Anguilla anguilla*) and haddock

(*Melanogrammus aegliefinus*) (Dyer, 1983; Gregersen and Jensen, 2003). Zooarchaeological studies have found ling (*Molva molva*), dab (*Limanda limanda*), salmon (*Salmo salar*), pike (*Esox lucius*), perch (*Perca fluviatilis*), bream (*Cyprinidae*) and sturgeon (*Acipenser sturio*) in medieval sites (Arcini, 1999). Fish were likely to be extremely important due to the religious dietary restrictions (Schoefield and Vince, 1994). The lower classes lived mainly on cereals and probably ate fish more frequently than terrestrial animals, as fish were often cheaper than animal meat. The poorest third of society consumed only small quantities of animal protein, especially before the mid-fourteenth century. The dietary restrictions were thus less of a hardship for the poorer classes, as they couldn't afford very much meat anyway (Dyer, 1994b).

Interestingly, one recent isotopic study of Danish diet found that although marine resources made up a portion of the medieval Danish diet, they were not as important as would be expected if the medieval fasting rules were strictly followed. This study also found that marine resources composed a smaller percentage of diet in women than in men (Becher, 2000). An isotopic study of Iron Age, Viking and medieval human skeletal remains from Orkney, Scotland also found that males had a more marine enriched diet than females. They also found that more individuals in the medieval period had a diet rich in marine foods than in earlier periods (Richards et al., 2005a).

Faunal analyses of medieval diet indicate that cattle, sheep and pigs constituted the main sources of protein in both the peasant and elite diets (Dyer, 1989; Grant, 1988). Although sheep and cattle bones comprise the majority of medieval faunal collections, it is probable that pigs and fish were an important source of animal protein as well (Grant 1988). Faunal analyses indicated that pigs were slaughtered at a young age, and thus their bones may not preserve as well as those of mature cattle and sheep. Fish bones are easily missed in archaeological excavations and thus are likely to be underrepresented in zooarchaeological accounts. Nonetheless, beef was likely to be the most commonly consumed animal. Meat was either dried or stored in soured milk or whey (Arcini, 1999).

Animal protein accounted for between a third and a half of the total food consumption in English landed aristocratic households. Most English aristocrats had fishponds located on their property. Historical documentation suggests that upper class households were more likely to follow the fasting proscriptions than were lower class households, and thus, fish were extremely important to the upper class diet (Dyer 1983). Freshwater fish likely provided variety to meals on non-meat days. The most commonly consumed fish by the elite in England were eel (*Anguilla anguilla*), bream (*Cyprinidae*), perch (*Perca fluviatilis*), pike (*Esox lucius*), roach (*Rutilus rutilus*) and tench (*Tinca tinca*) (Dyer, 1994b). Cereal grains were also important in the elite diet, but unlike the peasants, their bread was more often made of wheat (Arcini, 1999). All of the vegetable foods discussed above were also available to members of the upper class, however, historical sources indicate that vegetables were not considered to be a high class food and did not make up a large part of the elite diet (Dyer, 1983). Elite and noble households typically ate only two meals a day, a large meal around noon called "dinner" and a smaller meal in the evening called "supper" (Adamson, 2004).

Diet was also distinct for individuals in monastic groups. One of the main samples studied in this dissertation is the medieval Cistercian monastery of Øm Kloster, which thus fell under the strictures of the Benedictine Rule. From September 14th until Easter, the Rule states that monks were only to eat one meal a day, and that they were to abstain totally from the meat of four-footed animals all year (unless they were sick) (Bond, 2001; Lekai, 1977). Bread and legumes were the main foods consumed by the Cistercian monks. However, most monasteries had gardens where they would grow a number of types of vegetables and grains for daily consumption, like peas, oats, leeks, broad beans, onions, shallots, garlic, parsley, and cabbage. Orchards were important for producing fruit and cider. Fish were an important source of protein and, where available, were eaten often. In fact, stable isotopic analyses of human bone collagen from monastic samples in England and Belgium suggest that while the medieval diet there relied heavily on terrestrial foods, marine resources were an important protein source (Mays, 1997; Polet and Katzenberg, 2003). This is likely to be true for the monastic samples from Øm Kloster as well, as Øm was located between two fresh water lakes, and nowhere in Denmark was very far from the ocean (Gregersen and Jensen, 2003). At the main meal, monks were given a generous portion of bread, two cooked vegetables, and fruits that were in season. Supper, if eaten, consisted of green vegetables, fruit and any left-over bread. On heavy work days, during harvest, monks received 1.5 lbs of bread and honey milk. During advent and lent, they were not to use animal fat, cheese or eggs. On Fridays during lent, the monks ate only bread and water. Salt and homegrown spices were used in cooked dishes (Lekai, 1977). The Benedictine rule proscribed the times the main meal was to be served, which varied according to season. The rule stated that monks were to have two cooked meals a day in general, along with vegetables and fruits if available. They were also to receive one pound of bread a day for both dinner and supper on non-heavy work days (Bond, 2001).

Diet after 1350 A.D.

Historical sources indicate that after the mid-14th century European people, including the Danes, relied less on cereal grains and instead focused their agricultural energies on cattle production (Arcini, 1999; Dyer, 1989). Not surprisingly, this greater availability of meat is argued to have resulted in a change in diet. One recent paleodietary study noticed an increase in the consumption of animal protein between the 14th and 15th centuries in Grenoble, France. However, these authors attributed this increase to urbanization (Herrscher et al., 2001) rather than to a large scale shift to a pastoral diet. This hypothetical dietary shift needs to be more systematically analyzed in samples from both urban and rural settings before any real conclusions can be drawn. Archaeological evidence of the increasing number of ovens found in14th and 15th century English houses indicates that baking of grain as bread became more common through time (Dyer 1989), perhaps replacing porridge and pottages as the chief way of preparing the cereal grains.

The shift to a more pastoral diet likely affected individuals of different social classes in varying ways. The lower classes were likely the most effected by this change. Peasant diet changed in three main ways: wheat consumption increased, in proportion to other cereal grains, more ale was imbibed in proportion to other liquids, and more meat was eaten (Dyer, 1983; Mate, 1998) . As discussed in Chapter II, the economy of Denmark shifted toward cattle production after the mid 14th century. In addition to the increase in cattle production this period also witnessed a rise in importance of pigs in the agrarian economy. Large tracts of woody areas that had been cleared for agricultural expansion in the early period, regenerated after the depopulation of the mid 14th century.

Prior to the deforestation these woody areas had been used for the raising of pigs and their regeneration after the mid-14th century resulted in a large increase in the raising of pigs (Poulsen, 1997). As an example of these dietary shifts, English harvest workers in the 13th century consumed a great deal of bread, a little ale and dairy produce and very little meat. However, in the early 14th century the percentage of money spent on bread declined, while ale and meat expenditures went up (Dyer, 1994b). Finally, in the 15th century harvest workers received a pound of meat for every two pounds of bread, in comparison with one ounce of meat for every two pounds of bread in the mid 13th century (Dyer, 1989). The bread consumed was made mostly of wheat and rye, and rarely barley. However, for the general peasantry, while the amount of money spent on various food types differed from what it had been in earlier centuries, the general proportions of food types consumed were still similar (Dyer, 1994b). In England, and likely in other European countries as well, the dietary problems before the Black Death were mainly due to the shortage of animal protein, and the main dietary improvement after the Black Death represented a correction of this problem, in that there were fewer serious food shortages (Dyer, 1989). The wealthier peasant groups could now even occasionally afford more luxury food items, like spices (Dyer, 2002).

The diet of the upper classes was little altered by this change to a more pastoral agricultural system. They continued to eat large quantities of both grain and meats; some estimates put meat consumption at two to three pounds a day per person (Dyer, 1983). Elites ate less pork now, and ate more beef and mutton, with greater emphasis on younger animals (lamb and veal) (Mate, 1998). In the 15th century, the English nobility began eating a meal in the morning, in addition to the afternoon and evening meals that were typical of the noble diet in the earlier period (Adamson, 2004).

Interestingly, there was also a change in the diet of members of the Cistercian monastic order. However, this was not due to the greater availability of meat, but instead due to the general relaxation in the literal adherence to the Benedictine Rule in the monasteries. On festival occasions, they received a "pittance", or extra portion, of white bread or fish. Pittances were given at dinner (the large meal) (Lekai, 1977). The occurrence of these pittances grew through time (Jaritz, 1985). During the late 11th and early 12th century, Cistercian monks received the pittance weekly, regardless of festivals. During the 12th century, the pittances were served in the refectory several days a week (Bond, 2001). However, the monks were not supposed to be served a pittance three days in a row, nor during a General Chapter meeting (Lekai, 1977). During the first half of the 15th century, the monks at the Austrian abbey of Heiligenkreuz received pittances on 201-207 days of the year. Although the eating of meat was still not technically allowed, many monasteries must have been breaking the Rule as the consumption of meat was discussed in many General Chapter meetings (Lekai, 1977). A Papal Bull of 1335 A.D. stated that retired abbots and the company at the abbot's table did not have to follow the Rule's restriction on meat. Finally, the General Chapter of 1349 A.D. relented and said that at least two-thirds of the community must eat the regular diet and eat together, but the other third of the community could eat meat, but that no individual should eat meat more than twice a week. In 1486 A.D., the Rule was further relaxed and meat courses were allowed to be served on Sundays, Tuesdays and Thursdays (Lekai, 1977). During later centuries, everyone in the monastery received breakfast as well as the other two meals. Breakfast was a piece of bread soaked in wine, accompanied by wine, beer or cider to drink (Lekai, 1977). By the end of the 15th century, the monks no longer needed pittances as the food they received was now sufficient. There were also more imported foods included in the daily diet of the monks. Diet in the monasteries became similar to that of the nobility or wealthy townsmen (Jaritz, 1985). An inventory from the cellar at Øm Kloster in 1554 A.D., shortly after the monastery was abandoned, lists butter, cheese, mead, cider, ale, vinegar, herring eel, cod, pike, cereal grains, goose, mutton, pig, ox, and sheep (France, 1998).

Although they could eat meat in the latter part of this period, bread, ale and legumes were still the principle features of a monk's diet. Fish, too, were an extremely important component of diet in the monastery as meat was still prohibited during lent. Both freshwater and marine fish were important. Many monasteries kept their own ponds stocked with fish. They also ate birds and eggs (Bond, 2001). An example of the increased number of food choices in late medieval Cistercian monasteries comes from the Cistercian Whalley Abbey, in Lancashire, England. In the 16th century, this abbey spent two-thirds of its income on food and drink. Their main expenditures were on wheat and barley malt. They also bought meat (beef, mutton, veal, pork, young pigs, lamb, wild geese and fowl), red and white herrings, dried and salted fish, eels and salmon. In addition, they bought a large amount of wine, imported items like figs, raisins, currants, almonds, pepper, saffron, ginger, nuts, rice, nutmeg, spices, cloves, licorice, cinnamon, dates, olive oil, cakes, treacle, sugar, and sugar candy (Greene, 1992). It is not clear whether all the brothers had equal access to these new food resources, but the general breadth of purchases in monasteries certainly increased.

HEALTH IN MEDIEVAL EUROPE

Medieval medical knowledge

In the medieval period, disease was seen as something that had to be endured. Episodes of ill health were ordained by God because of the sin and wrong doings of the individual. It was believed that God could heal without human intervention, that medical skill was a blessing from God, and therefore, many clergymen were medical practitioners (Roberts, 1987). In addition to the clergy, a variety of individuals practiced medicine in the medieval period including: the barber, the physician, and the surgeon (Getz, 1998). All illness was thought to be a kind of poisoning, and the job of the medical practitioner was to purge the body of the poison (Getz, 1998). The medieval diagnostician had little available to him in the way of formal training, textbooks or sound medical tradition. The medical texts that were available were very vague and could have been interpreted as the user saw fit. In fact, it is very difficult to identify what diseases are being described in medieval texts. From a historical standpoint, the descriptions of health in medieval manuscripts are of limited value (Siraisi, 1990).

The prevailing medical doctrine of the medieval period was the theory of the four humors (Gottfried, 1986; Roberts, 1987). This theory proposed that the world was comprised of four elements: fire, air, water and earth, which were linked with one of four principal body humors. Each fluid was believed to take on the quality of the element it was associated with. Each humor was associated with a color, taste, age, season of the year, and temperament. Yellow bile was linked with fire, and therefore, it was hot and dry. Air was allied with blood, and was warm and wet. Water was associated with phlegm, and so it was considered to be moist and cold. Earth was the melancholic humor and was linked with black bile, and therefore, it was cold and dry. The proper balance of humors led to good health, whereas an imbalance in any of these could cause an alteration of the normal condition and ill health (Brody, 1974). The medieval physician understood that by examining the body's excretions, he could understand what was happening with the humors inside the body (Getz, 1998). Food was considered to be the most effective way to control the body's humoural balance. Many physicians wrote cook books describing the appropriate foods to keep a person well, and to help the sick get better (Montford, 2004)

Uroscopy was one of the principle diagnostic tools used by the medieval physician and was understood to measure the state of the liver. The color, texture, odor and even the taste of the urine were used to determine the nature of the disease. Pulse-reading was another important diagnostic tool and was used to measure the state of the heart. The heart beat and pulse rate were used to determine the stage that an ailment had reached (Gottfried, 1986). Phlebotomy, or bloodletting, was very important to regulate the body humours and ensure good health. The arrangement of the stars was used to guide when and how to let blood (Gottfried, 1986; Siraisi, 1990).

The treatment of the sick did not typically take place in the medieval hospital. In fact, the hospital of the Middle Ages was not similar to the hospital of today, but instead was more like a hospice. Little medical care was provided to those staying in the hospital. Instead the patients were given bed rest, warmth, cleanliness, and a more adequate diet. Medical care primarily took place in a private office or the home (Getz, 1998).

Bioarchaeological investigations of medieval health

Medieval health has been the focus of recent bioarchaeological investigations of medieval Europe, including an examination of activity, infectious disease and non-specific indicators of stress in England (Mays, 1996; Mays, 1999; Mays, 2000; Mays et al., 1998), infectious disease patterning in Serbia (Djuric-Srejic and Roberts, 2001), stress levels, dental disease and mortality in Croatia (Slaus, 1994; Slaus, 2000; Slaus et al., 2002; Slaus et al., 2000; Slaus et al., 1997), infant mortality in Germany (Huhne-Osterloh and Grupe, 1989) and childhood anemia in Poland (Pointek and Kozlowski 2002). Of particular interest in light of the research presented in this dissertation is recent research comparing urban and rural health (Lewis et al., 1995), health variations between the sexes (Slaus, 2000), health differences through time (Slaus et al., 2002), and childhood health (Pointek and Kozlowski, 2002). Recent research compared the prevalence of maxillary sinusitis in urban and rural populations in medieval England and has found that a higher prevalence in the urban samples than in the rural samples. This difference has been attributed to variations in occupation and air pollution for the inhabitants of urban York compared with those of the rural site of Wharram Percy (Lewis et al., 1995). In a biomechanical study of activity patterns in medieval populations in England, Mays (1999) found sex-based differences in activity. Mays found greater humeral asymmetry in males than in females and suggested that this was due to the greater use of heavy tools for crafts such as wood and stone cutting by males than females. Grauer (1993) examined the abundance of porotic hyperostosis and periosteal lesions in medieval English samples and found that overall health was not compromised by bouts of childhood anemia and in fact adult individuals who had anemia during childhood may have been better able to fight off infections as adults.

There have also been several intensive studies of health patterns in medieval Croatia (Slaus, 1994; Slaus, 2000; Slaus et al., 2002; Slaus et al., 2000; Slaus et al., 1997). Slaus (2000) found that subadult females had a higher incidence of linear enamel hypoplasias and defects than adults, and that female adults had higher rates of these pathologies than adult males, possibly suggesting differential survival of stress events between the sexes. Furthermore, he found that adult males had more caries than females, suggesting a differential access to food resources between the sexes. Males also had higher rates of vertebral osteoarthritis, Schmorl's nodes, and skeletal trauma than females, suggesting males had higher levels of physical stress and different patterns of activities than females (Slaus 2000). In a comparison of health through time, Slaus et al. (2002) found significantly higher levels of periosteal lesions, cranial and postcranial trauma and Schmorl's nodes in the late medieval (10^{th}- 13^{th} centuries) than in the earlier period (6^{th}-9^{th} centuries), possibly indicating much higher levels of stress in later medieval Croatia. In their study of populations in medieval Poland, Pointek and Kozlowski (2002) found higher levels of cribra orbitalia in subadults than in individuals who survived to adulthood. They attribute the presence of cribra orbitalia as the result of contagious disease, and therefore, postulate that the high frequency of the pathology in subadults reflects the population adapting to poor environmental conditions.

Until recently, paleopathological analyses of Medieval Denmark have either been case studies (Bennike and Bros-Rasmussen, 1989; Jackobsen et al., 1991; Tkocz and Bierring, 1984; Usher and Christensen, 2000)), or have focused on a particular disease, like leprosy (Boldsen, 2001; Boldsen, 2005b; Boldsen, 2005c; Boldsen and Mollerup, 2006; Moller-Christensen, 1953; Moller-Christensen, 1961; Moller-Christensen, 1978; Moller-Christensen and Faber, 1952). In fact, some of the most intensive paleopathological analyses of medieval Danish material to date have been focused on leprosy. Vilhelm Møller-Christensen pioneered the study of medieval lepers through his analysis of leprosaria, leper hospitals often referred to in Scandinavia as St. Jorgen's hospitals. Møller-Christensen's research greatly improved not only the paleopathological understanding of the osseous involvement in leprosy but also the modern clinical understanding of the disease's course as well. Boldsen's analysis of leprosy in medieval Scandinavian population indicates that individuals with leprosy were not always confined in leprosaria, but were also found among the general population. From his data he estimated that between one quarter and one half of the population of Tirup, a 12th- 14th century rural Danish village, suffered from some degree of leprosy (Boldsen, 2001), and in a later examination of leprosy at this site he estimated that 26% of the village suffered from some degree of leprosy (Boldsen, 2005b). This suggests that a relatively high proportion of rural medieval Danes may have been infected by leprosy in these centuries.

Paleopathologists have recently begun to take an interest in health trends in medieval Denmark(Bennike, 1985; Bennike et al., 2005; Boldsen, 1990; Boldsen, 1984; Boldsen, 1991; Boldsen, 1994; Boldsen, 1995; Boldsen, 1996; Boldsen, 1997; Boldsen, 1998; Boldsen, 2001; Boldsen, 2005a; Boldsen, 2005b; Boldsen and Mollerup, 2006; Usher, 2000). In his analysis of dental attrition in the medieval village of Tirup, Denmark, Boldsen found that attrition proceeded much more quickly in individuals who lived between 1300 A.D. and 1350 A.D. than those who lived before. He attributes this increase speed of attrition to the deteriorating living conditions in northern Europe, and to an increased consumption of cereal grains in the first half of the 14th century. Tirup was abandoned around 1350 A.D., and therefore, provides no information about later medieval attrition rates (Boldsen, 2005a). In another study, Boldsen (1996, 1997) examined childhood health in several Danish sites. He found there to be a very high level of mortality in medieval Denmark and that with the known mortality rates it is unlikely that urban areas would have been able to maintain their population size without migration from rural areas (Boldsen, 1996). He also looked at body proportions in a medieval Danish village and found that early incidences of ill-health such as enamel hypoplasias, had no effect on the attainment of adult stature, but did have an effect on body proportions (Boldsen, 1998), which he interpreted as evidence that early health stresses can have long-term and unexpected health consequences. Boldsen also found an association between the risk of death and the presence of an active carious lesion in women between the ages of 35-45 in the medieval Danish community of Tirup (Boldsen, 1997). Finally, in his analysis of stature in different areas of medieval Denmark, Boldsen found that on average, urban populations are taller than their rural counterparts. He attributed this result to the higher rates of immigration to the cities from several rural sites which resulted in increased heterogeneity in the urban population (Boldsen, 1990).

Arcini (1999) examined the health of 3,305 individuals who lived from 990-1536 AD in medieval Lund. Lund was an early urban center in medieval Denmark but is now part of Sweden. The population of Lund grew dramatically during the medieval period. She looked at changes due to urbanization in stature, oral health, joint disease, infectious disease, and trauma throughout this period. Arcini found that in general urban men and women were taller than their rural counterparts. She noted that the degree of sexual dimorphism was at its greatest in the early medieval period in urban samples, but that this dimorphism diminished through time; whereas the sexual dimorphism in the rural samples was smaller and stayed virtually the same through time. She also noted that average femur length was greater for urban males than rural males in the early period, whereas there are no major differences in average femur length between urban and rural female skeletons. She theorized that the difference in the early period urban samples possibly reflected a nutritional surplus that was enjoyed by males and that did not exist in the later urban period or in the rural samples. Arcini also found an increased rate of carious lesions and more teeth affected by caries in the late medieval period at Lund. She noted that this increase may be the result of a more cereal grain dependent diet or be due to older age at death in the late period sample in comparison with those from the earlier period.

In addition, she found that lower class individuals buried outside of one of the churches of Lund had a higher frequency of caries than the more affluent individuals buried within the church. Arcini attributed the higher caries rates to a diet composed primarily of porridge, which is sticky and can remain in the interstitial spaces between the teeth. Incidentally, other researchers have found an increased incidence of caries throughout the medieval period in populations from Halland and Scania, two Danish sites in the medieval period (Mellquist and Sandberg, 1939). However, they attributed this increase to either an increased consumption of vegetables or reduced dental attrition. Finally, Arcini found that the incidence of cribra orbitalia and osteomyelitis decreased through time and that poorer individuals had significantly more cribra orbitalia than elites. When she analyzed all of the health indicators together she noted no systematic trends in health patterning through time. She found that some of the health indicators suggested that health worsened through time, others that it improved and still others that there was no change in health through time. This led her to conclude that there were no major or systematic changes in health conditions through time in medieval Lund (Arcini, 1999).

Bennike examined human skeletal material that spanned 7,000 years of Danish history. She analyzed demographic trends, stature, trauma, arthritis, oral health and infectious disease. She found that individuals were taller in the medieval period than they had been in the preceding Viking period, but that they were shorter than modern Danes today. She also noted that women's dental health was worse on average than men's dental health in the medieval period, and that the medieval period had among the highest overall caries rates of all the periods examined. Unfortunately for the current study, Bennike's treatment of infectious disease was on a case study basis, and she did not conduct a comparative study of health trends through time (Bennike, 1985).

CONCLUSIONS

Historical documentation and paleodietary studies indicate that the medieval diet was heavily reliant on cereal grains, but this dependence lessened after the mid-14th century. Historical texts and stable isotopic analysis also indicate that there were differences in diet by social class. These studies of medieval diet provide a solid foundation and comparative dataset for my isotopic examination of diet in medieval Denmark. Although historical documentation on medieval health is of little use in this dissertation, the bioarchaeological analyses of health in medieval Europe are of great importance. They also provide a context in which to situate this analysis.

CHAPTER IV

RESEARCH DESIGN

The research presented in this dissertation seeks to determine whether there was an impact, and the degree of that impact, of the crises of the 14th century described in Chapter II on the diet and health status of the medieval population of Denmark. The goal of this research is to gain a more complete understanding of the Danish Middle Ages by examining a wider spectrum of the Danish population than is typically found in historical documents from the period. This chapter introduces the skeletal samples used in this analysis, discusses how health can be inferred from skeletal remains, and proposes the research hypotheses to be tested.

SITE DESCRIPTIONS

The samples analyzed in this dissertation are from three cemeteries in Jutland, Denmark: St. Mikkel, Øm Kloster and Ribe. Jutland is the large peninsula of Denmark. Figure 4.1 is a map of Denmark, illustrating the placement of each site in relation to one another (France, 1998).

The St. Mikkel cemetery is a cemetery from just outside the city of Viborg. Viborg is located in the middle of the Jutland peninsula and was a very important administrative and ecclesiastical center in the medieval period (Boldsen, 1996; Sawyer and Sawyer, 1993; Sawyer, 1986). It was a seat of royal power, as traditionally the King was crowned in Viborg. It became an episcopate in 1065 A.D. and housed a cathedral,

FIGURE 4.1. Map of Denmark (After France, 1998)

twelve parish churches and five monasteries. In addition to its ecclesiastical and royal importance, it also had trade activities. Viborg was located 13 km south of a harbor at Hjarbæk and had traditionally been a center for fairs. It was also connected by road to Slesvig, one of the largest trade centers of the period, easing trade between the two cities (Kristensen, 1987). One of the parish churches was called Sct. Mikkels, which was situated in the Lille Sct. Mikkels Gade, and is referred to in this dissertation as St. Mikkel. After the construction of a defensive wall around the city in 1150 A.D. this church and cemetery were located just outside of the town wall, as illustrated in Figure

4.2 (Kristensen, 1988). The excavation plan from the cemetery of St. Mikkel is presented in Figure 4.3. As is typical in Christian cemeteries, the burials are all oriented in an east-west direction. The total excavated skeletal sample from St. Mikkel consists of 500 graves and that date from the early 12th century to the early 16th century. For some of the period, the cemetery may have also been used by a local hospital. Historical documentation suggests that in 1440 A.D. the individual in charge of the hospital was also the head of the local Sct. Jørgens (George) hospital (Hjermind, unpublished manuscript). Sct. Jørgens hospitals were leprosaria and were used to house and treat individuals thought to have leprosy.

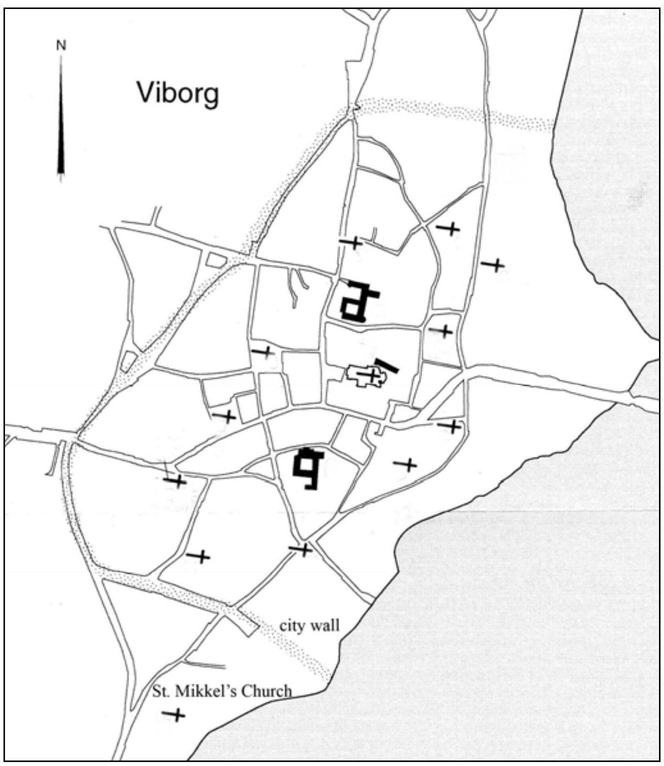

FIGURE 4.2. Placement of St. Mikkel's church in relation to the city of Viborg (After Kristensen 1998)

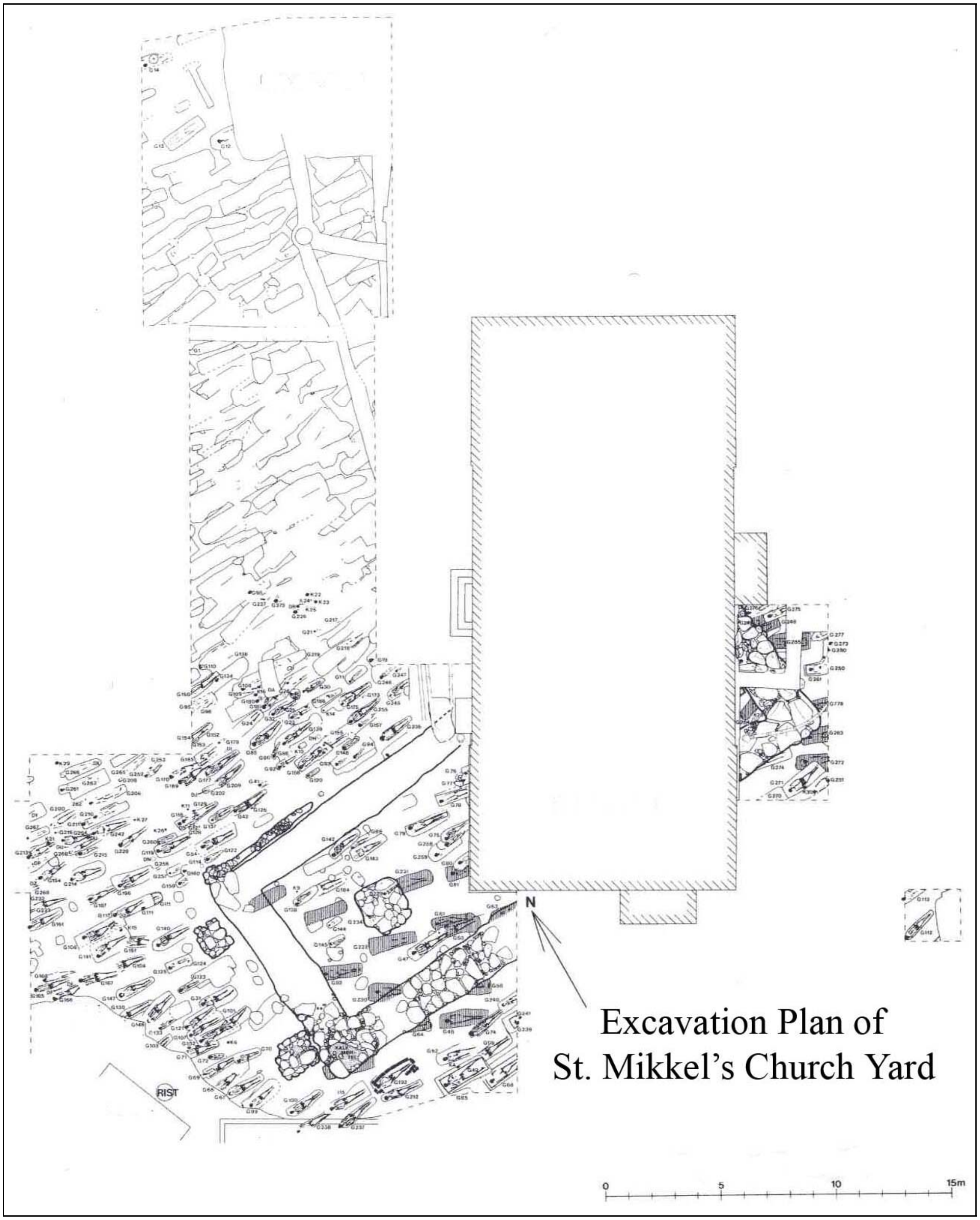

FIGURE 4.3. Excavation plan of St. Mikkel's church yard (Vellev, 1978)

Therefore, some of the residents of this leprosaria may have also been interred at St. Mikkel. Unfortunately, there is little written material about the cemetery of St. Mikkel. The skeletons from the St. Mikkel cemetery are housed at the Anthropological Data Base at Odense University (ADBOU) at the University of Southern Denmark in Odense, Denmark.

The second sample analyzed in this dissertation is the rural monastery cemetery of Øm Kloster which was used by both monastic and lay individuals. Øm is situated between two freshwater lakes near the center of Jutland. It was founded in 1172 A.D. and was called Cara Insula (beloved isle) by the monks who immediately set to work digging canals and building their monastery (McGuire, 1982). Øm Kloster was not in use after the mid 16th century and many of its buildings were taken apart so the stone could be re-used in other building projects (McGuire, 1982).

Archaeological excavations have revealed that there was no physical choir for lay-brothers at Øm Kloster. As indicated in Figure 4.4, the monastery also includes a fairly large library, laundry, bakery, large herb garden and possibly a hospital (Garner, 1998). The building that is thought to have been a hospital was erected in 1495 A.D. Hospitals are often found at Cistercian monasteries and their function was typically only to take care of the sick monks and lay-brothers. However, the hospital at Øm may have been different from those at other Cistercian monasteries. The large number of lay burials at this site, indicated by their placement in the churchyard, suggests that sick individuals from the surrounding countryside the hospital may have used this hospital (France, 1992). However, the large number of lay burials at this site from all time periods suggests that they could not all have been former patients at the hospital.

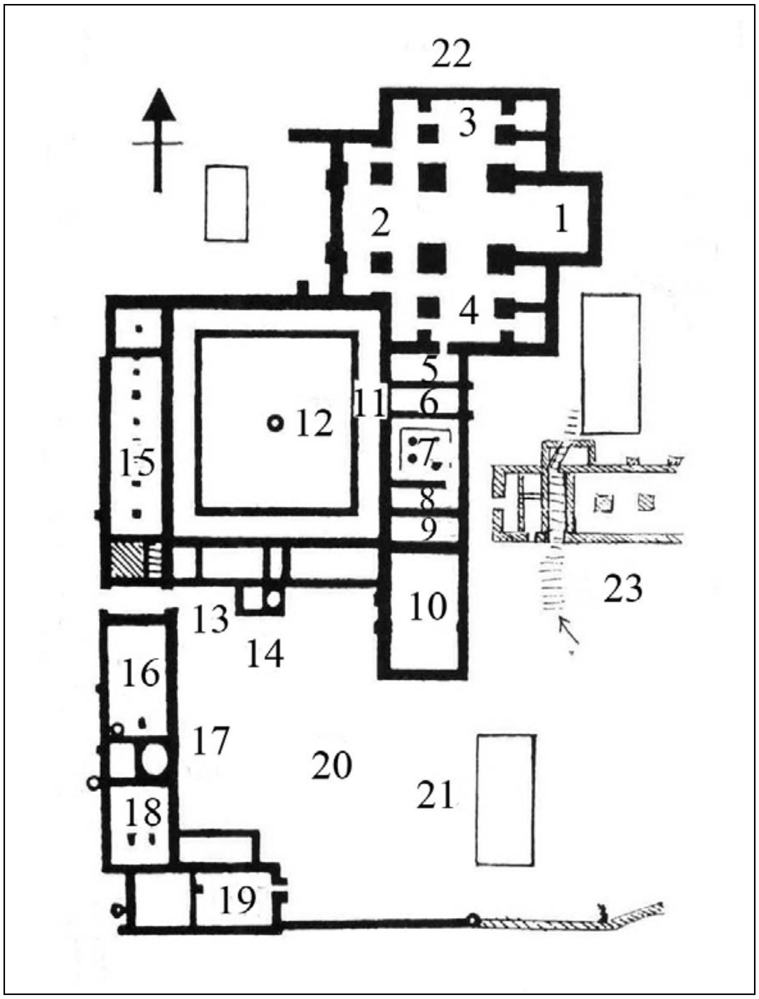

FIGURE 4.4. Schema of the Øm Kloster monastery. Key: 1-4: church, 5: vestry, 6: library, 7: chapter house, 8-9: day stairs, 10: monk's room, 11: cloister walk, 12: cloister, 13: dining room, 14: lavatory, 15: laybrother's quarters, 16: laundry, 17: bakery, 18: kitchen, 19: lodging house, 20: courtyard, 21: herb garden, 22: northern churchyard, 23: hospital (After Garner, 1998)

Instead, the large lay cemetery likely reflects the edict from the General Chapter Meeting of 1217 A.D. which allowed anyone who wished it to be buried on the monastery property if they had the permission of their parish priest (Canivez, 1933-41).

The monastery excavation plan is provided in Figure 4.5 (Gram, 2003). This sample includes monks, elites and peasant burials. The social class of these individuals can be distinguished by the location of burial in relation to the church. At Øm Kloster the monks were buried east of the church, in the cloister walk or in the chapterhouse. The lay population, including the *conversi*, were buried north of the abbey, on the far side of the cloister, away from the sacred spaces of the church (France, 1992; Greene, 1992; Sullivan, 2004). The elites, including any benefactors of the monastery, were buried in the abbey church, north of the church (Gregersen and Jensen, 2003), in the presbytery near the high altar, below the nave of the church, and its aisles, transepts and transept chapels (France, 1992; Greene, 1992).

Excavation began at Øm Kloster in 1911, but the first major excavation began in the 1930s. During this excavation, the church and part of the eastern wing and graves from the western part of the cemetery were uncovered. From 1974-1978, Moesgård University used the Øm Kloster site as a field school. They excavated the northern and southern wings of the monastery, as well as the cloister garth. In 1986, excavations resumed on the eastern wing, and from 1994-1996 Moesgård University excavated the hospital building located east of the eastern wing. The monastic skeletons are housed at the University of Copenhagen. At the time of analysis the lay and elite skeletons were housed in Aarhus, Denmark under the control of the Øm Kloster Museum. They are now housed at the Anthropological Data Base at Odense University (ADBOU) at the University of Southern Denmark in Odense, Denmark

The last sample discussed here is from the large and bustling trade city of Ribe. Ribe is the oldest city in Denmark and was among the largest cities in medieval Denmark. It had both a castle and cathedral (Clarke and Ambrosiani, 1995). The

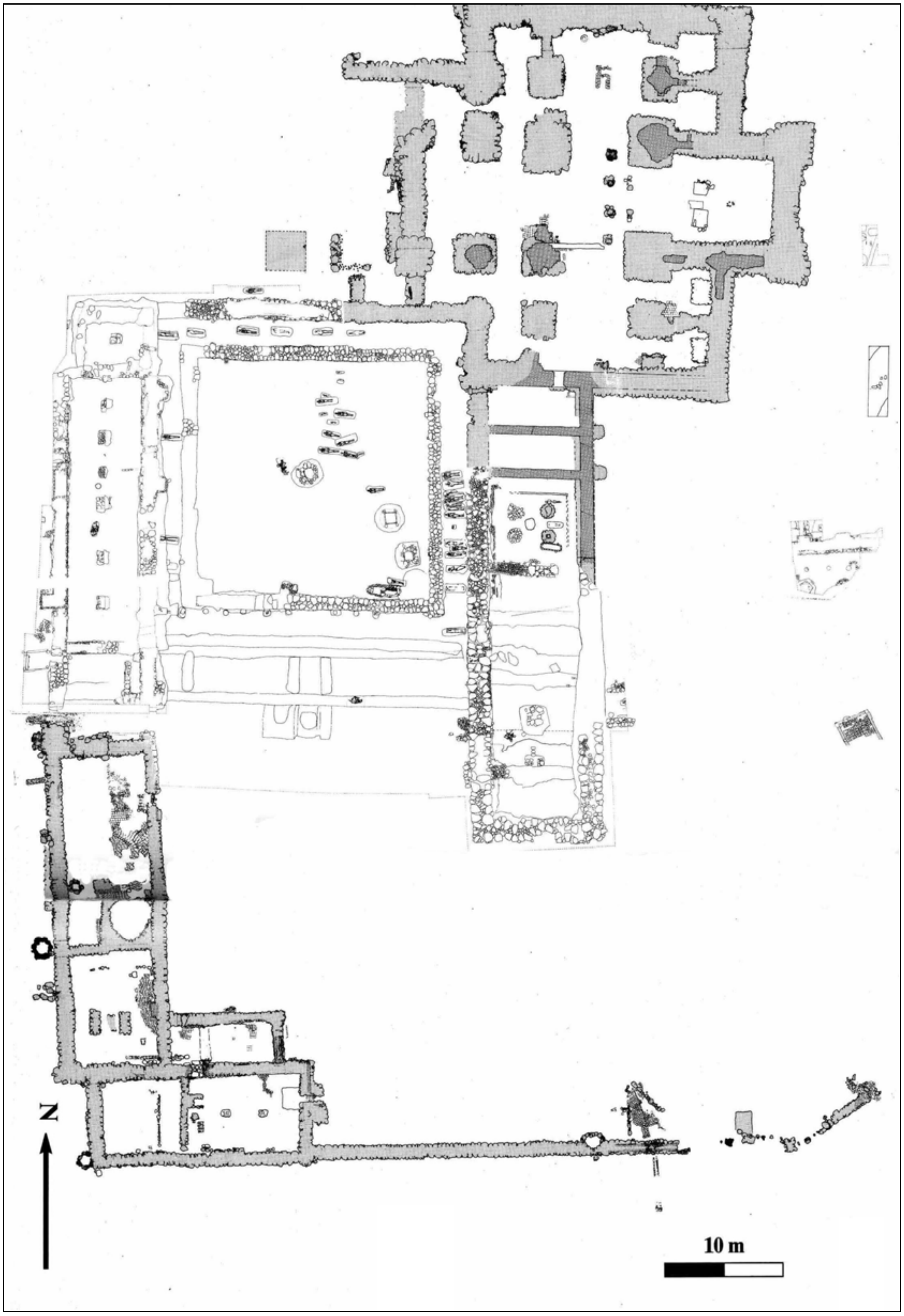

FIGURE 4.5. Drawing of the Øm Kloster monastery excavation (After Gram, 2003)

placement of the cemetery in relation to the Cathedral is illustrated in Figure 4.6. Ribe was founded in 705 A.D. (Sawyer and Sawyer, 1993; Sawyer, 1986) and by the mid 13th century had a population of around 4,000 individuals (Jacobsen, 1986; Sawyer and Sawyer, 1993). Since its foundation, Ribe has been a well planned, well organized merchant city. Its location on the Wadden Sea made it a natural point of contact with not only Western Europe but also Norway and the Black Sea (Andersson, 2003; Clarke and Ambrosiani, 1995; Vahtola, 2003).

The cemetery from Ribe analyzed in this dissertation is dated from 1250 A.D. until the early part of the 15th century and cannot be associated with any particular church. The excavation plan of this cemetery is provided in Figure 4.7 (Jantzen et al., 1994). The individuals interred at this site are town-people, many of whom may have been born in the countryside but left the countryside to earn a living in the city (Jantzen et al., 1994; Jantzen et al., 1995). This cemetery was excavated in 1993 by Dr. Jakob Kieffer-Olsen from the Ribe Museum as part of a salvage excavation project to make room for new growth in the city. Unfortunately, not a lot is known about this cemetery. The skeletal material from this cemetery is housed at the Anthropological Data Base at Odense University (ADBOU) at the University of Southern Denmark in Odense, Denmark.

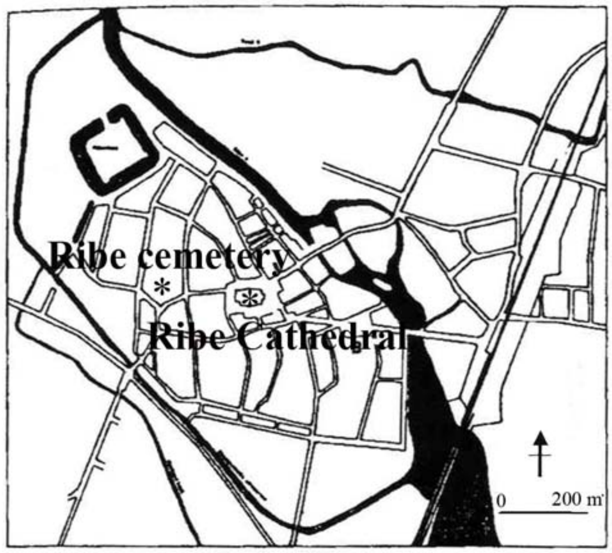

FIGURE 4.6. Placement of the Ribe cemetery in relation to the Ribe Cathedral (After Jantzen et al 1994)

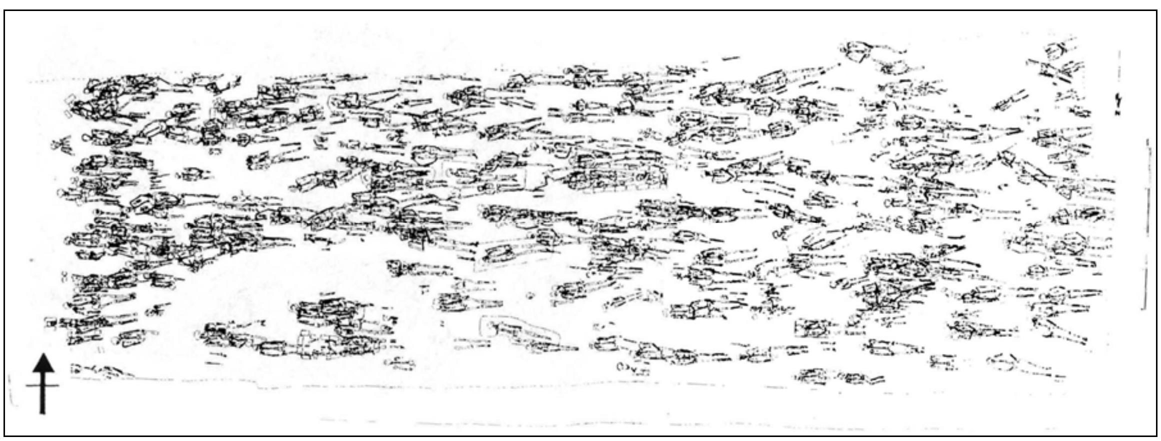

FIGURE 4.7. Excavation plan of the Ribe Cemetery (After Jantzen et al. 1994)

THE OSTEOLOGICAL PARADOX

One of the major questions in this dissertation concerns the health status of the medieval population. However, the interpretation of skeletal lesions in archaeological samples is not always straightforward, as individuals with many lesions were not necessarily less healthy than those with no lesions. This conundrum is known as the osteological paradox (Wood et al., 1992). This paradox involves three issues: demographic nonstationarity, selective mortality, and hidden heterogeneity in risk. Stated briefly, "demographic nonstationarity" recognizes that in populations that are not stationary, and changing populations never are, variations in fertility and not mortality have large effects on the age-at-death distribution. Thus, changes in the mean age-at-death speak more to changes in fertility than changes in mortality (Sattenspiel and Harpending, 1983). "Selective mortality" refers to the fact that physical anthropologists do not have a sample of all of the people who were at risk of death at a given age in the population; they only have those who in fact died at that age. Therefore, our sample may be biased and overestimate the true prevalence of the lesion in the general population. "Hidden heterogeneity in risk" refers to the fact the population from which our skeletal sample is drawn was made up of individuals who varied in terms of their frailty, that is their susceptibility to disease and death. This makes it very difficult to interpret aggregate levels of age-specific mortality rates in terms of the individual's risk of death (Wood et al., 1992).

All of these factors taken together mean that a cemetery sample with a low average age-at-death many not have been drawn from a population that was less healthy than a sample having a higher average age-at-death. This is because the first population may simply have been growing, and thus have had more young individuals than the second population. In addition to this, a population of individuals with few skeletal lesions may not be any healthier than a sample with many lesions; they may simply have died before the lesion could manifest osteologically (Wood et al., 1992). This is due to the fact that infectious disease affects individuals in one of four ways: individuals may be infected and quickly die, they may be infected but recover before a chronic illness develops and thus not form any bony lesions, they may be infected but survive with a chronic condition, or they may never get sick. The difficulty lies in the fact that the paleopathologists can only detect chronic illnesses that result in bone change. Therefore, an individual with a lesion free skeleton may: 1) have never been ill, 2) have developed an illness but was healthy enough successfully to fight the illness without lesion production, or 3) have developed the illness and died. All three of these conditions may produce identical skeletons.

This paradox has sparked a great deal of debate and reconsideration of interpretive methods among bioarchaeologists and paleopathologists (Cohen, 1994; Goodman, 1993; Wright and Yoder, 2002). In particular, physical anthropologists have begun to look at some of the dimensions that give rise to differential frailty among and between populations, such as, social differentials in diet and their possible relation to lesion abundance and frailty (Goodman, 1998; Storey, 1997). For example, one study of the burials from a medieval monastery in England examined the relationship among mortality, status and gender between upper and lower class individuals (Sullivan, 2004). Sullivan compared the age-at-death distribution of samples of different social statuses and found that low status females had the shortest lifespan, whereas moderate-status females had a mortality profile that was very similar to the monastic male sample, and therefore enjoyed a longer life than any lay sample. Researchers also use multiple indicators of health to aid in the interpretation of paradoxical findings. Differences in the patterning of health indicators can aid in the identification of paradoxical findings, and help to ensure a proper interpretation of the health data. Finally, one very important study examined selective mortality in the early medieval Danish site of Tirup using demographic modeling techniques (Usher, 2000). Usher examined the effects of a number of different skeletal pathologies on an individual's risk of death in order to identify conditions that were related to death and those that had no apparent relationship to an individual's risk of dying. All of this research builds a strong foundation for more comprehensive analyses of health throughout the medieval period.

The recent bioarchaeological research on the osteological paradox has brought to light several ways of interpreting health from skeletal populations that I use in this dissertation. I use multiple indicators of health to simplify complex interpretations of health status and change. Because of the synergistic relationship between diet and health, I also analyze these health interpretations in light of the dietary information provided by the stable isotopic analysis. In order to limit my sample heterogeneity, I examine health and dietary differences by social class, urban or rural location, and chronologically. Finally, I use the wealth of information provided by historical sources to aid in my interpretation of health changes through time.

RESEARCH QUESTIONS AND HYPOTHESES

This research seeks to evaluate the effects, if any, of climate change and the Black Death on the population of Denmark. What effects did the agricultural crisis and population loss have on the diet and health of the medieval population of Denmark? How did diet and health differ among different segments of the population, both before and after the onset of these crises? Are there differences in health or diet of the medieval Danish population: 1) between the sexes, 2) through time, 3) among the three sites or 4) among the social classes? The null hypothesis for this analysis is that there is no difference in health or dietary indicators in these four groups. However, based on the historical and bioarchaeological information presented in Chapters II and III, I expect to reject the null hypothesis. I expect that there are significant differences in the health and dietary indicators between the sexes, through time, among sites and among social classes.

As discussed in Chapter II, the historical literature suggests that males and females had very comparable activities. These similarities between the sexes suggests that men and women in medieval Denmark were exposed to the same level of infectious agents and therefore it is not likely that there will be significant differences in the proportion of male and female skeletons with periosteal reactions. Although women in medieval Denmark enjoyed greater independence and equality in comparison with other European women, they were still not considered to be equal to men. Therefore, women may not have had equal access to the same resources as males. It is expected that if there are differences between the sexes in the abundance of porotic hyperostosis and cribra orbitalia, the bony indicators of childhood anemia, that females will have a higher abundance of both of these indicators. The generally good treatment of women in medieval Danish society suggests that there will be little difference in diet between the sexes. However, if there is a disparity in diet it is likely that females had a more cereal grain reliant diet than males, and therefore, would have had a higher abundance of dental caries and that males, both peasant and elite, would have more enriched $\delta^{15}N$ and $\delta^{13}C$ ratios, indicating a diet containing more terrestrial and marine animal diet. Due to the general degree of sexual dimorphism in the human species, male femurs are of course expected to be significantly longer than female femurs.

The historical documentation suggests that the marked population growth and expansion into increasingly marginal soils resulted in increasingly difficult conditions for the peasant population at the start of the 14^{th} century. The population reduction and poorer climate due to the Black Death and Late Medieval Agrarian crisis may have resulted in a general improvement in the living conditions of peasants and a change to a more pastorally based diet after the mid 14^{th} century. Thus it can be predicted that the health status of peasants improved through time and their diet became increasingly centered on animal protein through time. Specifically, it is expected that individuals who lived before the start of the Late Medieval Agrarian Crisis and Black Death had a higher proportion of periosteal reactions and shorter average femur lengths than those from the late period. As the historical literature suggests, the reduction in population and concomitant surplus in land resulted in a change in diet from a more cereal-grain based one to a more pastorally based one. Thus, it is likely that individuals who lived in the middle and late period will have a lower abundance of cribra orbitalia, porotic hyperostosis, and dental caries than those who lived in the early period. In addition, it is expected that early period skeletons will be more depleted in ^{15}N and ^{13}C, and have a larger spacing between the $\delta^{13}C$ ratios from their apatite and collagen, than middle and late period skeletons.

As discussed above, there are differences in the social composition of each cemetery sample used in the analysis. The peasant individuals interred at Øm Kloster were rural workers from the countryside surrounding the monastery. Those interred at St.

Mikkel were likely to be poor peasants from the city of Viborg, and perhaps some residents of the nearby hospital, whereas the sample from Ribe is composed of townspeople from one of the largest trade cities in Denmark. Therefore, it is likely that there are significant regional differences in health and diet. In particular, it is expected that the skeletal sample from the St. Mikkel cemetery will demonstrate the shortest stature, the highest proportion of periosteal reactions and bony indicators of anemia of the three cemeteries studied here because it was composed of poorer peasants and perhaps hospital residents. In addition, for much of the period, the cemetery was located outside the Viborg town walls, and therefore, those interred in it may not have had access to the same resources as the inhabitants of the city itself.

Despite the fact that the city of Ribe was one of the largest trade cities in Denmark, and crowded city environments typically have higher rates of infectious disease than rural areas, it is still expected that the samples from this cemetery would have a lower proportion of individuals with skeletal pathologies and taller average femur lengths than those at St. Mikkel. The reason for this expectation is two-fold. First, although the city of Ribe was large by medieval Danish standards, it only had about 4,000 inhabitants in 1300 A.D. and so was not all that crowded (Sawyer and Sawyer, 1993). Second, the individuals interred in this cemetery were townspeople only and therefore were wage earners and craftsman, not agricultural peasants; unlike St. Mikkel, there was no known component of this cemetery that was used by a hospital, and those buried there likely had access to greater resources as city dwellers than individuals from the St Mikkel parish that was located outside the Viborg city wall.

It is expected that the samples from the rural monastery site of Øm Kloster had a similar proportion of individuals with skeletal pathologies and average femur lengths as the sample from Ribe in the early and middle periods. This is because the lay interments at Øm Kloster were from rural peasants who lived in communities with a lower population density, and were tied to the land and thus could produce their own food. As discussed above, however, there was a hospital located on the grounds of the Øm monastery in the late period. If this hospital were as widely used by the rural lay population as historians suggest, it is expected that the late period sample will have similarly high proportion of skeletal lesions as that of St. Mikkel.

In addition, it is expected that the sample from St. Mikkel and the peasant sample from Øm Kloster had the more cereal grain dependent diet, because they would have had less access to the variety of food resources found in the trade city of Ribe. It is expected that the skeletons from these two sites would have a higher proportion of cribra orbitalia, porotic hyperostosis, and dental caries, and more depleted $\delta^{15}N$ and $\delta^{13}C$ ratios, as well as larger $\delta^{13}C_{coll\text{-}ap}$ spacing than skeletons from the site of Ribe. As a large trade city, the inhabitants of Ribe may have had easier access to meat products. Ribe was also located on the water and thus its inhabitants may also have had better access to marine resources than those from Viborg which was 13 miles from the nearest port. The site of Øm Kloster is located near two lakes, and therefore, the lay population may have used this resource. However, freshwater resources in medieval England were often restricted from use by peasants, and so these fish may have been off limits to the rural lay population (Dyer, 1989).

Finally, due to the historical documentation of heterogeneity in diet and health among the social classes discussed in Chapters II and III, it is expected that there will be significant differences in the diet and health among the peasants, elites and monk at the rural site of Øm Kloster. Peasant skeletons are likely to have a higher proportion of periosteal reactions, the bony signs of anemia, and shorter femurs than elite or monks skeletons. It is also expected that monks and peasants had a more cereal grain based diet than elites in the early period. However, after the loosening of monastic dietary restrictions in the late period it is likely that the diet of monks became more meat focused and thus more closely resembled that of the elites. As discussed in Chapter III, the historical documents suggest that due to the fasting rules, fish made up a large portion of the diet of all three social classes throughout the medieval period. Therefore, elite skeletons are expected to be more enriched in ^{15}N and ^{13}C and that they will show a lower abundance of caries than peasant or monk skeletons in the early period. In the late period, it is likely that peasant skeletons were more depleted in ^{15}N and ^{13}C and had a higher abundance of caries than either elites or monks and thus had a more terrestrial plant based diet.

DATING TECHNIQUE

Research on cemeteries with documented spans of use has demonstrated that the position of the skeleton's arms changed systematically through the medieval period (Kieffer-Olsen, 1993). The arm positions used to date the skeletons are illustrated in Figure 4.8. The changes in arm position have been argued to be nearly instantaneous, perhaps within a generation (Boldsen, 2005b). Thus, arm position is recognized as a

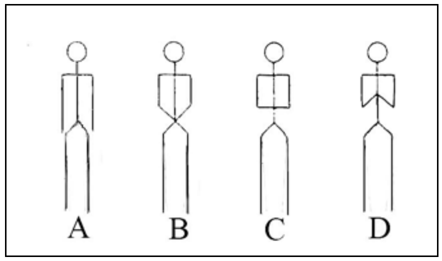

FIGURE 4.8. Arm position placement used for dating of skeletons (After Jantzen et al. 1994)

reliable dating method for the medieval period in Denmark and is used in this analysis (Becher, 2000; Boldsen, 1991; Boldsen and Mollerup, 2006). Using arm position as a means to date skeletons, I have divided the samples into chronological groups as follows. Individuals living prior to 1300 A.D. were buried with arm position A and constitute the pre-plague, pre-agrarian crisis sample. In this dissertation, this group will be referred to as the “early period”. Individuals living between 1300 and 1375 A.D. were buried with arm position B, and represent individuals who lived during the crises. This sample is referred to as the “middle period”. Finally, and individuals who lived between1375 A.D. and the close of the period were buried in arm positions C and D and characterize the post-plague, agrarian crisis sample, and will hence be referred to as the “late period”.

SAMPLE DEMOGRAPHY

I analyzed 332 individuals for pathological conditions and 197 individuals for dietary analysis (see Chapter V for more information of dietary sample distribution). The total sample distribution is shown in Table 4.1. I assessed the sex of each skeleton based on the morphology of the pelvic bones and cranium using standard techniques (Buikstra and Ubelaker, 1994). Skeletons that I was unable to assign definitively to a particular sex are only considered in comparisons for which the sexes are pooled. I assessed age-at-death using the Transition Analysis technique developed by Boldsen and colleagues (Boldsen et al., 2002). I was trained in this technique by Boldsen during the summer of 2000 (Yoder and Boldsen, 2001). All of the individuals in the sample are adults.

Table 4.2 compares the average age-at-death between different sub-sets of the total sample. There are no significant differences in mean age-at-death between individuals of different sexes or time periods. However, there are significant differences remains for males but not for the female sample. When the male sample is further divided by time period, the only significant difference in mean age-at-death is in the middle period sample. In all of these significant comparisons, the sample from Ribe has

TABLE 4.1. Peasant and elite sample distribution for the analysis of skeletal pathologies by sex, site and time period

Time Period and Sample	*Early*	*Middle*	*Late*	*Total*
Peasants				
Øm Kloster				
Males	29	18	19	66
Females	17	6	14	37
St. Mikkel				
Males	13	19	4	36
Females	15	16	5	36
Ribe				
Males	27	13	10	50
Females	15	11	9	35
Total				
Males	69	50	33	152
Females	47	33	28	108
Elites and Monks				
Male elites	5	6	10	21
Female elites	2	4	6	12
Monks	7	7	2	16

a significantly older mean average age-at-death than the sites when the sexes are pooled. When this sample is further divided by sex, the significant difference in mean age-at-death among the sites remains for the male sample in the middle period. However, as indicated in Table 4.3, there are no significant differences in the mean age-at-death of individuals with or without cribra orbitalia, porotic hyperostosis, a periosteal reaction or a caries in either the male sample from Ribe or the middle period male sample from Ribe. Therefore, the significant difference in the age-at-death between samples likely does not

TABLE 4.2. Comparison of average age-at-death in different sub-samples of the total sample

Comparison	*Mean Age*	*N*	χ^2	*p**
Sex	Males= 34.26	162	0.022	0.881
	Females= 35.16	104		
Time Period	Early= 35.41	118	2.278	0.320
	Middle= 33.01	87		
	Late= 34.89	69		
Site	Øm Kloster= 33.61	130	10.230	**0.006**
	St. Mikkel= 32.76	169		
	Ribe= 37.57	76		
Males	Øm Kloster= 33.31	81	7.597	**0.022**
	St. Mikkel = 32.71	36		
	Ribe = 37.17	45		
Females	Øm Kloster = 35.16	43	2.142	0.343
	St. Mikkel = 32.78	39		
	Ribe = 37.96	28		
Early period males	Øm Kloster = 35.93	29	1.317	0.518
	St. Mikkel = 30.53	13		
	Ribe = 35.58	24		
Middle period males	Øm Kloster = 27.44	25	12.941	**0.002**
	St. Mikkel = 33.94	19		
	Ribe = 41.45	11		
Late period males	Øm Kloster = 35.94	27	0.305	0.858
	St. Mikkel = 34.25	4		
	Ribe = 36.30	10		

*Kruskall-Wallis p-values in **bold** are significant at $\alpha = 0.05$

TABLE 4.3. Kruskall-Wallis H tests comparing mean age-at-death of individuals with and without the skeletal lesions in the male sample from Ribe

Sample and lesion type	With lesion Mean	N	Without lesion Mean	N	X^2	p*
Cribra orbitalia						
Ribe males	39.0	3	35.9	24	0.861	0.351
Middle period Ribe males	None	7	37.0	7		
Porotic Hyperostosis						
Ribe males	36.5	2	35.82	29	0.079	0.778
Middle period Ribe males	None	7	39.1	7		
With a periosteal lesion						
Ribe males	36.0	20	37.0	23	0.018	0.893
Middle period Ribe males	39.8	6	35.2	4	1.636	0.201
With a caries						
Ribe males	35.6	16	36.7	19	0.661	0.416
Middle period Ribe males	36.5	2	40.2	5	0.600	0.439

*Kruskall-Wallis p-values in **bold** are significant at $\alpha = 0.05$

hamper the analysis of lesion patterning among sites. There is no historical indication of differences in the diet by age in adults, and thus, the difference in mean age-at-death in the sub- samples analyzed in this dissertation are also unlikely to affect the interpretation of medieval Danish diet.

CONCLUSIONS

The sites chosen for analysis are well suited to help answer the research questions proposed in this chapter. They represent a wide section of the medieval population of Jutland in Denmark and will aid in the examination of diet and health differences in this population between the sexes, through time, among different sites and among social classes. The variety of health and dietary indicators employed in this analysis will aid in understanding the health of the skeletal sample and allow me to determine whether traditional or paradoxical interpretations of these health patterns are warranted. Finally, although there are differences in the mean age-at-death among the skeletal samples, these differences will likely not hamper health and dietary interpretations drawn from these samples, as there are no significant differences in the mean age-at-death and the presence of any health indicator studied here.

CHAPTER V

STABLE ISOTOPIC RECONSTRUCTIONS OF MEDIEVAL DANISH DIET

Historical and zooarchaeological sources provide a foundation for thestudy of diet in past populations. However, they provide only indirect evidence about diet (Dyer 1994). They can tell us what the medieval menu was, but not what was actually consumed, in what proportions, and by whom. A more complete understanding of the medieval Danish diet can be gained through the use of stable isotopic analysis of human skeletal remains. This chapter presents and discusses the results of the isotopic analysis of the diet of the individuals interred at the three cemetery sites studied in this dissertation.

The reconstruction of diet from stable isotopes rests on the premise that the isotopic composition of carbon and nitrogen in an animal's tissue is directly related to its diet. Isotopes of an element share the same number of protons but differ in the number of neutrons in the atom's nucleus. The difference in the number of neutrons changes the weight of the atom. Isotopes of an element are designated by the number of protons and neutrons in their nucleus (^{14}C, ^{13}C, ^{12}C for carbon, and ^{15}N, ^{14}N for nitrogen). While some isotopes of an element are unstable or radioactive, e.g. ^{14}C, others are stable and therefore their composition does not alter with time. Isotopes of an element react virtually the same in chemical reactions except that the heavier isotope moves more slowly (Ambrose 1993). This results in fractionation, or the discrimination against the heavier isotope in favor of the lighter one, in many natural chemical reactions. The fractionation of isotopes makes them useful tools for anthropological reconstructions of population movements and past diets. The isotopic ratios of nitrogen and oxygen are routinely used in the analysis of breastfeeding and weaning in prehistory (Dupras et al., 2001; Fuller et al., 2003; Fuller et al., 2001; Herring et al., 1998; Katzenberg et al., 1996; Schurr, 1997). As employed in this study, the isotopic ratios of carbon and nitrogen are useful for paleodietary reconstructions (Ambrose, 1986; Ambrose, 1991; Ambrose, 1995; Cox et al., 2001; DeNiro and Epstein, 1978b; DeNiro and Epstein, 1981; Harrison and Katzenberg, 2003; Katzenberg and Schwarcz, 1984; Schoeninger and Deniro, 1984; Schoeninger et al., 1983a; Schoeninger et al., 1983b; Sullivan and Krueger, 1983; Walker and Deniro, 1986). The fractionated isotopic signatures of plant and animal foods are passed on to the consumer, allowing researchers to determine the relative dependence on certain groups of food in the diet (Ambrose 1993, Klepinger 1984, Schwarcz and Schoeninger 1991, Katzenberg 2000, Ambrose and Krigbaum 2003, Schoeninger and Deniro 1984).

The comparison of the ratio of the two isotopes of an element to a standard is called the δ value. The δ is expressed in units permil (‰) and is calculated by:

$$\delta = ((R_{sample}/R_{standard})-1) \times 1000$$

where R is the ratio of the heavier isotope to the light isotope, e.g. $^{15}N/^{14}N$. The elements to be used in this analysis are carbon and nitrogen. The standard for carbon is PeeDee Belemnite (PDB), a formation of *Belemnitella americana,* a marine fossil limestone from South Carolina. Nitrogen samples are measured relative to atmospheric N_2 (AIR) (Ambrose, 1993). Isotopic ratios that contain fewer of the heavy isotope are considered to be depleted in that isotope or “lighter.” Isotopic ratios that are composed of proportionally more of the heavy isotope are said to be “heavy” or “enriched” in that isotope. The $\delta^{13}C$ ratios of most substances are more depleted in the heavier isotope of carbon than is the standard PDB and, therefore, are negative values. The $\delta^{15}N$ ratios of most substances are enriched in the heavier isotope of nitrogen and are higher values than the standard.

The earliest archaeological applications of stable isotopic analysis for the study of prehistoric diets took place in the Americas (van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). These early researchers were interested in studying the appearance of and dependence on maize in Eastern Woodland populations of North America. Stable isotopic analysis readily lends itself to these types of studies as it fairly easily distinguishes between C3 (Calvin-Benson) plants like cereal grains, beans, and most vegetables grasses, and C4 (Hatch-Slack) plants such as maize, amaranth and millet. This is because C4 plants discriminate less against the isotopically heavier ^{13}C isotope than do C3 plants, and therefore, C4 plants have higher $\delta^{13}C$ values than C3 plants (Larsen, 1997). As maize was a very important food source for most of the Americas, a number of early researchers of paleodiet in the Americas began using stable isotope analysis to track the spread of maize agriculture (Buikstra and Milner, 1991; Hutchinson et al., 1998; Katzenberg and Krouse, 1988; Katzenberg et al., 1993; Katzenberg et al., 1995; Schurr, 1992; Schurr and Schoeninger, 1995; Schwarcz, 1991; Schwarcz et al., 1985; White et al., 2001; Wright and White, 1996). Among other things, they have been interested in the introduction of maize (Buikstra et al., 1988; Ezzo, 1993), degree of maize consumption, and social status (Ambrose et al., 2003; Buikstra and Milner, 1991; Schurr and Schoeninger, 1995). Successful research on prehistoric diet using stable isotopic analysis has been carried out in North America with populations in Ontario

(Harrison and Katzenberg, 2003; Katzenberg, 1989; Katzenberg et al., 1995; Schwarcz et al., 1985), the Midwestern United States (Lambert et al., 1979; Lambert et al., 1982; Little and Schoeninger, 1995; Schurr, 1992; van der Merwe and Vogel, 1978), the southeast coast of the U.S. (Larsen et al., 1992), the Maya in Central America (White, 1997; Whittington and Reed, 1997; Wright, 1997; Wright and White, 1996), and South America (Tomczak, 2003).

However, comparably less research has been done on diet in European populations because there were no C4 cultigens in Europe (Tauber 1981, van Klinken 2000). The majority of the work in Europe has investigated Mesolithic and Neolithic diet (Day, 1996; Drucker and Bocherens, 2004; Durrwachter et al., 2005; Papathanasiou, 2003; Richards et al., 2003; Richards and Hedges, 1999; Richards et al., 2005b). European medieval period remains have only recently been analyzed (Richards et al. 2002, Fuller et al. 2001, Mays 1997, Polet and Katzenberg 2003, Herrscher et al. 2001) and very little research has been conducted using Scandinavian samples (Becher, 2000).

Stable isotopic analyses of human bone collagen from monastic samples in England and Belgium suggest that while the medieval diet there relied heavily on terrestrial foods, marine resources were an important protein source (Mays 1997, Polet and Katzenberg 2003). In England, monastic skeletons have a mean collagen ratio of $\delta^{13}C$ of -18.3‰ while lay individuals from the same cemetery have mean collagen ratios of $\delta^{13}C$ of -19.5‰, indicating that monastic diets were somewhat enriched in marine foods over lay diets (Mays 1997). One recent study described an increase in the consumption of animal protein between the 14th and 15th centuries in Grenoble, France, which they attributed to increased urbanization (Herrscher et al. 2001). Muldner and

Richards (2005) have examined stable isotope ratios in skeletons from several medieval English sites and found a mixed diet of terrestrial, freshwater and marine resources. They suggest that the freshwater and marine signal is the result of the medieval fasting rules, which prohibited the eating of terrestrial animal meat on Fridays, Saturdays, some Wednesdays, on the eve of important holidays and everyday during the forty days of lent. Significant marine signals have been found in medieval skeletons from Newark Bay in Orkney (Richards et al., 2005a). The study of the Newark Bay sample also noted that males ate significantly more marine protein than females. Bonsall and colleagues have found a shift in diet to isotopically heavier carbon from the Mesolithic to the Roman and medieval periods in the Danube river valley in southeast Europe (Bonsall et al., 2004). They attribute this shift to the introduction of the C4 plant millet.

Only one isotopic study has focused on adult diet in medieval Denmark. Becher (2000) utilized trace elements and carbon stable isotopes in an analysis of medieval diet and weaning. She measured trace elements in the rural cemetery of Tirup and stable isotopes of carbon at the rural cemetery of Nordby. Both cemeteries are located on the Jutland peninsula and neither was in use after 1250 A.D. Although marine resources made up a portion of the medieval diet, she found that they were not as important as would be expected if the medieval fasting rules had been followed strictly. She also noted that marine resources composed a smaller percentage of diet in women than in men. Unfortunately her research was inconclusive because of diagenetic factors and the small sample size used for stable isotope analyses (4 people). Recently, researchers have also begun addressing childhood diet in medieval Denmark (Rabb, personal communication 2004). Although these studies provide a strong foundation for future research and contribute to a better global understanding of diet and nutrition, its significance has been hampered by small sample sizes and by their sole use of bone collagen, which reflects the protein portion of diet, not the entire diet, as does bone apatite.

As there are no indigenous C4 or CAM plants in the cool climate of northern Europe (Tauber 1981, Schwarcz and Schoeninger 1991), carbon isotopes can be used to distinguish between the relative amounts of terrestrial versus marine resources (Schoeninger et al.1983a, Schoeninger and DeNiro 1984). Marine foods can be distinguished from terrestrial foods because there is about a 7‰ difference between the $\delta^{13}C$ of seawater bicarbonate and atmospheric CO_2 (Chisholm et al., 1982; Dufour et al., 1999; Tauber, 1981). Therefore, marine mammals and fishes have $\delta^{13}C$ values that are higher than animals feeding on C3 foods (by about 6‰) and lower than animals feeding on C4 foods (by about 7‰) (Larsen, 1997; Richards and Hedges, 1999; Schoeninger and Deniro, 1984). A purely marine diet should have collagen with $\delta^{13}C$ of -13‰ and a purely terrestrial, C3 diet would yield collagen with a $\delta^{13}C$ of -20‰ (Richards and Hedges 1999). Thus, $\delta^{13}C$ values can be very informative about the relative dependence on marine foods in areas with no C4 plants. Recent research has also been conducted examining the role of freshwater food resources on diet. There is greater variability in the $\delta^{13}C$ ratios of freshwater fish due to the greater variation in their carbon sources (detritous of terrestrial origin, dissolved CO_2, and dissolved carbonic acid). This variability in the $\delta^{13}C$ ratios is found not only in different species of fish, but also in the same species of fish found in different lakes, or different parts of the same large lake (Dufour et al., 1999; France, 1995; Katzenberg and Weber, 1999).

Nitrogen isotopes can be useful in determining the trophic level of the foods consumed as there is a step-wise enrichment of 3-4‰ in $\delta^{15}N$ values between trophic levels in the food-web (DeNiro and Epstein, 1978b). This is not only true in terrestrial food chains, where carnivorous animals are more enriched in the heavier nitrogen isotope than herbivorous animals, but also in marine settings due to the greater number of trophic levels in marine than terrestrial ecosystems (Schoeninger et al. 1983a, Schoeninger et al. 1983b). The $\delta^{15}N$ value of terrestrial plants is generally 4‰ lower than it is for marine plants, so marine animals have higher $\delta^{15}N$ values than terrestrial ones. Therefore, nitrogen isotopes are used to determine the relative contribution of animal versus plant resources and the contribution of terrestrial and marine food sources to the diet.

Stable carbon isotopic reconstructions of human diet can be based on either the organic or inorganic portion of bone. Bone collagen is the organic part of bone and, as discussed above, has been used in dietary reconstructions since the inception of the field (DeNiro and Epstein, 1978b; van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). As collagen is a protein, it preserves the isotopic ratios of both nitrogen and carbon. However, the carbon in bone collagen is derived disproportionally from the amino acids consumed, and thus primarily reflects the protein portion of the diet and not the whole diet, which is also composed of carbohydrates, lipids, etc. (Ambrose and Norr, 1993; Sullivan and Krueger, 1981). This has resulted in overemphasizing the importance of protein food sources and minimizing the role of plant resources in the diet (Harrison and Katzenberg, 2003; Katzenberg et al., 1995; Schwarcz et al., 1985). In recent years, the use of bone apatite has become increasingly common in bioarchaeological analyses of ancient diets. The carbon in bone carbonate is derived from dissolved bicarbonate in the blood which is derived from the entire diet not just the protein portion of the diet. However, bone apatite does not contain nitrogen and thus does not record the $\delta^{15}N$ ratio.

Bone apatite has only recently been used in dietary reconstructions. This is because it is more susceptible to diagenetic change than bone collagen. However, recent research has improved both apatite preparation techniques to remove exogenous carbonates(Garvie-Lok et al., 2004; Krueger, 1991; Wright and Schwarcz, 1996), and post-preparation examination of the samples for diagenesis. Fourier transform infrared spectroscopy (FTIR) can be used to analyze bone apatite samples for crystallinity and carbonate content as a means of monitoring the degree of diagenetic alteration. Wright and Schwarcz (1996) used FTIR to quantify the effect of diagenesis on bone apatite with great success. They compared the height of different peaks in the spectra to look at the degree of crystallinity and the carbonate content in the sample. The crystallinity index (CI) measures the extent of post-burial growth in crystal size. The ratio of the height of the peaks associated with CO_3 and PO_4, referred to as C/P, provides a measure of the remaining carbonate content in the bone. They determined that a high CI indicates a high degree of crystal size growth or dissolution of the more soluble crystals and that lower C/P ratios indicate lower carbonate content (Wright and Schwarcz, 1996). Modern human bone has a CI of ~2.90, and values approaching 4.25 indicate that the sample has been diagenetically altered due to a high degree of recrystallization. Low C/P ratios may suggest excessive loss of carbonate. Modern bone values reported in the literature generally lie between 0.23 and 0.26 for C/P ratio (Garvie-Lok *et al.* 2004; Wright and Schwarcz 1996), and values approaching 0.15 suggest that diagenetic alteration may have occurred. These refinements and new techniques have increased researcher confidence in dietary reconstructions based on bone apatite-carbonate (Prowse et al., 2004).

Due to the different compositions of bone collagen and apatite, the spacing between the $\delta^{13}C$ values in bone collagen ($\delta^{13}C_{col}$) and apatite ($\delta^{13}C_{ap}$) is another indicator of dietary composition. The difference between the $\delta^{13}C$ value of the diet and apatite is almost always 9.4‰, regardless of whether $\delta^{13}C$ values of dietary protein and energy are the same. It has been traditionally understood that the spacing between the $\delta^{13}C$ value of the diet and bone collagen is 5‰. However, recent controlled feeding experiments of animals show that this is only true if the $\delta^{13}C$ values of the dietary protein and energy are the same (Ambrose and Norr, 1993). If the values are different, then the spacing between $\delta^{13}C$ values of collagen and the diet will be greater or smaller. This spacing between the $\delta^{13}C$ values of bone apatite and bone collagen ($\delta^{13}C_{col-ap}$ spacing) can thus reveal important information about the kinds of protein in the diet. Small differences (less than 4.4‰) indicate that the protein portion of the diet is more enriched in ^{13}C than the diet as a whole, suggesting that the protein was from a marine or freshwater source. Large differences (greater than 4.4‰) indicate that the protein source was lighter than the whole diet, such as protein from terrestrial animals (Ambrose et al., 2003; Harrison and Katzenberg, 2003). Thus, the comparison of the $\delta^{13}C$ of carbonate and collagen provides information on the $\delta^{13}C$ of the protein and non-protein portions of the diet (Ambrose and Krigbaum, 2003; Ambrose and Norr, 1993; Harrison and Katzenberg, 2003; Tieszen and Fagre, 1993).

METHODS AND HYPOTHESES

As elaborated in Chapter IV, I am testing several historically derived hypotheses about health and dietary conditions in medieval Denmark. I make four main comparisons in this dissertation. I compare:

1) male and female skeletons

2) the skeletal sample through time

3) the skeletal sample by site

4) the skeletal sample from Øm Kloster by social class.

With reference to the stable isotopic comparison of diet, the null hypothesis is that there are no differences in $\delta^{15}N$, $\delta^{13}C_{coll}$, and $\delta^{13}C_{ap}$ ratios, and $\delta^{13}C_{coll\text{-}ap}$ spacing, among the groups as configured above. Based on historical evidence outlined in Chapters II and III, it is expected that the results will reject the null hypothesis for the comparison of the isotopic ratios of carbon and nitrogen through time, by site and by social class. As discussed in Chapter II, women in medieval Denmark enjoyed greater independence and equality in comparison with other European women, however, they were still not considered to be equal to men. The generally good treatment of women in medieval Danish society suggests that there will little difference in diet between the sexes. However, if there is a disparity in diet it is expected that females had a more cereal grain reliant diet than males and therefore, are more enriched in ^{15}N and ^{13}C , indicating a more terrestrial and marine animal rich diet. Differences in isotopic ratios through time are likely and peasant and monastic skeletons from the early period may be less enriched in ^{15}N, and ^{13}C, and larger $\delta^{13}C_{coll\text{-}ap}$ than later periods, reflecting the more cereal grain dependent diet of the early period as compared to later periods. Significant differences in the $\delta^{15}N$, $\delta^{13}C_{coll}$, and $\delta^{13}C_{ap}$ ratios, and $\delta^{13}C_{coll-ap}$ spacing in the elite sample through time are unlikely as there is no historical evidence for a significant change in elite diet through time. Site-based differences in the isotopic ratios are likely; the skeletal sample from Ribe is expected to be the most enriched in ^{15}N, and ^{13}C and have the smallest $\delta^{13}C_{coll-ap}$ of any site as it is located on the ocean and was a large trade city and thus its inhabitants likely had access to more varied food resources than those at the other sties. Lastly, in the early period the elite sample will likely have a more enriched $\delta^{15}N$, $\delta^{13}C_{coll}$, and $\delta^{13}C_{ap}$ ratios and smaller $\delta^{13}C_{coll-ap}$ than either the peasant or monastic samples from Øm Kloster, as historical evidence suggests that elites had a diet richer in protein from terrestrial and marine animals than peasants or monks. However, after the loosening of monastic dietary restrictions in the late period it is likely that the diet of monks became more meat focused and thus more closely resembled that of the elites. Therefore, in the middle and late periods it is likely that peasants were more depleted in ^{15}N and ^{13}C than either elites or monks and thus had a more terrestrial plant based diet.

I use the non-parametric Kruskal-Wallis H test in all of my stable isotopic ratio comparisons. This test evaluates the differences in two or more groups based on a single variable. As discussed above, I am testing four main hypotheses in this analysis. For each, I examine the data as a whole and then by different subgroups. For example, I compare the isotopic ratios between the sexes in the whole peasant population, through time, by site and through time at each site. Therefore, each hypothesis is in fact a set of four hypotheses. Running multiple independent comparisons increases the risk of obtaining a Type I error, or of falsely rejecting the null hypothesis. To keep the risk of a Type I error equal to 5% (i.e. a 95% confidence level) for four comparisons the alpha must be set at 0.0127 (Motulsky, 1995). Therefore, I only consider *p*-values that are 0.0127 or lower to be statistically significant. I describe *p*-values that are close to the accepted alpha with respect to their relationship to the statistically significant results, but only consider them to be of marginal significance.

Stable isotope methods

I collected long bone samples (primarily tibiae, femora and humeri) from 197 humans and 7 faunal samples. I processed approximately 1 gram of bone for apatite and between 1.5 and 2 grams for collagen. I manually cleaned all bone samples with a file to remove the outer stained cortex and any obvious contaminants. I then ultra-sonically cleaned the samples in double purified water, 95% ethanol, 100% ethanol and acetone for 1 minute. I then dried the samples overnight in a 90º oven.

Collagen

I soaked all bone samples in a 0.25M solution of HCl until only the organic portion of bone remained (until soft). I then rinsed the samples to neutrality with distilled water and then soaked them in a 0.125M solution of NaOH for 24 hours to remove humic contaminants. After 24 hours I again rinsed the samples to neutrality. I then solubilized the resulting collagen pseudomorphs in water with a pH of 3 at 90º for three days. I froze the resulting collagen overnight and then freeze-dried them. Mass spectrometry of the sample was performed on a Carlo Erba EA-1108 interfaced with a ThermoFinnigan Delta Plus isotope ratio mass spectrometer operating in continuous flow mode by Dr. Tom Boutton in the Department of Rangeland Ecology at Texas A&M University.

Apatite

I mechanically ground all bone samples to a fine powder (‹70µm). I then soaked the bone powder in 1.5% solution of sodium hypochlorite for 48 hours (refreshed after 24 hours) to remove the organic material. I rinsed the samples to neutrality and soaked them for 24 hours in a 1.0M solution of acetic acid buffered to a pH of 4.5 with NaOH to remove exogenous carbonates. I refreshed this solution after 12 hours. After soaking in acetic acid, I again rinsed the sample to neutrality and dried them overnight in a 90º oven. Apatite samples were analyzed by Dr. Ethan Grossman in the Department of Geology and Geophysics at Texas A&M University. Apatite samples were reacted with phosphoric acid in a Kiel II carbonate device and $\delta^{13}C$ ratios were measured on a ThermoFinnigan Delta Plus XP isotope ratio mass spectrometer.

EXAMINATION OF SAMPLE DIAGENESIS

In order to examine the collagen samples for signs of diagenetic alteration, C:N ratios and the percent collagen yield were measured for every sample (DeNiro 1985, Schoeninger et al 1989, van Klinken and Hedges, 1995, van Klinken 1999). Appendix A provides the percent yield and C:N ratios of all the collagen samples. The collagen yield is expressed as a weight percentage. The yield from fresh bone is about 22% and the collagen content drops at varying rates after burial. The rate of the decline depends on the burial environment. In temperate environments like Europe, collagen loss is relatively slow in comparison with the rate in warmer areas, like the tropics. For European samples, collagen yields lower than about 1% are likely diagenetically altered and therefore should not be analyzed (van Klinken 1999). Only one sample has a low percent collagen yield (Øm 91). Another commonly used indicator of collagen sample diagenesis is the carbon to nitrogen ratio or C:N ratio. The C:N ratio of modern human and animal bone is between 2.9-3.6 and therefore many researchers exclude samples that fall outside this range for being diagenetically altered (DeNiro 1985). However, van Klinken (1999) argues that this range is too wide to be useful and therefore suggest the narrower range of 3.1-3.5 for acceptable C:N ratios in collagen samples. Five of my samples fall outside of this narrower range (Øm 64, 72, 123, 125 and 126), however, none of my samples fall outside the wider range proposed by DeNiro (1985). The percent collagen yield and C:N ratio are more reliable indicators when examined together and with their corresponding $\delta^{13}C$ ratios. Samples with high C:N ratios and low % collagen yield may have been diagenetically altered. In addition, samples with high C:N ratios and more negative $\delta^{13}C$ ratios may indicate diagenesis. The samples listed above with high C:N ratios do not have corresponding low % collagen yields or more negative $\delta^{13}C$ ratios. In fact, the low % collagen yield of Øm 91 is likely a result of a problem with the lab balance, and not due to sample diagenesis.

To examine the apatite sample for diagenetic alteration, I also prepared 28 apatite samples for FTIR analysis. Bones sampled for FTIR analysis are from all time periods and all sites and therefore are likely representative of the diagenetic condition found in the total sample. Two milligram aliquots of bone apatite powder were ground with 200 milligrams of analytical quality KBr and pressed into a pellet at 10,000 psi. I scanned the pellets 100 times in a Nicolet Magna 500 FTIR analyzer. Spectra were collected from 2000 to 400 cm^{-1} and were baseline corrected. The peak heights at wavenumber 565, 590, 605, 1035 and 1415 cm^{-1} were measured. These peak heights were used in the calculation of the crystallinity index (CI) and carbonate content (C/P). The crystallinity index is derived from the height at (565+605)/590 and the carbonate content from the height of (1415/1035) (Wright and Schwarcz, 1996). Appendix A provides the carbonate content (C/P) and the crystallinity index (CI) of the 28 apatite samples examined by FTIR. As mentioned above, modern bone has a crystallinity index of about 2.90 and a carbonate content of between .23 and .26. Samples with a CI approaching 4.25 and a carbonate content of .15 or lower may be diagenetically altered. Three of my samples have low C/P values (Øm 38, 106 and 138). However, the $\delta^{13}C_{ap}$ ratios of these samples (Øm 38: -13.85‰, Øm 106: -13.44‰, and Øm 138: -15.47‰) are within the range of variation of the total apatite sample (-12.5‰ - -16.49‰), and they have acceptable C:N ratios and collagen yields. No samples have a CI that would suggest diagenesis. Therefore, I accept the entire sample selected for isotopic analysis as not adversely affected by diagenetic change.

STABLE ISOTOPE SAMPLE

The complete sample distribution is shown in Table 5.1. A total of 197 individuals were sampled for stable isotopic analysis. I took skeletal samples from each of the three sites, both sexes, each of the three time periods, and social classes. For the peasant sample, I sampled 55 skeletons for stable isotopic analysis from Øm Kloster, 45 skeletons from St. Mikkel, and 54 skeletal samples from Ribe. Øm Kloster is the only site with an elite or monastic component. Twenty-nine elite skeletons and 14 monk

TABLE 5.1- Sample distribution

Site	Period	Sex			Total
		Male	Female	Unknown	
Øm Kloster - peasants	Early	10	8	2	20
	Middle	9	4	2	15
	Late	12	8	0	20
Øm Kloster - elites	Early	5	2	0	7
	Middle	6	3	0	9
	Late	8	5	0	13
Øm Kloster - monks	Early	5			5
	Middle	7			7
	Late	2			2
St. Mikkel	Early	11	9	0	20
	Middle	7	8	1	16
	Late	4	5	0	9
Ribe	Early	10	9	1	20
	Middle	7	7	1	15
	Late	10	8	1	19
Total sample	Early	41	28	3	72
	Middle	36	22	4	62
	Late	36	26	1	63
	Total	123	76	8	197

skeletons were included for analysis. A total of 123 male skeletons, 76 female skeletons and eight skeletons of indeterminate sex are included in this analysis. Seventy-two skeletal samples were selected from the early period, 62 samples date to the middle period and 63 skeletal samples are from late period skeletons.

RESULTS

Parameters of medieval diet

Table 5.2 summarizes the isotopic ratios of selected fauna that would have been consumed in medieval Denmark. All of the fauna from the current study except the marine fish are medieval archaeological specimens from the excavation of Øm Kloster. The marine fish is a modern specimen obtained in October of 2003 from a fishmonger in

TABLE 5.2. Stable isotope ratios of faunal samples

Sample	*N*	*$\delta^{15}N$*	*$\delta^{13}C_{coll}$*	*$\Delta^{13}C_{ap}$*	*$\delta^{13}C_{coll-ap}$*	*Reference*
Elk	1	3.55	-21.43	-12.010	9.420	Current study
Deer	1	1.99	-21.53	-12.070	9.460	Current study
Pig	1	6.03	-21.28	-13.370	7.910	Current study
Goat	1	7.76	-21.81	-12.310	9.500	Current study
Chicken	1	10.34	-22.22	-14.945	7.275	Current study
Cow	1	6.34	-21.53	-13.720	7.810	Current study
Sheep	9	6.05	-21.66			Müldner and Richards 2005
Bream	1	10.20	-18.60			Müldner and Richards 2005
Eel	6	11.63	-22.21			Müldner and Richards 2005
Herring	3	10.67	-15.23			Müldner and Richards 2005
Pike	2	20.05	-23.95			Müldner and Richards 2005
Haddock	2	12.95	-13.10			Müldner and Richards 2005
Marine fish	1	12.24	-16.99	-2.290	14.700	Current study
Cod	5	14.24	-12.82			Müldner and Richards 2005
Ling	1	17.2	-12.40			Müldner and Richards 2005

Copenhagen. The remaining faunal samples are medieval archaeological specimens from various sites in England published by Müldner and Richards (2005). The nitrogen in the human skeletal samples is enriched 3-4‰ over the food source. Thus a human diet primarily composed of terrestrial animal protein should have δ^{15}N ratios of 5-10‰, whereas a diet primarily composed of marine or freshwater species should have δ^{15}N ratios between 13- 23‰. In areas without C4 plants, a purely marine diet should have collagen with δ^{13}C of -13‰ and a purely terrestrial diet should yield collagen with a δ^{13}C of -20 to -21‰ (Richards and Hedges 1999; Mays 1997). The δ^{13}C ratios from collagen of oats, wheat and barley, three staple grains in the medieval diet are typically between -27- -28‰ (Bender, 1968). The δ^{13}C ratios from modern plants are about 1.5‰ lighter than they were before modern levels of air pollution, thus, the carbon isotopic values from medieval grains was likely about -26‰ (Mays 1997).

Figure 5.1 illustrates the isotopic composition of the comparative faunal sample with the human bone samples from the three medieval Danish sites. All of the fauna except the haddock, herring, bream, cod, ling, and marine fish samples have more depleted $\delta^{13}C_{coll}$ ratios than the human samples. The pike and ling are the only sample with more enriched $\delta^{15}N$ ratios than the human samples, indicating that these fish were not staple foods in the medieval Danish diet. The majority of the faunal samples are from herbivores and thus have more depleted $\delta^{15}N$ ratios. The pig, goat, sheep, domestic fowl, cow and bream, eel and herring samples have $\delta^{15}N$ ratios that are 3-4 ‰ more depleted than the average $\delta^{15}N$ ratios of the total human sample studied here, and are thus likely contributors to the medieval Danish diet.

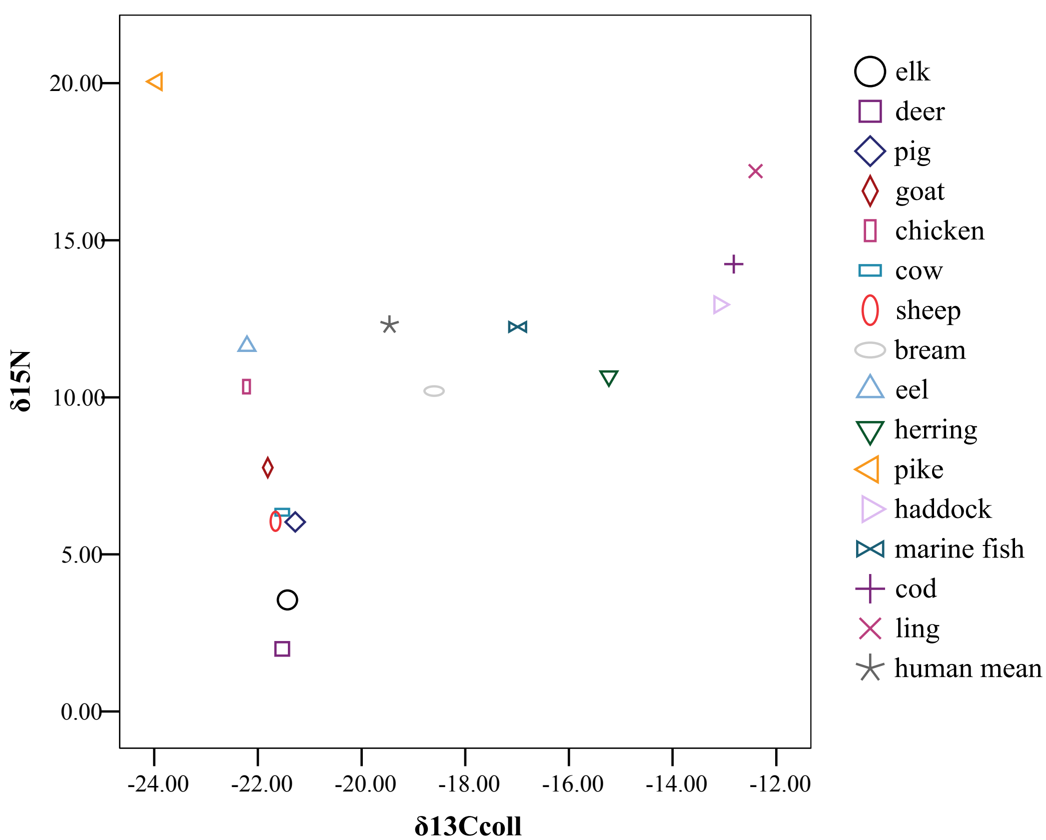

FIGURE 5.1. $\delta^{13}C_{coll}$ and $\delta^{15}N$ ratios of human and faunal samples

Results of the human isotopic analysis

Appendix B provides the isotopic ratios of every skeleton analyzed. Table 5.3 provides information on the average isotopic composition of the total skeletal sample for peasants, elites and monks when the time periods and sexes are pooled. The difference in average $\delta^{15}N$ and $\delta^{13}C_{coll}$ ratios in the sample is very small. However, there is a difference of more than one permil in the mean $\delta^{13}C_{ap}$ ratio between elites and the other social classes. There is a correspondingly large difference in $\delta^{13}C_{coll\text{-}ap}$ spacing between elites and the other classes.

TABLE 5.3. Mean stable isotopic composition of the sample (time periods and sexes pooled, in units ‰)

Sample	*Peasant sample*			*Elite sample*			*Monastic sample*		
	N	mean	s.d.	N	mean	s.d.	N	mean	s.d.
$\delta^{15}N$	154	12.28	0.952	29	12.47	0.923	14	12.25	0.891
$\delta^{13}C_{coll}$	154	-19.44	0.554	29	-19.40	0.471	14	-19.67	0.469
$\delta^{13}C_{ap}$	154	-14.12	0.741	30	-15.42	0.595	12	-14.16	0.942
$\delta^{13}C_{coll\text{-}ap}$	150	5.31	0.849	29	4.01	0.647	12	5.55	1.123

Comparisons between the sexes

As indicated in Table 5.4, there are no significant differences in isotopic signatures between the sexes in the peasant population when the alpha level is corrected for multiple comparisons. However, the difference in the collagen-apatite spacing between the sexes in the total peasant population are marginally significant ($p= 0.027$); males have a slightly larger collagen-apatite spacing than females. However, the magnitude of this difference is less than 0.49 ‰ and therefore may not be a repeatable measure, or if these results are accurate they likely don't reflect a large difference in diet

TABLE 5.4.Comparison of mean isotopic ratios between the sexes in the total peasant and by site and in the total elite sample

Sample	*Male*			*Female*			
	N	*mean*	*s.d.*	*N*	*mean*	*s.d*	p-*value*
Total peasant sample							
$\delta^{15}N$	80	12.26	1.000	66	12.30	0.879	0.755
$\delta^{13}C_{coll}$	80	-19.47	0.570	66	-19.38	0.524	0.321
$\delta^{13}C_{ap}$	80	-14.06	0.784	67	-14.22	0.702	0.268
$\delta^{13}C_{coll-ap}$	78	5.39	0.921	65	5.13	0.718	0.027
Øm Kloster							
$\delta^{15}N$	31	11.64	0.876	21	11.65	0.720	0.678
$\delta^{13}C_{coll}$	31	-19.82	0.403	21	-19.83	0.517	0.589
$\delta^{13}C_{ap}$	31	-14.10	0.948	22	-14.49	0.923	0.179
$\delta^{13}C_{coll-ap}$	30	5.71	1.017	21	5.29	0.986	0.080
St. Mikkel							
$\delta^{15}N$	22	12.41	0.627	22	12.38	0.801	1.000
$\delta^{13}C_{coll}$	22	-19.21	0.375	22	-19.26	0.440	0.542
$\delta^{13}C_{ap}$	22	-13.87	0.790	22	-14.01	0.468	0.240
$\delta^{13}C_{coll-ap}$	21	5.34	0.870	21	5.24	0.557	0.385
Ribe							
$\delta^{15}N$	27	12.85	1.010	23	12.77	0.777	0.657
$\delta^{13}C_{coll}$	27	-19.27	0.664	23	-19.11	0.391	0.336
$\delta^{13}C_{ap}$	27	-14.18	0.527	23	-14.19	0.569	0.880
$\delta^{13}C_{coll-ap}$	27	5.09	0.594	23	4.92	0.502	0.216
Total Elite							
$\delta^{15}N$	19	12.27	0.739	10	12.85	1.140	0.183
$\delta^{13}C_{coll}$	19	-19.53	0.418	10	-19.83	0.473	0.540
$\delta^{13}C_{ap}$	19	-15.39	0.597	10	-15.47	0.616	1.000
$\delta^{13}C_{coll-ap}$	19	4.13	0.702	10	3.76	0.462	0.099

No Kruskall-Wallis *H p*-values are significant at α=0.0127

between the sexes. There are also no significant differences in $\delta^{13}C$ ratios, $\delta^{15}N$ ratios or collagen-apatite spacing between the sexes in the elite sample from Øm Kloster. Table 5.5 compares average isotopic ratios between the sexes in the peasant sample from Øm Kloster by time period. There are no significant differences in the isotopic compositions between the sexes in peasants from this site in any time period. Table 5.6 demonstrates that there are no significant differences between the sexes in any time period at the site of

TABLE 5.5. Comparison of isotopic ratios and between the sexes by time period in the peasant sample from Øm Kloster

Period	*Male*		*Female*		p-*value*
	Mean	*s.d.*	*Mean*	*s.d.*	
Early	N=10		N=8		
$\delta^{15}N$	11.78	0.86	11.61	0.45	0.929
$\delta^{13}C_{coll}$	-19.86	0.31	-20.03	0.26	0.168
$\delta^{13}C_{ap}$	-14.07	0.74	-14.41	1.09	0.514
$\delta^{13}C_{coll\text{-}ap}$	5.74	0.84	5.49	1.08	0.630
Middle	N=9		N=4		
$\delta^{15}N$	11.59	1.07	11.38	0.45	0.643
$\delta^{13}C_{coll}$	-19.82	0.40	-19.74	0.56	1.000
$\delta^{13}C_{ap}$	-14.01	1.14	-14.64	0.89	0.280
$\delta^{13}C_{coll\text{-}ap}$	5.81	1.37	5.11	0.51	0.217
Late	N=12		N=8		
$\delta^{15}N$	11.56	0.78	11.82	0.82	0.263
$\delta^{13}C_{coll}$	-19.79	0.49	-19.69	0.49	0.758
$\delta^{13}C_{ap}$	-14.18	1.03	-14.51	0.90	0.537
$\delta^{13}C_{coll\text{-}ap}$	5.60	1.15	5.17	1.07	0.280

No Kruskal-Wallis *H p*-values are significant at α=0.0127

TABLE 5.6. Comparison of isotopic ratios and between the sexes by time period in the peasant sample from St. Mikkel

Period	*Male*		*Female*		p-*value*
	Mean	*s.d.*	*Mean*	*s.d.*	
Early	N=11		N=10		
$\delta^{15}N$	12.28	0.72	12.31	0.88	0.849
$\delta^{13}C_{coll}$	-19.22	0.46	-19.03	0.53	0.305
$\delta^{13}C_{ap}$	-13.86	0.89	-13.92	0.39	0.569
$\delta^{13}C_{coll\text{-}ap}$	5.36	1.04	5.10	0.74	0.259
Middle	N=7		N=8		
$\delta^{15}N$	12.69	0.46	12.67	0.84	0.417
$\delta^{13}C_{coll}$	-19.06	0.20	-19.37	0.40	0.064
$\delta^{13}C_{ap}$	-13.67	0.46	-13.97	0.39	0.247
$\delta^{13}C_{coll\text{-}ap}$	5.41	0.53	5.35	0.35	0.886
Late	N=4		N=5		
$\delta^{15}N$	12.29	0.57	12.04	0.56	0.462
$\delta^{13}C_{coll}$	-19.43	0.25	-19.52	0.12	0.461
$\delta^{13}C_{ap}$	-14.25	0.99	-14.21	0.74	1.000
$\delta^{13}C_{coll\text{-}ap}$	5.19	0.94	5.31	0.67	0.806

No Kruskal-Wallis *H p*-values are significant at α=0.0127

St. Mikkel. As indicated in Table 5.7, there are also no significant differences between the sexes in any time period at the site of Ribe. However, female skeletons in the middle period at Ribe have heavier mean $\delta^{13}C_{coll}$ ratios than male skeletons and this result is near statistical significance ($p = 0.035$), and is a mean difference of 0.6‰. As indicated in Table 5.8, there are also no significant differences in isotopic ratios of carbon, nitrogen or collagen-apatite spacing between the sexes in the elite sample when it is divided by time period.

TABLE 5.7. Comparison of isotopic ratios and between the sexes by time period in the peasant sample from Ribe

Period	*Male*		*Female*		p-*value*
	Mean	*s.d.*	*Mean*	*s.d.*	
Early	N=10		N=8		
$\delta^{15}N$	13.34	0.87	12.68	0.88	0.086
$\delta^{13}C_{coll}$	-19.15	0.66	-18.92	0.28	0.121
$\delta^{13}C_{ap}$	-14.18	0.54	-14.12	0.53	0.653
$\delta^{13}C_{coll-ap}$	4.97	0.54	4.80	0.49	0.348
Middle	N=7		N=7		
$\delta^{15}N$	12.12	0.69	12.72	0.95	0.201
$\delta^{13}C_{coll}$	-19.98	0.48	-19.38	0.38	0.035
$\delta^{13}C_{ap}$	-14.51	0.51	-14.52	0.62	0.898
$\delta^{13}C_{coll-ap}$	5.46	0.59	4.85	0.61	0.084
Late	N=10		N=8		
$\delta^{15}N$	12.91	1.08	12.91	0.56	0.722
$\delta^{13}C_{coll}$	-18.89	0.34	-19.09	0.39	0.214
$\delta^{13}C_{ap}$	-13.94	0.42	-13.98	0.49	0.859
$\delta^{13}C_{coll-ap}$	4.95	0.59	5.11	0.39	0.657

No Kruskal-Wallis *H* *p*-values are significant at $\alpha=0.0127$

TABLE 5.8. Comparison of isotopic ratios between the sexes in the elite sample at Øm Kloster by time period

Period	*Male*		*Female*		p-*value*
	Mean	*s.d.*	*Mean*	*s.d.*	
Early Period	N= 5		N=2		
$\delta^{15}N$	11.91	0.74	12.28	1.51	0.699
$\delta^{13}C_{coll}$	-19.61	0.45	-19.23	0.12	0.241
$\delta^{13}C_{ap}$	-15.45	0.48	-15.51	0.98	1.000
$\delta^{13}C_{coll-ap}$	4.16	0.70	3.72	1.02	0.699
Middle Period	N=6		N=3		
$\delta^{15}N$	12.29	0.81	12.23	0.48	0.796
$\delta^{13}C_{coll}$	-19.65	0.53	-19.39	0.49	0.606
$\delta^{13}C_{ap}$	-15.58	0.43	-15.59	0.72	1.000
$\delta^{13}C_{coll-ap}$	4.07	0.53	4.09	0.15	0.796
Late Period	N=8		N=5		
$\delta^{15}N$	12.48	0.69	13.44	1.17	0.143
$\delta^{13}C_{coll}$	-19.39	0.31	-18.94	0.52	0.606
$\delta^{13}C_{ap}$	-15.22	0.76	-15.37	0.57	0.942
$\delta^{13}C_{coll-ap}$	4.17	0.88	3.57	0.27	0.107

No Kruskal-Wallis *H p*-values are significant at α=0.0127

Comparisons through time

Table 5.9 illustrates there are no significant differences in $\delta^{15}N$, $\delta^{13}C$, or collagen-apatite spacing through time in the total peasant sample. However, when the peasant sample is further divided by time period significant differences emerge. When the sexes are pooled the skeletons from Ribe have significantly more depleted $\delta^{13}C_{coll}$ ratios in the middle period than during either the early or late periods. Although only of marginal significance, middle period skeletons from Ribe also have a more depleted $\delta^{13}C_{ap}$ ratios than during the other periods (p = 0.020). As the comparison of isotopic ratios between the sexes is marginally significant at this site, I have further divided the Ribe sample by sex. The collagen from male skeletons from Ribe is significantly more depleted in ^{13}C in

TABLE 5.9. Statistical comparisons of isotopic ratios through time in peasants (sexes pooled unless otherwise noted)

Time and Sample	$\delta^{15}N$ *Mean*	*s.d*	$\delta^{13}C_{coll}$ *Mean*	*s.d*	$\delta^{13}C_{ap}$ *Mean*	*s.d*	$\delta^{13}C_{coll\text{-}ap}$ *Mean*	*s.d*
Øm-peasant								
Early, n=20	11.71	0.68	-19.98	0.32	-14.21	0.87	5.71	0.92
Middle, n=15	11.49	0.87	-19.83	0.41	-14.11	1.03	5.72	1.17
Late, n=20	11.67	0.78	-19.75	0.48	-14.31	0.97	5.43	1.11
p-value	0.884		0.327		0.904		0.721	
St. Mikkel								
Early, n=20	12.29	0.78	-19.13	0.49	-13.88	0.68	5.24	0.90
Middle, n=16	12.64	0.66	-19.22	0.34	-13.80	0.44	5.41	0.42
Late, n=9	12.15	0.54	-19.48	0.18	-14.22	0.80	5.25	0.75
p-value	0.141		0.078		0.588		0.895	
Ribe								
Early, n=20	13.02	0.86	-19.06	0.52	-14.17	0.51	4.89	0.50
Middle, n=15	12.44	0.83	-19.63	0.53	-14.49	0.53	5.14	0.64
Late, n=19	12.98	0.90	-18.97	0.36	-13.95	0.44	5.02	0.50
p-value	0.154		**0.003**		0.020		0.344	
Ribe- male								
Early, n=10	13.34	0.87	-19.15	0.66	-14.18	0.54	4.97	0.54
Middle, n=7	12.11	0.69	-19.98	0.49	-14.51	0.51	5.46	0.59
Late, n=10	12.91	1.08	-18.89	0.34	-13.94	0.42	4.95	0.59
p-value	0.045		**0.003**		0.066		0.136	
Ribe- female								
Early, n=9	12.68	0.88	-18.92	0.27	-14.12	0.53	4.80	0.49
Middle, n=7	12.72	0.95	-19.38	0.38	-14.52	0.62	4.86	0.61
Late, n=8	12.91	0.56	-19.09	0.39	-13.98	0.49	5.11	0.39
p-value	0.978		0.095		0.200		0.422	

Kruskal-Wallis *H* *p*-values in **bold** are significant at α=0.0127

the middle period than during either the early or late periods. In the middle period male skeletons at Ribe also have lighter δ^{15}N ratio than in the other periods, although this result is not statistically significant (p = 0.045). There are no other statistically significant results in the comparison of stable isotopic ratios of carbon, nitrogen or collagen-apatite spacing in the peasant sample through time.

Table 5.10 demonstrates that there are also no significant differences in the elite or monastic samples through time. However, from the early to the middle period the average isotopic ratio of $\delta^{15}N$ in the monastic sample is over one-half permil higher, such that monk skeletons from the middle period are more enriched in the heavier isotope of nitrogen than those from the early period. There are larger differences in the isotopic composition of the skeletons of monks from the early period to those of the late period, however, only two monks comprise the late period sample. These two individuals are both enriched in the heavier isotope of nitrogen by almost one permil when compared to early period monk skeletons. The late period monks also have heavier $\delta^{13}C_{coll}$ ratios by one-half permil, lighter $\delta^{13}C_{ap}$ ratios by over one permil, and smaller $\delta^{13}C_{coll-ap}$ spacing by over one permil. If the isotopic compositions of these two skeletons are representative of late period monastic isotopic ratios, then these results may suggest that there was a change in monastic diet through time. However, the isotopic ratios of these two samples are not identical and therefore they may not be representative of monastic diet ($\delta^{15}N$: Øm 47= 12.20‰, Øm 155= 13.07‰; $\delta^{13}C_{coll}$: Øm 47= -19.90‰, Øm 155= -19.15‰; $\delta^{13}C_{ap}$: Øm 47= -15.98‰, Øm 155= -14.77‰; $\delta^{13}C_{coll-ap}$: Øm 47= 3.92‰, Øm 155= 4.38‰).

TABLE 5.10. Statistical comparisons of isotopic ratios through time in elites and monks from Øm Kloster (sexes pooled)

Time and Sample	$\delta^{15}N$		$\delta^{13}C_{coll}$		$\delta^{13}C_{ap}$		$\delta^{13}C_{coll-ap}$	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Øm-elite								
Early, n=7	12.01	0.88	-19.51	0.42	-15.47	0.54	4.04	0.74
Middle, n=9	12.27	0.68	-19.56	0.50	-15.58	0.52	4.08	0.43
Late, n=13	12.85	0.98	-19.57	0.45	-15.28	0.67	3.94	0.75
p-value	0.160		0.304		0.669		0.415	
Øm-monk								
Early, n=5	11.77	0.97	-20.01	0.59	-14.03	0.92	5.92	1.39
Middle, n=7	12.48	0.84	-19.68	0.34	-13.84	0.76	5.76	0.79
Late, n=2	12.63	0.61	-19.52	0.53	-15.37	0.85	4.15	0.32
p-value	0.228		0.277		0.194		0.226	

No Kruskal-Wallis *H* *p*-values are significant at α=0.0127

Thus, the interpretation of the late period results should be interpreted as merely suggestive of possible dietary change, and not indicating that a change in diet occurred.

Comparisons among the sites

As Øm Kloster is the only site with a monastic or an elite component, the comparison between the sites is limited to the peasant sample only. As illustrated in Figure 5.2 and in Table 5.11, there are significant differences in the average isotopic ratios in the total peasant sample among the three sites. The $\delta^{15}N$, and $\delta^{13}C_{coll}$ ratios and the collagen

TABLE 5.11. Statistical comparisons of isotopic ratios among the sites (sexes pooled)

Sample	$\delta^{15}N$		$\delta^{13}C_{coll}$		$\delta^{13}C_{ap}$		$\delta^{13}C_{coll-ap}$	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Total sample								
Øm-peasant, n=55	11.63	0.76	-19.85	0.42	-14.22	0.94	5.61	1.05
St. Mikkel, n=46	12.39	0.72	-19.23	0.41	-13.92	0.64	5.30	0.74
Ribe, n=53	12.84	0.89	-19.19	0.54	-14.18	0.53	5.00	0.54
p-value	**0.000**		**0.000**		0.040		**0.000**	
Early period								
Øm-peasant, n=20	11.71	0.68	-19.98	0.32	-14.21	0.87	5.71	0.92
St. Mikkel, n=20	12.29	0.78	-19.13	0.49	-13.88	0.68	5.24	0.90
Ribe, n=20	13.02	0.86	-19.06	0.52	-14.17	0.51	4.89	0.50
p-value	**0.000**		**0.000**		0.174		**0.011**	
Middle period								
Øm-peasant, n=15	11.49	0.87	-19.83	0.41	-14.11	1.03	5.72	1.17
St. Mikkel, n=16	12.64	0.66	-19.22	0.34	-13.81	0.44	5.41	0.42
Ribe, n=15	12.44	0.83	-19.63	0.53	-14.49	0.53	5.14	0.64
p-value	0.001		0.005		0.021		0.167	
Late period								
Øm-peasant, n=20	11.67	0.78	-19.75	0.48	-14.31	0.97	5.43	1.11
St. Mikkel, n=9	12.15	0.54	-19.48	0.18	-14.22	0.80	5.25	0.75
Ribe, n=19	12.98	0.90	-18.97	0.36	-13.95	0.44	5.02	0.50
p-value	**0.000**		**0.000**		0.471		0.101	

Kruskal-Wallis *H* *p*-values in **bold** are significant at α=0.0127

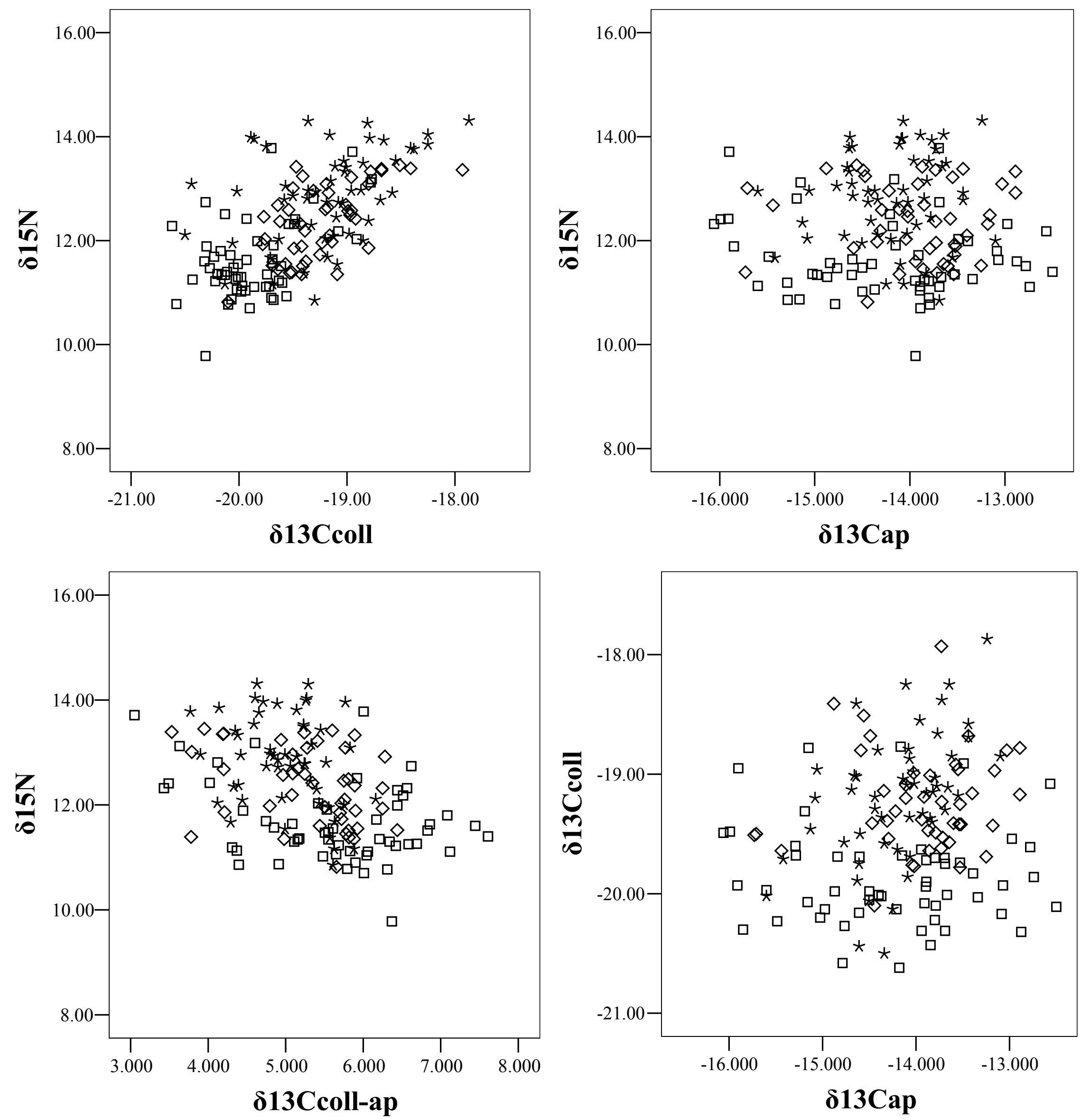

FIGURE 5.2. Distribution of $\delta^{15}N$, $\delta^{13}C_{coll}$, $\delta^{13}C_{ap}$ and $\delta^{13}C_{coll\text{-}ap}$ ratios among the sites in the total peasant sample (square= Øm Kloster, diamond= St. Mikkel, star= Ribe)

apatite spacing are all significantly different among the sites when the time periods are pooled. The collagen from the skeletal sample from Ribe is the most enriched in ^{15}N, whereas the Øm Kloster collagen is the most depleted in ^{15}NThe collagen in the Øm Kloster sample is on average more depleted in the heavier carbon isotope than the other sites. Interestingly, the $\delta^{13}C$ of the apatite from Ribe is the lightest whereas the apatite from the St. Mikkel sample is the most enriched in ^{13}C, although this result is only of marginal significance (p=0.040). The Øm Kloster sample has the largest collagen-apatite spacing (mean=5.61‰) and the Ribe sample has the smallest average spacing (mean= 5.00‰).

Table 5.11 also compares the isotopic composition of each site by time period. There are also significant inter-site differences when the sample is divided in this manner. In all three time periods, the sample from Øm Kloster has significantly lighter $\delta^{15}N$ ratios than the other sites. In the early and late periods the sample from Ribe is the most enriched in ^{15}N and in the middle period the samples from Ribe and St. Mikkel have similar $\delta^{15}N$ ratios. In all three time periods, the sample from Øm Kloster again has significantly lighter $\delta^{13}C_{coll}$ ratios. In the middle period the sample from St. Mikkel has the most enriched $\delta^{13}C_{coll}$ ratio of any site, and in the late period the sample from Ribe has the most enriched $\delta^{13}C_{coll}$ ratios of any site. In the middle period, the apatite from the St. Mikkel samples are the most enriched in ^{13}C, however, this difference is small and is only of marginal significance only (p=0.021). In all time periods the sample from Ribe has the lowest, and the sample from Øm Kloster has the highest, collagen-apatite spacing, although these differences are only significant in the early period.

Comparisons by social class

Figures 5.3 illustrate the differences in the average isotopic ratios among the social classes in the total Øm Kloster sample when the time periods are pooled. Table 5.12 provides the results of the Kruskal-Wallis *H* statistical comparisons of the isotopic

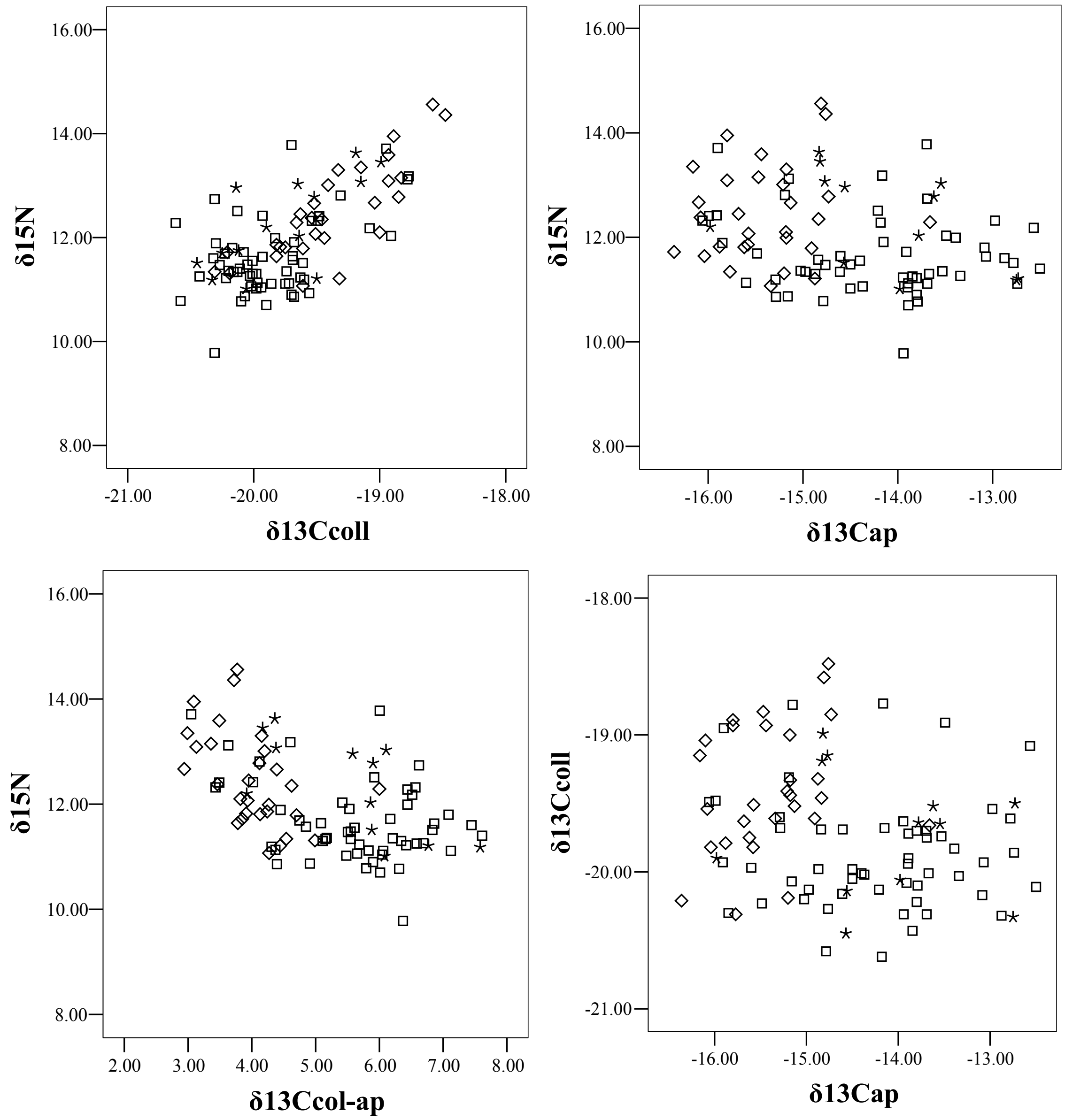

FIGURE 5.3. Distribution of $\delta^{15}N$, $\delta^{13}C_{coll}$, δ^{13}, $\delta^{13}C_{ap}$ ratios and $\delta^{13}C_{coll\text{-}ap}$ spacing among the classes in the total Øm Kloster sample (square= peasant, diamond= elite, star= monk)

ratio differences among the social classes. As Øm Kloster is the only site with elite and monastic skeletons all comparisons by social class are made only within this sample. There are statistically significant differences in all isotopic comparisons of social status in

TABLE 5.12 Statistical comparisons of isotopic ratios by social class

Time and Sample	*$\delta^{15}N$* Mean	s.d.	*$\delta^{13}C_{coll}$* Mean	s.d.	*$\delta^{13}C_{ap}$* Mean	s.d.	*$\delta^{13}C_{coll-ap}$* Mean	s.d.
Total Øm sample								
Øm-elite, n=29	12.47	0.92	-19.40	0.47	-15.42	0.59	4.01	0.64
Øm-monk, n=14	12.25	0.89	-19.77	0.47	-14.16	0.94	5.55	1.12
Øm-peasant, n=55	11.63	0.76	-19.85	0.42	-14.22	0.94	5.61	1.05
p-value	**0.000**		**0.000**		**0.000**		**0.000**	
Early period								
Øm-elite, n=7	12.01	0.88	-19.50	0.42	-15.46	0.54	4.04	0.74
Øm-monk, n=5	11.77	0.97	-20.01	0.59	-14.03	0.92	5.92	1.39
Øm-peasant, n=20	11.71	0.68	-19.98	0.32	-14.21	0.87	5.71	0.92
p-value	0.762		0.029		**0.006**		**0.007**	
Middle period								
Øm-elite, n=9	12.27	0.68	-19.56	0.50	-15.58	0.52	4.08	0.43
Øm-monk, n=7	12.48	0.84	-19.68	0.34	-13.84	0.75	5.76	0.79
Øm-peasant, 15	11.49	0.87	-19.83	0.41	-14.11	1.03	5.72	1.17
p-value	0.018		0.281		**0.001**		**0.001**	
Late period								
Øm-elite, n=13	12.85	0.98	-19.22	0.45	-15.28	0.67	3.94	0.75
Øm-monk, n=2	12.63	0.61	-19.52	0.53	-15.37	0.85	4.15	0.32
Øm-peasant, n=20	11.67	0.79	-19.75	0.48	-14.31	0.97	5.43	1.11
p-value	**0.007**		0.014		0.018		**0.004**	

Kruskal-Wallis *H* *p*-values in **bold** are significant at α=0.0127

the sample when the time periods are pooled. The collagen from the skeletons of the peasant sample is significantly more depleted in the heavier isotope of nitrogen than the elite or monk skeletal sample. The collagen of elite skeletons is more enriched in ^{13}C, the apatite is depleted in ^{13}C. Elite skeletons also have smaller collagen-apatite spacing than do peasant or monk skeletons. There are also significant differences in average isotopic ratios when the Øm Kloster sample is separated by time period. In the early and middle periods, elite skeletons are significantly depleted in ^{13}C from apatite and have smaller average $\delta^{13}C_{coll-ap}$ spacing than the other social classes. In the late period, peasants have significantly more depleted average $\delta^{15}N$ ratios in comparison to the elites and monks. In this period, peasants also have significantly larger, and elites smaller, average collagen-apatite spacing in comparison with the other social classes. In addition to these significant results, early period elites have depleted average $\delta^{13}C_{coll}$ ratios in comparisons with peasants and monks. This result is only of marginal significance ($p = 0.029$). In the middle period, peasant skeletons have more depleted average $\delta^{15}N$ ratios than elites or monks, although again this result is of marginal significance ($p= 0.018$). In the late period, peasants have marginally more depleted in ^{13}C from collagen and more enriched in ^{13}C from apatite than the other classes ($p= 0.014$ and $p= 0.018$ respectively).

DISCUSSION

Table 5.13 summarizes patterns in the isotopic comparison of diet among the different sub-samples analyzed in this chapter. There are no significant differences in isotopic ratios of carbon or nitrogen between the sexes in the peasant sample. However, female skeletons have smaller $\delta^{13}C_{coll\text{-}ap}$ spacing than males in the total peasant sample and female peasants from the site of Ribe have more enriched $\delta^{13}C_{coll}$ ratios than males during the middle period. These results are of only marginal significance and hence merely suggest dietary differences between the sexes. These patterns imply that female peasants consumed a diet composed of more marine foods than males. The very slight differences in $\delta^{15}N$ indicate that there was little difference in the trophic level of the protein consumed by males and females in this study, therefore, males may have eaten more terrestrial animal meat whereas females ate more marine or freshwater fish. There are no significant, or marginally significant, differences between the sexes in the elite sample.

The only significant chronological difference in the peasant skeletal sample is found at Ribe. Both in the total Ribe sample, and the male Ribe sample, the skeletons from the middle period have significantly lighter $\delta^{13}C_{coll}$ ratios than those from either the early or late period. In addition to this significant result, the middle period skeletons from Ribe also have marginally lighter $\delta^{13}C_{ap}$ and $\delta^{15}N$ ratios. Taken together, these results indicate that the diet at the urban site of Ribe was more heavily composed of terrestrial plants in the middle period than in either the early or late periods. The middle period witnessed to both the start of the Late Medieval Agrarian Crisis and the Black

TABLE 5.13. Summary of Results of Isotopic Comparisons

Comparison	Significant differences	Marginally significant differences
By sex *(M=male, F= female)*	None	M>F (total sample: $\delta^{13}C_{coll-ap}$ spacing) F>M (middle period Ribe: $\delta^{13}C_{coll}$)
Through time *(E= early, M= middle, L= late)*	M< E, L (total Ribe sample: $\delta^{13}C_{coll}$; male Ribe sample: $\delta^{13}C_{coll}$)	M< E, L (total Ribe sample: $\delta^{13}C_{ap}$, $\delta^{15}N$)
Among sites *(Ø= Øm Kloster, S=St. Mikkel, R= Ribe*	Ø < S, R (total peasant sample and all time periods: $\delta^{15}N$ and $\delta^{13}C_{coll}$) R < Ø, S (all time periods: $\delta^{13}C_{coll-ap}$ spacing)	S> Ø , R (total peasant sample and middle period sample: $\delta^{13}C_{ap}$)
Among classes *(P= peasant, E= Elite, M= monk)*	P < E, M (total, and late period Øm Kloster samples: $\delta^{15}N$ E > P, M (total Øm Kloster sample: $\delta^{13}C_{coll}$) E < P, M (total, early and middle period Øm Kloster samples: $\delta^{13}C_{ap}$) E < P (all periods: $\delta^{13}C_{coll-ap}$ spacing)	P < M and E (middle period Øm Kloster sample: $\delta^{15}N$) E >P, M (early and late period Øm Kloster samples: $\delta^{13}C_{coll}$) P> E (late period Øm Kloster sample: $\delta^{13}C_{ap}$)

Death plague. The generally unstable conditions produced by these two catastrophic events may have disrupted trade from both within and outside Denmark. As Ribe was one of the largest trade cities in Denmark, and served as a gateway to the rest of Europe, it may have been hit especially hard by the disruption in trade of food resources. The other sites sampled here may have been sufficiently autonomous to have been less affected by food shortages in the rest of Europe.

There are no significant, or marginally significant, chronological differences in isotopic ratios in the elite or monastic samples. The differences in the isotopic ratios from elite skeletons through time are very small. However, there are larger changes through time in the isotopic ratios in the monastic sample. From the early to middle period the $\delta^{15}N$ ratios of the monastic skeletons become heavier by over a half permil. This suggests a shift in the protein source or in the importance of that protein source through time. The heavy nitrogen value in comparison with the light carbon values and large spacing between the carbon values from collagen and apatite in both the early and middle periods suggest that the protein in the monastic diet was composed of either terrestrial animal meat or from freshwater fish resources. As monks were prohibited from eating terrestrial animal meat in the early period by the Benedictine Rule, and the monastery of Øm Kloster is located on two lakes, it is likely that this protein sources was freshwater fish in the early period. There was a loosening of the dietary proscriptions in the latter part of the middle period and so perhaps the monastic diet of this period was composed of both freshwater fish and terrestrial animal meat. Freshwater fish are enriched in the heavier isotope of nitrogen but have variable $\delta^{13}C$ ratios, for example the isotopic composition of the pike faunal sample has very heavy $\delta^{15}N$ ratio, 20.05‰, and a very light $\delta^{13}C_{coll}$ ratio, -23.95‰. The depleted ^{13}C of the apatite suggests that plant foods were still extremely important in the monastic diet, suggesting that although monks commonly ate fish, plant resources were likely the base of the monastic diet. The shift in nitrogen values from the early to the middle period suggests that freshwater fish, and perhaps terrestrial animal meat, became a more important resource for the monks in the middle period. Although there are larger changes in the isotopic compositions of the monastic samples from the early to the late period, the late period monastic sample is from only two individuals and, therefore, may not be representative of late period monastic diet. Thus, any interpretations of dietary change through time in the monks of Øm Kloster are restricted to comparisons of the early and middle period samples.

The comparison of isotopic compositions of the skeletal material from the different sites reveals that the peasants from the rural monastery site of Øm Kloster have the most depleted $\delta^{15}N$ and $\delta^{13}C_{coll}$ ratios in the overall sample and in every time period. The peasants from Øm Kloster also have the largest $\delta^{13}C_{coll-ap}$ spacing, whereas those from the site of Ribe have the smallest spacing. These results indicate that the individuals at the rural site of Øm Kloster have a more terrestrial diet than either of the urban sites. This is somewhat surprising as Øm Kloster is located near two lakes. The lighter $\delta^{15}N$ ratio in the peasant skeletons from this site may indicate that they either did not use, or did not have access to the food resources in these lakes. The skeletal sample from Ribe has the most enriched $\delta^{15}N$ of any site in the total sample, and in the early and middle period samples. In combination with the small $\delta^{13}C_{coll-ap}$ spacing at Ribe, this indicates that the individuals living at the large urban site of Ribe had the most marine/highest protein diet of any site (except in the middle period). The skeletons from the urban site of St. Mikkel are intermediate between the other sites in all of the dietary indicators except for the $\delta^{13}C_{ap}$ ratios, in which they are more enriched than the other sites. However, the difference in mean $\delta^{13}C_{ap}$ ratios is small and thus may not reflect a meaningful difference in diet.

There are also significant differences in diet among peasants, elites and monks in the sample from Øm Kloster. Peasants are more depleted in ^{15}N than either elites or monks when the time periods are pooled and in the late period. This trend is not contradicted by the marginally lighter $\delta^{15}N$ ratios in the middle period. In the early and middle period samples, the monk and peasant skeletons have similarly depleted $\delta^{15}N$ ratios, whereas the elites are more enriched in the heavier isotope of nitrogen. Elite skeletons also have more enriched $\delta^{13}C_{coll}$ ratios than peasant or monk skeletons in the total sample, and are marginally enriched in the early period and late periods. Elite skeletons have more depleted $\delta^{13}C_{ap}$ ratios in the total sample, the early and middle period samples, than the peasant and monk skeletons and have the smallest $\delta^{13}C_{coll\text{-}ap}$ spacing in every period. Monks and peasants have very similar isotopic signatures in the early period. In the middle period, monks and peasants have very similar $\delta^{13}C_{coll}$ and $\delta^{13}C_{ap}$ ratios and $\delta^{13}C_{coll\text{-}ap}$ spacing. However, monks in this period have similar $\delta^{15}N$ ratios to elites, indicating that monks ate more freshwater fish and perhaps terrestrial animal meat than peasants. Unfortunately, the late period monastic sample consists of only two individuals, and therefore, any interpretation of diet from this sample is problematic as these samples may not be representative of late period monastic diet. Overall these results suggest that elites had a more protein rich diet from both terrestrial and marine resources than peasants or monks. Monks and peasants had a very similar diet in the early period. The difference in monastic and peasant diet in the middle period likely reflects the loosening of the dietary proscriptions of the monks and the inclusion of more terrestrial animal meat into their diet. Unfortunately, comparisons among peasants, elites and monks can not be made for the late period as the sample of monks is too small to ensure confidence in the interpretation of the results.

CONCLUSIONS

The null hypothesis that there are no differences in $\delta^{15}N$, $\delta^{13}C_{coll}$, and $\delta^{13}C_{ap}$ ratios, and $\delta^{13}C_{coll\text{-}ap}$ spacing by sex, through time, among the sites or among the social classes cannot be supported by the data. The results of the comparison of the isotopic composition between the sexes reveal no significant differences and thus fail to reject the null hypothesis; males and females had similar diets in medieval Jutland. There are significant differences in the skeletal sample through time; therefore, I reject the null hypothesis of no temporal differences in medieval diet. Individuals in the middle period at the large urban site of Ribe had a diet more heavily composed of terrestrial plant food than in either the early or middle periods. As Ribe is the only site with significant chronological differences in diet this suggests that there was no large scale change in diet, throughout medieval Denmark as a whole. Instead, these results suggest that temporal changes in diet at Ribe may have been the result of its position in the trade network and, therefore, speaks more to the disruptions in trade with the rest of Europe and not to conditions within Denmark.

I also reject the null hypothesis of no regionally based differences in diet as there are significant differences in the isotopic composition among skeletal samples from different sites. The peasants at the rural monastery site of Øm Kloster had a more terrestrial diet than either of the urban sites. Of the urban sites, the individuals from Ribe, the large trade city, had the most marine/highest protein diet of any site. These results suggest that the residents of Ribe had easier/more affordable access to meat resources than residents from the rural site who primarily subsisted from cereal grains and other vegetables.

Finally, I reject the null hypothesis of no dietary differences among the social class, as there are also significant differences in the isotopic composition among these skeletal samples. Peasants had a diet more heavily composed of terrestrial plant foods whereas elites had a diet more heavily composed of terrestrial and marine proteins. The monks from the Cistercian order at Øm Kloster had a very similar diet to peasants in the early period, but their diet changed through time and became more heavily composed of freshwater fish and terrestrial animal products in the middle period. Thus the analysis of diet in Medieval Denmark reveals differences among individuals living in different time periods, sites and social classes.

CHAPTER VI

DENTAL CARIES

Dental caries are localized areas of demineralization of the enamel, dentine and/or cementum. The patterning in caries distribution is used by bioarchaeologists to aid in reconstructing the diet in past populations (Adler and Turner, 2000; Armelagos, 1966; Cucina and Tiesler, 2003; Delgado-Darias et al., 2005; Larsen et al., 1991; Lingstrom and Borrman, 1999; Lukacs, 1996; Milner, 1984; Moore and Corbett, 1971; Moore and Corbett, 1973; Moore and Corbett, 1975; Powell, 1985; Saunders et al., 1997; Schollmeyer and Turner, 2004; Sealy et al., 1992). This chapter first discusses the formation of dental caries and their relationship to diet. Next, the methods and hypotheses for the analysis of caries are presented. Finally, the results of the analysis of the distribution of carious lesions in the sample are presented and interpreted in order to gain a better understanding of the diet of the medieval inhabitants of Denmark.

Caries are formed when bacteria, typically *Streptococcus mutans* or *Lactobacilli,* affixed in dental plaque gain access to carbohydrates and begin to excrete acidic waste products. When the pH of the mouth falls below 5.7 the enamel begins to demineralize, forming a carious fissure or pit. If left untreated, the action of the acid may eventually perforate the pulp chamber, elevating the risk of the spread of infection to other areas of the body. Caries typically develop slowly, with periods of active destruction followed by a remineralization phase. Carious lesions can be formed in the fissures or pits of the crown surface, the smooth and interstitial surfaces of the crown, and/or the root. Since caries are the product of the acids produced by bacteria that live on food particles in the mouth, diet is necessarily an important factor in caries development.

The frequent consumption of sugar has been experimentally shown to increase caries abundance. The relationship of starchy foods to caries is somewhat more complicated. Starchy foods that are not themselves dense, and/or do not stick to the teeth, have a low cariogenicity. However, starchy foods that are also sugary have a much higher cariogenicity. Dairy products have been shown to have a somewhat protective effect on the tooth surface, inhibiting the adherence of foods to the crown surface. There is some experimental and anthropological data that suggests that proteins and fats are also associated with low caries frequencies (Hillson, 1996, (Newbrun, 1982)) .

In the anthropological literature, dental caries have been used to examine changes in diet in human populations. The first examination of change in caries presence through time was by Mummery in 1870. He examined 1600 dentitions from complex and noncomplex societies and noted that the caries frequency increased with the complexity of the society. He attributed this increase to the overtaxing of children's brains during the first 7 years of life in complex societies (Mummery, 1870)! Today we understand that caries are not the result of the reallocation of energy from the teeth to the brain but are instead the result of changes in diet. In fact much modern research has been done studying differences in caries frequencies between hunter-gatherers and agricultural populations in the New World (Cassidy, 1984; Milner, 1984; Powell, 1985; Rose et al., 1991), in Europe (Bennike, 1985; Brinch and Moller-Christensen, 1949; Meiklejohn et al., 1984; Mellquist and Sandberg, 1939; Moore and Corbett, 1971; Moore and Corbett, 1973; Moore and Corbett, 1975; Whittaker, 1993), and in Asia (Fujita, 1995; Lukacs, 1990; Lukacs, 1992; Lukacs et al., 1989; Turner, 1979). Almost universally, these studies have found that hunter-gatherer populations generally have a significantly lower frequency of carious lesions than do populations that have adopted agriculture.

Another interesting feature of the anthropological literature on caries frequencies is that female skeletons often have a significantly higher frequency of carious teeth than do male skeletons (Larsen, 1983; Larsen, 1997; Larsen et al., 1991; Lukacs, 1996; Walker and Erlandson, 1986). This is a very common, but not universal, world-wide phenomenon and suggests that the difference in lesion frequency between the sexes is not due to biological differences between the sexes, but is instead due to cultural differences in diet between the sexes where males consume more meat and females eat more carbohydrate-rich foods (Lukacs 1996, Larsen 1997). Sex-based differences in caries have also been noted in medieval Danish populations. In her examination of 7,000 years of Danish health, Bennike (1985) found that females had worse dental health than males in the medieval period, and that the medieval period had among the highest overall caries rates of all the periods examined.

Differences in caries frequencies are also often found among members of different social classes (Frayer, 1984; Suzuki et al., 1967; Swardstedt, 1966; Wells, 1975). Frayer noted that the prevalence of caries with peasants of medieval Hungary was much higher than that in the upper class. He argued that this difference reflected the greater consumption of animal protein by the upper class than the by lower class (Frayer 1984). In her study of medieval Lund, Arcini also found that lower class individuals had a higher frequency of caries than the more affluent individuals in her sample. She attributed the higher caries rates in the lower class to a diet heavily composed of sticky carbohydrate-rich porridge and the increased availability of sugar in the later medieval period. Overall, Arcini (1999) found an increased rate of carious lesions and more teeth affected by caries in the late medieval period.

METHODS AND HYPOTHESES

Due to the information that dental caries can provide about diet, I have included them in this analysis as another means of assessing dietary change through time and among populations. As elaborated in Chapter IV, the null hypotheses with respect to dental caries are that there are no differences in caries presence or the percent of carious teeth between the sexes, through time, by site or social class. Based on previous studies of caries that have found significant differences in caries between the sexes, and on the historical record, which indicates that males and females may have had equal access to resources during this period, it is likely that a higher proportion of female dentitions will have caries and that female dentitions will have a higher percentage of carious teeth than males. In addition, due to the historically indicated shift from a reliance on cereal grains to meat and meat products, it is likely that both the number of individuals with a caries and the percentage of carious teeth will decrease through time. Furthermore, it is expected that the sample from St. Mikkel and the peasant sample from Øm Kloster had the most cereal grain dependent diet, because they may have had less access to the variety of food resources found in the trade city of Ribe. Therefore, it is expected that the skeletons from these two sites will have a higher proportion of dental caries. Due to the historical documentation of heterogeneity in diet among the social classes discussed in Chapters II and III, it is also expected that monks and peasants had a more cereal grain based diet than elites in the early period. However, after the loosening of monastic dietary restrictions in the late period it is likely that the diet of monks came to include more meat and thus more closely resembled the diet of the elites. Therefore, in the late period it is likely that peasants will have a higher abundance of caries than either elites or monks and thus will have had a more terrestrial plant based diet.

The caries literature abounds with different ways of examining and comparing caries abundance in a population. A common method of documenting caries in a population is to compute an observed caries rate (# of carious teeth/total # of observable teeth). However, this method does not account for ante-mortem tooth loss, and therefore, in samples with high ante-mortem tooth loss it may under-represent the true caries rate. For this reason, several different methods have recently been formulated for obtaining a more realistic assessment of caries prevalence for populations with high ante-mortem tooth loss, such as the Diseased-Missing Index (DMI) and the caries correction factor (Kelley et al., 1991; Lukacs, 1995). These techniques have not been universally adopted and many researchers still report observed caries rates, caries rates per tooth class, # of individuals with at least one caries and other similar measures (Delgado-Darias et al., 2005; Larsen et al., 1991; Littleton and Frohlich, 1993; Schollmeyer and Turner, 2004; Sealy et al., 1992). The samples analyzed in this dissertation do not exhibit a high degree of ante-mortem tooth loss and therefore I do use the DMI or the caries correction technique of Lukacs.

I scored the

1) number of carious teeth: the total number of carious teeth in the dentition

2) the number of caries: the total number of caries in the dentition

3) the number of teeth per individual

from every individual in the sample. For statistical analysis I compare the number of individuals with at least one carious lesion (referred to here as the the proportion of individuals with at least one carious lesion, the presence of caries, or caries presence) and the percentage of carious teeth (# carious teeth x 100/total # of teeth) (Delagado-Darias 2005). As the likelihood of having a carious tooth increases with the number of teeth present, I only compare individuals with at least 8 teeth present. As there are no differences in having a carious lesion or not with the individual's age-at-death, I have not further broken down the sample by age (χ^2=0.726, p= 0.394).

I use the Pearson chi-square test to compare the number of individuals with at least one caries for all of my two by two comparisons with a sample size larger than five (between the sexes and in comparisons between peasant and elite females). For comparisons with less than five cases, I use Fisher's exact tests. I use the non-parametric Kruskal-Wallis H test to compare the distribution of the number of individuals with at least one caries in all of my three by two comparisons (through time, by site, and by social class for males). As the percentage of carious teeth is not normally distributed, all statistical analyses of these data also use the non-parametric Kruskall-Wallis H test.

As discussed above, I am testing four main hypotheses in this analysis. For each hypothesis, I examine the data as a whole and then by different subgroups. For example, I compare the percentage of carious teeth between the sexes in the whole peasant population, through time, by site, and through time at each site. Therefore, each hypothesis is in fact a set of four hypotheses. Running multiple independent comparisons increases the risk of obtaining a Type I error, or of falsely rejecting the null hypothesis.

To keep the risk of a Type I error equal to 5% (i.e. a 95% confidence level), for four comparisons the alpha must be set at 0.0127. Therefore, I only consider p-values that are 0.0127 or lower to be statistically significant. P-values close to the accepted alpha will be discussed with respect to their relationship to the statistically significant results. In addition to these main hypotheses, I also compare the proportions of individuals with a carious tooth and the percentage of carious teeth in the total skeletal sample by sex, through time and by site. The alpha level for these tests is 0.017, the appropriate α to reduce the risk of a Type I error for three comparisons (Motulsky, 1995).

RESULTS

Two-hundred twenty seven individuals have eight or more teeth and therefore, are included in the analysis of caries. The average number of teeth per skeleton in the total sample is 23.18, or 72.4% of the total dental arcade. Table 6.1 indicates that there are no significant differences in the average number of observable teeth between male and female skeletons, among the sites, time periods or among the different social classes. Of the total sample, 27% (93/227) of dentitions have at least one carious tooth and an average of 3.9% carious teeth. Twenty-nine percent (57/138) of male skeletons and 28.1% (34/81) of female skeletons in the total sample have at least one carious lesion. Male skeletons have a caries on an average of 3.6% of their teeth and female skeletons have an average of 4.6% of their teeth affected by caries. There is no significant relationship between average age-at-death and the presence of a caries in the total sample (χ^2= 0.726, p=0.394). As indicated in Table 6.2, the difference in both the presence of

TABLE 6.1. Statistical comparisons of the average number of observable teeth in the total sample

Comparison	*Mean # teeth*	*Statistic*	*p*
Between sexes	M = 23.83 F = 22.34	t=1.615	0.108
Among time periods	Early = 23.04 Middle = 24.18 Late = 21.96	F=1.688	0.187
Among sites	Øm Kloster = 22.35 St. Mikkel = 24.00 Ribe = 23.92	F= 1.703	0.185
Among social classes	Peasant =21.80 Elite = 23.33 Monk =23.71	F= 0.759	0.471

No values are significant at α= 0.127

caries and the percentage of carious teeth in the total sample are not significant when compared among the sexes, by time period or among sites.

TABLE 6.2. Statistical comparisons of caries distribution in the total sample

Comparison	*Lesion*			χ^2	*p*
Caries presence		# affected/N			
Between sexes	M = 57/138	F = 34/81		0.009	0.923
By time period	E = 45/105	M = 28/71	L = 19/50	0.399	0.819
Among sites	Ø = 41/111	S = 28/52	R = 24/64	4.610	0.100
% carious teeth		%			
Between sexes	M = 3.6	F = 4.6		0.238	0.626
By time period	E = 3.9	M = 3.1	L = 5.1	0.738	0.819
Among sites	Ø = 4.3	S = 3.9	R = 3.1	3.070	0.215

M = Male, F = Female; E = Early, M = Middle, L = Late;
Ø = Øm Kloster, S = St. Mikkel, R = Ribe
No values are significant at α= 0.017

Comparisons between the sexes

Table 6.3 provides the distribution of carious lesions and the statistical comparisons of caries presence and the percentage of carious teeth between the sexes in the peasant sample. There are no statistically significant differences between the sexes in either the number of individuals with a carious tooth or the percentage of carious teeth in either the total peasant sample or when the sample is broken down by site, time period or by time and site. However, in the late period sample overall, and specifically the late period at Øm Kloster, female dentitions have a higher percentage of carious teeth than male dentitions. These results are not statistically significant for this analysis ($p = 0.038$ and $p = 0.028$, respectively), however, they do suggest that there may have been slight dietary differences between the sexes in the late period at Øm Kloster.

Øm Kloster is the only site with an elite or monastic component, therefore, all discussions of caries distribution in elites or monks are limited to this sample. Table 6.3 also illustrates that there are no significant differences in caries distribution between the sexes in the total elite sample (N=19). Due to the very small elite sample size it is not feasible to break the elite sample further by time period.

Comparisons through time

Table 6.4 provides information on the presence of caries and the percentage of carious teeth through time. There are no significant differences in either the number of dentitions with a caries or the percentage of carious teeth in the total peasant sample. There are also no significant differences when the peasant sample is further divided by site. However, the p-values from the comparisons of both the number of dentitions with

TABLE 6.3. Statistical comparisons of carious lesions between the sexes in the peasant and elite sample

Comparison	Lesion by sex		df	χ^2	*P*
Caries presence	# affected/N				
Total Peasant sample	M = 49/111	F = 33/74	1	0.004	0.952
Peasants at Øm Kloster	M = 16/45	F = 15/29	1	1.894	0.169
Peasants at St. Mikkel	M = 14/27	F = 13/23	1	0.109	0.741
Peasants at Ribe	M = 19/39	F = 5/22	1	3.981	0.046
Elite sample	M = 5/12	F = 1/7			0.333
Peasants in Early period	M = 27/52	F = 14/34	1	0.952	0.329
Øm Kloster	M = 6/20	F = 5/12			0.703
St. Mikkel	M = 6/10	F = 6/13			0.680
Ribe	M = 15/22	F = 3/9			0.114
Peasants in Middle period	M = 16/39	F = 7/19	1	0.093	0.760
Øm Kloster	M = 7/15	F = 1/5			0.603
St. Mikkel	M = 6/15	F = 6/8			0.193
Ribe	M = 3/9	F = 0/6			0.229
Peasants in Late period	M = 6/20	F = 11/20	1	2.558	0.110
Øm Kloster	M = 3/10	F = 8/11			0.086
St. Mikkel	M = 2/2	F = 1/2			1.000
Ribe	M = 1/8	F = 2/7			0.569
% of carious teeth	%				
Total Peasant sample	M = 3.8	F = 4.9	1	0.271	0.630
Peasants at Øm Kloster	M = 4.1	F = 7.4	1	1.450	0.229
Peasants at St. Mikkel	M = 3.0	F = 4.9	1	1.618	0.203
Peasants at Ribe	M = 4.1	F = 1.8	1	3.201	0.074
Elite sample	M = 3.6	F = 0.5	1	2.059	0.151
Peasants in Early period	M = 4.6	F =3.8	1	0.248	0.618
Øm Kloster	M = 3.0	F = 2.4	1	0.135	0.713
St. Mikkel	M = 3.9	F = 5.9	1	0.507	0.476
Ribe	M = 6.4	F = 2.4	1	2.650	0.104
Peasants in Middle period	M = 3.5	F = 1.9	1	0.276	0.760
Øm Kloster	M = 6.0	F = 1.0	1	1.517	0.208
St. Mikkel	M = 2.1	F = 3.9	1	2.693	0.101
Ribe	M = 1.7	F = 0.0	1	2.299	0.129
Peasants in Late period	M = 2.4	F = 10.0	1	4.301	0.038
Øm Kloster	M = 3.3	F = 16.2	1	4.833	0.028
St. Mikkel	M = 5.8	F = 1.9	1	2.400	0.121
Ribe	M = 0.5	F = 2.6	1	0.828	0.363

M = Males, F = Females

No values are significant at α=0.0127

TABLE 6.4 Comparisons of carious lesions through time in the peasant sample

Comparison	Lesions by period	Df	χ^2	*P*
Caries presence	#affected/N			
Total peasant sample	E = 43/93 M = 23/59 L = 17/40	2	0.781	0.677
Male	E = 27/52 M = 16/39 L = 6/20	2	3.025	0.220
Female	E = 14/34 M = 7/19 L = 11/20	2	1.467	0.480
Øm Kloster peasant	E = 12/34 M = 8/21 L = 11/21	2	1.632	0.442
Male	E = 6/20 M = 7/15 L = 3/10	2	1.185	0.552
Female	E = 5/12 M = 1/5 L = 8/11	2	4.249	0.120
Øm Kloster elite	E = 1/6 M = 3/5 L = 2/8			
Øm Kloster monks	E = 1/6 M = 2/7 L = 0/1			
St. Mikkel peasant	E = 13/25 M = 12/23 L = ¾	2	0.765	0.682
Male	E = 6/10 M = 6/15 L = 2/2	2	2.857	0.240
Female	E = 6/13 M= 6/8 L = ½	2	1.640	0.440
Ribe peasant	E = 18/34 M = 3/15 L = 3/15	2	7.264	0.026
Male	E = 15/22 M = 3/9 L = 1/8	2	8.174	0.017
Female	E = 3/9 M = 0/6 L = 2/7	2	2.365	0.307
% carious teeth	%			
Total peasant sample	E = 4.2 M = 2.9 L = 6.2	2	1.700	0.428
Male	E = 4.6 M = 3.5 L = 2.4	2	3.462	0.177
Female	E = 3.7 M = 1.9 L = 10.0	2	4.190	0.123
Øm Kloster peasant	E = 2.9 M = 4.5 L = 10.0	2	2.887	0.236
Male	E = 3.0 M = 6.0 L = 3.2	2	1.755	0.416
Female	E = 2.4 M = 1.0 L = 16.2	2	8.062	0.018
Øm Kloster elite	E = 2.6 M = 4.6 L = 0.9			
Øm Kloster monks	E = 0.5 M = 2.9 L = 1.7			
St. Mikkel peasant	E = 4.9 M = 2.7 L = 3.8	2	1.669	0.434
Male	E = 3.9 M = 2.1 L = 5.8	2	3.770	0.152
Female	E = 5.9 M = 3.9 L = 1.9	2	1.011	0.603
Ribe peasant	E = 4.8 M = 1.0 L = 1.5	2	7.602	0.022
Male	E = 6.4 M = 1.7 L = 0.5	2	8.821	0.021
Female	E = 2.4 M = 0 L = 2.6	2	2.268	0.322

E= Early period, M= Middle period, L=Late period
No values are significant at α=0.0127

a carious lesion and the percentage of carious lesions at the site of Ribe are near the significance level set for this analysis (p = 0.026 and p = 0.022, respectively). Therefore, I divided each site by sex to gain further information on the distribution of caries through time. In both the total Ribe sample and the male Ribe sample more dentitions from the early period have a carious lesion and a higher percentage of teeth with a carious lesions than those from the middle or late periods. However, these results are not statistically significant ($p = 0.017$ and $p = 0.021$ respectively), and merely suggest that the proportion of dentitions with caries diminished through time at Ribe. Although not statistically significant, it is interesting that the female dentitions in the Øm Kloster sample have a higher percentage of carious teeth in the late period than during the early or middle periods ($p = 0.018$). There are no significant, or near significant values through time at the other sites when broken down by sex. The sample size of the elite and monastic sample is too small for significance testing in caries distribution through time, however, Table 6.4 provides the proportion of elite and monastic individuals with at least one caries and the average percentage of carious teeth in these samples.

Comparisons among the sites

As indicated in Table 6.5, there are no significant differences among the sites in carious lesions in the total peasant sample, or when the sample is further divided by time period. In comparing the sites through time, there are a few p-values near the α-level set for these tests that are clarified by breaking the sample down by sex. Therefore, I have, also divided the sample by sex to compare lesion distribution among the sites. There are no significant differences among the sites in proportion of individuals with at least one caries or the percentage of carious teeth in the total male or female skeletal samples. Figure 6.1 illustrates caries presence and the percentage of carious teeth when the sample is divided by both time and sex. Although none of these differences are significant at the

TABLE 6.5 Comparisons of the proportion of individuals with a carious lesion and the mean percentage of carious teeth per dentition among the sites in the peasant sample

Comparison	Lesions by site			df	X^2	*P*
Caries presence	# affected/N					
Total peasant	Ø = 32/77	S = 28/52	R = 24/64	2	3.303	0.192
Male	Ø = 16/45	S = 14/27	R = 19/39	2	2.307	0.316
Female	Ø = 15/29	S = 13/23	R = 5/22	2	6.095	0.047
Early Period	Ø = 12/34	S = 13/25	R = 18/34	2	2.559	0.278
Male	Ø = 6/20	S = 6/10	R = 15/22	2	6.318	0.042
Female	Ø = 5/12	S = 6/13	R = 3/9	2	0.352	0.839
Middle Period	Ø = 8/21	S = 12/23	R = 3/15	2	3.895	0.143
Male	Ø = 7/15	S = 6/15	R = 3/9	2	0.413	0.813
Female	Ø = 1/5	S = 6/8	R = 0/6	2	8.636	0.013
Late Period	Ø = 11/21	S = 3/4	R = 3/15	2	5.533	0.053
Male	Ø = 3/10	S = 2/2	R = 1/8	2	5.542	0.063
Female	Ø = 8/11	S = 1/2	R = 2/7	2	3.223	0.200
% carious teeth	%					
Total peasant	Ø = 5.3	S = 3.9	R = 3.1	2	2.311	0.315
Male	Ø = 4.0	S = 3.0	R = 4.1	2	0.706	0.703
Female	Ø = 7.4	S = 4.9	R = 1.8	2	6.044	0.049
Early Period	Ø = 2.9	S = 4.9	R = 4.8	2	3.249	0.197
Male	Ø = 3.0	S = 3.9	R = 6.4	2	5.181	0.075
Female	Ø = 2.4	S = 5.9	R = 2.4	2	2.502	0.286
Middle Period	Ø = 4.5	S = 2.7	R = 1.0	2	3.304	0.192
Male	Ø = 6.0	S = 2.1	R = 1.7	2	1.791	0.408
Female	Ø = 1.0	S = 3.9	R = 0.0	2	7.862	0.020
Late Period	Ø = 10.0	S = 3.8	R = 1.4	2	5.431	0.066
Male	Ø = 3.2	S = 5.8	R = 0.5	2	6.864	0.032
Female	Ø = 16.2	S = 1.9	R = 2.6	2	5.156	0.076

Ø = Øm Kloster, S = St. Mikkel, R = Ribe
No values are significant at α=0.0127

α=0.0127 used to avoid Type I errors, a fewer proportion of male dentitions in the early period have a carious tooth at the site of Øm Kloster (*p*=0.042), more female skeletons in the middle period from the site of St. Mikkel have a carious lesion and a higher percentage of carious teeth than among the female skeletons from the other sites (*p*=0.013 and *p*=0.020 respectively). These results are very close to the alpha level set for this

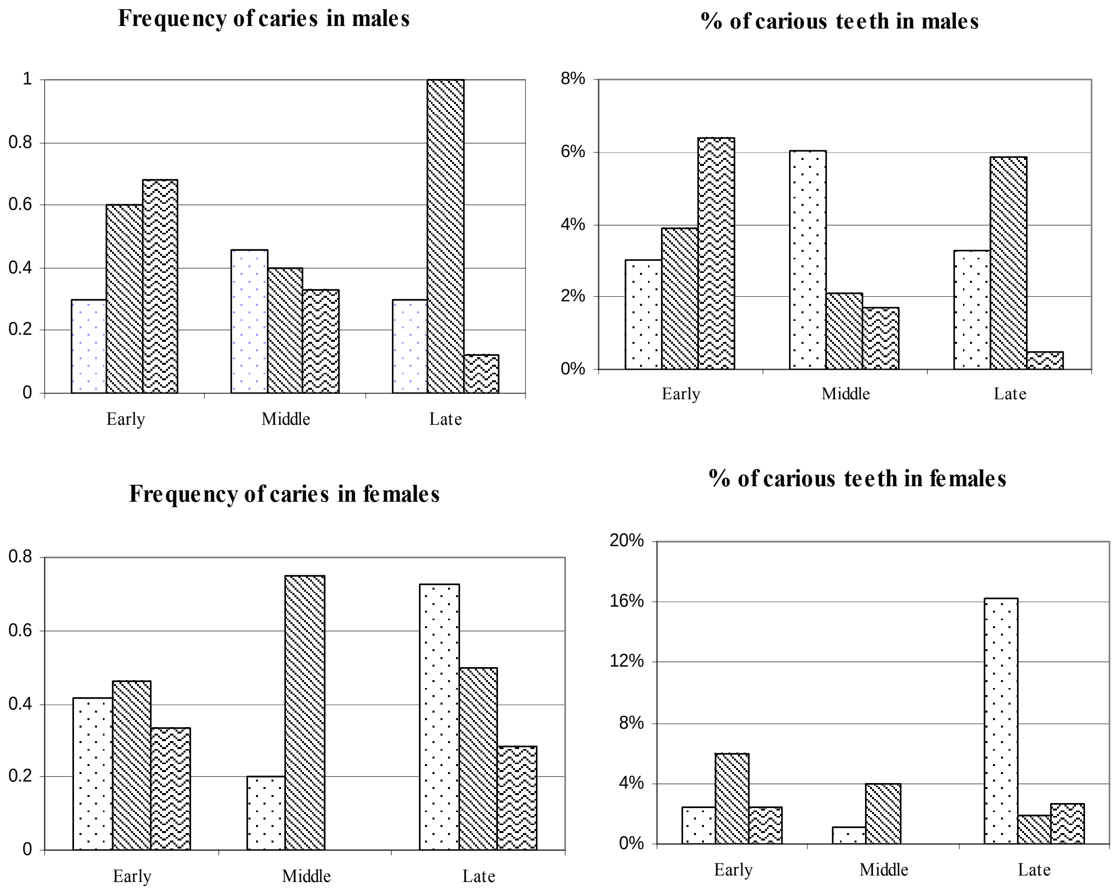

FIGURE 6.1. Frequency and percentage of carious teeth by site (Øm Kloster= dots, St. Mikkel= diagonal lines, Ribe= wavy lines)

analysis. In addition, female dentitions from Ribe have the lowest percentage of carious teeth than the other sites in the total peasant sample and male skeletons from the late period at St. Mikkel have a higher percentage of carious teeth than from the other sites (p=0.049 and p = 0.032 respectively).

Comparisons by social class

Table 6.6 provides statistical comparisons of carious lesions among the social classes at Øm Kloster. There are no significant differences in either the number of dentitions with a carious tooth or the percentage of carious teeth between elites and peasants when the sexes are pooled. The types of social classes represented in the sample differ by sex. Therefore, I have further divided the Øm Kloster sample by sex. There are

TABLE 6.6.Comparison of carious lesions by social status at Øm Kloster

Comparison	Lesions by status	df	χ^2	*P*
Caries presence	# affected/N			
Total sample	P = 32/77 E = 6/19 M = 3/14	1	0.635	0.426
Males	P = 16/45 E = 5/12 M = 3/14	2	1.332	0.514
Females	P = 15/29 E = 1/7	1		0.104
Early period	P = 12/34 E = 1/6 M = 1/6			0.643
Males	P = 6/20 E = 1/5 M = 1/6	2	0.516	0.772
Females	P = 5/12 E = 0/1			1.000
Middle period	P = 8/21 E = 3/5 M = 2/7			0.620
Males	P = 7/15 E = 3/4 M = 2/7	2	2.127	0.345
Females	P = 1/5 E = 0/1			1.000
Late period	P = 11/21 E = 2/8 M = 0/1			0.238
Males	P = 3/10 E = 1/3 M = 0/1	2	0.412	0.814
Females	P = 8/11 E = 1/5			0.106
% carious teeth	%			
Total sample	P = 5.3 E = 2.4 M = 1.7	1	1.000	0.317
Males	P = 4.1 E = 3.6 M =1.7	2	1.332	0.514
Females	P = 7.4 E = 0.1	1	3.565	0.059
Early period	P = 2.9 E = 2.6 M = 0.1	1	0.406	0.524
Males	P = 3.0 E = 3.1 M = 0.1	2	0.707	0.702
Females	P = 2.4 E = 0.0	1	0.580	0.446
Middle period	P = 4.6 E = 4.7 M = 2.9	1	0.335	0.563
Males	P = 6.0 E = 5.8 M = 2.9	2	1.295	0.523
Females	P = 1.0 E = 0.0	1	0.200	0.655
Late period	P = 10.0 E = 0.9 M = 0.0	1	2.929	0.087
Males	P = 3.3 E = 1.4 M = 0.0	2	0.386	0.824
Females	P = 16.2 E = 0.7	1	4.787	0.029

P = Peasant, E = Elite, and M = Monk
No values are significant at α=0.0127

no significant differences among male elites, peasants and monks overall or in any time period. There are no significant differences in the presence of a carious tooth or the percentage of carious teeth between elite and peasant females in the total Øm Kloster sample or in the female skeletal sample in any time period. However, in the late period, peasant females have a higher percentage of carious teeth than elite females. This result is not significant ($p = 0.029$), and merely suggests that of a class-based differences in caries distribution might be found in a larger sample. The lack of significant differences may be the result of the very small sample size of the elite and monastic samples.

DISCUSSION

Table 6.7 summarizes the patterning in the distribution of caries for each hypothesis. There are no significant differences in caries distribution between the sexes in the total, peasant or elite samples. There are also no statistically significant differences when the sub-samples are further divided by both site and period. However, a higher proportion of peasant female dentitions have a carious lesion and a higher percentage of carious teeth than male dentitions from both the late period sample as a whole, and in the late period sample from the site of Øm Kloster. These results are only of marginal significance, but may suggest dietary differences between the sexes in the late period. Females in the late period possibly had a more cariogenic diet than males, suggesting that females perhaps ate more cereal grains than their male counterparts in the late period. As these results are not statistically significant, they do not reject the null hypothesis that

TABLE 6.7. Summation of differences in caries distribution in the study sample

Comparison	Statistically significant differences (*p*-values <0.0127)	Marginally significant differences (*p*-values:0.05 - 0.0128)
By sex *(M=male, F= female)*	None	F>M (Late period)
Through time *(E= early, M= middle, L= late)*	None	E > M, L (Males at Ribe) L>E, M (females at Øm Kloster)
Among sites *(Ø= Øm Kloster, S=St. Mikkel, R= Ribe*	None	S> Ø , R (Middle period females) S> Ø , R (Late period males)
By class *(P= peasant, E= Elite, M= monk)*	None	P > E (Late period females)

there are no differences in caries lesion distribution by sex. However, they do provide a very tentative support to the expectation that females had a more cariogenic diet than males. There are no significant differences in carious lesions between the sexes in the elite sample which indicates that there were no significant differences in the cariogenicity of the diet between elite males and females.

There are no significant differences in carious lesion distribution when the peasant, elite or monastic samples are examined through time. However, both the total Ribe sample and the male sample from Ribe have a higher proportion of dentitions with a carious tooth and a higher percentage of carious teeth in the early period than the later periods. As in the discussion of carious lesion distribution by sex, these results are not significant at the alpha set for this analysis. However, they do suggest that the cariogenicity of the diet may have decreased slightly through time among the peasants at

Ribe. This tentatively supports my expectation that the abundance of caries would decrease through time as the diet became less dependent on cereal grains. There are no statistically significant differences in the abundance of carious lesions in peasants at Øm Kloster through time when the sexes are pooled or when divided by sex. However, female peasants in the late period have a higher percentage of carious teeth than in earlier periods. As at Ribe, this result is only of marginal significance, but contrary to my hypothesis may suggest that, the cariogenecity of the diet of the female peasants at Øm Kloster increased through time, perhaps indicating a strong reliance on cereal grains in late period females. There are no statistically significant, or marginally significant, differences in caries in the St. Mikkel sample, indicating that there was no major change in the abundance of caries through time at this site. If real, the difference in patterning of caries abundance through time at Øm Kloster and Ribe may be the result of the difference in the nature of the sites. As a trade city Ribe was involved in the export of cattle from the Danish countryside with cities in Germany, and therefore the residents of Ribe may have had greater access to meat than their rural counterparts at Øm Kloster (Poulsen, 1997).

The comparison of caries abundance among the sites reveals no significant differences in caries distribution in the total peasant sample or when compared by sex. However, in the middle period more females from St. Mikkel, and fewer at Ribe, have a carious tooth and a lower percentage of carious teeth than at any other sites. Males from the late period at St. Mikkel have a higher percentage of carious teeth than at the other sites. Interestingly, in both the male and female sub-samples, the site of Ribe has the lowest abundance of caries. As discussed above, meat and meat products were likely more readily available to the individuals living in Ribe because of its role in the trade network, whereas those interred at St. Mikkel were very poor and likely subsisted mainly on cereal grains. These results are not statistically significant at the $p = 0.0127$ level, and therefore, only suggest a site based differences in diet. They do support the prediction that the individuals interred at St. Mikkel ate the highest abundance of caries of any site, and therefore, that individuals at St. Mikkel had a more cereal grain dependent diet than those at the other sites. However, the cemetery of St. Mikkel was located outside the Viborg city walls, possibly indicating a more marginal status, and was used by both the local peasant population as well as the residents of a local hospital. Thus, in comparison with the other sites, the higher reliance on cereal grains in the diet of those interred at St. Mikkel, likely reflects their low status in society and not the diet of the general population at Viborg, i.e. this is may be a class difference and not a regional trend. As these results are not statistically significant, they fail to reject the null hypothesis that there is no site-based patterning to the distribution of carious lesions.

The comparison of caries by social class at Øm Kloster reveals no statistically significant differences, likely due to the small sample size of the elite and monastic sample. Female peasants have a higher percentage of carious teeth than female elites in the late period, although this result is not statistically significant. However, this may indicate that female peasants and elites had different diets in the late period, and perhaps supports the findings from medieval Hungary and Lund that elites ate more animal products and less cereal grains than peasants (Frayer 1984, Arcini 1999).

CONCLUSIONS

The caries data presented here only tentatively support the prediction that females had a higher abundance of caries than males in the medieval period of Denmark, due to their more cereal grain reliant diet. Although female dentitions have a higher abundance of caries than males, these differences are not statistically significant. Therefore, while these differences provide tentative support to the prediction, they do not reject the null hypothesis that there are no significant differences in caries between the sexes. Moreover, there are no statistically significant differences in the distribution of caries through time. Although not significant, males at Ribe have a higher incidence of caries in the early period than in later periods and females at Øm Kloster have a higher percentage of carious teeth in the late period than in the earlier periods. The result for males tentatively supports the prediction that the abundance of caries decreased through time as the diet became more meat based. However, the result for females at Øm Kloster implies that the cariogenicity of the diet was higher in the late period than during earlier periods for the females at this site, suggesting that there was a difference in dietary patterning between the sexes through time. As none of these differences are statistically significant, they fail to reject the null hypothesis that there are no differences in caries abundance through time.

There are also no statistically significant differences in the distribution of caries among the sites. However, there are differences that near significance. These differences suggest that the individuals interred at the St. Mikkel cemetery have a higher abundance of carious lesions than those from the other sites, and thus that individuals at St. Mikkel had a more cereal grain reliant diet than those from the other sites. However, instead of reflecting a regional dietary shift, this may represent a class-based difference in diet as the highest abundance is found in the poorest cemetery population. As none of these differences was statistically significant, the null hypothesis that there are no differences in caries distribution by site can not be rejected. Finally, there are no significant differences in caries abundance among elites, peasants and monks, likely due to the small sample size of elites and monks. Although female peasants have a higher abundance of caries than elites in the late period, this result is not significant, and therefore, it is not possible to reject the null hypothesis that peasants have a higher abundance of caries than elites or monks.

CHAPTER VII

CRIBRA ORBITALIA AND POROTIC HYPEROSTOSIS

Cribra orbitalia and porotic hyperostosis are porotic lesions of the cranium that are generally considered to be bony responses to long-term childhood anemia(El-Najjar, 1976; El-Najjar et al., 1975; Stuart-Macadam, 1985; Ubelaker, 1992; Walker, 1986). Anemia is the condition of reduced hemoglobin concentration or low red blood cell count that results in a lower oxygen content in the blood. It can be caused by a variety of disorders that result in the reduced ability of the red blood cells to carry and exchange oxygen to the body's tissues (Ortner, 2003). Anemia affects the individual's ability to fight disease, their activity level, work capacity and cognitive abilities (Lozoff et al., 1991; Pollitt, 1994; Ryan, 1997; Viteri and Torun, 1974; Walter et al., 1989). This chapter presents the results and discussion of the patterning of cribra orbitalia and porotic hyperostosis in the skeletons from the three cemetery samples analyzed in this dissertation.

In children suffering from anemia, the hemopoeitic tissue inside the diplöic space between the internal and external table of the cranial vault and orbits expands to allow for greater red blood cell production. As the diplöe expands, the diplöic trabeculae are reoriented to a vertical, hair-on-end pattern. The result of this is hyperostosis and/or porosity on the outer table of the skull vault and orbits from the protrusion of the diplöe through the outer table. Porotic hyperostosis refers to hyperostosis and porosity on the skull vault and cribra orbitalia is hyperostosis and porosity on the orbits (Ortner, 2003).

There are four stages in the development of porotic hyperostosis (Schultz, 1993; Schultz, 2001). The superficial feature of the first of these stages is the regular, fine pitting in small circumscribed areas of the external vault of the parietal, frontal and occipital. During the second stage, the affected area is enlarged and the pitting becomes more irregular. The diplöe are oriented perpendicularly to the external table in the hair-on-end pattern. In the third stage, the affected areas are notably thickened and the pores are enlarged. In the final, stage the affected areas are very thick and the pores are confluent, forming labyrinth-like structures. In all stages, the internal skull vault shows only limited involvement because the diploe growth is outward, not inward. In adults, the marrow of the diplöe does not produce red blood cells, thus cribra orbitalia and porotic hyperostosis are the result of childhood anemia only (Stuart-Macadam, 1985). The bony lesions of anemia are only very slowly remodeled and typically preserve well into adulthood, allowing the investigation of childhood anemia in adult crania. However, others argue that although the hemopoeitic marrow is largely replaced by fatty marrow in the long bones of adults, the marrow between the cranial vaults and in orbit retains some of its red blood cell production capabilities into adulthood (Sullivan, 2005). Therefore, Sullivan argues that porotic hyperostosis and cribra orbitalia may be the results of adult anemia as well as childhood anemic events. As this understanding of these lesions has not been substantiated by more intensive research, I instead interpret cribra orbitalia and porotic hyperostosis in the traditional manner, as bony indicators of childhood anemia.

Anemia can be the result of a genetic defect in hemoglobin (thalassemia and sickle cell anemia), an acquired iron deficiency, a deficiency in vitamin B_{12} or folic acid, or be due to chronic disease. There is no indication that the genetic anemias were present in medieval Europe (Ortner, 2003; Pointek and Kozlowski, 2002; Roberts and Manchester, 1985; Salvadei et al., 2001; Sullivan, 2005). Iron is essential to the production of hemoglobin, and it is the hemoglobin in the red blood cells that transports oxygen to the body's tissues (Ortner, 2003; Roberts and Manchester, 1985). In addition, iron is important for the initiation of collagen synthesis and plays an important role in cell-mediated immunity (Roberts and Manchester, 1985). A deficiency of iron in the body may be the result of an iron poor diet, excessive blood/iron loss from parasitic infection, and inadequate intestinal absorption of iron due to diarrhea (from parasites or other disease) (Ortner, 2003). Recent research suggests that the total amount of iron in the diet may not be the most important factor in the development of iron-deficiency anemia. Instead, the specific foods eaten, either alone or with other foods, may play a more important role in the occurrence of iron-deficiency anemia. Iron from meat sources is more easily absorbed by the body than iron from vegetal sources. In addition, some foods retard the absorption of iron by the body, no matter the source. These include tannins found in tea and phytates found in cereals (Danforth, 1999; Gillooly et al., 1983; Layrisse et al., 1984). The body may also be inhibited from absorbing iron from food as the result of extreme cases of diarrhea or vomiting due to intestinal parasites or infection. A high degree of blood loss from parasitism may also result in anemia. The medieval diet was likely heavily reliant on fish, both fresh and salt water, which are known to carry parasites, and intestinal parasites such as *Trichuris* and *Ascaris* spp., have been found in several sites in medieval York, England (Jones, 1982a; Jones, 1982b; Jones, 1985; Jones, 1992).

Megaloblastic anemia is the result of inadequate consumption or absorption of vitamin B_{12} or folic acid often due to diarrheal disease or intestinal parasites. Vitamin B_{12} is primarily found in liver, meat, marine fish, oysters and dairy products. Folic acid is found in leafy green vegetables, liver and many fruits (Baik and Russell, 1999; Hawkes and Villota, 1989; Sullivan, 2005). Parasitism from high B_{12} consumption of parasites found in some fresh water fish species can also result in megaloblastic anemia (Sullivan, 2005).

Finally, anemia may be the result of chronic disease. This form of anemia is a response to an existing infection in the body in which the body reduces the concentration of hemoglobin in the blood, the amount of iron in the blood and the absorption of iron from the diet as a means of providing an inhospitable environment for the invading pathogen (Cook, 1990; Weinberg, 1984, Stuart-Macadam 1992). Sanitation and health conditions in medieval Europe were poor, especially in urban environments, making the transmission of parasites from one individual to another easier. In addition to the general level of infectious disease present, the medieval period witnessed several famines and plague epidemics, suggesting that chronic disease and episodes of ill health were common features of life (Dyer, 1989; Dyer, 1994a; Dyer, 1994b; Dyer, 2002), perhaps that might result in anemia due to chronic disease.

The thickening of the diplöe of the cranial vault and the associated porosity on the external table and the orbits, which are referred to as porotic hyperostosis and cribra orbitalia, have been discussed in the paleopathological literature since the early 20th century. They have been attributed to a variety of different causes in this time, from a racial trait, to the effects of activity, to a toxic disorder, and finally to a dietary inadequacy (Stuart-Macadam, 1992). Researchers now widely understand these two conditions to be the result of anemia. Dietary iron deficiency is the most widely attributed cause of anemia in the paleopathological literature. This is largely due to the close correlation between the high consumption of cereal grains and maize and the presence of cribra orbitalia and porotic hyperostosis (Cohen and Armelagos, 1984; El-Najjar, 1976; El-Najjar et al., 1975; El-Najjar et al., 1976; El-Najjar, 1982). However, other research has emphasized the important role that parasites can play in the development of iron-deficiency anemia (Hengen, 1971). In recent years, some researchers have attributed the development of iron-deficiency anemia as an adaptive response to high parasite or disease loads in the population (Kent and Weinberg, 1989; Stuart-Macadam, 1992). They argue that cribra orbitalia and porotic hyperostosis are not nutritional stress indicators, but are instead indicators of environmental pathogen loads, and should be viewed as a successful adaptation to the environment (Stuart-Macadam, 1992). However, withholding of iron from an infectious organism also withholds iron from the human host, and, as mentioned above, this has its own costs. As the long term positive effects of iron withholding on the individual, or the adaptive benefit, is unknown at this time, but the short-term negative consequences of iron deficiencies are well understood, I do not consider an individual with porotic hyperostosis and/or cribra orbitalia to be undergoing a healthy response to infection (Goodman, 1994; Holland and O'Brien, 1997). Instead, I understand cribra orbitalia and porotic hyperostosis to be the result of a stress event, either nutritional, pathogenic or parasitic. Therefore, individuals with anemia are interpreted as having had a childhood health crisis.

METHODS

I have examined every individual in the sample for the presence of cribra orbitalia and porotic hyperostosis. I considered an individual to be well enough preserved for analysis if at least 60% of the surface of each bone to be examined was well preserved. I noted the presence or absence of cranial thickening and/or porosity on the parietals and the squamous portion of the superior occipital bone, for porotic hyperostosis and, on the upper margins of the orbits, for cribra orbitalia. If I observed porosity and/or cranial thickening, I scored the degree of expression of the lesion following Buikstra and Ubelaker (1994), as indistinct porosity only, true porosity, coalescing porosity, or coalescing porosity and vault thickening. I noted all lesions as either active or healed, and wrote descriptions of any severe cases. I found only healed lesions in the samples examined for this dissertation, suggesting that these lesions are in fact the result of childhood conditions. As I have only examined adults, I have restricted this analysis to only individuals who survived their childhood anemic event, not those individuals who were too frail to survive childhood.

For both porotic hyperostosis and cribra orbitalia, I scored both the right and left sides of the cranial vault bones and orbits (if it was a paired bone). Therefore, for statistical analysis, I consider the individual to have cribra orbitalia if they have porosity on the right, the left, or both of the orbits. For statistical purposes, I consider the individual to have porotic hyperostosis if a lesion is present on the left, right, or both parietals, or the occipital, if at least two of these three areas are well enough preserved for analysis. Individuals with only one of these areas (either the left or right parietal or the occipital) are not considered sufficiently well preserved for scoring. I consider the individual to have cribra orbitalia if they have a lesion on either their left, right or both orbits.

I use the Pearson chi-square test for all 2x2 comparisons, such as in the comparison of the prevalence of porotic hyperostosis between the sexes in the total sample. The Pearson chi-square test assumes that each cell has a minimum frequency of at least five, therefore, for comparisons with less than five cases I use Fisher's exact tests. I use the non-parametric Kruskal-Wallis *H* test for all 3 by 2 comparisons, for example to compare the distribution of porotic hyperostosis among the three sites. The Kruskal-Wallis *H* test compares a single variable for two or more groups. As discussed above, I have four main hypotheses that I am testing in this analysis. For each of these hypotheses I examine the data as a whole and then by different subgroups. For example, I compare cribra orbitalia and porotic hyperostosis between the sexes in the whole peasant population, through time, by site and through time at each site. Therefore, each hypothesis that I am testing is in fact a set of four hypotheses. Running multiple independent comparisons increases the risk of obtaining a Type I error, or of falsely rejecting the null hypothesis. To keep the risk of a Type I error equal to 5% (i.e. a 95% confidence level) for four comparisons the alpha must be set at 0.0127. Therefore, I only consider *p*-values that are 0.0127 or lower to be statistically significant. An α-level of 0.05 is the conventional value used for significance testing in anthropology. Therefore values with a *p*-value above 0.0127 and below 0.05 will also be discussed with respect to their relationship to the statistically significant results (Motulsky, 1995).

HYPOTHESES

As elaborated in Chapter IV, I am testing several historically-derived hypotheses about health and dietary conditions in medieval Denmark. I make four main comparisons:

1) male and female skeletons

2) the skeletal sample through time

3) the skeletal sample by site

4) the skeletal sample from Øm Kloster by social class.

With reference to cribra orbitalia and porotic hyperostosis, the null hypothesis is that there are no differences in the abundance of these lesions among the groups as configured above. Based on historical evidence elaborated in Chapter IV, the results are expected to reject the null hypothesis for cribra orbitalia and porotic hyperostosis lesion patterning through time, by site and by social class. As discussed in Chapter II, women in medieval Denmark enjoyed greater independence and equality in comparison with other European women, however, they were still not considered to be equal to men and therefore, women may not have had equal access to the same resources as males. It is expected that if there are differences between the sexes in the abundance of porotic hyperostosis and cribra orbitalia, that females will have a higher abundance of both. As the historical literature suggests that there was a reduction in population and concomitant surplus of land that resulted in a change from a more cereal-grain based diet to a more pastorally based diet from the early to the late period, it is likely that individuals who lived in the middle and late period will have a lower proportion of cribra orbitalia and porotic hyperostosis than the early period samples. As discussed above there are differences in the composition of each cemetery sample used in the analysis. It is expected that the skeletal sample from the St. Mikkel cemetery will demonstrate the highest abundance of porotic hyperostosis and cribra orbitalia of the three cemeteries studied here because it was composed of poorer peasants and hospital residents. In addition, for much of the period the cemetery was located outside the Viborg town walls, and therefore, those interred in it may not have had access to the same resources as the inhabitants of the city itself. It is expected that the samples from the rural monastery site of Øm Kloster and Ribe had a similar proportion of individuals with cribra orbitalia and porotic hyperostosis. Due to the historical documentation of differential access to resources among the social classes discussed in Chapters II and III, it is expected that there are significant differences in the diet and health among the peasants, elites and monk at the rural site of Øm Kloster, such that peasant skeletons likely have a higher proportion of cribra orbitalia and porotic hyperostosis

RESULTS

Table 7.1 provides the basic distribution of cribra orbitalia in the total sample. Of the 332 individuals in my total sample, 211 are well enough preserved to be included in the examination of cribra orbitalia. Ten percent of the sample included for analysis exhibits signs of cribra orbitalia. Table 7.2 presents the distribution of porotic

TABLE 7.1.Distribution of cribra orbitalia in the total sample (# affected/N)

Sex	L. orbit	R. orbit	Cribra orbitalia
Male	11/126	11/123	11/128
Female	10/74	8/74	11/76
Unknown	0/6	0/7	0/7
Total	21/206	19/204	22/204

TABLE 7.2.Distribution of porotic hyperostosis in the total sample (# affected/N)

Sex	L. parietal	R. Parietal	Occipital	Porotic Hyperostosis
Male	21/121	21/122	32/128	34/126
Female	9/70	9/72	9/73	10/72
Unknown	1/8	0/6	2/7	2/8
Total	31/199	30/200	43/208	46/206

hyperostosis in the total sample. Of the total sample 206 individuals are sufficiently preserved to be included in the analysis of porotic hyperostosis and twenty-two percent of individuals in the total sample have porotic hyperostosis. Cribra orbitalia and porotic hyperostosis are significantly correlated with one another (Pearsons correlation p=.001). There are no statistical differences in the presence of porosity on the right or left sides of paired bones (Kruskal-Wallis H test, orbits: χ^2= 0.090, p=0.764; parietals: χ^2= 0.026, p=0.873), nor is there a significant difference in the preservation of either the left or right side of paired bones (Kruskal-Wallis H test, orbits: χ^2= 0.026, p=0.873; parietals: χ^2= 0.006, p=0.937). I included 128 males and 76 females in the analysis of cribra orbitalia. I included 126 males and 72 females in the analysis of porotic hyperostosis. There is no relationship between the average age-at-death of the individual and the presence of either cribra orbitalia (Kruskal-Wallis H test, χ^2= 0.014, p=0.904) or porotic hyperostosis (Kruskal-Wallis H test, χ^2= 1.692, p=0.193) in the total sample.

Comparison between the sexes

Table 7.3 provides information on sex differences in lesion distribution in both the peasant sample and the elite sample. Using an α= 0.0127 level, no results of the comparison of the abundance of cribra orbitalia or porotic hyperostosis between the sexes are statistically significant. However, many of the comparisons are of marginal significance. Male skeletons have more porotic hyperostosis than female skeletons in the total sample (*p*=0.033). More male skeletons also have a higher abundance of porotic hyperostosis than female skeletons in the total peasant sample (*p*=0.020). A higher

TABLE 7.3. Differences in cribra orbitalia and porotic hyperostosis distribution between the sexes

Comparison	#affected/N Males	Females	*df*	χ^2	*P*
Cribra orbitalia:					
Total sample	11/128	11/76	1	1.714	0.191
Peasant sample	11/103	11/68	1	1.104	0.293
Elite sample	0/11	0/8			-*
Øm Kloster- peasants	4/51	4/31			0.469*
St. Mikkel	4/22	2/17			0.679*
Ribe	3/30	5/20			0.240*
Early period peasants	7/47	7/32	1	0.636	0.425
Middle period peasants	3/37	2/17			0.645*
Late period peasants	1/19	2/18			0.604*
Early period elites	0/5	0/2			-*
Middle period elites	0/3	0/1			-*
Late period elites	0/3	0/5			-*
Porotic Hyperostosis:					
Total sample	34/126	10/72	1	4.546	0.033
Peasant sample	30/103	9/66	1	5.437	0.020
Elite sample	2/10	1/6			1.000*
Øm Kloster- peasants	16/47	3/25	1	4.082	0.043
St. Mikkel	11/22	6/21	1	2.064	0.151
Ribe	3/34	0/20			0.287
Early period peasants	13/46	6/33	1	1.069	0.301
Middle period peasants	13/36	2/18	1	3.738	0.053
Late period peasants	4/21	0/14			0.113*
Early period elites	2/5	0/1			1.000*
Middle period elites	0/3	0/1			0.250*
Late period elites	0/2	0/4			-*

*Fisher's exact p-value, all other Pearson chi-square p-values
No values are significant at α=0.0127

proportion of male skeletons at the rural monastery site of Øm Kloster have porotic hyperostosis than female skeletons (*p*=0.043). In the early period sample, male skeletons have a marginally higher abundance of porotic hyperostosis than female skeletons (Fisher's exact *p*=0.034). When I compared the abundance of porotic hyperostosis and cribra orbitalia between the sexes through time, regardless of site, I found no significant or marginally significant differences. There are also no significant, or marginally significant, differences between the sexes in either the proportion of skeletons with cribra orbitalia or porotic hyperostosis in the total elite sample from Øm Kloster, or in any time period.

Comparison through time

Table 7.4 provides sample and lesion distribution information for the total peasant population through time. As there are no significant differences between the sexes in any period (see Table 7.3), I have pooled the sexes for a comparison of lesion patterning through time. There are no significant differences in the prevalence of cribra orbitalia and porotic hyperostosis in the peasant sample through time when the sexes and sites are pooled. There are also no significant differences in the prevalence of cribra orbitalia or porotic hyperostosis in the elite sample at Øm Kloster through time when the sexes are pooled. As there is only one monk skeleton from the late period the comparison of anemia through time is restricted to the early and middle periods for the monastic sample. There are no significant differences in the prevalence of cribra orbitalia or porotic

TABLE 7.4. Differences in lesion distribution by time period

Comparison	*# affected/N*[+]			*df*	X^{2*}	*p*
Cribra Orbitalia	E	M	L			
Total sample	14/97	5/66	3/44	2	3.036	0.219
Total peasant sample	14/85	5/55	3/37	2	2.459	0.292
Total elite sample	0/7	0/4	0/8	2	0.000	1.000
Total monk sample	0/5	0/7	0/1	2	0.000	1.000
Peasant sample at Øm Kloster	5/38	1/21	2/25	2	1.188	0.552
Peasant sample at St. Mikkel	3/18	2/18	1/4	2	0.552	0.759
Peasant sample at Ribe	6/29	2/16	0/8	2	2.173	0.337
Porotic Hyperostosis	E	M	L			
Total sample	21/95	18/67	6/43	2	2.539	0.281
Total peasant sample	19/84	17/57	4/35	2	4.156	0.125
Total elite sample	2/6	1/4	0/6	2	2.179	0.336
Total monk sample	0/5	0/6	0/1	2	0.000	1.000
Peasant sample at Øm Kloster	11/35	5/20	3/19	2	1.563	0.458
Peasant sample at St. Mikkel	7/20	11/21	0/3	2	3.429	0.180
Peasant sample at Ribe	1/29	1/16	1/13	2	0.375	0.829

[+] E= early period, M= middle period, L= late period
*Kruskall-Wallis $H\ \chi^2$ value
Values in **bold** are significant at α=0.0127

hyperostosis in the monastic sample. There are no significant differences through time in the abundance of cribra orbitalia or porotic hyperostosis in the peasants from any of the sites.

Comparison among the sites

Table 7.5 provides sample and lesion distribution information for the total peasant sample by site. As there are no statistically significant, or marginally significant, differences between the sexes in the distribution of cribra orbitalia among the sites, I have pooled the sexes for further statistical analysis. There are no significant differences in cribra orbitalia lesion distribution among the sites when the time periods are pooled, or when the sample is divided by time period. However, there are significant differences in the abundance of porotic hyperostosis among the sites in the total peasant sample, as the individuals at St. Mikkel have a significantly higher prevalence of porotic hyperostosis than those from the other sites as demonstrated in Table 7.5 and shown in Figure 7.1. When divided by sex, male skeletons from St. Mikkel have significantly higher abundance of porotic hyperostosis than male skeletons from the other sites (Kruskall-Wallis $H\ \chi^2$= 11.867, p=0.003). Although of only marginal significance the same trend is true in the female skeletal sample (Kruskall-Wallis $H\ \chi^2$= 7.083, p=0.029).

There are also significant differences in the abundance of porotic hyperostosis by site when the sample is divided into early, middle and late periods. For the early period, the skeletons from the site of Ribe have the lowest prevalence of porotic hyperostosis of any site, whereas the abundance of porotic hyperostosis is similar between Øm Kloster and St. Mikkel. Though not statistically significant, this pattern is not contradicted when the sample is further divided by sex. Males interred at the site of Ribe in the early period have a lower prevalence of porotic hyperostosis than males from other sites (Kruskall-

TABLE 7.5. Differences in lesion distribution among the sites

Comparison	*# affected/N*[+]			*df*	χ^{2*}	*p*
Cribra Orbitalia	Ø	S	R			
Total peasant sample	8/85	6/40	8/53	2	1.298	0.523
Early period sample	5/38	3/18	6/29	2	0.671	0.715
Middle period sample	1/21	2/18	2/16	2	0.776	0.679
Late period sample	2/25	1/4	0/8	2	2.178	0.337
Porotic Hyperostosis	Ø	S	R			
Total peasant sample	20/75	18/44	3/58	2	18.744	**0.000**
Early period sample	11/35	7/20	1/29	2	9.281	**0.010**
Middle period sample	5/20	11/21	1/16	2	9.408	**0.009**
Late period sample	3/19	0/3	1/13	2	0.897	0.639

[+] Ø= Øm Kloster, S= St. Mikkel, R= Ribe
*Kruskall-Wallis $H\ \chi^2$value
Values in **bold** are significant at α=0.0127

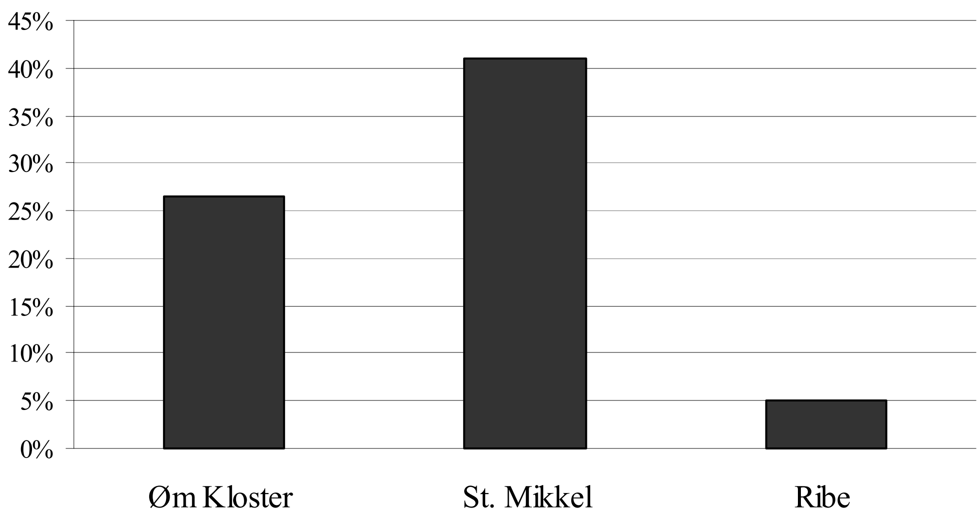

FIGURE 7.1. Porotic hyperostosis by site in the total peasant sample

Wallis H χ^2= 7.511, p=0.023). There are no significant differences in the abundance of porotic hyperostosis in the early period among the sites in the peasant female sample (Kruskall-Wallis H χ^2= 3.586, p=0.166). In the middle period the skeletons from St. Mikkel have the highest prevalence of porotic hyperostosis of any site. As before, this pattern is not contradicted when the sample is divided by sex, though the results are not statistically significant. Middle period male skeletons from St. Mikkel have a higher abundance of porotic hyperostosis than those from other sites (Kruskall-Wallis H χ^2= 6.248, p=0.044). As with the early period, there are no significant differences in the prevalence of porotic hyperostosis among the sites in the middle period female sample (Kruskall-Wallis H χ^2= 3.339, p=0.188). There are no significant differences in the abundance of porotic hyperostosis in the late period among the sites when the sexes are pooled, or when divided by sex (Kruskall-Wallis *H,* males: χ^2= 0.452, p=0.798; females: χ^2= 0.000, p=1.000).

Comparison by social class

Table 7.6 compares the distribution of cribra orbitalia and porotic hyperostosis lesions by social class. As Øm Kloster is the only site with an elite and monastic component, all comparisons by social class use only the Øm Kloster skeletal material. As there is only one monk skeleton from the late period comparisons among the social class in the late period are only made between peasants and elites. There are no significant differences in the prevalence of cribra orbitalia in the total sample or when the sample is further divided by time. There are also no significant differences in the abundance of porotic hyperostosis in the total Øm Kloster sample and when it is divided by time

TABLE 7.6. Differences in lesion distribution among peasants, elites and monks at the rural Øm Kloster site

Comparison	*# affected/N*[+]			*df*	X^{2*}	*P*
Cribra orbitalia	P	E	M			
Total Øm Kloster sample	8/85	0/19	0/13	2	3.205	0.201
Early period sample	5/38	0/7	0/5	2	1.719	0.338
Middle period sample	1/21	0/4	0/7	2	0.524	0.770
Late period sample	2/25	0/8		2	0.743	0.690
Porotic Hyperostosis	P	E	M	2		
Total Øm Kloster sample	20/75	3/16	1/12	2	2.144	0.342
Early period sample	11/35	2/6	0/5	2	2.171	0.338
Middle period sample	5/20	1/4	0/6	2	1.813	0.404
Late period sample	3/19	0/6		2	6.340	0.042

[*]Kruskal-Wallis *H* p-value,
[+]P= Peasant, E= Elite, M= Monk
No values are significant at α=0.0127

period. However, peasant skeletons have marginally more porotic hyperostosis in the late period than elite skeletons.

DISCUSSION

As summarized in Table 7.7, there are no significant differences in the distribution of cribra orbitalia or porotic hyperostosis between the sexes. Though of only marginal significance, male skeletons have more porotic hyperostosis than female skeletons in the total peasant sample and at the rural site of Øm Kloster when the sexes are pooled and in this site in the early period. These results are interesting and may suggest that male children may have had slightly more anemia than females, however, they did not have significantly more anemia. Therefore, the results of the examination of cribra orbitalia and porotic hyperostosis between the sexes indicate that the abundance of anemia between the sexes was very similar in these medieval Danish samples, as the result of a similar diet, disease or parasite load.

Table 7.7 demonstrates that there are also no significant differences in porotic hyperostosis or cribra orbitalia through time in either the peasant or elite samples. This suggests that although the historical evidence indicates a subsistence shift from the early to the late period, there was no corresponding change in the prevalence of childhood anemia. This is somewhat surprising as the hypothesized subsistence shift was from a cereal rich diet to one that was more reliant on animal products, which might lead to a reduction in anemia. However, this result would not be surprising if anemia in medieval Denmark was not due to dietary iron deficiency, but instead largely the result of blood loss due to intestinal parasites or iron-withholding due to chronic disease. As fish are

TABLE 7.7. Summary of significant and marginally significant differences in distribution of anemia in the sample

Comparison	*Statistically significant differences (p-values <0.0127)*	*Marginally significant differences (p-values: 0.05 - 0.0128)*
By sex *(M=male, F= female)*	None	M>F (total peasant sample; Øm Kloster peasant sample; early period Øm Kloster peasant sample)
Through time *(E= early, M= middle, L= late)*	None	None
Among sites *(Ø= Øm Kloster, S=St. Mikkel, R= Ribe*	S> Ø , R: (early and middle period samples)	None
Among classes *(P= peasant, E= Elite, M= monk)*	None	P>E (late period)

well-known vectors of parasites that infect humans, and were likely a common part of the medieval diet regardless of the time period, it is possible that the prevalence of anemia through time is the result of fish-borne parasites. Another possibility is that children's diet did not change through time, and the difference in subsistence was in adults only.

There are no significant differences in the prevalence of cribra orbitalia among the sites; however, as presented in Table 7.7, there are significant differences in the distribution of porotic hyperostosis among the sites. The individuals buried at the urban cemetery of St. Mikkel in the early and middle periods have the highest incidence of porotic hyperostosis, whereas those from the urban cemetery sample from Ribe have the lowest proportion of affected skeletons. This result follows the prediction laid out earlier; St. Mikkel represents a poorer peasant parish, hence the higher abundance of anemia at this site likely reflects their low status. Although the individuals from St. Mikkel have the highest abundance of porotic hyperostosis in the early and middle period samples, there are no significant differences among the sites in the late period, perhaps suggesting that there are few differences in the abundance of anemia among the sites in the late period. Alternatively, the lack of significant differences in lesion abundance among the sites in the late period may instead be the result of the smaller size of the St. Mikkel sample in the late period. However, if the lack of significant differences among the sites in the late period reflects a real decrease in the abundance of anemia through time at St. Mikkel this result would suggest that conditions improved for the residents in the St. Mikkel parish. In Chapter IV it was predicted that due to the change in subsistence from the early to the late period the abundance of anemia would decrease through time, and that this change would be the most marked in the St. Mikkel sample. Although the comparison of anemia through time resulted in no significant differences at the site of St. Mikkel, as discussed above, the lack of significant differences in anemia among the sites in the late period may reflect a decrease in lesion abundance through time at St. Mikkel. Although the higher abundance of lesions at St. Mikkel was expected and conforms to the hypothesis outlined above, the occurrence of anemia may not be the result of dietary iron deficiency at St. Mikkel and may instead/also reflect differences in the pathogen loads among the sites.

There are no significant differences in the prevalence of cribra orbitalia and porotic hyperostosis between elite and peasants in any period, or when divided by sex. This indicates that overall there were few differences in the abundance of childhood anemia by social class, suggesting that, there was little advantage to being an elite in the rural countryside around Øm Kloster. As discussed above, it is likely that this finding is the result of blood loss due to parasitism or the constant presence of chronic infectious disease.

CONCLUSIONS

Taken together, these results fail to reject the null hypothesis that there are no differences in the abundance of anemia between the sexes, through time, and among the social classes. The lack of significant differences in anemia through time may reflect the consistent presence of fish in the diet and their associated parasites. The null hypothesis that there are no differences in the abundance of anemia among the sites is also rejected by these results. The comparison of anemia among the sites supports the prediction that the prevalence of anemia was highest at the poor urban site of St. Mikkel and that the prevalence possibly decreased through time at this site.

CHAPTER VIII

PERIOSTEAL REACTIONS

Infectious disease has been among the leading causes of death throughout human history and is a vital part of any study of human health in the past. Unfortunately, many infectious disease processes leave no skeletal manifestations, making them invisible to the paleopathologist. Infectious diseases that do result in osseous lesions are often chronic in nature and may not be the direct cause of death. Inflammation is among the body's first responses to infection, and the effects of inflammation are often the initial osseous response. Periosteal reactions are one of the most common pathological conditions found in paleopathological analyses and they are routinely used by bioarchaeologists to interpret of infectious disease levels in past populations. The abundance of periosteal reactions is examined in this chapter to gain a better understanding of the health status of the samples studied here.

Periosteal reactions, or periostoses, are a response of the periosteum, the membrane that surrounds bone, to inflammation. The periosteum retains its osteoblastic capabilities throughout life and forms new bone when an inflammatory process disturbs it, as often occurs in infectious diseases. The new bone that is formed by the periosteum is woven in appearance and is superficial to the underlying cortical bone. This woven bone may later be remodeled and incorporated into the underlying bone. Periosteal bone deposited over long periods of time is generally thicker and/or irregular in appearance, and very dense. Given enough time, most periosteal lesions will be remodeled by the body and may eventually heal leaving little trace. Although periosteal reactions are often the result of infectious disease processes, they may also be the result of localized trauma, especially on bone surfaces near the skin, such as the anterior tibia (Ortner, 2003).

Distinguishing the origin of a periosteal lesion is not always straightforward as many traumas occur without fracture and many infections have no pathognomic features. Goodman and Martin (Goodman and Martin, 2002) argue that traumatically induced periosteal reactions are small, localized lesions whereas those due to infectious disease are more widespread and larger. Periosteal lesions of an infectious origin are more likely to affect multiple long bones and be systemic in nature. Periostoses of an infectious origin may be the primary result of the infection or may be secondary to a larger disease syndrome (Ortner, 2003).

In fact, abnormal periosteal bone formation is the result of many disease processes, and often cannot be used to distinguish a specific infectious agent**.** For example, periosteal reactions can be the result of bone tumors like osteiod osteoma, pulmonary conditions like hypertrophic osteoarthropathy, infectious diseases like osteomyelitis, or be the result of an overlying skin infection like an ulcer. Osteoid osteomas are small benign tumors of poorly mineralized woven bone, typically in the cortex of a long bone. Pulmonary hypertrophic osteoarthropathy is most commonly associated with cancer and is manifested in the skeleton by symmetrical periostitis on the diaphysis, usually of the tibiae, fibulae, radii and ulnae. The periosteal bone that is formed is often very dense and uneven in appearance and is thickest at the midshaft. Osteomyelitis results from the introduction of pyogenic bacteria, usually *Staphylococcus aureus* or *Streptococcus,* into the bone. This can occur due to trauma, an infection of the nearby soft tissue or through the blood stream from an infection elsewhere in the body.

The diagnostic features of osteomyelitis are the cloaca, a drainage canal in the bone, from the infected bone, and the involucrum, the periosteal bone formed around the diseased bone known as the sequestrum. In the absence of these features osteomyelitis is difficult to differentiate from other inflammatory bony lesions. Skin ulcers can result in periosteal reactions, especially on bone, or areas of the bone, that are close to the skin, like the anterior tibia. The resulting periosteal lesion typically mimics the shape of the ulcer that caused it (Ortner, 2003).

All of the above-mentioned conditions, as well as a host of others, produce periosteal reactions and may be difficult to distinguish from each other in archaeological specimens. When periosteal reactions cannot be assigned to a particular disease syndrome they are still useful to the bioarchaeologist as a non-specific indicator of infection or ill health. They indicate that the individual's health was compromised in some way (Larsen, 1997; Ortner, 2003). In addition, due to the relationship between diet and health, individuals with poor diets may be more susceptible to infection than those with more nutritious diets (Cohen and Armelagos, 1984; Larsen, 1997), and therefore, the analysis of periosteal reactions can play an important role in the discussion of both diet and health in past populations. For this reason, bioarchaeologists routinely use periosteal lesion presence as a health indicator in archaeologically derived skeletal samples (Cook and Buikstra, 1981; Goodman and Martin, 2002; Larsen, 1997; Powell, 1988; Steckel and Rose, 2002).

In addition to the nonspecific forms of infection that are normally the cause of periosteal reactions, there are two infectious diseases likely present in medieval Denmark that may produce periosteal lesions: leprosy and venereal syphilis. Unlike the conditions mentioned above, these can often be identified due to either their distinctive suite of lesions or the presence of pathognomic lesions. Leprosy has been extensively studied in medieval northern Europe, both by historians and paleopathologists (Boldsen, 2001; Boldsen and Mollerup, 2006; Moller-Christensen, 1953; Moller-Christensen, 1961; Moller-Christensen, 1978; Moller-Christensen and Faber, 1952; Moller-Christensen and Inkster, 1965). Leprosy is caused by *Mycobacterium leprae*, and was a common and much feared disease in medieval Europe (Brody, 1974). Its symptoms were clearly visible and the afflicted individual was stigmatized by society. Special institutions, leprosaria, were built to house and treat individuals thought to have leprosy (Boldsen, 2005b; Brody, 1974; Manchester and Roberts, 1989; Moller-Christensen, 1961; Moller-Christensen, 1978; Moller-Christensen and Inkster, 1965; Richards, 1977; Roberts, 1986; Roberts, 1987). By the middle of the 16th century, however, leprosy had virtually disappeared from Denmark (Boldsen, 2001). In fact, the number of reported cases of leprosy sharply declined in the latter part of the medieval period for most of Europe. This decline has been linked by some researchers to the increased presence of tuberculosis in Europe at this time (Roberts, 1987). The skeletal manifestations of tuberculosis are readily distinguished from that of leprosy, and in general, tuberculosis produces little reactive periosteal bone formation.

The body's response to leprosy is highly variable and can range from very mild to very extreme. The degree of severity is dependent on the degree of natural resistance to infection and the intensity of antibody production by the individual. If the tissue response is effective, the milder "tuberculoid" form of leprosy is the result. If the tissue response can not overcome the leprosy bacilli, then the individual suffers from the very extreme "lepromatous" form of leprosy (Brody, 1974; Ortner, 2003; Richards, 1977). The skeleton is only affected in five percent of leprosy cases. (Resnick and G., 1995). The bone changes in leprosy can consist of absorption, rarefaction or destruction of bones of the hands, feet and skull; osteomyelitis and periosteal lesions of the long bones; neurotrophic bone and joint lesions; and septic arthritis (Ortner, 2003). Among the most striking osseous changes in leprosy is the gradual resorption of the metacarpals and metatarsals, making the bones appear as if they have melted away. Periosteal bone formation on the tibiae, and especially the fibulae, is common in leprosy and is typically the result of secondary infection from the feet (Moller-Christensen, 1953; Ortner, 2003). Because this is a secondary reaction from the feet, the periosteal bone formation on the tibiae and fibulae is most extensive near the ankles and diminishes in severity toward the knee (Ortner, 2003). As the tibia is the bone most commonly affected by periosteal lesions from all causes, Boldsen recommends analyzing the fibula for periosteal changes that might indicate leprosy in any paleopathological study of skeletons that may have the disease (Boldsen, 2001).

Three of the four disease syndromes associated with infection by the spirochetal bacterium *Treponema* also result in periosteal deposition. It has been argued that the particular disease syndrome present in a given geographic region is determined by the specific climatic and social conditions in that area. In urban temperate environments, such as that of Europe, the treponemal disease known as syphilis is transmitted both venereally and congenitally from mother to fetus. In warmer, more humid climates infection is passed through direct skin-to-skin contact among children and is referred to as yaws. Endemic syphilis, or bejel, is a non-venereal form common in warm, dry climates. The final syndrome, pinta, only affects the skin and is only found in Central America today (Baker and Armelagos, 1988; Hackett, 1976; Ortner, 2003). Until recently it has been unclear whether these four syndromes are caused by different species of treponema or whether they are caused by variants of the same species (Hoeprich, 1989). However, recent DNA research suggests that there may be differences in the bacteria associated with venereal and nonvenereal forms (Centurion-Lara et al., 1998) (Ortner, 2003).

There is some debate as to the presence of venereal syphilis in Europe prior to contact with the New World (Baker and Armelagos, 1988; Dutour et al., 1994; Hackett, 1963; Ortner, 2003). There are three main hypotheses to explain the origin and spread of venereal syphilis. The Columbian hypothesis argues that different treponemal syndromes are the result of different agents and posits that venereal syphilis originated in the Americas and was introduced to the Old World by Columbus's crew. The pre-Columbian hypothesis suggests that venereal syphilis was present in the Old World before Columbus, but was not differentiated at the time from leprosy. The last hypothesis argues that syphilis was present in both the New and Old World during the Age of Discovery. Proponents of this theory argue that the different manifestations or types of treponemal infection are due to its simultaneous evolution with the wide variety of human populations. Therefore, any examination of skeletal material from this period is important as it may help clarify to this debate.

Venereal syphilis produces the most extreme bone changes of the treponematoses. The skeletal manifestations occur during the third stage of the disease, usually after two to ten years of infection. Typically the disease affects more than one bone and the involvement is usually bilateral. The tibia, the bones making up the nasal cavity, and those of the cranial vault are the most commonly affected, although any bone may be affected. The most specific and unique feature of venereal syphilis involves the gummatous lesions of the cranial vault. This lesion was named "caries sicca" by Virchow in 1858 (Ortner, 2003). This lesion results in a strong sclerotic response around the lytic focus on the outer table. These lesions heal, leaving the characteristic stellate scar, as new lytic lesions appear elsewhere on the cranial vault. Thus the series of healed and active lesions results in areas of confluent pitting surrounded by hard reactive bone. Veneral syphilis also causes destruction of the nasal bones, nasal septum, hard palate and maxillary antrum.

As mentioned above, the tibia is the most commonly affected long bone, although any long bone may be involved in syphilitic destruction. The gummatous lesions of the long bones are also a diagnostic feature of syphilis. The hypervascular periosteal bony reactions surround "scooped-out" defects that mark the location of the destructive gumma in the soft-tissue. The appearance of the long bone affected by gummatous lesions is similar to that of the caries sicca of the cranial vault (Ortner, 2003). Nongummatous lesions on the long bones resemble those of venereal syphilis, but are not diagnostic in isolation. These result in bone deposition of varying thickness on the cortex. . This periosteal bone formation is often followed by cortical thickening and, in severe cases, may fill the entire medullary cavity (Ortner, 2003).

In this study I consider periosteal reactions, of either a specific or non-specific infectious nature, to be a skeletal response to some episode of ill health. No skeletons could be identified with a particular infection. All lesions, specific or not, will be statistically analyzed in this study in order to gain a better understanding of infectious disease in medieval Denmark.

HYPOTHESES

As elaborated in Chapter IV, I am testing several historically-derived hypotheses about health and dietary conditions in medieval Denmark. I make four main comparisons in this dissertation. I compare

1) male and female skeletons

2) the skeletal sample through time

3) the skeletal sample by site

4) the skeletal sample from Øm Kloster by social class.

With reference to periosteal reactions, the null hypothesis is that there are no differences in periosteal reaction patterning among the groups as configured above. Based on historical evidence it is expected that the results will reject the null hypothesis for periosteal reactions through time, by site and by social class. As discussed in Chapter II, the activities of the sexes were very similar in medieval Denmark and therefore it is likely that both sexes were exposed to the same level of infectious agents. Hence, it is not likely that there will be significant differences in the proportion of male and female skeletons with periosteal reactions. It is expected that individuals who lived before the start of the Late Medieval Agrarian Crisis and Black Death had a higher proportion of periosteal reactions than those from the late period due to the reduction in population density and the historically noted improvement in the living conditions of the peasant class. There was likely little change in the living conditions for the elite or monastic class, and therefore, differences through time in the abundance of periosteal reactions are not expected.

As discussed in Chapter IV, it is expected that the skeletal sample from the St. Mikkel cemetery will demonstrate the highest proportion of periosteal reactions of the three cemeteries studied here because it was composed of poorer peasants and hospital residents. The sample from city of Ribe is expected to have a lower proportion of individuals with skeletal pathologies than those at St. Mikkel as the individuals interred at this cemetery were towns-people only, and there is no known component of this cemetery that was used by a hospital, unlike St. Mikkel. It is expected that the peasant sample from the rural monastery site of Øm Kloster had a similar proportion of individuals with a periosteal lesion as the sample from Ribe in the early and middle periods, because this sample is composed of rural peasants who lived in communities with a lower population density. However, as discussed in Chapter IV, there was a hospital located on the grounds of the Øm monastery in the late period, and therefore, if this hospital was widely used by the rural lay population it is expected that the late period sample from Øm Kloster will have a higher proportion of skeletal lesions similar to that of St. Mikkel. Due to the historical documentation on differences in treatment and lifestyle among the social classes presented in Chapter II, it is expected that there are significant differences in health among the peasants, elites and monk at the rural site of Øm Kloster. Peasant skeletons likely have a higher proportion of periosteal reactions than elite or monk skeletons.

PERIOSTEAL REACTION SCORING METHODS

I examined all of the sufficiently preserved long bones in my sample for the presence of periosteal reactions. I deemed a bone sufficiently preserved if at least 60% of the bone surface is in a good state of preservation. I scored any lesion I found as healed, active or mixed at the time of death and made a detailed description of the appearance and location. For statistical analyses, I consider the long bone to be affected if there is a periosteal lesion on the left side; if the left bone is not present, then the right side is counted in its place. Periosteal reactions that are adjacent to healed or healing fractures are not counted in this analysis as they may be the result of trauma and not infectious disease. To aid in statistical analysis, I also scored other composite categories. For all composite categories described below, at least half of the bones in question must be sufficiently preserved in order to be counted for scoring. I define the following composite scores:

1) "with a lesion": a skeleton with at least one long bone with a periosteal reaction,

2) "systemic infection": a skeleton with two or more long bones affected by a periosteal lesion,

3) "active lesion": a skeleton with at least one active periosteal reaction on a long bone,

4) "% affected": the number of long bones with a periosteal lesion (right and left sides) divided by the total number of observable long bones in the skeleton multiplied by 100.

I use the Pearson chi-square test for all of my comparisons of periosteal reactions between the sexes and in comparisons between peasant and elite females. For comparisons with less than five cases, I use Fisher's exact tests. I use the non-parametric Kruskal-Wallis H test to compare the distribution of periosteal reactions through time, by site and by social class in the total Øm Kloster sample and by class in the male skeletons at Øm Kloster. In addition, I use this test in all comparisons of the percentage of bones affected by a periosteal reaction as they are not normally distributed. The Kruskal-Wallis H test evaluates the difference in two or more groups based on a single variable.

As discussed above, I have four main hypotheses that I am testing in this analysis. For each of these hypotheses, I examine the data as a whole and then by different subgroups. For example, I compare periosteal reactions between the sexes in the whole peasant population, through time, by site and through time at each site. Therefore, each hypothesis that I am testing is in fact a set of four hypotheses. Running multiple independent comparisons increases the risk of obtaining a Type I error, or of falsely rejecting the null hypothesis. To keep the risk of a Type I error equal to 5% (i.e. a 95% confidence level) for four comparisons the alpha must be set at 0.0127. Therefore, I only consider *p*-values that are 0.0127 or lower to be statistically significant. An α-level of 0.05 is the conventional value used for significance testing in anthropology. Therefore, values above 0.0127 and below 0.05 will also be discussed with respect to their relationship to the statistically significant results and are referred to as marginally significant (Motulsky, 1995). In addition to these main hypotheses, I also examine the sample as a whole (sex, time period, site and social status pooled). The alpha level set for statistical significance is different for these tests. The α-level set for the correlation of the presence of a periosteal reaction on the right and left sides of the long bones is 0.05, as it is the only comparison of its kind. I also compare the total skeletal sample by sex, through time, and by site. The alpha level for these tests is 0.017, the appropriate α to reduce the risk of a Type I error for three comparisons (Motulsky, 1995).

RESULTS

The sample as a whole

Table 8.1, provides the results of a Pearson's correlation between the presence of a periosteal lesion on the left and right side of each long bone. There is a significant correlation between lesion presence on the right and left side of each long bone. Therefore, I have used the left side in all further analyses, if the left side is absent then I have substituted the right in its place. Table 8.2 provides the sample distribution used for this analysis. Appendix B provides information on the distribution periosteal reactions (# affected/*N*) of the total sample by sex, time period, site and social class. Not surprisingly, the tibia has the highest frequency of periosteal lesions in the sample overall (31%) followed by the fibula (26%). The humerus is the least affected bone (2%). In the total

TABLE 8.1. Correlation between periosteal lesion distribution on the left and right sides of the long bones and distribution of lesions in sample used in analysis

Bone	*Left*		*Right*		*Pearson's*	p
	#Affected	*N*	*#Affected*	*N*	*correlation*	
Humerus	6	261	5	268	0.537	**0.000**
Radius	8	236	5	249	0.155	**0.024**
Ulna	8	244	7	253	0.712	**0.000**
Femur	17	267	20	264	0.174	**0.009**
Tibia	81	179	89	177	0.500	**0.000**
Fibula	55	212	58	200	0.673	**0.000**

TABLE 8.2. Distribution of periosteal lesions in the total sample

Bone	*# affected/N*	*%*
Humerus	6/301	1.9
Radius	9/284	3.2
Ulna	9/285	3.1
Femur	18/301	5.9
Tibia	88/284	30.9
Fibula	63/241	26.1
With a lesion	147/289	50.8
Systemic infection	92/289	31.8
Active lesion	52/292	17.8
% affected		12

sample, 50.9% of skeletons have at least one periosteal lesion, 31.8% of skeletons have a systemic infection and 17.8% of the skeletons have at least one active lesion. There is no relationship between the average age-at-death and the presence of at least one periosteal reaction (χ^2= 1.375, p=0.241), a systemic infection (χ^2= 1.556, p=0.212) or an active infection (χ^2= 0.000, p=0.992) in the total sample. The skeletons used in this analysis have an overall average of 12% of their long bones with a periosteal reaction. None of the periosteal reactions examined in this analysis can be easily attributed to a specific infectious disease, like syphilis or leprosy, and instead likely represent a non-specific episode of ill-health.

Table 8.3 provides statistical comparisons of the distribution of periosteal lesions by sex, time period, and site in the total sample. In the sample overall male skeletons have significantly more periosteal lesions on the tibia than female skeletons. Male skeletons are also significantly more likely to have at least one periosteal lesion and a higher percentage of elements with a periosteal lesion than female skeletons. In addition to these significant results, the proportion of male skeletons that have a systemic infection

TABLE 8.3. Statistical comparisons of periosteal lesion distribution in the total sample

Bone	*Comparison by sex*	*Comparison through time*	*Comparison among sites*
Humerus	0.370	0.212	0.637
Radius	1.000	0.968	0.088
Ulna	0.322	0.115	0.101
Femur	0.635	0.626	**0.007**
Tibia	**0.007**	0.730	0.221
Fibula	0.264	0.571	0.184
With a lesion	**0.001**	0.201	**0.005**
Systemic infection	0.024	0.288	0.079
Active lesion	0.139	0.676	0.231
% affected	**0.001**	0.347	**0.008**

Values of *p* in **bold** are significant at α=0.17

is higher than females (*p*= 0.024). Although this result is not significant at the α=0.017 level, it does not contradict the trend that male skeletons have more periosteal lesions than female skeletons in the total sample. There are no significant differences through time in any long bone in the total sample. When compared by site, skeletons from Øm Kloster have significantly more periosteal lesions on the femur than those from the other sites. Significantly more skeletons from Øm Kloster also have at least one periosteal lesion and a higher percentage of long bones with periosteal lesions per skeleton.

Comparison between the sexes

Table 8.4 provides statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample overall and in the samples from each time period. In the total peasant sample, male skeletons have significantly more periosteal lesions on the tibia than do female skeletons. More male skeletons in the total peasant skeletal sample also have at least one periosteal lesion, a systemic infection, and a greater percentage of long bones with a periosteal reaction than do female skeletons. Male skeletons in the early period have more periosteal reactions on their tibiae than do female skeletons. In addition, a higher proportion of male skeletons in the early period have a systemic infection than do female skeletons, although this result is not significant, and is only of marginal significance (p=0.041). As illustrated in Figure 8.1, more middle period male skeletons have a periosteal reaction on their fibula than female skeletons from this time. In this period, significantly more male skeletons in the sample also have at least one periosteal lesion, a systemic infection, and a higher percentage of elements with a periosteal lesion per skeleton than female skeletons. Although not a statistically significant result for this analysis, a higher proportion of male skeletons in the middle period have more periosteal reaction on their tibia than female skeletons (p= 0.021). There are no significant differences in periosteal lesion abundance between the sexes in the late period.

TABLE 8.4. Statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample in each time period

Bone	*Statistical test*	*Total peasant*	*Early period*	*Middle period*	*Late period*
Humerus	Fishers exact	1.000	1.000	-	0.429
Radius	Fishers exact	0.685	0.556	1.000	1.000
Ulna	Fishers exact	0.497	0.161	0.520	0.669
Femur	Fishers exact	0.158	0.154	0.073	0.235
Tibia	Pearson's χ^2	**0.002**	**0.006**	0.021	0.776
Fibula	Pearson's χ^2	0.066	0.731	**0.008**	0.424
With a lesion	Pearson's χ^2	**0.001**	0.282	**0.000**	0.227
Systemic infection	Pearson's χ^2	**0.002**	0.041	**0.002**	0.795
Active lesion	Pearson's χ^2	0.164	0.081	1.000	0.853
% affected	Kruskal-Wallis	**0.000**	0.117	**0.001**	0.309

Values of p in **bold** are significant at α=0.0127

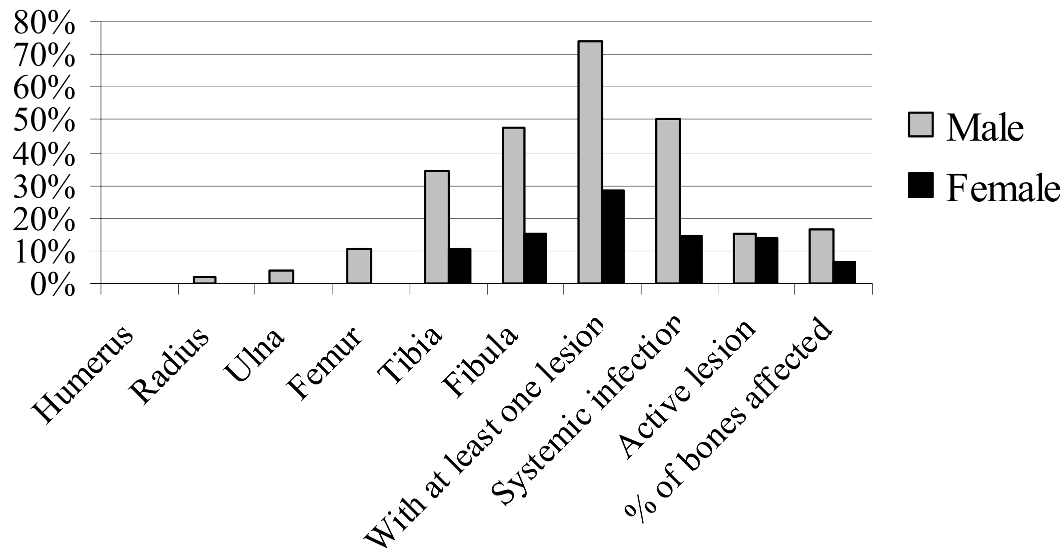

FIGURE 8.1. Differences by sex in the middle period peasant sample

Table 8.5 provides *p*-values for statistical comparisons between the sexes when the total peasant sample is divided by site. Significantly more male skeletons have at least one periosteal lesion than do female skeletons from the rural site of Øm Kloster. The male skeletons from Øm Kloster also have a marginally higher percentage of bones affected by a periosteal reaction than the do the female skeletons. Although this result is not significant at the α=0.0127 level, it does not contradict the trend that male skeletons have more periosteal reactions than female skeletons. At the site of St. Mikkel, significantly more male skeletons have evidence of systemic infections than female skeletons. Although not significant at α=0.0127, male skeletons at St. Mikkel also have more periosteal reactions on the tibia and fibula, as well as a higher percentage of bones with a periosteal lesion than female skeletons. These three results are close to the significance

TABLE 8.5. Statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample in each site

Bone	*Statistical test*	*Øm Kloster*	*St. Mikkel*	*Ribe*
Humerus	Fishers exact	0.276	-	1.000
Radius	Fishers exact	0.323	1.000	-
Ulna	Fishers exact	0.421	-	1.000
Femur	Fishers exact	0.740	0.492	1.000
Tibia	Pearson's χ^2	0.104	0.016	0.185
Fibula	Pearson's χ^2	0.683	0.021	0.515
With a lesion	Pearson's χ^2	**0.003**	0.067	0.536
Systemic infection	Pearson's χ^2	0.243	**0.005**	0.211
Active lesion	Pearson's χ^2	0.968	0.355	0.081
% affected	Kruskal-Wallis	0.029	0.023	0.323

Values of p in **bold** are significant at α=0.0127

level set for this analysis and support the general trend that male skeletons at St. Mikkel have more periosteal reactions than female skeletons. There are no significant differences, or values near significance, between the sexes at the urban site of Ribe Tables 8.6 to 8.8 indicate that there are also significant differences in periosteal lesion abundance between the sexes when the peasant sample is divided by time period and site. Table 8.6 shows that in the Øm Kloster sample during the early period significantly more male skeletons have a periosteal reaction on their tibia than do female skeletons. More male skeletons in the early period also have a periosteal reaction, a systemic infection and a higher percentage of periosteal lesions than do female skeletons. These results are close to the significance level set for this analysis and do not contradict the trend that male skeletons in the early period at this site have more periosteal reactions than female skeletons. There are no significant differences between the sexes in the middle or late periods at Øm Kloster. As indicated in Table 8.7, there are no significant

TABLE 8.6. Statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample in each time period at Øm Kloster

Bone	*Statistical test*	*Early period*	*Middle period*	*Late period*
Humerus	Fishers exact	1.000	-	0.400
Radius	Fishers exact	0.253	-	1.000
Ulna	Fishers exact	0.394	1.000	0.311
Femur	Fishers exact	0.282	0.546	0.096
Tibia	Fishers exact	**0.001**	0.546	0.198
Fibula	Fishers exact	0.613	0.505	0.395
With a lesion	Pearson's χ^2	0.018	0.088	0.064
Systemic infection	Pearson's χ^2	0.032	0.218	0.056
Active lesion	Pearson's χ^2	1.000	1.000	0.374
% affected	Kruskal-Wallis	0.019	0.078	0.636

Values of *p* in **bold** are significant at α=0.0127

TABLE 8.7. Statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample in each time period at St. Mikkel

Bone	*Statistical test*	*Early period*	*Middle period*	*Late period*
Humerus	Fishers exact	-	-	-
Radius	Fishers exact	-	1.000	-
Ulna	Fishers exact	-	-	-
Femur	Fishers exact	1.000	1.000	-
Tibia	Fishers exact	0.665	0.037	0.444
Fibula	Fishers exact	1.000	0.025	0.167
With a lesion	Pearson's χ^2	0.302	**0.009**	0.167
Systemic infection	Pearson's χ^2	0.645	0.014	0.167
Active lesion	Pearson's χ^2	0.645	1.000	0.167
% affected	Kruskal-Wallis	0.589	**0.009**	0.094

Values of *p* in **bold** are significant at α=0.0127

differences between the sexes in periosteal lesion abundance between the sexes in the early or late periods at St. Mikkel. However, in the middle period significantly more male skeletons have at least one long bone with a periosteal lesion, and a higher percentage of bones with periosteal lesions than female skeletons. In addition to these significant results, male skeletons at St. Mikkel in the middle period have marginally more periosteal reactions on both the tibia and fibula and a higher proportion of skeletons have evidence of a systemic infection than female skeletons (p=0.037, p=0.025, and p=0.014, respectively). These results are not statistically significant but do not contradict the significance of the results described above. Table 8.8 demonstrates that there are no significant differences in periosteal lesion distribution between the sexes in any period at the urban site of Ribe.

As shown in Table 8.9, there are no significant differences in periosteal lesion distribution between the sexes in elite skeletons (all of which are from the rural site of Øm Kloster) either when the time periods are pooled or when compared within each time period. However, late period elite female skeletons have more periosteal reactions on their fibulae than do elite male skeletons. Although this result is not considered statistically significant for this analysis it is near the significance level of 0.0127 (p=0.035).

TABLE 8.8. Statistical comparisons of periosteal lesion abundance between the sexes in the peasant sample in each time period at Ribe

Bone	*Statistical test*	*Early period*	*Middle period*	*Late period*
Humerus	Fishers exact	1.000	-	-
Radius	Fishers exact	-	-	-
Ulna	Fishers exact	0.341	-	1.000
Femur	Fishers exact	1.000	-	-
Tibia	Fishers exact	1.000	0.642	0.282
Fibula	Fishers exact	1.000	0.338	0.569
With a lesion	Fishers exact	1.000	0.387	1.000
Systemic infection	Fishers exact	1.000	0.642	0.576
Active lesion	Fishers exact	0.074	0.455	1.000
% affected	Kruskal-Wallis	0.722	0.466	0.415

No values of p are significant at α=0.0127

TABLE 8.9. Statistical comparisons of periosteal lesion abundance between the sexes in the elite sample in each time period at Øm Kloster

Bone	*Statistical test*	*Total elite*	*Early period*	*Middle period*	*Late period*
Humerus	Fishers exact	0.355	-	-	0.333
Radius	Fishers exact	1.000	-	0.600	-
Ulna	Fishers exact	-	-	-	-
Femur	Fishers exact	0.133	-	-	0.125
Tibia	Fishers exact	0.237	1.000	1.000	0.245
Fibula	Fishers exact	0.059	-	-	0.035
With a lesion	Pearson's χ^2	0.765	1.000	0.524	0.627
Systemic infection	Fishers exact	0.139	0.333	1.000	0.277
Active lesion	Fishers exact	1.000	1.000	1.000	0.429
% affected	Kruskal-Wallis	0.719	0.617	0.304	0.278

No values of *p* are significant at α=0.0127

Comparison through time

As indicated in Table 8.10, there are no significant differences in periostoses through time in the total peasant sample. When the peasant sample is further divided by sex there are also no significant differences in periosteal lesion abundance through time.

TABLE 8.10. Statistical comparisons of periosteal lesion abundance through time in the peasant sample

Bone	Statistical test	*Total peasants*	*Male peasants*	*Female peasants*
Humerus	Kruskal-Wallis	0.209	0.284	0.569
Radius	Kruskal-Wallis	0.926	0.851	0.495
Ulna	Kruskal-Wallis	0.062	0.147	0.155
Femur	Kruskal-Wallis	0.821	0.241	0.014
Tibia	Kruskal-Wallis	0.587	0.873	0.077
Fibula	Kruskal-Wallis	0.415	0.051	0.634
With a lesion	Kruskal-Wallis	0.205	0.019	0.576
Systemic infection	Kruskal-Wallis	0.353	0.102	0.224
Active lesion	Kruskal-Wallis	0.878	0.453	0.817
% affected	Kruskal-Wallis	0.296	0.102	0.518

No comparisons are significant at α=0.0127

However, marginally more male skeletons have a periosteal lesion in the middle period than in either the early or late periods and more female skeletons have a periosteal reaction on the femur in the late period than in either of the earlier periods. These results are close to the level of statistical significance designated for this analysis, but are not statistically significant. Table 8.11 indicates that there are no significant differences in periosteal lesion distribution through time at Øm Kloster when the sexes are pooled or in the male skeletal sample. However, female skeletons at Øm Kloster have significantly more periosteal lesions on their tibia in the late period than in either of the earlier periods. Tables 8.12 and 8.13 present the results of the comparisons of periosteal lesion abundance through time at St. Mikkel and Ribe. There are no significant differences through time in either of these samples either when the sexes are pooled or when the sample is divided by sex.

TABLE 8.11. Statistical comparisons of periosteal lesion abundance through time in the peasant sample at Øm Kloster

Bone	*Total* p	*Male* p	*Female* p
Humerus	0.552	0.497	0.814
Radius	0.450	0.627	0.692
Ulna	0.299	0.289	0.336
Femur	0.324	0.151	0.069
Tibia	0.317	0.198	**0.001**
Fibula	0.824	0.502	0.404
With a lesion	0.116	0.244	0.279
Systemic infection	0.811	0.073	0.055
Active lesion	0.781	0.945	0.417
% affected	0.498	0.249	0.185

Kruskal-Wallis H p-value, *p*-values in **bold** are significant at $\alpha=0.0127$

TABLE 8.12. Statistical comparisons of periosteal lesion abundance through time in the peasant sample at St. Mikkel

Bone	*Total* p	*Male* p	*Female* p
Humerus	0.440	1.000	1.000
Radius	0.373	0.624	1.000
Ulna	1.000	1.000	1.000
Femur	0.818	0.837	1.000
Tibia	0.651	0.689	0.304
Fibula	0.717	0.627	0.257
With a lesion	0.386	0.145	0.068
Systemic infection	0.621	0.319	0.666
Active lesion	0.847	0.983	0.593
% affected	0.370	0.180	0.112

No Kruskal-Wallis H p-values are significant at α=0.0127

TABLE 8.13. Statistical comparisons of periosteal lesion abundance through time in the peasant sample at Ribe

Bone	*Ribe*		
	Total p	*Male* p	*Female* p
Humerus	0.635	0.665	1.000
Radius	1.000	1.000	1.000
Ulna	0.491	0.082	0.545
Femur	0.607	0.665	1.000
Tibia	0.931	0.661	0.876
Fibula	0.343	0.234	0.993
With a lesion	0.404	0.472	0.663
Systemic infection	0.305	0.454	0.859
Active lesion	0.410	0.124	0.350
% affected	0.376	0.412	0.994

No Kruskal-Wallis H p-values are significant at α=0.0127

Table 8.14 demonstrates that there are no significant differences in the distribution of periosteal lesions in the elite sample through time when the sexes are pooled. I have not further divided the elite sample by sex as the resulting sample size

TABLE 8.14. Statistical comparisons of periosteal lesion abundance through time in the elite sample at Øm Kloster

Bone	*Total elite*	*Monk*
Humerus	0.587	1.000
Radius	0.387	0.083
Ulna	1.000	1.000
Femur	0.356	1.000
Tibia	0.289	0.617
Fibula	0.249	0.789
With a lesion	0.929	1.000
Systemic infection	0.515	0.789
Active lesion	0.280	0.453
% affected	0.910	0.820

No Kruskal-Wallis *H* p-values are significant at $\alpha=0.0127$

is too small for statistical comparison. The late period monastic sample is also too small for a statistically valid comparison and so the chronological comparison of this sample is between the early and middle period samples only. There are no significant differences in periosteal reaction distribution in the monastic sample from the early to the middle period.

Comparison among sites

Table 8.15 provides information on the statistical comparisons of the peasant sample among the sites. As illustrated in Figure 8.2, when the sexes are pooled, the skeletons from Øm Kloster have a significantly higher abundance of periosteal lesions on the femur than do skeletons from the other sites. The skeletal sample from Øm Kloster also has significantly more individuals with at least one periosteal lesion and a higher percentage of bones affected by a lesion than the other skeletal samples. In addition, the

TABLE 8.15. Statistical comparisons of periosteal lesion abundance among the sites in the peasant sample

Bone	*Total* p*	*Male* p*	*Female* p*
Humerus	0.601	0.714	0.128
Radius	0.087	0.437	0.025
Ulna	0.024	0.263	0.062
Femur	**0.001**	0.123	0.045
Tibia	0.280	0.999	0.522
Fibula	0.243	0.043	0.614
With a lesion	**0.003**	**0.009**	0.817
Systemic infection	0.043	0.300	0.169
Active lesion	0.251	0.744	0.132
% affected	**0.002**	0.049	0.518

*Kruskal-Wallis H *p*-values in **bold** are significant at α=0.0127

skeletons at Øm Kloster have more periosteal reactions on the ulna and the fibula. These results approach significance and do not contradict the trend that the peasant skeletons from Øm Kloster have more periosteal reactions than those from the other sites. When the total peasant sample is divided by sex, more male peasant skeletons at Øm Kloster have at least one periosteal reaction than those from the other sites. Although not significant, more male skeletons at Øm Kloster also have a higher percentage of periosteal reactions than male skeletons from the other sites. More male skeletons at St. Mikkel have a periosteal reaction on the fibula than at the other sites, although this result is also not significant at the α-level set for this analysis. There are no significant differences among the sites at α=0.0127 in the female peasant skeletal sample, however,

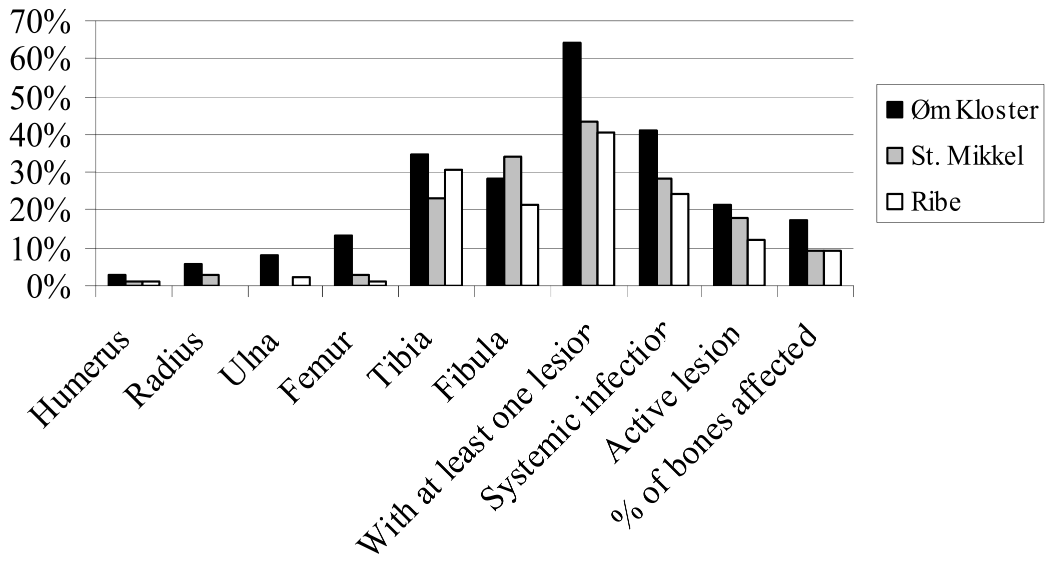

FIGURE 8.2. Distribution of periosteal lesions among the sites in the total peasant sample

females at Øm Kloster have a marginally higher proportion of periosteal reactions on their radius and femur than do the female skeletons from the other sites. These results support the trend that in the peasant skeletal sample more skeletons from Øm Kloster, both male and female, have a periosteal reaction than at the other sites.

Table 8.16 provides the statistical comparisons of periosteal lesion patterning among the sites in the early period when the peasant skeletal sample is further divided by time period. There are no significant differences in periosteal lesion distribution among the sites in the early period when the sexes are pooled or when each sex is examined separately. Table 8.17 presents results of the comparison of periosteal lesion abundance patterning among the sites in the middle period when the sexes are pooled. Significantly more skeletons from Øm Kloster have a periosteal lesion on the femur than do skeletons from the other sites in the middle period. Although not statistically significant for this

TABLE 8.16. Statistical comparisons of periosteal lesion abundance among the sites in the peasant sample in the early period

Bone	*Early period*		
	Total p*	*M* p*	*F* p*
Humerus	0.811	0.790	0.355
Radius	0.062	0.444	0.099
Ulna	0.713	1.000	0.609
Femur	0.383	0.590	1.000
Tibia	0.755	0.360	0.127
Fibula	0.149	0.258	0.513
With a lesion	0.175	0.084	0.244
Systemic infection	0.074	0.067	1.000
Active lesion	0.904	0.941	0.338
% affected	0.099	0.055	0.489

*No Kruskal-Wallis H *p*-values are significant at α=0.0127

TABLE 8.17. Statistical comparisons of periosteal lesion abundance among the sites in the peasant sample in the middle period

Bone	*Middle period*		
	Total p*	*M* p*	*F* p*
Humerus	1.000	1.000	1.000
Radius	0.308	0.447	1.000
Ulna	0.068	0.130	1.000
Femur	**0.006**	0.090	1.000
Tibia	0.809	0.473	0.359
Fibula	0.894	0.448	0.667
With a lesion	0.036	0.188	0.894
Systemic infection	0.558	0.802	0.616
Active lesion	0.554	0.234	0.638
% affected	0.077	0.311	0.818

*Kruskal-Wallis H *p*-values in **bold** are significant at α=0.0127 analysis, more skeletons at Øm Kloster also have at least one periosteal reaction than do the skeletons from the other sites in the middle period. There are no significant differences in periosteal lesion abundance patterning among the sites in the middle period when the samples are divided by sex. Table 8.18 indicates that there are also no significant differences in lesion distribution among the sites in the late period when the sexes are pooled or when the sample is divided by sex. However, although not statistically significant, more female skeletons from the late period at Øm Kloster have a systemic infection than those from either St. Mikkel or Ribe (p=0.039).

TABLE 8.18. Statistical comparisons of periosteal lesion abundance among the sites in the peasant sample in the late period

Bone	*Late period*		
	Total p*	*M* p*	*F* p*
Humerus	0.656	1.000	0.607
Radius	0.401	0.466	0.554
Ulna	0.415	0.737	0.196
Femur	0.111	1.000	0.149
Tibia	0.161	0.603	0.051
Fibula	0.857	0.567	0.238
With a lesion	0.065	0.474	0.111
Systemic infection	0.406	0.423	0.039
Active lesion	0.174	0.812	0.103
% affected	0.075	0.986	0.080

*No Kruskal-Wallis H *p*-values are significant at α=0.0127

Comparisons by social class

As the rural site of Øm Kloster is the only site with an elite and monastic component it is the only site examined for differences by social class. The analysis of lesion distribution by class for males includes peasants, elites and monks. For females only peasants and elites are included because there are no nuns at Øm Kloster. As indicated in Table 8.19, there are no significant differences in periosteal lesion distribution among the social classes when the sexes are pooled. Table 8.20 demonstrates that there are also no significant differences in periosteal lesion distribution among the social classes when the Øm Kloster skeletal sample is divided by sex. Although not statistically significant for this analysis, male peasant skeletons have a higher percentage of bones affected by periosteal lesions than male elites or monks. There are no significant differences in periosteal lesion distribution among the social classes in the total Øm Kloster skeletal sample when each time period is examined separately. There are also no significant differences by social class when his sample is further divided by sex. However, more monks in the early period have a periosteal reaction on the radius than either male elites or peasants, although this result is not statistically significant.

TABLE 8.19 Statistical comparison of periosteal lesion distribution by social class at Øm Kloster

Bone	*Total* p-*value**	*Male* p-*value**	*Female* p-*value*+
Humerus	0.826	0.766	1.000
Radius	0.732	0.674	0.548
Ulna	0.200	0.417	0.557
Femur	0.242	0.121	0.598
Tibia	0.808	0.451	0.131
Fibula	0.287	0.081	0.694
With at least one lesion	0.429	0.173	0.554
Systemic infection	0.460	0.200	0.292
Active lesion	0.337	0.330	1.000
% of bones affected	0.125	0.039	0.742

*Kruskal-Wallis p-value, +Fishers exact p-value
No values are significant at α=0.0127

TABLE 8.20. Statistical comparisons of periosteal lesion distribution by social class in each period in the total (T), male (M) and female (F) skeletal samples

Bone	*Early period*			*Middle period*			*Late period*		
	T	*M*	*F*	*T*	*M*	*F*	*T*	*M*	*F*
	p*	p*	p+	P*	p*	p+	p*	p*	p+
Humerus	0.761	0.835	1.000	1.000	1.000	-	0.816	1.000	0.515
Radius	0.091	0.042	1.000	0.273	0.160	-	0.589	0.709	1.000
Ulna	0.879	1.000	1.000	0.535	0.522	-	0.319	0.693	0.522
Femur	0.631	0.624	-	0.143	0.206	-	0.835	1.000	1.000
Tibia	0.415	1.000	0.059	0.841	0.800	1.000	0.561	0.477	1.000
Fibula	0.535	0.746	1.000	0.223	0.317	-	0.730	0.317	0.596
With at least one Lesion	0.977	0.756	0.476	0.145	0.153	1.000	0.846	0.644	1.000
Systemic infection	0.460	0.122	0.371	0.607	0.590	1.000	0.512	0.732	1.000
Active lesion	0.780	0.983	0.371	0.152	0.263	-	0.271	0.361	1.000
% of bones affected	0.726	0.461	0.445	0.076	0.107	1.000	0.629	0.601	0.757

*Kruskal-Wallis p-value, +Fishers exact p-value
No values are significant at α=0.0127

DISCUSSION

As indicated above and summarized in Table 8.21, the comparison of periosteal lesion frequency between the sexes reveals that peasant male skeletons have a higher proportion of periosteal lesions than do female skeletons. This is true in the total peasant sample, and in the early and middle period peasant samples. Male skeletons also have a higher proportion of periosteal reactions in the total peasant sample from Øm Kloster and St. Mikkel; and in the early period samples from Øm Kloster and middle period sample from St. Mikkel. There are no significant differences between the sexes in the late period, from the urban site of Ribe, or in the elite skeletal sample from Øm Kloster.

TABLE 8.21. Summary of significant and marginally significant differences in periosteal reaction distribution

Comparison	Statistically significant differences (p-values <0.0127)	Marginally significant differences (p-values between 0.05 and 0.0128)
By sex *(M=male, F= female)*	M>F (total peasant sample: tibia, with a lesion, systemic infection, and % affected; early period peasant sample: tibia; middle period peasant sample: fibula, with a lesion, systemic infection, % affected; Øm Kloster peasant sample: with a lesion; St. Mikkel peasant sample: systemic infection; early period Øm Kloster peasant sample: tibia; middle period St. Mikkel peasant sample: with a lesion, % affected)	M>F (early period peasant sample: systemic infection; middle period peasant sample: tibia; Øm Kloster peasant sample: % affected; St. Mikkel peasant sample: tibia, fibula and % affected; early period Øm Kloster peasant sample: with a lesion, systemic infection and % affected; middle period St. Mikkel peasant sample: tibia, fibula and systemic infection) F>M (late period elite: fibula)
Through time *(E= early, M= middle, L= late)*	L >E, M (Øm Kloster female peasants: tibia)	M > E, L (male peasant sample: with a lesion) L>E, M (female peasant sample: femur)
Among sites *(Ø= Øm Kloster, S=St. Mikkel, R= Ribe*	Ø > S, R (total peasant sample: femur, with a lesion, % affected; male peasant sample: with a lesion; middle period peasant sample: femur)	Ø > S, R (total peasant sample: ulna, systemic infection; male peasant sample: % affected; female peasant sample: radius, femur; middle period peasant sample: with a lesion; late period female peasants: systemic infection) S> Ø , R (fibula male peasant sample)
Among classes *(P= peasant, E= Elite, M= monk)*	None	P > E, M (Øm Kloster male sample: % affected) M> P, E (early period male sample: radius)

Therefore, the results generally do not support the null hypothesis that there are no significant differences between the sexes in periosteal lesion abundance.

The higher abundance of periosteal reactions in male skeletons may indicate that male health was generally poorer than female health, perhaps due to differences in activity patterning between the sexes with males having more contact with infectious agents than females or due to better buffering and immune reactivity in females. There is some evidence from studies of growth and development patterning between the sexes in non-industrialized societies to suggest that males are more sensitive to environmental factors than females are. This has led some researchers to conclude that females in general may have a stronger immune response than men, and therefore, may be better buffered against illness than their male counterparts (Stinson, 1985). Alternatively, these results could be the paradoxical result of hardier males surviving earlier health insults, and therefore who, show a higher proportion of individuals with periosteal reactions than comparatively more frail females who did not survive the health insult, and thus died before producing the osseous lesions. The historical evidence suggests that males and females were not considered to be equal or treated equally in medieval society, which suggests that the latter interpretation may be the better one (Bennett, 1987; Gies and Gies, 1990; Gies and Gies, 1969; Jewell, 1996; Mate, 1998; Rowling, 1968). The analysis of sex differences in other health and diet indicators may help to distinguish between these two interpretations.

The examination of periosteal lesions through time reveals no significant chronological differences in the total peasant, elite or monastic samples. There are significant differences in lesion distribution only when the peasant sample is divided by sex. More skeletons of female peasants from the late period have a periosteal lesion on the femur than in the earlier period samples. Although only of marginal significance, more males in the middle period have a periosteal lesion than in either the early or late periods. While there are no significant differences in the male sample when it is further divided by site, females do show inter-site patterning in lesion abundance. Late period female skeletons from Øm Kloster have more periosteal lesions on the tibia than in earlier periods. The higher abundance of periosteal lesions in the later periods than the early period for both males and females is contrary to the historically generated hypothesis that health would improve through time. Instead it suggests that the disruption in food production, due to both the inclement weather and the population loss of the Little Ice Age, Late Medieval Agrarian Crisis and Black Death, did not result in an improvement in health as a result of the decreased population size and improved diet, but instead led to a possible increase in infectious disease. Conversely, these results may indicate that individuals living in the early period did not survive early health insults and thus died before any osseous lesions could develop, whereas those living in the later period survived their health insult, and therefore, have more periosteal reactions. The analysis of other health and dietary indicators may help differentiate between these interpretations. There are no significant differences through time in the monastic sample, the total elite sample, or the male or female elite samples. This suggests that there were no major health consequences due to the changing climate of the Late Medieval Agrarian Crisis or the population loss as a result of the Black Death plague epidemics for the elite or monastic population at Øm Kloster.

In comparing health among the sites it is clear that the peasant individuals at Øm Kloster have a higher abundance of periosteal lesions than peasants at the other sites. This is true in the total peasant skeletal sample, in the male sample, and in the female peasant sample. The male sample from the site of Ribe has the lowest abundance of periosteal lesions of any site. Interestingly, the male sample from the poor urban cemetery of St. Mikkel has the highest abundance of periosteal lesions on the fibula, whereas the males interred at Øm Kloster have more individuals with at least one periosteal lesion, and a higher percentage of bones with a periosteal lesion. The higher abundance of periosteal lesions on the fibula in the St. Mikkel sample may be the result of leprosy. As mentioned above, one of the features of leprosy is periosteal bone growth on the fibula. There is some paleopathological evidence to suggest that lepers were not always confined to leprosaria in medieval Denmark. Boldsen found a high prevalence of leprosy in the rural site of Tirup that had no leprosarium (Boldsen, 2001; Boldsen, 2005b). All of the cases from Tirup are mild and do not exhibit the severe lesions described in classic cases. Furthermore, Boldsen (2001) has also noted evidence of leprosy in the skeletons from St. Mikkel. Since I did not analyze the hands, feet or facial bones in this study, the attribution to leprosy of periosteal lesions on the studied fibula from St. Mikkel should be considered hypothetical at best. The generally higher abundance of periosteal lesions at the rural monastery site of Øm Kloster suggests that the peasant individuals at this site experienced more infectious disease than those at the other sites. This is somewhat surprising as one might expect that the rural site would have the lowest abundance of periosteal lesions, due to the lower population density. However, the monastery of Øm Kloster ran a hospital. The full extent of its use has not been determined at this time (Gregersen and Jensen, 2003), but the higher abundance of periosteal lesions in this sample raises the possibility that at least some of the individuals interred at Øm Kloster may have been patients at the hospital.

There are few significant differences between individuals of different social classes, likely due to the small elite and monk samples. There are no significant differences between elite and peasant females overall or in any time period. Peasant males have a higher percentage of bones with a periosteal lesion than elite males or monks when the time periods are pooled and in the middle period sample. This supports the hypothesis that the peasant sample has a higher proportion of individuals with a periosteal lesion than elite sample. Monks, however, have a higher abundance of periosteal lesions on the radius than elites or peasants in the early period. As one of the tenets of the Cistercian order was heavy manual labor, and the lesions are on the radius and are not systemic in nature, they may be traumatically induced periosteal lesions and not the result of infections. However, this result is not statistically significant and is not supported by any other comparison of periosteal lesion patterning by social class, and therefore, may not be of any significance.

CONCLUSIONS

The analysis of periosteal lesion distribution through time suggests that contrary to the hypothesis that the proportion of individuals with periosteal lesions would decrease after the crises of the mid-14th century, instead there is some evidence to suggest that the proportion of affected individuals increased following the Late Medieval Agrarian Crisis and the Black Death plague epidemic. These results also suggest that individuals in the sample from Øm Kloster generally had higher rates of periosteal lesions than those in the other site samples. These results are contrary to the expectation that the sample from St. Mikkel would have the highest proportion of skeletons with a periosteal reaction. One possible explanation for this is that at least some of the peasant individuals interred at this site were patients of the hospital on the monastery grounds. In addition, the male skeletons at St. Mikkel have more periosteal reactions on their fibulae than those from the other sites. The fibula is the only bone from St. Mikkel in comparison with the other sites that has an occurrence of periosteal lesions approaching significance, as the fibula is a common site of leprosy and as there is some corroborating paleopathological evidence to suggest the presence of leprosy at St. Mikkel, I tentatively suggest that the periosteal reactions on the fibulae may be the result of leprosy. Overall, male peasants have a higher abundance of periosteal lesions than females. This result may be due to differential activities between the sexes such that males were more exposed to infectious agents than females or perhaps may be due to the paradoxical interpretation that females were more frail than males and did not survive health insults as well as their male counterparts. The analysis of other health and dietary indicators may help to illuminate this issue. Finally, the comparison of health among the different social classes supports the expectation that peasant males would have a higher abundance of periosteal lesions than their monastic and elite counterparts, suggesting that peasants were disproportionably affected by infectious diseases.

CHAPTER IX

STATURE

The analysis of attained adult stature can provide insight into the nutrition of a population, as skeletal growth is one of the first things sacrificed in individuals with poor nutrition. Growing individuals with a nutritious diet and low pathogen load are more likely to attain their genetic potential for stature than those with poor diet and health (Steckel 1995, 1999). Therefore, attained stature serves as a proxy measure of the cumulative index of childhood nutritional and health status (Falkner and Tanner, 1986). Studies of modern human populations reveal an inverse link between health, growth and mortality. Tall people tend to be healthier and live longer than growth stunted individuals (Silventoinen et al., 1999). Gunnell and colleagues (Gunnell et al., 2001) examined an archeologically derived sample from the site of Barton on Humber in England to determine whether this link was also true in past populations. They found that the link between height and health was present in the past populations. This research has been supported by numerous other studies, including one that examined this phenomenon in medieval and post-medieval European populations (Kemkes-Grottenthaler, 2005).

In fact, the assessment of growth is practically synonymous with assessments of nutritional status for archaeologically derived populations (Goodman and Martin, 2002). Stature may be affected by maternal nutrition and health as well as breastfeeding (Bhandari et al., 2003; Chang et al., 2003). A study analyzing the growth of Mayan Indians in Guatemala suggests that growth during the early childhood years is more sensitive to nutritional disruption than is the adolescent growth spurt (Bogin, 1998). Interestingly, one is less likely to make up for growth stunting in the early childhood, than stunting during adolescence (Tanner, 1990). Thus, there is a strong correlation between childhood growth retardation and adult stature (Larsen, 1997).

In many studies of growth between the sexes, males are shown to be less well buffered than females against environmental stressors. One of the earliest studies of the differential effects of environmental stress on growth between the sexes was by Greulich (1951) who examined the growth of children in Guam who grew up under the Japanese occupation and thus faced periods of food deprivation as well as other stressors. He found that boys had more retarded growth than girls and concluded that boys are less able to withstand environmental stressors than girls (Greulich, 1951). Although there is some debate on the universality of this buffering (Stinson, 1985), the relative degree of sexual dimorphism in a population is often used as an indicator of the degree of environmental stress faced by that population (Bielicki and Charzewski, 1977; Hiernaux, 1968; Stini, 1972; Tobias, 1972). As male growth is often more retarded than female growth under environmental stress, sexual dimorphism in adult stature should be reduced in populations facing high levels of stress (Relethford and Lees, 1981; Stini, 1975). The relative degree of sexual dimorphism is often expressed as ratio of male stature/female stature. The range of the male/female ratio is typically between 1.04 and 1.09 (Stini, 1975). However, some research has found a strong genetic component to sexual dimorphism and thus comparisons between different populations should be undertaken with caution (Eveleth, 1975). Alternatively, a high degree of sexual dimorphism may be the result of differential treatment between the sexes. In cultures where women are undervalued they often have poorer diets and more retarded in growth than males are (McKee, 1984; Rosenberg, 1980). A study of differences in mortality profiles of different subsets of the medieval English population of York found that low-status females had the shortest mean lifespan. This study also found that moderate-status females had the longest lifespan of any lay group examined (Sullivan, 2004). Thus, status and gender play a marked role in the life experience of the population of medieval England. However, as discussed in Chapter II, there is no historical indication that females in medieval Denmark were routinely mistreated (Sawyer and Sawyer, 1993). This suggests that a high degree of sexual dimorphism in medieval Danish samples may not indicate that there was a great degree of differential treatment between the sexes. However, as the mistreatment of women in Denmark may have occurred even if it has not been recorded in the historical documentation, attention should be paid not only to the degree of sexual dimorphism among groups, but also to differences in the actual femur lengths.

The null hypothesis in this analysis is that there are no significant differences in femur length in the sample between the sexes, through time, among the sites or among social classes. However, due the degree of sexual dimorphism evident in all human populations it would be highly unusual not to observe differences in stature between males and females, and thus, I predict that the results will reject the null hypothesis for differences between the sexes, and that males are significantly taller than females in all time periods and all sites. The historical literature suggests that there was a shift in diet from cereal grains to more animal products throughout the medieval period, therefore we might expect to find differences in average femur length through time, with skeletons in the late period having the longest femurs. In addition, it is expected that the degree of sexual dimorphism increase through time as the dietary conditions improved. The St.

Mikkel cemetery sample is thought to represent poor urban peasants, and therefore, it is predicted that the individuals interred at this site will have significantly shorter femurs, and a lower degree of sexual dimorphism, in comparison to those from the other sites, and thus reject the null hypothesis. Due to the relationship between nutrition and stature and the heterogeneity in diet based on social class discussed in Chapter III it is expected that there are significant differences in femur length and degree of sexual dimorphism by social class. As all of the individuals in this sample are from a fairly localized area in Denmark, they likely come from the same gene pool. This suggests that any differences among the samples are not due to genetics, but instead the result of differential access to resources. It is predicted that elites will be significantly taller, and have a higher degree of sexual dimorphism than their peasant or monastic counterparts due to their better diet.

METHODS

I measured the maximum femur length from every available individual in the sample. I use the left femur for all comparisons; if the left femur was unavailable or incomplete for a given skeleton, I substitute the measurement for the right femur. As there is error involved in any stature estimation from long bone length, I use only femur length in my comparison of stature differences between the sexes, through time, by site and status. The sample used for this analysis is not normally distributed. Therefore, I used the non-parametric Kruskall-Wallis H test for all statistical analyses. In addition, I calculated the mean male/female ratio for each time period, site and status. I have also calculated the mean male/female ratio when each site and social class are divided by time period. I use a modified t-test for all statistical comparisons of the male/female ratio among the different groups as outlined above (Relethford and Hodges, 1985). As discussed above, I am testing four main hypotheses in this analysis. For each of these hypotheses, I examine the data as a whole and then by different subgroups. For example, I examine differences in average stature between the sexes in the whole peasant population, through time, by site and through time at each site. Therefore, each hypothesis that I am testing is in fact a set of four hypotheses. Running multiple independent comparisons increases the risk of obtaining a Type I error, or of falsely rejecting the null hypothesis. To keep the risk of a Type I error equal to 5% (i.e. a 95% confidence level) for four comparisons, the alpha must be set at 0.0127. Therefore, I only consider p-values that are 0.0127 or lower to be statistically significant. P-values close to the accepted alpha will be discussed with respect to their relationship to the statistically significant results and are referred to as marginally significant. In addition to these main hypotheses, I also compare the total skeletal sample by sex, through time and by site. The alpha level for these tests is 0.017, the appropriate α to reduce the risk of a Type I error for three comparisons (Motulsky, 1995).

RESULTS

Of the total sample, 249 femurs are complete and included in this study of stature. The mean femur length of the total sample is 46.20 cm (s.d.= 3.24 cm). Of the total sample, 153 femurs are from male skeletons, and their mean femur length is 47.67 cm (s.d.= 2.72 cm), while 96 femurs are from female skeletons, and their mean femur length is 43.91 cm (s.d.= 2.33 cm). Table 9.1 provides information on average femur length at

TABLE 9.1 Mean femur length by site and time period (in cm)

Site and Period	Male			Female		
	N	mean	s.d.	N	mean	s.d.
Øm Kloster elites	15	48.64	1.79	10	45.09	2.91
Early period	3	49.60	0.65	1	47.60	
Middle period	6	48.70	1.89	3	46.03	3.31
Late period	6	48.10	2.09	6	44.20	2.84
Øm Kloster monks	12	47.84	2.59			
Early period	4	48.15	1.64			
Middle period	6	47.55	3.32			
Late period	2	48.10	3.11			
Total peasant	122	47.60	2.79	86	43.77	2.23
Early period	52	47.50	3.11	35	43.99	1.82
Middle period	44	47.59	2.35	26	43.41	2.32
Late period	26	47.82	2.92	24	43.95	2.65
Øm Kloster peasants	51	48.19	2.47	30	44.35	2.66
Early period	20	48.44	2.25	13	44.64	2.07
Middle period	17	47.71	2.40	5	43.98	3.17
Late period	14	48.43	2.90	11	44.47	3.17
St. Mikkel	31	47.82	2.12	31	43.02	1.91
Early period	10	47.44	2.45	11	43.27	1.49
Middle period	17	48.06	2.11	15	42.93	2.01
Late period	4	47.75	1.52	5	42.74	2.73
Ribe	40	46.67	3.40	25	44.00	1.79
Early period	22	46.67	3.83	11	44.95	1.65
Middle period	10	46.56	2.54	6	44.13	2.41
Late period	8	46.80	3.45	8	43.98	1.74

each site and by time period. The difference between average femur lengths through time, among the sites and by social status is slight.

Comparisons by sex

As demonstrated in Table 9.2, and illustrated in Figure 9.1, males are taller than females in all time periods and at all sites. These differences are significant in all time periods when the sites are pooled, and in all sites when the time periods are pooled.

TABLE 9.2. Kruskal-Wallis H comparisons of femur length between the sexes (M= male, F= female)

Comparison	N M	N F	χ^2	*p*
Peasant sample	124	88	65.899	**0.000**
Peasants in Early period	54	36	20.716	**0.000**
Peasants in Middle period	44	27	26.572	**0.000**
Peasants in Late period	26	24	16.635	**0.000**
Peasants at Øm Kloster	51	30	27.287	**0.000**
Early period	20	13	13.453	**0.000**
Middle period	17	5	4.642	0.031
Late period	14	11	7.498	**0.006**
Peasants at St. Mikkel	33	31	30.070	**0.000**
Early period	12	11	4.645	0.031
Middle period	17	15	20.760	**0.000**
Late period	4	5	4.901	0.027
Peasants at Ribe	40	27	7.989	**0.005**
Early period	22	12	2.8721	0.090
Middle period	10	7	1.158	0.282
Late period	8	8	3.007	0.083
Total Elite sample	16	10	6.538	**0.011**
Early period	3	1	1.800	0.180
Middle period	6	3	1.667	0.197
Late period	7	6	2.041	0.153

Values of *p* in **bold** are significant at $\alpha = 0.0127$

However, when the sample is divided by both site and period, there are no significant differences between the sexes in the sample from Ribe in any period, perhaps due to small sample size from this site. Differences between the sexes are significant, or near significant, in all three time periods at both Øm Kloster and St. Mikkel. There are also significant differences between the sexes in the total elite period sample at Øm Kloster. However, when I further divided the elite sample by time period, there are no significant differences between the sexes, again likely due to the small elite sample size. As there are significant differences in average femur length between the sexes I have divided these samples by sex for the analysis of femur length through time, by site, and by status.

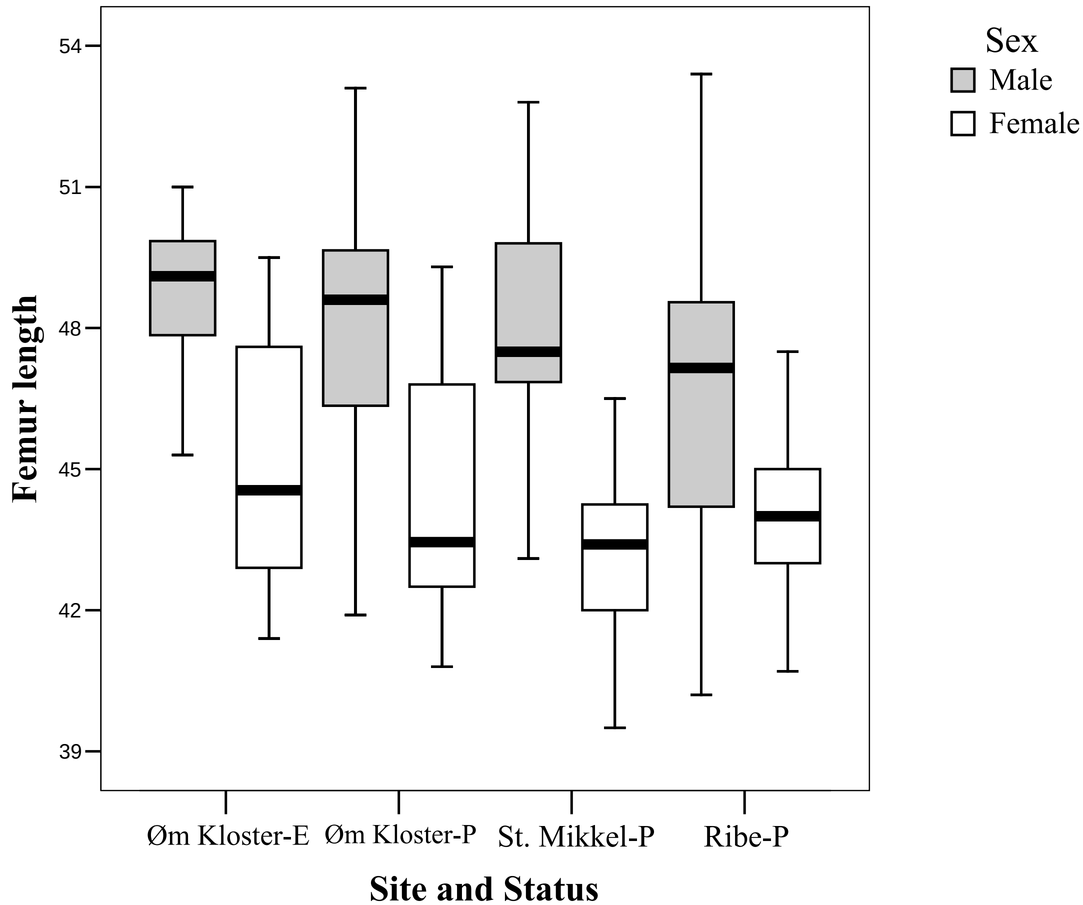

FIGURE 9.1. Comparison of average femur length between the sexes by site with time periods pooled (E=Elite, P=Peasant)

Comparisons through time

Table 9.3 illustrates that there are no significant differences in average femur length in either male or female peasants through time at any site. There are also no significant differences in average femur length through time in the elite males and females or monks at Øm Kloster. Moreover, none of the *p*-values are close to significance.

TABLE 9.3. Statistical comparisons of average femur length through time(E= early, M= middle, L=late)

Comparison	N E	M	L	df	χ^2	*p*
Øm Kloster elites						
Males	3	6	6	2	0.725	0.696
Females	1	3	6	2	1.569	0.456
Øm Kloster monks	4	6	2	2	0.231	0.891
Total peasant sample						
Males	52	44	26	2	0.193	0.908
Females	35	26	24	2	1.115	0.561
Øm Kloster peasants						
Males	20	17	14	2	0.689	0.709
Females	13	5	11	2	0.736	0.692
St. Mikkel peasants						
Males	10	17	4	2	0.268	0.875
Females	11	15	5	2	0.241	0.887
Ribe peasants						
Males	22	10	8	2	0.015	0.993
Females	11	6	8	2	0.109	0.947

No values in of *p* are significant at $\alpha = 0.0127$

Table 9.4 provides information on the male/female ratio in the total peasant sample, the peasant sample at each site and the elite sample from the site of Øm Kloster, and is used as a measure of the relative degree of sexual dimorphism in these samples. These ratios suggest that there is little difference in the degree of sexual dimorphism in the total peasant sample, and the peasant samples from Øm Kloster and Ribe through time. There are larger differences in the male/female ratio in the skeletal sample from St. Mikkel and the elite sample from Øm Kloster through time. The largest difference in the relative degree of sexual dimorphism is from the early to the middle period in the skeletons from St. Mikkel. The sample sizes in these comparisons are too small to

TABLE 9.4. Mean male/female ratio through time (M=male, F=female)

Sample	*Early period*			*Middle period*			*Late period*		
	M	*F*	*ratio*	*M*	*F*	*ratio*	*M*	*F*	*ratio*
Total peasants	47.50	43.99	1.08	47.59	43.41	1.09	47.82	43.95	1.09
Øm Kloster	48.44	44.64	1.08	47.71	43.98	1.08	48.43	44.47	1.09
St. Mikkel	47.44	43.27	1.09	48.06	42.93	1.12	47.75	42.74	1.12
Ribe	46.67	43.95	1.06	46.56	44.13	1.05	46.80	43.98	1.06
Elites	49.60	47.6	1.08	48.70	46.03	1.04	48.10	44.20	1.09

statistically detect differences, for example, the difference in the degree of sexual dimorphism through time between the early and middle period in the St. Mikkel sample is not statistically significant (t=0.480, df= 49, p= 0.6312) . Interestingly, the degree of sexual dimorphism is greatest in the middle and late period sample from St. Mikkel. This is the result of the relatively shorter femur length of the female skeletons from these periods by comparison with the early period. The degree of sexual dimorphism is smallest in the early period elite skeletal sample from Øm Kloster. However, the results from the elite sample from Øm Kloster should be interpreted with caution, as the sample size is small.

Comparisons among the sites

As indicated in Table 9.5, the differences in femur length among the sites are not large. In fact, there are no significant differences in either males or females in the total peasant sample in average femur length among the sites. There are also no differences when the sites are compared in each time period. As only one site, Øm Kloster, has an elite or monastic component I cannot compare these samples among the sites.

TABLE 9.5. Statistical comparisons of mean femur length among the sites (Ø= Øm Kloster, S= St. Mikkel, R=Ribe)

Comparison	N Ø	N S	N R	df	χ^2	*p*
Total peasant sample						
Males	51	31	40	2	4.883	0.087
Females	30	31	25	2	3.782	0.151
Early period sample						
Males	20	10	22	2	2.487	0.288
Females	13	11	11	2	2.136	0.334
Middle period sample						
Males	17	17	10	2	1.771	0.413
Females	5	15	6	2	1.249	0.536
Late period sample						
Males	14	4	8	2	1.206	0.547
Females	11	5	8	2	1.554	0.460

No values of *p* are significant at $\alpha = 0.0127$

As indicated in Table 9.6 there are differences in the mean male/female ratio among the three sites. In the total peasant sample and when this sample is divided by time period the skeletal sample from Ribe demonstrates the smallest degree of sexual dimorphism of any site, whereas the sample from St. Mikkel demonstrate the largest male/female ratio. In the early period there is little difference among the sites in the degree of sexual dimorphism. However, there is a much greater difference in the male/female ratios among the sites in the middle and late periods. This difference is the

TABLE 9.6. Mean male/female ratio among the sites (M=male, F=female)

Sample	*Øm Kloster*			*St. Mikkel*			*Ribe*		
	M	*F*	*ratio*	*M*	*F*	*ratio*	*M*	*F*	*ratio*
Total Peasant	48.19	44.35	1.08	47.82	43.02	1.11	46.67	44.00	1.06
Early period	48.44	44.64	1.08	47.44	43.27	1.09	46.67	43.95	1.06
Middle period	47.71	43.98	1.08	48.06	42.93	1.12	46.56	44.13	1.05
Late period	48.43	44.47	1.09	47.75	42.74	1.12	46.80	43.98	1.06

result of shorter femurs in the female skeletons at the site of St. Mikkel in the middle and late periods as compared with the femur lengths at Øm Kloster and Ribe.

Comparisons by social status

Table 9.7 reveals that there are no significant differences in average femur length by social status at the rural site of Øm Kloster for either male or females. There are also no significant differences in average femur length among members of different social classes when the samples are further divided by time period. Table 9.8 provides the mean male/female ratios of elites and peasants at the rural site of Øm Kloster. Overall, the difference in the degree of sexual dimorphism is small between elites and peasants. The only exception to this is the early period sample, where elites have a lower male/female ratio than peasants.

TABLE 9.7. Kruskal-Wallis H comparisons of femur length by social status at Øm Kloster (P=peasant, E= elite, M=monk)

Comparison	N			df	χ^2	*p*
	P	E	M			
Males						
All time periods	51	15	12	2	0.690	0.708
Early period	20	3	4	2	1.315	0.518
Middle period	17	6	6	2	0.842	0.656
Late period	14	6	2	2	0.237	0.888
Females						
All time periods	30	10		1	0.494	0.482
Early period	13	1		1	1.862	0.172
Middle period	5	3		1	1.800	0.180
Late period	11	6		1	0.041	0.841

No values of *p* are significant at $\alpha = 0.0127$

TABLE 9.8. *Mean male/female ratio by social class at Øm Kloster*

Sample	Elite			Peasant		
	M	*F*	*ratio*	*M*	*F*	*ratio*
Total Øm Kloster	48.64	45.09	1.08	48.19	44.35	1.08
Early period	49.60	47.60	1.04	48.44	44.64	1.08
Middle period	48.70	46.03	1.06	47.71	43.98	1.08
Late period	48.10	44.20	1.09	48.43	44.47	1.09

DISCUSSION AND CONCLUSIONS

As was expected, due the general degree of sexual dimorphism found in all human populations, male skeletons have longer femur lengths than female skeletons in all time periods and at all sites. Males also have longer femurs than females when each site is divided by time period. These results are significant in the Øm Kloster and St. Mikkel skeletal samples. There are no significant differences between the sexes in femur length in any time period in the sample from Ribe, however, this is likely the result of the small size of the sample analyzed from this site.

There are no statistically significant differences in mean femur length through time in the sample overall or at each site; however, the lack of significant differences may be the result of the small size of some of the samples. There are interesting differences in the relative degree of sexual dimorphism through time at each site. The male/female ratios in the peasant skeletal sample from the sites of Øm Kloster and Ribe are very similar through time, indicating no major changes in the degree of environmental stress or disparity in the treatment of the sexes through time at these sites. However, there are larger changes in the degree of sexual dimorphism at the site of St. Mikkel as the male/female ratio increased from the early to middle period. This may suggest that the degree of environmental stress lessened at this site through time, indicating that living conditions for the individuals interred at St. Mikkel improved through time.

Alternatively, as this difference is due to a decrease in femur length in women and there is historical documentation indicating that there was a disparity in the treatment of each sex in medieval Europe (Sullivan, 2004), the increase in sexual dimorphism may instead be the result of increasing disparity in the treatment of the sexes. In the middle period, males from Viborg may have had better health or access to food resources than females, resulting in growth in males and stunting in females. The degree of sexual dimorphism is very similar between the middle and late period at St. Mikkel, which suggests that conditions remained the same at this site from the 14^{th} century till the close of the period.

There is also a change in the male/female ratios of the elite sample through time. Skeletons from the middle period sample have the lowest degree of sexual dimorphism, whereas those from the early and late periods have very similar male/female ratios. This suggests that elite individuals living in the middle period faced more extreme environmental stress than those living during the other periods, although the elite sample size is small and therefore this result should be interpreted tentatively. Thus, the results from the comparison of average femur length through time do not support the hypothesis that stature increased through time due to improved diet and lower infectious disease load with the reduction in population. The interpretation of the relative degree of sexual dimorphism through time is unclear. This issue may be clarified by the analysis of the other health and dietary indicators examined in this dissertation.

There are also no significant differences in average femur length among the sites in the overall sample, or when divided by time period. It was expected that the individuals interred at St. Mikkel would have the shortest average femur length as this urban cemetery is thought to have been composed of poorer peasants than the other sites. This expectation is not supported by these data, possibly suggesting that childhood and/or adolescent health was very similar regardless of site. Boldsen (Boldsen, 1984) argues that the high mortality of many small to medium size medieval Danish cites was such that the population was unable to sustain itself without high migration from the countryside into the city. The city of Viborg, where the St. Mikkel sample is from, was a medium sized city in the medieval period. Therefore, the similarity of stature in these samples may be the result of the similarity of their childhood and early adolescent rural environment and may not reflect the environmental differences faced by the three communities.

The examination of the relative degree of sexual dimorphism among the sites suggests that in the middle and late periods the individuals who were members of the St. Mikkel's parish may have experienced the lowest degree of environmental stress. The skeletal sample from the urban site of Ribe has the lowest male/female ratio and thus may be interpreted as having faced the greatest environmental stress of the three sites. If the relative degree of sexual dimorphism is interpreted as providing information about environmental stress, these results suggest that contrary to the hypothesis that the individuals at St. Mikkel faced the highest degree of environmental stress and thus had the shortest femur lengths, the conditions improved at this site and by the close of the medieval period these individuals faced the lowest environmental stress. However, if the male/female ratio is instead interpreted as providing cultural information about the relative treatment of women these results instead suggest that there was a greater disparity in the treatment of the sexes at the site of St. Mikkel than at the other sites. The proper interpretation of these results may be elucidated when all of the health and dietary indicators are considered together.

There are also no significant differences in average femur length among members of different social status at Øm Kloster. This does not support the historically derived hypothesis that elites enjoyed a better diet and health conditions than peasants or monks, and would thus have longer femur lengths. However, the small size of the elite and monastic samples may obscure differences in stature. The relative degree of sexual dimorphism between elites and peasants is very similar in the middle and late periods. In the late period, however, peasants have a larger male/female ratio than elites, possibly suggesting that peasants faced fewer environmental stressors than elites. As this result is highly unlikely given the historical data on the relations among the social classes (Dyer, 1989), it is instead likely that this result is due to the small elite sample size, or due to greater disparity in the treatment of the sexes in the peasant sample.

These results support the null hypothesis that there would be no significant differences in femur length through time, among the sites and social classes. These results are contrary to the historically derived expectation that there would be an increase in stature through time with improved diet; that stature would be shortest in the poor urban sample of St. Mikkel in comparison with the other sites; and that elites would be taller than peasants and monks due to their more nutritious diet. This suggests that childhood and/or adolescent health was very similar for all medieval Danes, regardless of time period, location or social status. However, the comparisons of femur length can only address differences in childhood/adolescent diet and health and thus does not speak to any differences in adult diet and health that may have existed. The examination of the relative degree of sexual dimorphism through time indicates that there may have been some reduction in the environmental stress faced by the medieval population, and that there was disparity in environmental stress among the different sites.

CHAPTER X

SUMMARY AND CONCLUSIONS: DIET AND HEALTH PATTERNS IN MEDIEVAL DENMARK

The purpose of this dissertation is to examine health and dietary patterning in the medieval population of Denmark. This was a dynamic period in history that witnessed great changes in both population size and climate. This research addressed changes in health and diet between the sexes, through time, among different sites and among social classes. Previous chapters have explored individual health or dietary indicators in isolation. This chapter examines the relationship among these indicators to obtain a more holistic picture of life in Jutland in the medieval period. In addition, the results drawn from each indicator are considered together by each research question to obtain a more complete understanding of the relationships among the diverse segments of the population examined. Finally, to illustrate how the diet and health patterning found in this research fits into the larger diet and health trends in medieval Europe, these results are also examined in relation to the findings other bioarchaeological studies of medieval Europe.

RELATIONSHIPS AMONG HEALTH AND DIETARY INDICATORS

As discussed in Chapter IV, the osteological paradox posed by Wood et al. (1992) brought to light issues of regarding the interpretation of past health from archaeological samples. Skeletons with more pathological lesions are not necessarily those of individuals who were less healthy than those whose skeletons are without pathological lesions. In fact, skeletons with pathological lesions may have been healthier individuals, because they were stronger and better able to survive the health insult than their lesion-free counterparts, who died before producing bony lesions. The use of multiple indicators of diet and health may aid in the interpretation of health in past populations, as the patterning of the lesions may reveal paradoxical interpretations (Goodman, 1993). Therefore, I use Pearson's chi-square and Kruskal-Wallis *H* tests to examine the relationship among the different health indicators to understand whether a skeleton with one pathological lesion is more or less likely to have another type of lesion. Pearson's chi-square tests are used to compare the presence or absence of two categorical variables with each other, such as the comparison of the presence of a periosteal reaction and the presence of cribra orbitalia (Thomas, 1986). I chose the Kruskal-Wallis *H* test because it is a non-parametric test that can compare the presence of one of the categorical variables, such as the presence or absence of a periosteal reaction, with any of the continuous data, such as femur length (Thomas, 1986). The results of these tests are presented in Table 10.1. In addition, Table 10.2 presents the results of the Kruskal-Wallis *H* tests and Kendall's tau-b correlation of the isotopic ratios and the presence of one of the pathologies. I use the Kendall's tau-b correlation to compare the continuous data to itself, for example the comparison of femur length and δ^{15}Nratios. Kendall's tau-b correlations are appropriate to use for tests where the variables are not linearly associated, as is the case with the isotopic ratios and femur length, and the sizes of the samples are small (Thomas, 1986).

As indicated in Table 10.1, there are no significant relationships among skeletons that show anemia and the presence of any other health indicator. This suggests that individuals who survived childhood anemia, as represented by cribra orbitalia and porotic hyperostosis, did not make the individuals in this sample any more or less likely to develop any other pathology later in life. Individuals who had childhood anemia also did not significantly affect the individual's adult attained height, suggesting that any reduction in growth that may have occurred due to the anemia was made up, perhaps in catch-up growth.

Table 10.1 also indicates that there is no significant relationship between having a carious tooth and either anemia or periosteal reactions. However, there is a significant relationship in both males and females between having a carious tooth and femur length. Males without a carious lesion have a longer average femur length, 48.53 ± 2.52 cm, than those with a carious lesion, 47.09 ± 2.61 cm. Females without a caries have an average femur length of 44.47 ± 1.77 cm, whereas those with a caries have an average femur length of 43.25 ± 2.57cm. These results may suggest that individuals who had a more

TABLE 10.1. Relationships among health indicators

Comparison	Test statistic value	p-*value*
Cribra orbitalia and a periosteal reaction	0.918*	0.338
Cribra orbitalia and a carious lesion	0.133*	0.715
Cribra orbitalia and femur length in males	0.226$^+$	0.635
Cribra orbitalia and femur length in females	0.053$^+$	0.818
Porotic hyperostosis and a periosteal reaction	1.939*	0.164
Porotic hyperostosis and a carious lesion	0.107*	0.743
Porotic hyperostosis and femur length in males	0.518$^+$	0.472
Porotic hyperostosis and femur length in females	0.070$^+$	0.791
A periosteal reaction and a carious lesion	0.245*	0.621
A periosteal reaction and femur length in males	2.807$^+$	0.094
A periosteal reaction and femur length in females	3.657$^+$	0.056
A carious lesion and femur length in males	4.755$^+$	**0.029**
A carious lesion and femur length in females	9.053$^+$	**0.003**

*Pearson χ^2 value, $^+$Kruskal-Wallis H χ^2 value
values in **bold** significant at α=0.05

nutritious diet in childhood, and thus grew taller, also had a less cariogenic diet in adulthood than the shorter individuals who had a less nutritious childhood diet. The relationship between femur length and diet may be clarified with the examination of the relationship between femur length and the isotopic indicators presented in Table 10.2 and discussed below.

There is also a significant relationship between having a periosteal reaction and femur length. Table 10.1 demonstrates that female skeletons with a periosteal reaction may have longer femurs than those without a periosteal reaction, as this difference is close to statistical significance with a p-value of 0.056. Female skeletons with a periosteal reaction have a mean femur length of 44.33 ± 2.20 cm, whereas those without a periosteal reaction have a mean femur length of 43.41 ± 2.31cm. This result indicates that females with periosteal reactions were slightly taller on average than those without a lesion, and suggests that there may be a paradoxical relationship between these two health indicators. The taller females likely had better health and a more nutritious diet during their growing years than the shorter females. The better health and diet may have made these individuals better able to withstand health insults later in life, and thus, to have survived the health insult long enough to produce a bony lesion. The shorter individuals with poorer childhood and adolescent health may not have been able to withstand health insults and have died before they produced a periosteal reaction. The relationship between diet and health may be illuminated by the comparison of the isotopic ratios of carbon and nitrogen with the other health indicators presented in Table 10.2 and discussed below. While the p-value for the comparison of the mean femur length and the presence of a periosteal reaction in males is not statistically, or marginally, significant (p=0.09), it does not contradict the result for females, and perhaps suggests that a similar relationship between health and diet existed for the males in the sample as well. Males with a periosteal reaction have a mean femur length of 48.00 ± 2.56 cm, whereas those without a periosteal reaction have a mean femur length of 47.19 ± 2.93 cm.

As indicated in Table 10.2, there is also a significant relationship between the presence of infectious disease and adult diet. Skeletons with at least one periosteal reaction have significantly more depleted $\delta^{13}C_{coll}$ ratios than those without a periosteal reaction. The mean $\delta^{13}C_{coll}$ ratio of skeletons without a periosteal reaction is -19.36‰, whereas the mean $\delta^{13}C_{coll}$ ratio of skeletons with a periosteal reaction is -19.55‰. There is also a nearly significant relationship between having at least one periosteal reaction and the mean $\delta^{13}C_{coll\text{-}ap}$ spacing (p=0.052). Skeletons with at least one periosteal reaction have a mean $\delta^{13}C_{coll\text{-}ap}$ spacing of 5.28‰, whereas those without a periosteal reaction have a mean spacing of 4.98‰. The mean $\delta^{15}N$ ratios of skeletons with (12.23‰) and without (12.44‰) a periosteal reaction, although not significantly or marginally different, do not contradict the trend found in the $\delta^{13}C_{coll}$ ratio and $\delta^{13}C_{coll\text{-}ap}$ spacing. Although these differences in the $\delta^{13}C_{coll}$ ratios and $\delta^{13}C_{coll\text{-}ap}$ spacing are statistically significant, or nearly significant, the mean differences among the groups are very small and thus may not be repeatable measures. If these differences do reflect a difference in diet between individuals with a periosteal reaction and those without one, they suggest that individuals with a reaction had only a slightly more terrestrially based diet than those without a periosteal lesion, and thus they do not really imply that adult diet had a large impact on the individual's susceptibility to infection.

Although there is a significant relationship between femur length, the presence of a periosteal reaction and a caries as indicated in Table 10.1, Table 10.2 demonstrates that there is no corresponding significant relationship between femur length and a skeleton's $\delta^{15}N$ and $\delta^{13}C$ ratios or $\delta^{13}C_{coll-ap}$ spacing. This suggests that childhood health and nutrition status, as measured by femur length, is not significantly related to adult diet. There is also no significant relationship between having cribra orbitalia or porotic

TABLE 10.2. Comparisons of diet and health indicators

Comparison	Test statistic value	p-*value*
$\delta^{15}N$ and cribra orbitalia	0.066^{+}	0.798
$\delta^{15}N$ and porotic hyperostosis	2.497^{+}	0.114
$\delta^{15}N$ and a periosteal lesion	2.888^{+}	0.089
$\delta^{15}N$ and a carious lesion	0.142^{+}	0.706
$\delta^{15}N$ and femur length, male	-0.079*	0.271
$\delta^{15}N$ and femur length, female	-0.007*	0.939
$\delta^{13}C_{coll}$ and cribra orbitalia	1.639^{+}	0.200
$\delta^{13}C_{coll}$ and porotic hyperostosis	0.076^{+}	0.783
$\delta^{13}C_{coll}$ and a periosteal lesion	5.140^{+}	**0.023**
$\delta^{13}C_{coll}$ and a carious lesion	0.001^{+}	0.979
$\delta^{13}C_{coll}$ and femur length, male	-0.040*	0.571
$\delta^{13}C_{coll}$ and femur length, female	0.036*	0.688
$\delta^{13}C_{ap}$ and cribra orbitalia	0.080^{+}	0.770
$\delta^{13}C_{ap}$ and porotic hyperostosis	1.912^{+}	0.167
$\delta^{13}C_{ap}$ and a periosteal lesion	1.035^{+}	0.094
$\delta^{13}C_{ap}$ and a carious lesion	1.559^{+}	0.212
$\delta^{13}C_{ap}$ and femur length, male	-0.093*	0.196
$\delta^{13}C_{ap}$ and femur length, female	-0.052*	0.554
$\delta^{13}C_{coll-ap}$ and cribra orbitalia	0.018^{+}	0.892
$\delta^{13}C_{coll-ap}$ and porotic hyperostosis	2.193^{+}	0.139
$\delta^{13}C_{coll-ap}$ and a periosteal lesion	3.769^{+}	0.052
$\delta^{13}C_{coll-ap}$ and a carious lesion	1.614^{+}	0.204
$\delta^{13}C_{coll-ap}$ and femur length, male	-0.084*	0.248
$\delta^{13}C_{coll-ap}$ and femur length, female	-0.125*	0.165

$^{+}$ Kruskal-Wallis H χ^2 value, * Kendall's tau b correlation coefficient
values in **bold** significant at α=0.05

hyperostosis and a skeleton's $\delta^{15}N$ and $\delta^{13}C$ ratios or $\delta^{13}C_{coll-ap}$ spacing, indicating that there is no relationship between having suffered childhood anemia and later adult diet. Together, these results suggest that there is a relationship between childhood health status, as indicated by femur length, and the presence of infectious disease, as indicated by the abundance of periosteal reactions, and the cariogenicity of the adult diet, as measured by the abundance of carious lesions. However, there is no relationship between childhood health status and adult diet, as indicated by the examination of stable isotopic ratios of carbon and nitrogen. This may suggest that children who were better fed and generally healthier did not necessarily have a different adult diet than those who had a less healthy childhood experience. Interestingly, adult diet also plays only a very small role in the development of infectious disease in adults. This may suggest that the diet in medieval Denmark was neither so nutritious nor so poor as to result in big changes in health.

The relationship found between these indicators aids in the overall interpretation of health and diet, and suggests that individuals with a more cariogenic diet were shorter than those with a less cariogenic diet. These results also suggest that a paradoxical relationship may have existed between infectious disease, as indicated by periosteal lesions and stature, as measured by average femur length. Lastly, these results indicate that the medieval Danish diet only played a small role in the health of the population of medieval Denmark, and thus that differences in the diet of different segments of the Danish population resulted in only minor differences in the health status of these groups.

HEALTH AND DIET BETWEEN THE SEXES

One of the research questions addressed in this dissertation asks whether there were any diet or health differences between the sexes in medieval Denmark. As discussed in Chapter II, the historical literature suggests that women in Scandinavia were treated with greater equality than those in many other areas of medieval Europe. Scandinavian women could inherit property and run their own businesses (Sawyer and Sawyer, 1993). However, more equality under the law does not necessarily translate into equality of treatment or activities between the sexes. Thus, one of the goals of this dissertation was to examine possible differences in health status and diet between the sexes.

Table 10.3 provides a summary of the significant and marginally significant differences between the sexes for each health and dietary indicator studied. Male skeletons in the total sample have larger spacing between their $\delta^{13}C$ ratios of collagen and apatite, indicating a more terrestrially based diet than female skeletons; however, this result is only of marginal statistical significance. Although also of only marginal significance, females in the middle period sample from Ribe have more enriched $\delta^{13}C_{coll}$ ratios than males, suggesting that they had a more marine dependent diet than males in this period. Female peasants also have a marginally higher abundance of caries in the late period sample than males, which suggests that they may have been more reliant on cereal grains for subsistence than males in the late period. Together, these results may suggest that females had a diet containing proportionally more marine foods and cereal grains whereas males may have eaten more terrestrial animals.

The comparison of health between the sexes at each site suggests that the health status between the sexes was not uniform throughout medieval Denmark. As expected, male skeletons have significantly longer femurs than do females from all sites. However, there are differences in the degree of sexual dimorphism among the sites. The degree of sexual dimorphism remained virtually the same through time in the Øm Kloster and Ribe

TABLE 10.3. Significant and marginally significant differences in health and dietary indicators between the sexes (M=male, F=female)

Indicator	*Statistically significant differences (p-values <0.0127)*	*Marginally significant differences (p-values: 0.05 - 0.0128)*
Periosteal Lesions	M>F (total peasant sample: tibia, with a lesion, systemic infection, and % affected; early period peasant sample: tibia; middle period peasant sample: fibula, with a lesion, systemic infection, % affected; Øm Kloster peasant sample: with a lesion; St. Mikkel peasant sample: systemic infection; early period Øm Kloster peasant sample: tibia; middle period St. Mikkel peasant sample: with a lesion, % affected)	M>F (early period peasant sample; systemic infection; middle period peasant sample: tibia; Øm Kloster peasant sample: % affected; St. Mikkel peasant sample: tibia, fibula and % affected; early period Øm Kloster peasant sample: with a lesion, systemic infection and % affected; middle period St. Mikkel peasant sample: tibia, fibula and systemic infection) F>M (late period elite: fibula)
Stable isotopes	None	M>F (total sample: $\delta^{13}C_{coll-ap}$ spacing) F>M (middle period Ribe: $\delta^{13}C_{coll}$)
Caries	None	F>M (Late period)
Femur length	M>F (total peasant sample; Øm Kloster peasant sample, St. Mikkel peasant sample; Ribe peasant sample; early and late period Øm Kloster peasant samples; middle period St. Mikkel peasant sample; total elite sample)	M>F (middle period Øm Kloster peasant sample; early and late period St. Mikkel peasant samples)
Anemia	None	M>F (total, peasant sample; Øm Kloster peasant sample; early period Øm Kloster peasant sample)

samples. However, the degree of sexual dimorphism was much larger in the middle andlate period samples than in the early period sample from St. Mikkel. As discussed in Chapter IX, the relative degree of sexual dimorphism is commonly understood to reflect the level of environmental stress faced by the population (Bielicki and Charzewski, 1977; Hiernaux, 1968; Stini, 1972; Tobias, 1972). Groups with a high degree of sexual dimorphism are typically associated with lower levels of environmental stress than groups with a lower degree of sexual dimorphism (Relethford and Lees, 1981; Stini, 1975). However, a high degree of sexual dimorphism may also occur in cultures where women have dramatically poorer diets and health care than males. As discussed above, there is no correlation between any of the isotopic indicators and femur length in either sex. However, this only suggests that there was little relationship between growth in childhood and adult diet in medieval Denmark, and does not directly address the association of differences in diet between the sexes in adolescence and their subsequent differences in growth trajectory. Regardless of the interpretation of the degree of sexual dimorphism, these results indicate that there was a change in the disparity among the sites in the relative health between the sexes or in environmental stress from the early to middle period.

Male peasants have a significantly higher abundance of periosteal reactions than females in the early and middle periods overall, and from the early and middle periods at the sites of Øm Kloster and St. Mikkel. Although only of marginal significance, male skeletons also have a higher abundance of porotic hyperostosis, especially in the early period sample from Øm Kloster. Taken together, the results of the analysis of infectious disease and anemia may suggest that males in these periods and at both Øm Kloster and

St. Mikkel had poorer health than females. However, given the paradoxical relationship between stature and periosteal reactions in both sexes mentioned above, and the historical literature which suggests that any disparity in health and diet between the sexes was likely to be to the detriment of females (Jewell, 1996), these results may instead suggest that a paradoxical interpretation for the St. Mikkel sample is correct, and that the greater abundance of lesions in males reflects the better living conditions that males enjoyed and that they survived the health insult for long enough to produce a bony reaction.

The higher abundance of periosteal reactions in males than females at Øm Kloster in the early and middle periods, combined with the higher abundance of porotic hyperostosis in the early period, and the low degree of sexual dimorphism may suggest that a traditional interpretation of health is correct for the Øm Kloster sample. Rural males may have had poorer health than their female counterparts. This may be due to a heavier workload for males or to different work activities around the farm that exposed them to more pathogens. Perhaps proportionally more of the males in the samples were patients at the hospital on the Øm Kloster grounds than were females. There were no significant differences in any health indicator between the sexes from the site of Ribe, suggesting that the health conditions at this urban site were very similar for both sexes. In the late period, there were no health differences between the sexes at any site, although this should be interpreted cautiously because the lack of non-significant results may be due to the small sample sizes for some indicators.

Thus, although the historical literature pertaining to medieval Scandinavia suggests that women in Denmark enjoyed more freedom and more equitable treatment than their counterparts in other medieval European countries, this research suggests that there was still disparity in the living conditions between the sexes in the Danish Middle Ages. However, the relative degree of disparity between the sexes varied by site, suggesting that there was no uniformity in the treatment of the sexes. Therefore, the living conditions faced by each sex may have been the result of local conditions or activity patterns, that is they may have been context dependent and did not necessarily reflect socially proscribed modes of behavior and treatment between the sexes.

HEALTH AND DIET THROUGH TIME

The medieval period in Denmark witnessed both the Late Medieval Agrarian Crisis and the Black Death plague epidemic and thus the individuals experienced devastating famines, disease and population loss (Benedictow, 2004; Cipolla, 1993; Gottfried, 1983; Hatcher, 1994). Historical documentation suggests that the population decimation caused by these catastrophic events resulted in an increase in the standard of living and a shift to a more pastoral subsistence strategy and economy (Poulsen, 1997); (Dyer, 1989; Dyer, 1994b; Dyer, 2002). Therefore, the second research question addressed in this dissertation concerns how extreme the effects of these historically documented changes were on different segments of the medieval population of Denmark.

As illustrated in Table 10.4, the results of this analysis suggest that peasants had somewhat poorer health and a more terrestrially based diet in the middle and late periods than during the early period. Female peasants had poorer health and a more cariogenic diet in the late period than in earlier periods. The late period skeletons of female peasants have a significantly higher abundance of periosteal reactions, indicating infectious disease, than found in skeletons from earlier periods in the total sample and in the sample

TABLE 10.4. Significant and marginally significant differences in health and dietary indicators through time (E= early period, M= middle period and L=late period)

Indicator	*Statistically significant differences (p-values <0.0127)*	*Marginally significant differences (p-values: 0.05 - 0.0128)*
Periosteal Lesions	L >E, M (Øm Kloster female peasants: tibia)	M > E, L (male peasant sample: with a lesion) L>E, M (female peasant sample: femur)
Stable isotopes	M< E, L (total Ribe sample: $\delta^{13}C_{coll}$; male Ribe sample: $\delta^{13}C_{coll}$)	M< E, L (total Ribe sample: $\delta^{13}C_{ap}$, $\delta^{15}N$)
Caries	None	E > M, L (Males at Ribe) L>E, M (females at Øm Kloster)
Femur length	None	None
Anemia	None	None

from the rural site of Øm Kloster. Late period female skeletons from Øm Kloster also have a marginally greater abundance of caries than those from earlier periods. This may suggest that, in addition to the greater abundance of infectious disease, females may also have had a more cereal grain dependent diet in the late period than in earlier periods. The increase in the relative abundance of infectious disease through time in the female skeletons from Øm Kloster may not reflect the general status of rural women's health, but instead may be the result of differences in the composition of the site through time, as a hospital was built on the monastery grounds in the late period. The degree of sexual dimorphism remained the same through time at this site, indicating that the degree of stress faced by each sex in adolescence stayed proportionally the same. This supports the supposition that the increased abundance of infectious disease in the late period female skeletal sample was not the result of poorer health conditions for adult women in the countryside, but instead was due to use of the hospital by adult females in the late period.

When the sites are pooled, male peasants have marginally more periosteal reactions in the middle period than in the early or late periods. The collagen from the middle period male skeletal sample from the urban site of Ribe is significantly more depleted in ^{13}C, suggesting a more terrestrially based diet in this period. In the middle period, skeletons of both sexes from Ribe are marginally depleted in ^{13}C compared with early and later times. The collagen from this sample is also marginally depleted in ^{15}N. In addition, proportionally more males at Ribe in the early period have caries than in later periods, although this result is only of marginal significance. These results suggest that males had a more cariogenic diet at Ribe in the early period, likely from the heavier reliance on cereal grains, and during the middle period they had a less marine and more terrestrially based diet than during the other periods.

The poorer diet in the middle period male peasant sample from Ribe may reflect disruption in trade of foodstuffs to this city because of the general social upheaval associated with the Black Death and Late Medieval Agrarian Crisis. Ribe was the main center for trade between Jutland and the rest of Europe, and the population loss and famines may have hampered the movement of goods to this city, resulting in a change in diet for its inhabitants, whereas the town of Viborg and the rural site of Øm Kloster were likely less reliant on trade for their subsistence needs and therefore, were less affected by trade disruptions. However, there are no significant differences in the proportion of individuals with a periosteal reaction, or anemia through time at Ribe. In addition, the mean femur length of both sexes, and the degree of sexual dimorphism remained virtually the same through time in the Ribe sample. These results suggest that the degree of environmental stress at Ribe remained the same through time and that the difference in diet in the middle period sample from Ribe may not have been severe enough to have resulted in a change in growth in childhood and adolescence.

In the St. Mikkel sample, the degree of sexual dimorphism was much larger in the middle and late period samples than in the early period, possibly suggesting that the degree of environmental stress lessened through time at this site. However, there are no corresponding reductions in the abundance of the other health indicators, no change in male mean femur length, or in diet through time at this site. In addition, the change in the degree of sexual dimorphism through time at St. Mikkel is due to a reduction in the female mean femur length in the middle and late period. This suggests that the relative degree of sexual dimorphism at St. Mikkel may instead reflect either a change in the treatment of women or a change in the composition of the types of individuals who were interred at this cemetery through time, rather than an improvement of the living conditions at this site. This interpretation is supported by the historical records for the St. Mikkel sample which suggest that this cemetery was used by a poorer parish and the residents of a nearby hospital, and therefore, a change in the relative proportion of hospital inmates to local peasants may be the cause of the differences in the relative degree of sexual dimorphism in this cemetery sample through time.

While there is no change in elite diet through time, there is some suggestion of a change in diet through time for monks. The isotopic composition of the monk skeletons in both the early and middle periods suggests that monastic diet was very dependent on freshwater fish resources. The heavier nitrogen values in the middle period monastic skeletons suggest that the diet of monks who lived during the middle period was more reliant on freshwater resources and perhaps terrestrial animal products than in the early period. The increased consumption of animal products corresponds with the historically documented loosening of the Cistercian dietary proscriptions. Unfortunately, the small sample of monks from the late period precludes interpretation of late period monastic diet. Although there is a significant difference in the abundance of porotic hyperostosis through time in the monastic sample, the late period sample is composed of only one individual.

Overall, the results of the comparison of health and diet through time revealed few differences in the peasant and elite samples. This is surprising given the historical documentation suggesting that the population decimation and deteriorating climate resulted in substantial shifts in the living conditions of peasants. However, the differences in diet found in the monastic sample support the historically documented understanding of Cistercian diet and changes in the dietary proscriptions of Cistercian monks through time, and suggests that the Cistercians in Denmark adhered closely to the Benedictine Rule and the precepts of their order.

HEALTH AND DIET AMONG THE SITES

To obtain a more holistic understanding of life in medieval Denmark, I examined three different sites from the Jutland peninsula of Denmark. I have examined one rural site, the monastery of Øm Kloster, and two urban sites, the St. Mikkel cemetery from the town of Viborg and a cemetery sample from Ribe, one of the largest cities in medieval Denmark. The cemetery sample from Øm Kloster is composed of not just monks and church benefactors but also of the lay-brothers from the monastery and the lay population from surrounding rural countryside (Gregersen and Jensen, 2003). In addition, during the late period there may have been a hospital located on the monastery grounds that also treated the surrounding lay population. The St. Mikkel sample is composed of peasants who lived just outside the Viborg city walls. In addition, for a large part of the period, this cemetery was also used to inter patients from a nearby hospital (Hjermind n.d.). The cemetery from the city of Ribe is composed of townspeople who lived and worked in this large and bustling trade city (Jantzen et al., 1994; Jantzen et al., 1995). Therefore, the third question addressed in this dissertation concerns possible differences in diet and health among these sites.

Table 10.5 summarizes inter-site patterning in the distribution of the health and dietary indicators. Overall, the skeletons of peasants interred at the rural monastery site

TABLE 10.5. Significant and marginally significant differences in health and dietary indicators by site (Ø= Øm Kloster, S= St. Mikkel, R= Ribe)

Indicator	*Statistically significant differences (p-values <0.0127)*	*Marginally significant differences (p-values: 0.05 - 0.0128)*
Periosteal Lesions	Ø > S, R (total peasant sample: femur, with a lesion, % affected; male peasant sample: with a lesion; middle period peasant sample: femur)	Ø > S, R (total peasant sample: ulna, systemic infection; male peasant sample: % affected; female peasant sample: radius, femur; middle period peasant sample: with a lesion; late period female peasants: systemic infection) S> Ø , R (fibula male peasant sample)
Stable isotopes	Ø < S, R (total peasant sample and all time periods: $\delta^{15}N$ and $\delta^{13}C_{coll}$) R < Ø, S (all time periods: $\delta^{13}C_{coll-ap}$ spacing)	S> Ø , R (total peasant sample and middle period sample: $\delta^{13}C_{ap}$)
Caries	No significant differences	S> Ø , R (Middle period females) S> Ø , R (Late period males)
Femur length	None	None
Anemia	S> Ø , R: (early and middle period samples)	None

of Øm Kloster have a higher proportion of periosteal reactions than those from any other site. As mentioned in Chapter VII, the greater abundance of infectious disease at the rural site of Øm Kloster may be the result of the inclusion of residents from the hospital located on the monastery grounds. However, peasant individuals interred at Øm Kloster also had the most terrestrial plant based diet, which may suggest that they were more nutritionally compromised than the individuals from the other samples. Therefore, the higher abundance of infectious disease may be the result of their greater dependence on cereal grains. There is a synergistic relationship between diet and health; individuals with poorer diets are more susceptible to illness than those with a more nutritious diet.

The greater reliance on cereal grains at this rural site in comparison with the two urban sites studied here likely reflects the nature of food procurement. It is probable that rural peasant individuals primarily ate the foods they grew and raised on their farms. The historical literature describes a shift to emphasize more animal husbandry through time, and suggests that the majority of livestock raised were not butchered at the farm but were instead driven to the cities alive for sale (Poulsen, 1997). Thus, the rural individuals may have raised cattle for profit, not for food. Therefore, individuals who lived in the cities may have had greater access to more protein rich foods as some meat was probably butchered in the city, while the rest of the cattle were exported to other areas of Europe (Poulsen, 1997).

The skeletons from both the urban sites, Ribe and St. Mikkel, have collagen that is more enriched in the heavier isotopes of nitrogen and carbon than those from Øm Kloster, which indicates that they had a more animal protein rich diet than those from the rural site. Furthermore, as indicated by the small $\delta^{13}C_{coll\text{-}ap}$ spacing, the individuals interred at Ribe have the most marine-based diet of all the sites. Although the apatite from the individuals at St. Mikkel is marginally more enriched in the heavier isotope of carbon than those interred at either Øm Kloster or Ribe, the difference is small and therefore, may not reflect a meaningful difference in diet. Although only of marginal significance, more females in the middle period, and males in the late period have caries at St. Mikkel than any other site. Although animal proteins made up a large part of the diet of individuals interred at this site, this caries pattern suggests that starchy and/or sugary foods remained an important component of their diet. As the individuals interred at St. Mikkel were from a poor parish, it is unlikely that this cariogenic food was sugar, which was a very expensive item in the medieval period. Instead, they likely consumed large quantities of cereal grains, cooked either in stew-like pottages or as bread. Individuals at St. Mikkel also have a higher abundance of porotic hyperostosis in the early and middle periods than those at any other site. The high nitrogen signature found in this sample suggests that these individuals had a diet composed of proportionally more terrestrial and animal proteins, and suggests that it is unlikely that this anemia was the result of dietary iron-deficiency, unless these iron rich proteins were not given to children. Instead, the anemia may have been caused by parasitism due to either the consumption of infected food, like fish, or the generally unsanitary conditions found in medieval cities, especially for members of a poor parish.

Although there are no significant differences in femur length among the sites, there are differences in the relative degree of sexual dimorphism among the sites. In the early period, there is little difference in the degree of sexual dimorphism among the sites.

However, in the middle and late period samples there are much greater differences in the relative degree of sexual dimorphism among the sites. For these periods, the sample from St. Mikkel has a much greater degree of sexual dimorphism than do the samples from both Øm Kloster and Ribe. As discussed in Chapter IX, the relative degree of sexual dimorphism is commonly understood to reflect the level of environmental stress faced by a population. Groups with a high degree of sexual dimorphism are typically associated with lower levels of environmental stress than groups with a lower degree of sexual dimorphism (Bielicki and Charzewski, 1977; Hiernaux, 1968; Stini, 1972; Tobias, 1972). However, a high degree of sexual dimorphism could also occur in a population with a high degree of disparity in the treatment of the sexes. As individuals from St. Mikkel in the early and middle period have a higher abundance of anemia, and in the middle and late period have a higher abundance of caries than the other sites, it seems unlikely that the degree of sexual dimorphism is the result of better environmental conditions at the site of St. Mikkel than at the other sites. Instead, as discussed above, these results suggest that there may have been a greater degree of disparity in the treatment of the sexes, or a change in the composition of the St. Mikkel sample in the middle and late periods. The cemetery of St. Mikkel was used by members of a poor parish outside the city walls of Viborg, and the inhabitants of a nearby hospital. A change in the relative use of this cemetery by the parish or the hospital may have resulted in a difference in the relative degree of sexual dimorphism.

Thus, the results of this research suggest that there was variation in health and diet based on location. However, although the skeletons from the sample from Øm Kloster have the highest abundance of periosteal reactions of any site, this likely reflects the presence of the hospital located on the monastery grounds, and not rural health in general. There is also regional patterning in diet, as peasants from the rural site had a significantly different diet from those from the urban sites.

HEALTH AND DIET BY SOCIAL CLASS

The medieval period in Europe was a time of great differences in activity patterns and living conditions for members of different social classes. Although Denmark was never as hierarchical or entrenched in the feudal system as England, the historical documentation suggests that there were still differences in diet and lifestyle among the social classes in Denmark (Poulsen, 1997). Therefore, the final comparison made in this dissertation regards differences in diet and health due to social class.

As summarized in Table 10.6, there are no severe health differences evident among the social classes. Peasants have marginally more bones with a periosteal reaction than either elites or monks. Late period female peasants have more caries than elite females, but these differences are also not statistically significant. However, there are significant differences in the isotopic indicators of diet. As indicated by the higher $\delta^{15}N$ and $\delta^{13}C_{coll}$ ratios as well as the small $\delta^{13}C_{coll-ap}$ spacing, the elites from Øm Kloster had a more protein-rich diet from both terrestrial and marine resources than peasants or monks. Monks and peasants have a very similar diet in the early period. In the middle period the monastic skeletons have higher $\delta^{15}N$ and $\delta^{13}C$ ratios than peasants, indicating that the monastic diet was richer in both freshwater fish resources and terrestrial animal products than was the diet of peasants in this period. No comparisons can be made between monastic diet and either elite or peasant diet in the late period due to the small sample of

TABLE 10.6. Significant and marginally significant differences in health and dietary indicators among the social classes (P=peasants, E= Elite, M=monk)

Indicator	*Statistically significant differences (p-values <0.0127)*	*Marginally significant differences (p-values: 0.05 - 0.0128)*
Periosteal Lesions	None	P > E, M (Øm Kloster male sample: % of bones affected) M> P, E (early period male sample: radius)
Stable isotopes	P < E, M (total, and late period Øm Kloster samples: $\delta^{15}N$ E > P, M (total Øm Kloster sample: $\delta^{13}C_{coll}$) E < P, M (total, early and middle period Øm Kloster samples: $\delta^{13}C_{ap}$) E < P (all periods: $\delta^{13}C_{coll-ap}$ spacing)	P < M and E (middle period Øm Kloster sample: $\delta^{15}N$) E >P, M (early and late period Øm Kloster samples: $\delta^{13}C_{coll}$) P> E (late period Øm Kloster sample: $\delta^{13}C_{ap}$)
Caries	None	P > E (Late period females)
Femur length	None	None
Anemia	None	P > E (late period)

monks from this period. However, the elite diet was more heavily composed of higher trophic level protein resources, such as terrestrial animal products and fish than was the peasant diet, which was more heavily composed of plant resources. Taken together, these results suggest that peasants had a more cereal grain dependent diet than either elites or monks.

Although there were large differences in the diet of the different social classes at Øm Kloster, there were no correspondingly large differences in health status among monks, elites and peasants. This suggests that the dietary differences among the different social classes at Øm Kloster did not translate into measurable health differences.

INTERPRETATIONS IN LIGHT OF OTHER STUDIES OF MEDIEVAL DIET AND HEALTH

Historical documents suggest that women in medieval Scandinavia were treated better than elsewhere in medieval Europe (Sawyer and Sawyer, 1993). In Denmark, women typically worked alongside their husbands in the agricultural fields or in their shops (Hanson, 1992; Orrman, 2003). Based on these documents that suggest little disparity in treatment of the sexes or activity patterns between the sexes in medieval Denmark, it was expected that there would be few significant health or dietary differences between the sexes in any time period or at any site (Sawyer and Sawyer, 1993). However, the health indicators examined in this dissertation indicate that the differences between the sexes in health status varied by site. Male and female individuals interred at the urban cemetery of St. Mikkel, and the rural site of Øm Kloster, in the early and middle periods had different health patterns, whereas the males and females interred in the cemetery from the large trade city of Ribe had very similar health conditions and show no sex differences in health. This suggests that although there were sex-based differences in health in medieval Denmark, the disparity between the sexes varied by location, and thus was not a universal pattern.

The finding of differences in health between the sexes is supported by research from other areas of medieval Europe. In medieval Croatia, Slaus (2000) found that females had a higher abundance of linear enamel hypoplasias than males, indicating more early childhood stress in females than males. However, he found that adult males had more caries, higher rates of vertebral osteoarthritis, Schmorl's nodes, and skeletal trauma than females, suggesting that there was differential access to food resources, different sex related activity patterns, and higher levels of physical stress between the sexes in medieval Croatia (Slaus 2000). Other studies of medieval Europe have also found differential access to food resources between the sexes. In an isotopic examination of sex differences in diet from medieval Newark Bay, Orkney, found that males ate significantly more marine protein than females did (Richards et al., 2005a). The differences in diet between the sexes in the present study reveal the opposite trend. In the middle period, females at Ribe had a diet marginally richer in marine products than males, who may have obtained more of their protein from terrestrial animals.

The results of the examination of temporal change in diet change suggest that there were no extreme changes in diet for the peasant or elite samples as a result of the Late Medieval Agrarian Crisis and Black Death in medieval Denmark. However, there is isotopic evidence for a change in diet through time in the monastic samples from Øm Kloster. The monastic diet may have become more heavily composed of terrestrial animal products in the late period. This change in diet was likely due to the loosening dietary restrictions for Cistercian monasteries and may not be the result of the catastrophic events of the mid 14th century.

The examinations of diet in other sites in medieval Denmark have found differences in diet through time. In an analysis of dental attrition in medieval Tirup, Denmark, Boldsen (2005) found that attrition occurred more severely at a younger age in individuals who lived between 1300 A.D. and 1350 A.D. than those who lived before, which he attributed to an increased consumption of cereal grains in the first half of the 14th century. The site of Tirup was abandoned in the mid-14th century and thus can not be used to compare the diets of individuals living before and after the catastrophic events of the mid-14th century.

Arcini (1999) also found an increased rate of carious lesions and more teeth affected by caries in the late medieval period at Lund. She also suggested that this change may be the result of a more cereal grain dependent diet in the later period in comparison with the earlier period. Mellquist and Sandberg (Mellquist and Sandberg, 1939) found an increased incidence of caries throughout the medieval period in populations from Halland and Scania in medieval Denmark. They attributed the increased abundance of caries to either an increased consumption of vegetables or reduced attrition. There is little difference in the abundance of caries through time in the Danish samples examined here. The lack of a systematic increase in the abundance of caries through time may be the result of the importance of the cattle industry in Jutland. Jutland was one of the prime areas for the raising of livestock in Denmark and the cities on this peninsula were major exporters of cattle to the rest of Europe. Therefore, individuals from Jutland may have had a comparatively less cereal grain, more meat dependent diet than other, more cereal grain farming, areas of Denmark and the rest of Europe (Poulsen, 1997).

An isotopic study on dietary change in Grenoble, France, found an increase in the consumption of animal protein between the 14th and 15th centuries, which was attributed to increased urbanization (Herrscher et al. 2001). There are no corresponding shifts in the isotopic ratios from the Danish samples examined here, suggesting that there was little change in the sources of the medieval Danish diet through time. Most areas in Jutland are either on some body of water or have easy access to a body of water, and therefore, fish were easily obtainable for the majority of the population. Thus, the consumption of marine and freshwater fish may have masked the importance of animal meat resources as fish are more enriched in the heavier isotope of nitrogen and will dominate the $\delta^{15}N$ ratio of the consumer.

Contrary to the historically derived expectation that health would improve through time, the results of this dissertation instead indicate that middle period males, especially at the site of Ribe, had the poorest health in comparison with the early and late period male samples. These results may be due to trade disruption during the catastrophic events of the mid-14^{th} century. The poorer health in late period females may be the result of the increased use of the cemetery at Øm Kloster by the residents of the monastery hospital. Overall, however, there were very few differences in health through time in any sample. Support for the lack of broad changes in health through time in medieval Denmark is found in Arcini's (1999) examination of health change through time in the Danish city of Lund. She noted that although there were changes in the health indicators through time, these changes were not systematic and thus she concluded that there were no major changes in health conditions through time in medieval Lund (Arcini, 1999).

These results of both the examination of diet and health through time in this dissertation are surprising in the light of the historical documentation, which depicts widespread population loss and climate deterioration resulting in better living conditions for the survivors and a shift to a more pastorally-based diet. The lack of significant differences through time in the samples studied in this dissertation could be the result of several different factors. The historical literature may overstate the severity of the change in medieval Europe or at least in medieval Denmark. As indicated above, the examination of dietary change through time in other medieval samples revealed some chronological changes in the composition of diet. The smaller degree of change in the samples analyzed in this dissertation may reflect more stable conditions in Jutland than in other areas of Denmark and Europe. Jutland continued to export both cereal grains and cattle throughout the medieval period, and thus may not have been as heavily affected as elsewhere (Poulsen, 1997). The lack of large differences in health found not only in this dissertation, but also in Arcini's (1999) investigation of health in Lund, may suggest that the changing environmental conditions may not have translated into changes in health. This may be due to the relatively small population size in Denmark throughout the medieval period. Although the population of Denmark grew precipitously from the beginning of the medieval period until 1300 A.D, the population density in Denmark was never very dense; at its height Denmark had at most one and half million people in the medieval period (Becher, 2000; Boldsen, 1997; Cipolla, 1993; Jordan, 1996). At the peak of medieval Danish population density only about ten percent of medieval Danes lived in urban centers and these cities and towns typically only comprised 100 to 1000 people (Boldsen 1996, Sawyer and Sawyer 1993). Therefore, the population density in Denmark may never have been sufficiently great to have adversely affected health to a measurable degree or put undue stress on the availability of food resources.

The lack of significant health patterning may also be due to the imprecision inherent in paleopathological analyses. That is, the methods of analysis may not be sensitive enough to detect small changes in health, and thus may under-represent small health changes. Another possible explanation is that the time periods analyzed here may be too broad to detect changes in diet or health in the mid-14th century, and thus underestimate any changes in diet and health that were of a short duration. However, historians argue that the population in Europe did not recover from the Black Death for several centuries (Hatcher, 1994), suggesting that the broad nature of the time periods used in this dissertation is not a likely reason why major health and dietary changes were not detected.

Finally, the lack of significant results may be due to imprecision in the dating method employed. The primary method of chronological dating used in this analysis is based on arm position in the grave. This method is routinely used in studies of cemeteries in medieval Denmark (Becher, 2000; Boldsen, 1991). However, there may be more variation in the use of different arm positions among different sites, resulting in less accurate dating of individual skeletons. Radiocarbon dating of the skeletons in the samples tested here would help clarify the results and provide a better understanding of the chronological patterning of health and dietary indicators. In addition, larger late period sample sizes might help illuminate differences in health patterning through time.

The health patterning found among the sites indicates that the individuals interred at the rural monastery site of Øm Kloster had the highest levels of infectious disease of any of the three sites. Rural populations often have a proportionally lower abundance of disease than those from urban settings, due to the lower population density, and better sanitary conditions of the countryside. For example, in England, the medieval population from the city of York had a higher prevalence of maxillary sinusitis in comparison with the rural village of Wharram Percy. Lewis et al (1995) attribute this difference to the greater air pollution in York (Lewis et al., 1995). The higher prevalence of periosteal reactions at the rural site of Øm Kloster as compared with the urban sites is likely not a reflection of overall differences in urban and rural Danish populations, and is instead likely the result of the inclusion of patients from the hospital in the rural skeletal sample. In addition, medieval Danish cities were smaller than and not as crowded as the cities of medieval England. Therefore, the lack of correspondence between the results of the urban-rural comparison in this analysis and those conducted in other studies also likely reflects the smaller size of medieval Danish cities in comparison with medieval English cities.

In his analysis of stature in different areas of medieval Denmark, Boldsen found that urban populations were taller than their rural counterparts. He attributed this result to the higher rates of immigration to the cities from several rural sites which resulted in increased heterogeneity in the urban population (Boldsen, 1990). Arcini (1999) also found that urban men and women were taller than their rural counterparts in medieval Lund. She noted that the degree of sexual dimorphism was at its greatest in the early medieval period in urban samples, but that this dimorphism diminished through time; whereas the sexual dimorphism in the rural samples was smaller and stayed virtually the same through time. She also noted that average femur length was greater for urban males than rural males in the early period, whereas there are no major differences in average femur length between urban and rural female skeletons. She theorized that the difference in the early period urban samples possibly reflected a nutritional surplus that was enjoyed by males and that did not exist in the later urban period or in the rural samples.

There are no significant differences in femur lengths among the sites analyzed in this study. However, the degree of sexual dimorphism does differ. Unlike at Lund, however, these differences are not attributed to the degree of environmental stress faced by the inhabitants of Viborg, but are instead likely due to differences in nutritional stress between the sexes among the sites or differences in composition of the sample from St. Mikkel. The degree of sexual dimorphism remained the same through time at the other urban site, Ribe, and at the rural site of Øm Kloster, suggesting no large differences in treatment between the sexes or environmental conditions among the sites through time. Individuals interred at both urban sites, St. Mikkel and Ribe, enjoyed a more animal protein rich diet than those from the rural site of Øm Kloster. As has been found in other examinations of medieval European health patterns, this finding supports the inference that there was a disparity in diet between urban and rural populations in medieval Denmark.

The results of comparisons made among members of different social classes suggest that there was little difference in health among rural peasants, elites or Cistercian monks. However, the sample size of elite and monastic individuals is small, and therefore, differences might be found with larger sample sizes. Research in England has found differences in the mortality profiles of different status groups, suggesting that there were differences in the health status among members of different social classes in England. Sullivan (2004) analyzed the mortality profiles of individuals interred at the Gilbertine Priory of St. Andrew in York, and found that low-status females had the shortest lifespan of any subgroup analyzed, whereas moderate-status females enjoyed comparably longer lives.

As was expected there are differences among the social classes in diet. Peasants had the most plant based diet, whereas elites ate a diet containing more animal and marine proteins. These results are supported by research from other areas of medieval Denmark. In her examination of diet at Lund, Arcini (1999) found that lower class individuals buried outside the church had a higher frequency of caries than the more affluent individuals buried within the church, which she attributed to a diet composed primarily of porridge, which is sticky and can remain in the interstitial spaces between the teeth. A similar patterning was found in a medieval population in Hungary (Frayer 1984). Frayer noted that the prevalence of caries of peasants in medieval Hungary was much higher than that of the upper class, likely reflecting the greater consumption of animal protein by the upper class than by the lower class. It is interesting that the dietary differences among the different social classes at Øm Kloster did not translate into differences in caries rates, although, as mentioned above, this may be the result of the small sample size. Larger elite samples might also aid in understanding trends in the health and diet of these populations through time and possible heterogeneity in health and diet among individuals of different social classes.

In the early period, monastic diet was very similar to that of peasants, whereas in the middle and late periods it was more similar to the elite diet, and was composed of more terrestrial animal and marine proteins. The importance of marine foods in monastic diet has been found in other isotopic examinations of medieval diet. Stable isotopic analyses of human bone collagen from monastic samples in England and Belgium suggest that while the medieval diet there relied heavily on terrestrial foods, marine resources were an important protein source (Mays 1997, Polet and Katzenberg 2003). In

England, monastic skeletons that date to the 13th – 14th centuries have collagen with a mean $\delta^{13}C$ ratio of -18.29±0.56‰ while lay individuals from the same cemetery have mean collagen ratios of carbon of -19.5±0.76‰, indicating that monastic diets were somewhat enriched in marine foods than lay diets (Mays 1997). The difference in mean $\delta^{13}C_{coll}$ is very slight at Øm Kloster (early period peasants = -19.98 ± 0.32‰, monks = -20.01 ± 0.59‰). The monk skeletons from this period have skeletons with heavy $\delta^{15}N$ ratios (monks = 11.77 ± 0.97‰), suggesting that marine resources were an important part of the monastic diet at this site. Polet and Katzenberg (2003) analyzed the carbon and nitrogen ratios of monks from the medieval Cistercian monastery Koksijde in Belgium. The samples date to the 12th-15th centuries and have a mean $\delta^{13}C$ ratio of -19.1 ± 0.5‰, and a mean $\delta^{15}N$ ratio of 11.1 ± 0.9‰. The mean $\delta^{13}C$ ratio from collagen for the total monastic sample from Øm Kloster is -19.77 ±0.47‰, and the mean $\delta^{15}N$ ratio is 12.25 ± 0.89‰, thus the sample from Øm Kloster is both more depleted in the heavier isotope of carbon and more enriched in the heavier isotope of nitrogen suggesting the Øm Kloster sample had a more fish dominated diet.

A similar result was found in an isotopic examination of diet of elites, friars and lay people at three sites in medieval England (Muldner and Richards 2005). They found that there was very little difference in the ratios of the isotopes of carbon and nitrogen from collagen among these status groups. However, they noted that the total sample had high $\delta^{15}N$ ratios, 12.2 ± 0.9‰, but showed no corresponding enrichment in ^{13}C, -19.4 ± 0.6‰. They argue that $\delta^{15}N$ ratio is too high to be explained by the consumption of terrestrial animal protein alone, but the mean $\delta^{13}C$ ratio indicates that there was little consumption of marine proteins. They instead attribute these results to either the consumption of omnivores, like pigs, or freshwater fish. As discussed in Chapter IV, the Øm Kloster sample is located between two lakes and freshwater resources were an important food source for the medieval population in Denmark. Thus, the higher $\delta^{15}N$ and $\delta^{13}C$ ratios at Øm Kloster monastery sample than at the monasteries in England and Belgium discussed above may be the result of the greater exploitation of freshwater fish at Øm Kloster.

CONCLUSIONS

The Middle Ages in Europe was a tumultuous period that witnessed wars, severe famines and one of the most severe plague epidemics on historical record. Thus the medieval population faced great social, subsistence and demographic changes. This dissertation examined the effects, if any, of these changes on the diet and health of the inhabitants of the Jutland peninsula of Denmark. The results of the analyses of the diet and health in the skeletal samples studied here suggest that there were differences between the sexes, through time, among sites and among social classes. Nonetheless, these results support other research that has found no extreme health changes in Denmark in the wake of the calamitous events of the 14th century. This is in contrast to the historical literature which posits much larger shifts in diet and health, and suggests that the Late Medieval Agrarian Crisis and Black Death did not have a large longterm effect on the health and diet of the population of Denmark.

However, there were large differences in diet and health indicators among the peasants from different sites. This suggests that there were differences in the experiences of peasant individuals living in diverse areas of the Jutland peninsula. There was also a disparity in the health experiences of the two sexes. The differences between the sexes also varied by site, as the disparity between the sexes were greater at some sites than at others, once again suggesting differences in the life experience at each site. Finally, the data presented in this dissertation also support both the historical literature, and bioarchaeological studies that have found dietary differences among medieval peasant, elite and monastic populations. Surprisingly, the variation in diet among the social classes was not matched by differenes in the health of these groups, suggesting that the dietary differences among the social classes were not sufficiently large to have impacted the health of peasants, elites or monks.

Overall, these results provide a more holistic picture of life in the Middle Ages for diverse segments of the Danish population. The use of historical documents allows for a clearer interpretation of the results of the bioarchaeological analysis, such as, the interpretation of the relative degree of sexual dimorphism as indicating the relative treatment of women, rather than as a measure of overall environmental stress faced by all of the inhabitants of a site. The use of bioarchaeological techniques provides a more detailed understanding of historical events, for example the effect of the events of the mid 14^{th} century on the diet and health status of the Danish peasantry. This dissertation also supports the supposition of Goodman (1993) that the use of several health and dietary indicators in concert can aid in the interpretation of paleopathological data. In addition the comparison of the results of these indicators aided in the interpretation of contradictory results, for example the relationship between infectious disease and adult stature (Wright and Yoder, 2002). Future research that expands the sample sizes for the late period peasants, the elite and monastic samples, as well as refinements in dating the individual skeletons should provide a more complete understanding of the effects of the Late Medieval Agrarian Crisis and the Black Death plague epidemic on life in medieval Denmark.

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APPENDIX A

STABLE ISOTOPIC RATIONS IN THE TOTAL SAMPLE

Sample	*$\delta^{15}N$*	*$\delta^{13}C_{coll}$*	*$\delta^{13}C_{ap}$*	*$\delta^{13}C_{coll-ap}$*	*$\delta^{18}O$*	*C:N*	*% yield*	*C.I.*	*C/P*
Øm 1	13.18	-18.77	-14.165	4.605	-5.64	3.24	12.32	.	.
Øm 2	11.30	-19.98	-14.870	5.110	-6.29	3.28	8.31	.	.
Øm 3	13.09	-18.93	-15.800	3.130	-5.59	3.28	13.12	3.30	.24
Øm 5	11.60	-20.32	-12.875	7.445	-5.81	3.24	6.80	3.48	.19
Øm 7	11.57	-19.69	-14.840	4.850	-5.93	3.26	15.69	.	.
Øm 8	11.64	-19.82	-16.040	3.780	-5.55	3.25	8.05	.	.
Øm 10	12.28	-20.62	-14.180	6.440	-7.47	3.26	11.91	.	.
Øm 12	11.89	-20.30	-15.850	4.450	-5.69	3.30	11.06	.	.
Øm 13	11.80	-20.17	-13.085	7.085	-5.91	3.26	4.07	.	.
Øm 14	11.72	-20.08	-13.910	6.170	-5.45	3.25	7.14	.	.
Øm 20	9.78	-20.31	-13.940	6.370	-4.74	3.24	9.34	.	.
Øm 21	12.45	-19.63	-15.680	3.950	-5.92	3.26	6.57	3.13	.31
Øm 23	11.22	-20.22	-13.800	6.420	-5.93	3.30	8.53	.	.
Øm 25	13.95	-18.89	-15.800	3.090	-6.14	3.26	8.23	.	.
Øm 26	11.99	-19.83	-13.390	6.440	-5.65	3.29	7.50	.	.
Øm 27	11.36	-20.20	-15.025	5.175	-6.44	3.27	17.01	.	.
Øm 29	11.06	-20.02	-14.370	5.650	-6.28	3.27	7.00	.	.
Øm 30	11.35	-19.74	-13.530	6.210	-6.37	3.28	4.86	.	.
Øm 31	.	.	-16.485	.	-5.16	3.22		.	.
Øm 32	11.13	-19.97	-15.600	4.370	-5.73	3.24	12.95	.	.
Øm 33	14.56	-18.58	-14.810	3.770	-5.78	3.26	4.40	.	.
Øm 34	10.90	-19.70	-13.800	5.900	-5.72	3.27	9.18	.	.
Øm 35	11.11	-19.75	-13.690	6.060	-5.74	3.28	6.08	.	.
Øm 36	13.78	-19.70	-13.695	6.005	-5.82	3.25	6.45	.	.
Øm 37	11.04	-19.94	-13.895	6.045	-5.13	3.21	5.11	.	.
Øm 38	11.25	-20.43	-13.845	6.585	-6.00	3.37	1.49	3.86	.15
Øm 39	11.40	-20.11	-12.500	7.610	-5.96	3.22	6.43	3.37	.22
Øm 42	11.91	-19.68	-14.150	5.530	-5.72	3.18	12.19	.	.
Øm 43	11.07	-19.61	-15.340	4.270	-6.35	3.20	8.75	.	.
Øm 44	10.87	-20.07	-15.160	4.910	-5.86	3.25	18.26	.	.
Øm 45	11.30	-20.01	-13.670	6.340	-5.60	3.27	7.96	.	.
Øm 46	11.34	-20.16	-14.610	5.550	-5.56	3.20	8.45	.	.
Øm 47	12.20	-19.90	-15.980	3.920	-5.41	3.25	3.73	3.34	.24
Øm 50	11.11	-19.86	-12.740	7.120	-6.09	3.23	9.45	.	.
Øm 51	11.34	-20.31	-15.770	4.540	-5.82	3.26	8.55	.	.
Øm 52	13.30	-19.33	-15.175	4.155	-4.67	3.57	7.06	.	.
Øm 53	11.31	-20.19	-15.200	4.990	-5.03	3.26	11.99	.	.
Øm 54	11.01	-20.06	-13.980	6.080	-6.01	3.24	10.44	.	.
Øm 55	11.12	-19.72	-13.890	5.830	-6.25	3.22	11.22	.	.
Øm 56	12.78	-18.85	-14.730	4.120	-5.79	3.23	9.06	.	.
Øm 57	13.12	-18.78	-15.150	3.630	-4.71	3.25	8.88	.	.
Øm 58	12.66	-19.52	-15.130	4.390	-5.42	3.23	8.26	.	.

Sample	$\delta^{15}N$	$\delta^{13}C_{coll}$	$\delta^{13}C_{ap}$	$\delta^{13}C_{coll\text{-}ap}$	$\delta^{18}O$	***C:N***	***% yield***	***C.I.***	***C/P***
Øm 59	10.86	-19.68	-15.285	4.395	-5.50	3.26	10.62	.	.
Øm 60	11.21	-19.32	-14.875	4.445	-5.41	3.26	9.57	.	.
Øm 61	11.48	-20.05	-14.500	5.550	-6.55	3.29	10.62	.	.
Øm 62	11.19	-19.60	-15.290	4.310	-5.92	3.31	15.32	.	.
Øm 63	11.81	-19.75	-15.620	4.130	-5.42	3.31	9.53	.	.
Øm 64	11.86	-19.82	-15.580	4.240	-6.03	3.52	3.54	.	.
Øm 65	13.71	-18.95	-15.900	3.050	-6.13	3.31	8.36	3.29	.27
Øm 69	11.99	-19.44	-15.175	4.265	-5.35	3.30	6.45	.	.
Øm 70	13.59	-18.93	-15.440	3.490	-5.73	3.33	12.02	.	.
Øm 72	13.01	-19.41	-15.210	4.200	-4.50	3.55	6.70	.	.
Øm 77	11.63	-19.93	-13.070	6.860	-5.37	3.50	5.96	.	.
Øm 81	11.55	-20.01	-14.400	5.610	-6.26	3.50	7.35	.	.
Øm 84	11.26	-20.03	-13.340	6.690	-5.38	3.44	8.97	.	.
Øm 87	11.64	-19.69	-14.605	5.085	-7.29	3.30	12.08	.	.
Øm 89	10.77	-20.10	-13.790	6.310	-5.85	3.48	7.14	.	.
Øm 90	14.36	-18.48	-14.760	3.720	-5.14	3.35	13.27	.	.
Øm 91	12.41	-19.48	-15.990	3.490	-5.84	3.40	.69	.	.
Øm 92	11.82	-19.79	-15.880	3.910	-6.32	3.19	8.89	.	.
Øm 93	12.18	-19.08	-12.565	6.515	-5.83	3.23	1.27	.	.
Øm 95	11.02	-19.98	-14.500	5.480	-5.67	3.33	14.37	.	.
Øm 96	12.29	-19.66	-13.660	6.000	-5.35	3.31	12.89	.	.
Øm 99	12.51	-20.13	-14.210	5.920	-5.58	3.33	6.63	.	.
Øm 102	12.10	-19.00	-15.180	3.820	-5.45	3.32	4.89	.	.
Øm 104	.	.	-13.440	.	-5.07	.	.	3.96	.15
Øm 106	10.93	-19.56	.	.	.	3.34	4.05	.	.
Øm 107	11.72	-20.21	-16.360	3.850	-5.94	3.29	16.01	.	.
Øm 108	12.74	-20.31	-13.690	6.620	-6.46	3.31	10.75	.	.
Øm 117	12.38	-19.54	-16.080	3.460	-5.91	3.30	7.85	.	.
Øm 118	11.51	-19.61	-12.780	6.830	6.49	3.29	9.60	.	.
Øm 122	12.32	-19.54	-12.975	6.565	-6.39	3.30	6.21	3.70	.28
Øm 123	12.42	-19.93	-15.910	4.020	-6.37	3.59	9.81	.	.
Øm 125	12.32	-19.49	-16.060	3.430	-5.59	3.55	14.61	3.30	.27
Øm 126	11.69	-20.23	-15.485	4.745	-5.54	3.58	4.11	.	.
Øm 127	11.34	-20.13	-14.975	5.155	-5.72	3.28	7.85	.	.
Øm 128	12.35	-19.46	-14.836	4.624	-4.24	3.33	3.34	2.84	.37
Øm 129	12.67	-19.04	-16.100	2.940	-5.88	3.28	5.07	.	.
Øm 130	11.47	-20.27	-14.765	5.505	-4.55	3.36	9.29	.	.
Øm 131	11.79	-19.61	-14.910	4.700	-5.32	3.21	1.52	.	.
Øm 132	12.07	-19.51	-15.575	3.935	-5.21	3.30	10.10	.	.
Øm 134	12.81	-19.31	-15.190	4.120	-5.92	3.28	8.26	.	.
Øm 135	13.35	-19.15	-16.160	2.990	-5.44	3.21	19.14	.	.
Øm 137	12.03	-18.91	-13.490	5.420	-6.18	3.27	5.28	3.00	.14
Øm 138	13.15	-18.83	-15.470	3.360	-5.14	3.23	11.27	.	.
Øm 139	10.78	-20.58	-14.786	5.794	-5.80	3.37	4.22	.	.
Øm 141	11.23	-19.63	-13.945	5.685	-5.61	3.35	7.20	.	.
Øm 148	.	.	-13.460	.	-4.91	.	.	.	.
Øm 150	10.70	-19.90	-13.890	6.010	-6.00	3.31	9.41	.	.

Sample	$\delta^{15}N$	$\delta^{13}C_{coll}$	$\delta^{13}C_{ap}$	$\delta^{13}C_{coll\text{-}ap}$	$\delta^{18}O$	***C:N***	***% yield***	***C.I.***	***C/P***
Øm 151	11.21	-19.50	-12.730	6.770	-6.05	3.22	5.51	.	.
Øm 152	13.03	-19.65	-13.545	6.105	-5.25	3.23	11.56	3.35	.21
Øm 153	11.18	-20.33	-12.750	7.580	-5.84	3.31	6.06	.	.
Øm 154	13.45	-18.99	-14.820	4.170	-6.45	3.19	9.58	.	.
Øm 155	13.07	-19.15	-14.770	4.380	-5.38	3.22	13.48	.	.
Øm 156	12.96	-20.14	-14.560	5.580	-7.03	3.18	9.58	.	.
Øm 157	11.75	-20.12	.	.	.	3.18	14.59	.	.
Øm 158	12.03	-19.64	-13.780	5.860	-5.51	3.20	7.65	.	.
Øm 159	12.78	-19.52	-13.620	5.900	-6.67	3.23	8.16	.	.
Øm 160	11.51	-20.45	-14.570	5.880	-6.18	3.21	15.50	.	.
Øm 161	13.63	-19.19	-14.830	4.360	-5.96	3.24	13.18	.	.
Øm 163	11.70	-20.25	.	.	-6.18	3.29	6.91	.	.
SM 165	13.45	-18.51	-14.560	3.950	-6.01	3.22	9.27	.	.
SM 175	12.19	-19.39	-14.310	5.080	-6.76	3.30	8.60	.	.
SM 178	12.59	-19.54	-14.295	5.245	-4.79	3.29	6.42	.	.
SM 179	11.35	-19.42	-13.540	5.880	-5.58	3.19	10.02	.	.
SM 181	12.37	-19.62	-13.730	5.890	-5.88	3.22	6.32	.	.
SM 182	12.96	-19.31	-14.220	5.090	-5.67	3.21	9.36	3.35	.24
SM 188	12.32	-19.43	-13.180	6.250	-5.56	3.26	5.56	.	.
SM 189	11.60	-19.38	-13.940	5.440	-5.56	3.29	12.31	.	.
SM 191	11.45	-19.64	-13.860	5.780	-5.09	3.30	8.59	.	.
SM 193	13.35	-18.68	-14.490	4.190	-5.74	3.33	9.12	.	.
SM 194	11.85	-19.49	-13.790	5.700	-5.72	3.34	8.47	.	.
SM 195	13.33	-18.78	-12.890	5.890	-5.44	3.34	7.00	.	.
SM 196	11.73	-19.25	-13.530	5.720	-5.57	3.36	5.61	.	.
SM 197	11.52	-19.69	-13.250	6.440	-5.21	3.37	7.30	3.03	.30
SM 198	11.39	-19.51	-15.730	3.780	-6.09	3.29	12.37	3.64	.17
SM 199	12.92	-19.17	-12.890	6.280	-6.37	3.39	4.80	.	.
SM 200	11.86	-18.80	-14.590	4.210	-6.03	3.21	8.73	.	.
SM 201	13.36	-17.93	-13.730	4.200	-6.05	3.38	6.38	.	.
SM 202	13.39	-18.41	-14.880	3.530	-4.88	3.23	9.98	.	.
SM 203	12.46	-19.77	-14.020	5.750	-5.47	3.44	9.14	.	.
SM 205	13.38	-18.68	-13.440	5.240	-5.62	3.45	8.06	.	.
SM 206	12.57	-18.99	-14.025	4.965	-5.13	3.26	8.91	.	.
SM 209	11.96	-19.23	-13.725	5.505	-5.64	3.23	10.14	.	.
SM 210	12.64	-19.18	.	.	.	3.21	11.51	.	.
SM 211	13.24	-19.41	-14.470	4.940	-5.68	3.23	7.50	3.29	.24
SM 212	11.93	-19.78	-13.530	6.250	-6.01	3.24	7.62	.	.
SM 215	13.22	-18.96	-13.550	5.410	-5.82	3.25	7.84	.	.
SM 217	13.09	-18.80	-13.030	5.770	-6.30	3.21	7.20	.	.
SM 218	11.55	-19.57	-13.645	5.925	-5.87	3.24	7.75	.	.
SM 220	12.42	-18.92	-13.575	5.345	-5.61	3.26	5.95	.	.
SM 221	13.09	-19.19	-13.915	5.275	-5.76	3.25	11.36	.	.
SM 222	11.38	-19.53	-13.715	5.815	-4.89	3.25	10.39	.	.
SM 223	10.82	-20.10	-14.445	5.655	-5.28	3.25	8.91	.	.
SM 224	12.58	-18.96	.	.	.	3.29	4.01	.	.
SM 225	13.42	-19.47	-13.870	5.600	-5.62	3.29	9.58	.	.

Sample	$\delta^{15}N$	$\delta^{13}C_{coll}$	$\delta^{13}C_{ap}$	$\delta^{13}C_{coll-ap}$	$\delta^{18}O$	***C:N***	***% yield***	***C.I.***	***C/P***
SM 226	.	.	-13.530	.	-4.03	.	.	.	.
SM 227	12.69	-19.01	-13.850	5.160	-5.43	3.27	8.40	.	.
SM 229	12.10	-19.16	-13.400	5.760	-5.24	3.29	5.79	3.22	.22
SM 230	13.01	-19.50	-15.710	3.790	-5.29	3.27	17.95	.	.
SM 232	11.98	-19.14	-14.345	4.795	-7.09	3.29	11.06	.	.
SM 233	.	.	-13.690	.	-4.92	.	.	.	.
SM 234	12.60	-19.20	-14.110	5.090	-5.55	3.29	7.45.	.	.
SM 236	11.51	-19.41	-13.600	5.810	-5.09	3.26	6.82	.	.
SM 238	12.03	-19.76	-14.040	5.720	-6.66	3.27	8.11	.	.
SM 239	12.49	-18.97	-13.160	5.810	-5.96	3.25	3.69	.	.
SM 240	12.68	-19.64	-15.440	4.200	-5.43	3.29	13.33	.	.
SM 241	11.89	-19.42	-13.520	5.900	-5.62	3.25	9.64	.	.
R 242	11.35	-19.09	-14.110	4.980	-4.91	3.27	7.65	3.53	.21
R 243	13.78	-18.41	-14.640	3.770	-5.96	3.30	6.97	.	.
R 247	14.26	-18.81	.	.	.	3.27	10.02	.	.
R 248	11.16	-19.69	-14.065	5.625	-6.41	3.36	8.50	.	.
R 249	12.30	-19.33	-13.930	5.400	-5.22	3.36	10.39	.	.
R 250	11.16	-20.13	-14.250	5.880	-5.74	3.34	6.69	3.56	.19
R 251	12.11	-20.50	-14.340	6.160	-5.26	3.50	6.13	.	.
R 252	12.78	-18.69	-13.440	5.250	-4.38	3.37	6.98	.	.
R 253	13.15	-19.15	-13.820	5.330	-4.90	3.48	11.75	.	.
R 254	13.54	-18.55	-13.960	4.590	-4.38	3.38	4.40	.	.
R 255	14.30	-19.36	-14.070	5.290	-6.17	3.49	6.74	.	.
R 256	12.72	-19.04	-14.140	4.900	-5.25	3.47	10.99	.	.
R 257	11.37	-19.40	-13.830	5.570	-5.03	3.44	6.29	.	.
R 258	13.09	-20.44	-14.610	5.830	-5.76	3.46	3.01	.	.
R 259	13.49	-18.85	-13.620	5.230	-4.57	3.41	8.45	.	.
R 260	13.76	-18.38	-13.725	4.655	-5.73	3.45	7.38	3.68	.21
R 261	12.74	-19.08	-14.020	5.060	-4.88	3.39	8.93	.	.
R 263	13.53	-19.03	-13.800	5.230	-7.10	3.47	11.56	3.43	.21
R 264	12.09	-19.13	-14.690	4.440	-5.95	3.42	1.02	.	.
R 265	12.81	-19.37	-13.850	5.520	-4.51	3.49	6.91	.	.
R 266	13.43	-19.11	-13.660	5.450	-4.41	3.37	6.29	4.00	.18
R 267	12.95	-20.02	-15.600	4.420	-5.63	3.36	11.36	.	.
R 269	12.97	-18.87	-14.070	4.800	-5.37	3.30	9.93	.	.
R 270	14.04	-18.25	-13.645	4.605	-4.71	3.25	7.19	.	.
R 271	10.85	-19.30	-13.690	5.610	-5.10	3.24	6.45	.	.
R 272	12.96	-19.36	-14.370	4.990	-5.24	3.25	6.50	.	.
R 273	12.00	-18.85	-13.100	5.750	-6.32	3.23	5.56	.	.
R 275	12.45	-19.10	-13.780	5.320	-4.97	3.27	6.86	.	.
R 278	13.93	-18.66	-13.770	4.890	-4.26	3.21	5.20	.	.
R 281	12.79	-19.58	-14.340	5.240	-5.61	3.25	8.41	.	.
R 283	11.68	-19.18	-13.550	5.630	-4.86	3.22	7.45	.	.
R 284	12.03	-19.63	-14.200	5.430	-4.92	3.44	8.51	.	.
R 285	13.33	-19.02	-14.640	4.380	-5.52	3.23	11.89	3.15	.25
R 286	12.96	-18.96	-15.060	3.900	-5.58	3.24	6.50	.	.
R 287	11.95	-20.06	-14.505	5.555	-4.83	3.49	8.64	.	.

Sample	$\delta^{15}N$	$\delta^{13}C_{coll}$	$\delta^{13}C_{ap}$	$\delta^{13}C_{coll\text{-}ap}$	$\delta^{18}O$	*C:N*	*% yield*	*C.I.*	*C/P*
R 290	11.54	-19.09	-14.100	4.990	-4.92	3.22	10.87	.	.
R 292	14.03	-19.16	-13.890	5.270	-4.82	3.46	9.23	.	.
R 293	13.85	-18.25	-14.110	4.140	-5.10	3.21	7.12	.	.
R 296	13.99	-19.89	-14.630	5.260	-5.42	3.22	.6.89	.	.
R 297	13.81	-19.75	-14.610	5.140	-4.90	3.20	8.13	.	.
R 298	12.04	-19.20	-15.080	4.120	-5.35	3.23	7.97	.	.
R 299	12.35	-19.46	-15.130	4.330	-5.63	3.20	8.46	.	.
R 301	12.94	-19.29	-14.440	4.850	-5.89	3.21	7.98	.	.
R 302	12.38	-18.80	-14.410	4.390	-5.39	3.21	5.26	.	.
R 304	13.41	-19.01	-14.660	4.350	-4.57	3.20	16.85	.	.
R 305	12.92	-18.58	-13.440	5.140	-5.33	3.22	8.09	.	.
R 306	12.13	-18.98	-14.030	4.950	-5.34	3.24	5.21	3.60	.22
R 307	13.96	-19.86	-14.090	5.770	-5.11	3.27	5.28	.	.
R 308	11.67	-19.71	-15.420	4.290	-5.78	3.25	6.94	3.30	.26
R 309	13.05	-19.57	-14.770	4.800	-5.36	3.25	.18	.	.
R 310	14.31	-17.87	-13.240	4.630	-4.22	3.22	.4.63	.	.
R 311	12.74	-19.19	-14.440	4.750	-4.77	3.19	3.33	.	.
R 317	13.97	-18.79	-14.080	4.710	-5.19	3.26	7.11	.	.
R 320	12.86	-19.50	-14.600	4.900	-5.69	3.22	6.79	.	.

APPENDIX B

DISTRIBUTION OF PERIOSTEAL LESIONS

Distribution of periosteal lesions in males (M), females (F) and monks in the total sample (# affected/N)

Period	*Øm Kloster-peasant*		*Øm Kloster-Elite/monk*			*St. Mikkel*		*Ribe*	
	M	*F*	*M*	*F*	*monk*	*M*	*F*	*M*	*F*
Early									
Humerus	1/25	1/14	0/5	0/2	0/4	0/13	0/15	1/27	0/14
Radius	1/24	2/12	0/4	0/2	1/2	0/13	0/13	0/26	0/14
Ulna	0/20	1/13	0/5	0/1	0/3	0/12	0/13	0/27	1/14
Femur	3/27	0/16	0/4	0/2	0/4	1/12	0/12	1/27	0/14
Tibia	12/24	0/16	2/4	1/1	2/4	3/10	3/14	8/25	2/8
Fibula	4/17	2/10	0/2	0/2	1/4	4/10	5/14	3/22	1/7
With a lesion	15/23	3/13	2/4	1/2	2/4	4/12	7/13	10/27	4/13
Systemic infection	12/23	2/13	0/4	1/2	1/4	3/12	2/13	6/27	2/13
Active lesion	5/23	2/13	1/4	1/2	1/4	3/12	2/13	7/27	0/13
% of bones affected	19.31	8.03	6.20	8.30	15.00	7.27	7.96	8.39	6.60
Middle									
Humerus	0/17	0/5	0/5	0/4	0/6	0/19	0/16	0/12	0/8
Radius	0/16	0/3	1/6	0/4	0/6	1/18	0/16	0/13	0/9
Ulna	2/16	0/5	0/5	0/4	0/5	0/19	0/16	0/13	0/9
Femur	4/17	0/4	0/6	0/4	0/6	1/17	0/16	0/13	0/11
Tibia	4/17	0/4	1/6	1/4	2/6	7/16	1/16	4/11	2/9
Fibula	5/12	0/3	0/4	0/3	2/6	9/15	3/15	4/11	1/8
With a lesion	15/17	1/3	4/6	1/4	3/6	12/17	4/16	7/12	3/9
Systemic infection	9/17	0/3	2/6	1/4	2/6	9/17	2/16	5/12	2/9
Active lesion	3/17	0/3	1/6	0/4	3/6	4/18	3/16	0/12	1/9
% of bones affected	20.39	3.70	8.99	4.17	9.72	16.37	5.22	12.12	9.88
Late									
Humerus	0/18	1/12	0/10	1/5	0/2	0/4	0/4	0/10	0/8
Radius	1/16	1/11	0/9	0/4	0/2	0/4	0/5	0/9	0/8
Ulna	1/15	3/13	0/9	0/5	0/2	0/4	0/5	1/8	0/8
Femur	0/13	3/12	0/10	2/6	0/2	0/4	0/5	0/9	0/9
Tibia	5/16	7/13	1/8	3/6	1/2	1/4	0/5	4/8	1/7
Fibula	5/16	4/11	0/8	3/5	0/1	2/4	0/5	3/8	1/7
With a lesion	11/16	7/13	4/8	4/6	1/2	2/4	0/5	4/9	4/8
Systemic infection	3/16	7/13	2/8	4/6	0 /2	2/4	0/5	3/9	1/8
Active lesion	3/16	4/13	0/8	1/6	0/ 2	1/4	0/5	1/9	0/8
% of bones affected	13.03	20.26	6.34	25.6	6.25	9.17	0.000	16.36	5.42

VITA

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Teaching Experience

2005-2006 Lecturer, Peoples and Cultures of the World, Texas A&M University

2002-2003 Lecturer, Introduction to Physical Anthropology, Texas A&M University

Fall 2002 Visiting Lecturer, Introduction to Physical Anthropology, Baylor University

1998-2002 Laboratory Instructor, Introduction to Physical Anthropology, Texas A&M University

Peer- Reviewed Journal Articles

2003 Wright, L.E. and C.J.Yoder. Recent progress in Bioarchaeology: Approaches to the osteological paradox. Journal of Archaeological Research. 11(1): 43-70.

2001 Yoder, C.J., D.H.Ubelaker and J.F. Powell. Examination of Variation in Sternal Rib End Morphology Relevant to Age Assessment. Journal of Forensic Sciences. 46 (2):223-227.

Scherer, A.K., L.E. Wright and C.J.Yoder. Bioarchaeological Evidence for Social and Temporal Differences in Diet at Piedras Negras, Guatemala. Latin American Antiquity. In press.

External Research Grants

2005-2006 National Science Foundation Dissertation Improvement Grant, $12,000.