

“You are what you eat”

- A regional study on late medieval diet, and how it differs between sexes.



Figure 1: A group of peasants sharing a simple meal of bread and drink; Livre du roi Modus et de la reine Ratio, 14th century, located at [Bibliothèque nationale](https://upload.wikimedia.org/wikipedia/commons/a/a7/Peasants_breaking_bread.jpg) (https://upload.wikimedia.org/wikipedia/commons/a/a7/Peasants_breaking_bread.jpg).

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- A regional study on late medieval diet, and how it differs between sexes.

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BA3 Thesis (1083VTHESY-1920ARCH)

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Leiden 20.07.2020

(Final version)

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1. Introduction

1.1. Diet in medieval times

This research studies differences in diet between males and females in north-western European medieval populations between AD 1250 to 1500. Historical evidence for diet in the medieval period is mostly based on texts and cookbooks (van Hattum 2014, 35). However, cookbooks tend to represent a certain type of socioeconomic group and historical text are often are unreliable. The archaeological evidence for medieval diet has mainly been centred around animal and plant remains, as well as extensive isotope and dental caries research (e.g., Larsen 2005; Müldner and Richards 2005; van Hattum 2014; Walter *et al.* 2016).

Studies done in the Netherlands report changes in diet during late medieval times in relation to urbanization and commercialization. People became less self-sufficient as the market became more important, and new and exotic items were introduced to villagers and townspeople (Schats 2016, 12). Another study done in the Netherlands report the incorporation of dairy products, grains, meat and fish. While vegetables form an important part of diet today, it appears to not have been an important part of diet during medieval times (van Hattum 2014, 35). Focusing in on these staple foods we can find differences in diet between classes. For example, the rich used different types of grains in breadmaking than the poor, and eating meat was far less common for the lower and middle class than it was for the rich. Meat was expensive and the lower class would often rely on more basic foods such as porridge (van Hattum, 2014, 34).

While it is clear that differences in diet within medieval Europe occurred based on class structure, it is possible that gender also influenced diet. This would be the case if diet appeared to have been different between males and females regardless of their hierarchy in the class system. Dietary differences based on sex is less studied than differences in diet based on class, and it will be the focus of this thesis.

1.2. Dietary differences based on gender in medieval times

General differences between males and females in medieval Europe can already be observed in the historical record where it is reported that males and females had different social and financial rights (Duncan 2016, 1). Differences between sexes is also observed in a physical sense, where skeletal markers indicate differences in disease prevalence and differences in activity (Duncan 2016, 205; Schats 2016, 112-114).

While differences between males and females can be observed in a physical sense, the relationship between diet, culture and society is limited in the archaeological record, when compared to historical research. Generally, most of what is known about medieval diet today is based on the historical record (Müldner and Richards 2005, 39). Diets are an integral part of life, and what we eat is determined by economic, ecological and cultural factors. Studying diet can tell us about these different aspects of human life. Sex and gendered differences are of relevance and interest today, and studying these aspects in late medieval times is important for our understanding of late medieval society. Dietary differences between males and females is important to study because it would imply differences in gender roles, and gender roles form an important part of culture and can suggest hierarchy in the genders. As diet and gendered differences in diet is the focus on this thesis, a more nuanced understanding of medieval diet, dietary gender norms, and culture can be obtained.

Relevant for this thesis is that differences in diet between males and females have been established through archaeological research. In a study of medieval towns in the Netherlands, a significant difference in caries frequency between males and females could be observed in some sites, indicating different reliance on foods rich in carbohydrates (Schats 2016, 116-119). In the same study, differences in stable isotope values between males and females could be documented for one of the studied sites, indicating differences in protein consumption (Schats 2016, 181). Similar discoveries of dietary differences between males and females have been documented in medieval cemeteries in London, where a higher frequency of molar caries in females could be seen, and an increase in caries frequency with age (Walter *et al.* 2016).

1.3. Aims of research and research questions

The sections above demonstrate that some is known about medieval gendered and socio-economic differences, and that some is known about medieval diet through historical and archaeological research. As also mentioned, diet is an integral part of life, and studying differences in diets between sexes may give insight into gender norms in regard to diet. In recent years, there has been a small increase in independent studies on medieval diet through the lens of isotope analysis and dental caries where the two sexes have been compared. Yet, most studies use a single-method for their research: either isotope analysis or dental caries, and in addition to that, no study has been done to gain knowledge on dietary differences between sexes on a regional basis. In addition to lack of a multi-method study on a regional basis, differences between groups have been heavily understudied. It is difficult to give a nuanced image of medieval diet, and also gendered differences in diet in Europe as a whole, when most of what is known is based on single method local studies.

In light of these factors, this thesis will combine the methods of dental caries and stable nitrogen/carbon isotope analysis to generate new data, creating a more complete image of medieval diet in late medieval north-western Europe. With that, this thesis will investigate differences in diet between sexes, and perhaps be able to give men and women, individually, a better podium in history. By studying gender differences through diet, this thesis will be able to examine men and women's place in society through their skeletal remains, define what differences can be observed, and what they say about gender relationships in the past. The following research question, and sub-questions can be formulated:

The main research question:

- To what extent can dietary differences be seen between males and females in late medieval north-western Europe, and what are the possible explanations for these dietary differences?

The sub-questions that will help answer the main research question:

- Can differences be seen in diet between males and females in late medieval North-western Europe when investigating dental caries?

- Can differences be seen between males and females in late medieval North-western Europe when looking at stable nitrogen/carbon isotope analysis?

1.4. Approach: methods and materials

This study will focus on north-western Europe due to similarities in available produced data, but some clarification is needed. Although this thesis aims to collect regional data on dental caries and stable isotopes, a larger number of case studies used are from the Netherlands and from England. Studies from France and Germany, Sweden and Denmark will also be included, albeit to a lesser extent due to the more limited availability of data. Differences in diet between males and females will be studied in form of secondary data, meaning that the data that will be investigated has already been gathered, interpreted and published by someone else. The aim is to combine these independent studies to create a broader look at late medieval diet in Europe, and potential differences in diet between sexes.

Looking at dental caries and stable isotopes will each give different but equally valuable insights into diet. As the presence of dental caries will increase with the consumption of carbohydrates, looking at dental caries will make it possible to say something about the reliance on foods rich in carbohydrates. Stable isotopes on the other hand can reveal information on the protein component of diet, and also certain plants. Although this thesis will not directly apply these methods, it will focus on dietary investigations where isotope analysis and dental caries have been the methods of investigation. Since little research has been done where both methods have been applied to the same case study, the majority of the articles this thesis will focus on are studies where isotope analysis and dental caries have been researched independently. This thesis will combine these different datasets to study dietary differences in diet between males and females in late medieval times.

1.5. Thesis outline

The second chapter of this thesis will present background information on dental caries and isotope analysis. This chapter aims to explain the formation and causes of dental caries and what information we can extract from it. This chapter will also explain the nature of isotope analysis, how and what information can be extracted from it, as well as potential problems with the method.

The third chapter aims to give information on the context in which the data samples were collected. It will give background information on the individual sites used in this thesis, as well how many individuals were investigated, how sex was determined, how caries was scored, and how stable isotope samples were collected. The chapter will present an overview of the site locations, and a table which informs on dates, method and number of individuals per site.

The fourth chapter is reserved for the results. Graphs and diagrams will be presented for the isotope studies, the caries studies, and studies using both methods, accordingly. It will explain the results, provide information average values, and if the results hold statistical significance.

The fifth chapter is dedicated to discussing and interpreting the results of the previous chapter. Data from studies on isotope analysis will be compared to an animal baseline to be able to determine what kind of diet individuals from each site had. Further, data from the isotope studies as well as the dental caries studies will be compared individually in order to determine animal protein consumption, as well as the reliance on foods rich in carbohydrates. Lastly, the chapter will discuss the dietary differences between males and females in north-western Europe looking at the isotope and dental caries results separately.

The sixth chapter will conclude and answer the research questions. Results from dental caries and isotope analysis as an indicator of diet, as well as findings made in the discussion chapter, will be presented to provide evidence for dietary differences between males and females in north-western late medieval Europe. Problems that occurred during this research and possible improvements, as well as suggestions for further research on this topic, will be mentioned.

2. Dietary reconstruction in archaeology

This chapter focuses on the methods used to investigate diet in this thesis. First, it will explain the nature of stable isotope analysis and its relation to diet, it will elaborate on stable carbon and nitrogen isotopes separately, and will discuss how they play a vital role in understanding diets. This section will end with a discussion on how the method has been applied in archaeology. Secondly, this chapter will introduce the nature of dental caries, the tooth and the relation it has to diet. It will elaborate on causes of dental caries in teeth, and also discuss how dental caries investigations have been applied to archaeology. Finally, this chapter will summarize how both stable isotope analysis and dental caries together contribute to the study of diet in archaeology.

2.1. Isotope analysis and diet

A collaboration between archaeologists and geochemists on the analysis of stable isotope compositions in the late 1970s prompted a revolution in past dietary reconstructions, and it has since been heavily incorporated into archaeology. As a result, stable isotopes have since become a relatively standard data set for investigating vital questions in regards to past diets in the field of archaeology, and with greater precision than conventional methods with the recovery of animal and plant remains alone (Larsen 2015, 301). To understand how and why isotopes are useful to archaeologists in reconstructing past diets, it is necessary to look into what isotopes are, and how isotope values can be interpreted.

Isotopes are chemical elements with the same number of electrons and protons, but with different numbers of neutrons in each atom. Stable isotopes, unlike radioactive or unstable isotopes such as C^{14} , do not decay over time, and out of several stable isotopes, some hold biological significance (Katzenberg 2008, 415). It is necessary for the stable isotope to have at least two isotopes with biological significance in order for scientists to use its data to reconstruct diets (Larsen 2015, 302). Carbon and nitrogen are examples of such isotopes that have gained popularity amongst researchers, and for researchers to be able to tell something about diets in past populations using stable carbon/nitrogen isotopes, an organic component such as bone (collagen) and teeth (dentin) is needed

(Larsen 2015, 302). Due to the isotope's popularity and applicability in archaeology, they will be the focus in this thesis in reconstructing dietary patterns.

2.1.1. Stable carbon isotopes- ^{12}C and ^{13}C

In dietary reconstruction, carbon can provide information on the plant-component of a diet. Stable carbon isotopes have two isotopes that are of interest for dietary reconstruction, namely ^{12}C and ^{13}C . Research experiments involving controlled feeding experiments on animals showed that stable isotope ratios in the animal's bone and tissue also reflect ratios in diet (Larsen 2015, 302; Lee-Thorp 2008, 925). Important about these values are that they highlight differences that originate in plant photosynthesis, including either C_3 , C_4 , or CAM (crassulacean acid metabolism) plants. When using CO_2 , C_4 plants differentiate less against the heavier ^{13}C isotope and will as a result have less negative $\delta^{13}\text{C}$ values than C_3 plants (Lee-thorp 2008, 927-929).

Most plants in temperate regions, such as grasses, trees, tubers etc. are C_3 plants, and will have $\delta^{13}\text{C}$ values ranging between -24‰ to -36‰ (Lee-Thorp 2008, 297). C_4 plants such as maize, sugarcane, chenopods etc. are typically adopted to dry and hot climates, and since C_4 plants differentiate less against the ^{13}C isotope, they will have $\delta^{13}\text{C}$ values ranging between -9‰ to -21‰ (Katzenberg 2008, 423; Larsen 2015, 303). CAM plants such as cacti and succulents have $\delta^{13}\text{C}$ values that overlap the values of both C_3 and C_4 plants because they use C_3 or C_4 pathways that is ultimately determined by circumstances related to the environment (Katzenberg 2008, 424; Larsen 2015, 303). Marine plants will due to a variation of carbon sources have values between C_4 and C_3 plants (Larsen 2015, 304).

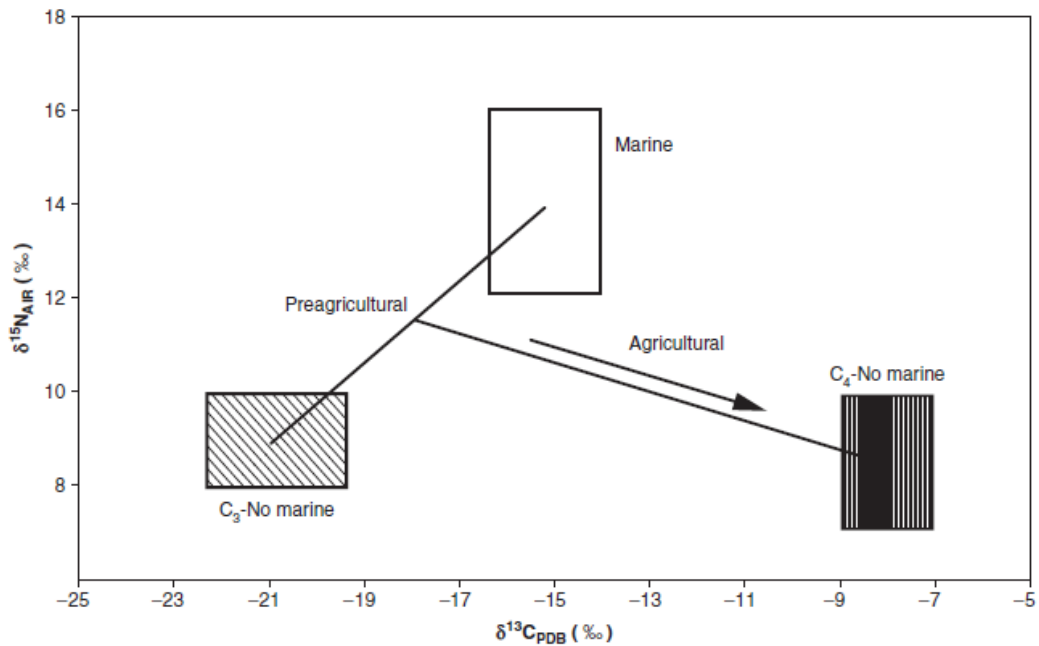


Figure 2: C₃, C₄ and marine plants, and how they score in δ¹³C values (Larsen 2015, 303).

The domesticated plants with economic value in medieval Europe were mostly C₃ plants such as barley, rye and wheat, but with an important exception to millet as a C₄ plant. Because of this, it is expected to see more δ¹³C values belonging to C₃ plants rather than C₄ plants in medieval Europe (Larsen 2015, 316). Figure 2 display how the different groups of plants score, and as visible in the graph, the isotopes ratios in the investigated tissues are expressed in parts per thousands (‰) relative to an international standard from the Pedee geological formation in South Carolina [PDB] as delta values(δ) (Larsen 2015, 302).

2.1.2. Stable nitrogen Isotopes- ¹⁴N and ¹⁵N

Like stable carbon isotopes, stable nitrogen isotopes also have two isotopes with biological significance for the reconstruction of diet, namely ¹⁴N and ¹⁵N. Like carbon, nitrogen samples from bone and tissues are expressed in parts per thousands (‰), but relative to an international standard of atmospheric nitrogen, AIR (Ambient Inhalable Reservoir) (Larsen 2015, 320). The stable nitrogen ratio within an organism depends on levels of nitrogen in local foods, and as local foods are consumed, ¹⁴N breaks down at a

faster rate than those containing ^{15}N . As a result, the consuming organism will have higher ^{15}N values than what has been consumed, differentiating the organism and the feed, meaning that a carnivore will for example have higher ^{15}N values than a herbivore (Katzenberg 2008, 425). Simply put, because there is an increase in ^{15}N values as one moves up the food chain, it is possible to determine the trophic level and dietary source of the investigated subject (Larsen 2015, 321)

Plants are unable to derive atmospheric nitrogen, so instead they get it from either bacteria, decomposing material or natural fertilizers in the surrounding soil of the roots, and will consequently have different ratios in $\delta^{15}\text{N}$ (Katzenberg 2008, 425). Because nitrogen levels within bone or tissues depend on what has been consumed, it is natural that different species of both animal and plants score differently in $\delta^{15}\text{N}$ values, and all groups of animals or plants will therefore have an average $\delta^{15}\text{N}$ value corresponding to either herbivore, carnivore, etc. (Katzenberg 2008, 425). Although these averages vary considerably, herbivores will average in $\delta^{15}\text{N}$ values at about 6‰, and carnivores will average around 9‰, while omnivores such as ourselves will be somewhere between herbivores and carnivores. Marine vertebrates will show higher $\delta^{15}\text{N}$ values than animals on land, being around 10‰ more positive than plants and animals on land. This is due to the fact that there are more steps in the marine food chain, and they will therefore display a higher trophic level than land animals (Larsen 2015, 320-321).

Because plants and animals are enriched in ^{15}N through what is being consumed, is it possible to conclude with the help of analysis of bone and tissues on the dietary sources of plants and animals. Relevant for this thesis, and particularly in regards to humans, is that an increase in ^{15}N values will likely reflect an increase in protein consumption derived from animal protein.

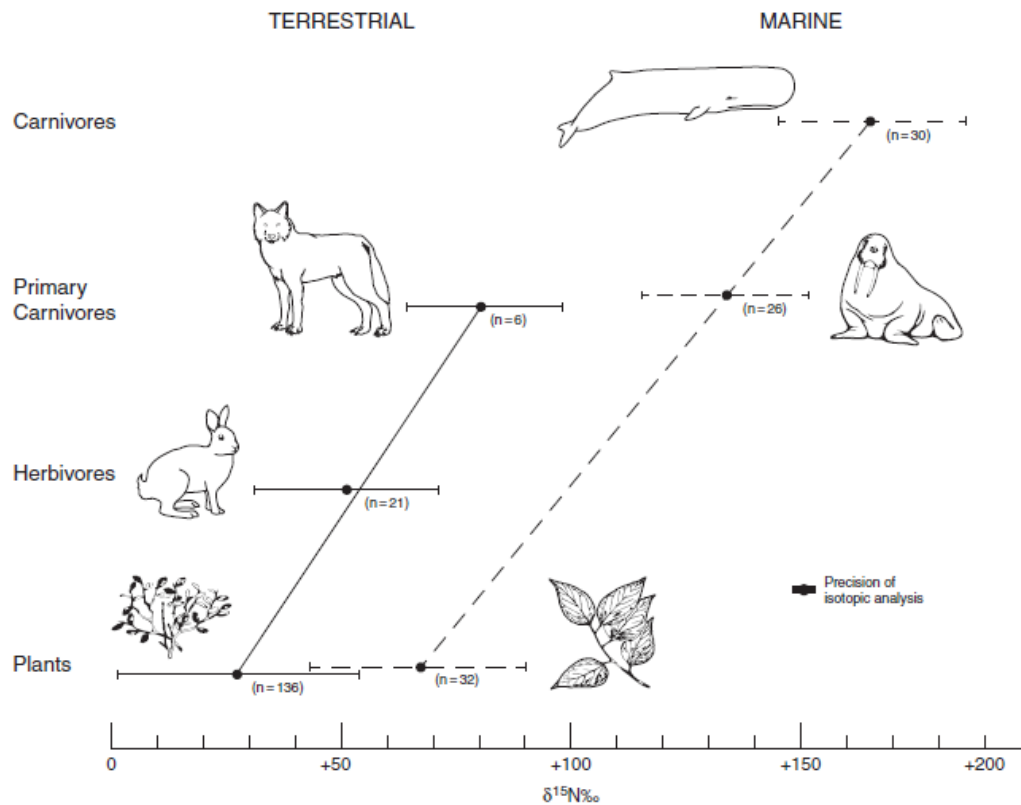


Figure 3: Marine and terrestrial plants and animals, and how they score in $\delta^{15}\text{N}$ values (Larsen 2015, 321)

2.1.3. Stable carbon/nitrogen isotopes applied in archaeology

Stable carbon/nitrogen isotopes are today used on a broad spectrum of topics in archaeology, including mobility, social practices, and diet and subsistence (Lee-Thorp 2008). With stable carbon/nitrogen isotopes as a method of investigation, researchers have been able to better understand past diets in many corners of the world. With the application of $\delta^{13}\text{C}$ on human remains from multiple sites in North America, researchers were able to get insight into importation and the increased consumption of the C_4 crop maize (Makarewicz and Sealy 2015, 146). The methods proved valuable in reconstructing coastal diets, where investigations into $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from coastal Mesolithic sites in Denmark, researchers were able to determine high consumption of marine foods (Lee-thorp 2008, 935). Similar trends can be observed in Anglo-Saxon settlements in England, where high status individuals in riverine sites showed elevated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, indicating that they exploited freshwater resources (Mays and

Beavan 2012, 867). $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis has also been applied to investigate the diets of soldiers in Napoleon's army. Both values showed a wide variation between the tested subjects, ranging from predominantly C_3 to C_4 with variations in freshwater, marine and terrestrial animal protein consumption (Holder *et al.* 2017, 53). The method has also been applied to prehistoric samples, where $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$ research on Neanderthal remains were able to determine that the $\delta^{15}\text{N}$ values were higher than herbivores and also carnivores, indicating that the Neanderthals were relying on herbivores with high $\delta^{15}\text{N}$ for their subsistence, such as mammoths or bears (Lee-Thorp 2008, 939-940). Studies into carbon and nitrogen ratios have also been applied to reconstruct breastfeeding and weaning practices in the byzantine era (Bourbou *et al.* 2013, 3903).

Stable carbon/nitrogen isotope analysis is undoubtedly a powerful tool that is well suited for archaeology. It is a quantitative and accurate method that can be used as a dietary tracker on the basis of individuals, that with a large enough sample size can provide information on dietary patterns on a communal scale. With a large enough sample size, it is therefore also possible to compare results between individuals, but also between communities which is ultimately the goal of this thesis (Makarewicz and Sealy 2015, 147-148).

The methods limitations lie in where the samples are collected. Bones remodel over time, and as a result the stable carbon/nitrogen values will only reflect diet from the past 10 years before death (Larsen 2015, 302). As a result, researchers using bone collagen to investigate diet will not be able to detect changes in diet that goes past 10 years. Dentin on the other hand is fully formed by the time humans become juveniles, and as a result it will only reflect diet up until the point where permanent teeth have fully formed (Larsen 2015, 302). Another thing to be aware of is that today, stable isotope analysis is a relatively cheap method that can be done by seemingly anyone, yet it is a method that is often considered to be part of specialist knowledge due to accurate interpretations of the results require extensive knowledge of the environment (Makarewicz and Sealy 2015, 148).

2.2. Dental caries and diet

Dentition is perhaps one of the best indicators of diets, not only because they form during critical periods during growth and development, but also because we use our teeth to process the food that we consume (Martin *et al.* 2013, 160). Teeth, unlike bone, are static in nature, and where bones might weaken, fracture and remodel, teeth stay the same once they are formed. This in turn makes them excellent for assessing nutrition (Martin *et al.* 2013, 160). One way of investigating dietary patterns when looking at dentition is by investigating infectious diseases such as dental caries.

Dental caries is a disease process that is defined by progressive demineralization of the hard tissues of the tooth, caused by organic acids produced by bacterial fermentation of dietary carbohydrates such as sugars and starches (Larsen 2015, 67; Martin *et al.* 2013, 160; White *et al.* 2011, 455). Dental caries has been around for a very long time and can be traced back as far as 570-250 million years in the teeth of fish. Dental caries is also a very common disease, and most people are to various degrees familiar with the disease as many develop it during their lifetime (Lanfranco and Egges 2011, 4). Caries can develop in many shapes and forms, ranging from just small spots on the enamel, to large cavities, and eventually even the complete destruction of the tooth crown and roots (Fig. 4; White *et al.* 2011, 455). Caries lesions take long to develop but are easily recognizable due to its destructive nature, and because it is so easily observable both in living and archaeological populations, an abundance of research has been published on the topic all around the world (Lanfranco and Egges 2011, 3; Larsen 2015, 67).



Figure 4: Caries infection severity in various degrees in teeth
(<https://i.pinimg.com/736x/82/cf/38/82cf388a70b15a7a62704eccae630cd8.jpg>).

2.2.1. Factors responsible for caries development

There are several factors that contribute to the development of dental caries. Essential factors include presence of oral bacteria, which teeth surfaces are exposed, salivary glycol-proteins, plaque, and finally diet (Larsen 2015, 68).

A normal concentration of oral bacteria responsible for the dental caries is too low to cause great harm to the tooth, but as food (glycol-proteins) get stuck in grooves and crevices of the teeth it creates the perfect condition for microbes to flourish (Aufderheide *et al.* 1998, 403). Naturally, not all tooth surfaces are equally vulnerable to dental caries. Most tooth surfaces are smooth enough to be self-cleaning, but the chewing surface of the tooth, or the occlusal surface, particularly of posterior teeth such as the molars, are developed in such a way that the surface will have irregularities in form of grooves and fissures (Fig. 5). In these grooves and fissures food can get easily stuck and caries will consequently develop quicker in these areas (Fig. 6; Aufderheide *et al.* 1998, 403). Food consistency and processing, as well as what types of foods are eaten play a large role on the development of dental caries. Soft foods rich in carbohydrates such as starches and sugars are central in promoting dental caries, but there is also a

genetic aspect to the development of dental caries, particularly concerning enamel formation and saliva composition (Larsen 2015, 68).



Figure 5: Mandibular teeth with grooves and fissures (Garot et al. 2019, 753).

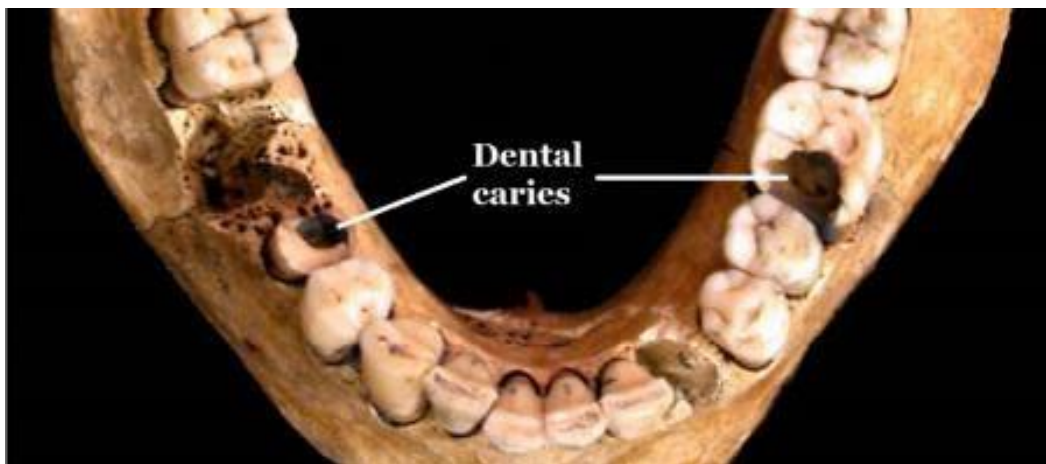


Figure 6: Crown caries where the occlusal surface has been attacked in a premolar (left) and molar (right) (<https://allthingsaafs.files.wordpress.com/2015/07/dental-caries.jpg?w=619>).

2.2.2. Diet as the main driver of dental caries development in archaeology

Strong evidence suggests a global trend towards an increase in caries prevalence and severity with an increased consumption of carbohydrates and a decreased consumption of protein (Larsen 2015, 69). This shift in diet correlates with a shift to an agricultural subsistence, when people went from having a more diverse diet to a diet that relied more on farmed foods with high contents of carbohydrates (Martin *et al.* 2013, 160). The impact of this shift in subsistence strategy in regards to caries was tested when a sample of populations globally was drawn. The results showed that caries prevalence in human teeth was 5.2% higher in populations practicing agriculture over populations with foraging as a subsistence strategy, and 4.2% higher than populations with a mixed subsistence (Larsen 2015, 69). This increase in caries prevalence and its connection to an increase in carbohydrate consumption has been documented in many populations from all over the world. Amongst Inuit tribes in Canada, Greenland and Alaska a change from a diet mostly consisting of animal protein and fat to a diet rich in carbohydrates resulted in a dramatic increase in caries (Forshaw 2014, 530). Access to food rich in carbohydrates such as flour and sugar in post-medieval England for middle-class and working-class groups made it so that both groups experiences equal dental caries prevalence (Mant and Roberts 2015, 201). A study on dental caries prevalence from individuals in multiple Neolithic and Early Bronze Age sites in Germany indicate that the early farmers had higher caries prevalence than those in the late Neolithic. This drop in caries prevalence is assumed to be reflecting a reliance on cereals in the early Neolithic period, and then a later increased reliance on meat and dairy products. In this study sex-specific differences were investigated, and results showed that females were more affected by dental carries and had a higher number of infected teeth than men (Nicklisch *et al.* 2016, 90).

2.2.3. Social and biological differences in caries prevalence

Dental caries prevalence displays biological and social differences, observable in sex and status. Datasets from a wide range of archaeological populations from different time periods and locations show common results on dental caries having higher prevalence in females rather than males (Larsen 2015, 74; White *et al.* 2011, 455). In these

populations a clear sexual division in labour can be observed, where women were responsible for gathering plants and other agricultural activities, and men had hunting as their primary subsistence task. Historic accounts also confirm that men ate more of what they hunted than women did, and as a result women ate more plants as a result of their subsistence responsibilities (Larsen 2015, 74). Yet, the higher prevalence of caries in females over males cannot be only attributed to labour activities. Research on the formation of dental caries show that women are more prone to developing the disease due to female sex hormones that affect the composition and flow of saliva and an increase in cravings during pregnancy (Lukacs 2008, 901). Like an increase in dental caries is associated with agriculture, agriculture is also associated with an increase in sedentism and fertility (Lukacs 2008, 901).

Differences in caries prevalence can also be seen in social ranking where members with high ranking status have higher caries prevalence in examples such as Edo-period Japanese, Shang dynastic China, Dynastic Egypt and Classic Maya (Larsen 2015, 77). This trend suggests that people of different social ranking consumed different kinds of foods that had different kind of consistency. High-ranking people would generally consume more soft refined foods than people of lower classes, which in turn promotes caries development (Larsen 2015, 77). In medieval Europe however there are conflicting results from comparing dental caries from lower- and upper-class, where one study pointed to dietary differences, and another one did not (Larsen 2015, 77).

2.3. How can stable isotopes and dental caries contribute to the study of diet in archaeology?

While isotope analysis and dental caries alone contribute significantly to the study of diet, the two of them combined give a more wholesome look on diets. From stable carbon/nitrogen studies this thesis will be able to determine what kind of plant groups were consumed amongst people in medieval Europe, and thereby also what kind of plants were part of subsistence. It will also be able to inform what kind of meats were consumed, and thereby also the ratio in which protein and plants were consumed by the individual. The caries studies will be able to inform on the levels in which starchy and carbohydrate rich foods were consumed, and by comparing females and males this

thesis should be able to pinpoint exact differences in diet amongst the groups. The two methods combined form a strong scope in which diets can be investigated.

3. Materials and methods

This chapter focuses on the skeletal collections that has been used for this thesis to assess diet in the medieval period. First this thesis will present the studies used for this research, and an overview of the sites can be seen in Figure 7. It will give historical background on the different case studies and briefly discusses the site and excavation context. Furthermore, information on how dental caries was scored, and how isotope samples were collected and analysed from the sample collection will be discussed. How sex was estimated will also be stated, alongside other introductory aspects of the studies. Finally, an overview of the sites, with corresponding dates, methods and number of individuals analysed can be seen at the end of the chapter in Table 1.



Figure 7: Overview of location of sites in North-Western Europe (Eidissen 2020).

3.1. Isotope case studies

3.1.1. Petriplatz cemetery in present-day Berlin

Petriplatz is located in present-day Berlin in Germany, in what was once the medieval town of Cölln. Cölln was founded in the mid-13th century at the same time as Berlin, and together they formed a so-called Doppelstadt where Cölln was located on Spree island, and Berlin on the banks of Spree river (Zechini 2017, 19). Petriplatz, which used to be the town centre of Cölln, included the medieval church of St. Peter, its cemetery, the town hall and its surrounding living area (Zechini 2017, 12).

In response to building development on Spree island, archaeologists in a period between 2007 and 2010 began excavating St. Peter's church and its associated cemetery with over 3000 buried individuals (Zechini 2017, 3). While the exact founding of the cemetery is unknown, historical documents date the cemetery to at least the 13th century, and it is known that the cemetery was in use for about 500 years before closing down in 1717 (Zechini 2017, 3).

From this study carbon and isotope isotopes were analysed from 66 individuals uncovered from the Petriplatz cemetery (Zechini 2017, x). From these 66 individuals, data on seven individuals were extracted to fit the aims of this thesis. Out of these seven individuals three males were documented, three females and one probable female. Sex estimation was only done on adults in this study, and it was done by researchers in Berlin using Museum of London Archaeology (MOLA) methods. The individuals were analysed using macroscopic investigations of features of the pelvis and skull (Zechini 2017, 26). To better understand diet in medieval Berlin, ribs from adult individuals were analysed through stable carbon and nitrogen isotopes (Zechini 2017, 5)

3.1.2. St. Giles by Brompton Bridge, North Yorkshire

Between 1988 and 1990, rescue excavations were carried out at the small medieval rural hospital of St. Giles, to protect it from river erosion (Cardwell et al. 1995, 109). The rural hospital, located in the county of North Yorkshire, between Swalendale and the Vale of Mowbray, was a religious hospital, that instead of giving medical treatment, cared for the sick, elderly and poor (Cardwell *et al.* 1995, 109; Müldner and Richards

2005, 41). The hospital was a humble and low-status establishment that was founded in the second half of the 12th century and went out of use during the second half of the 15th century (Cardwell *et al.* 1995, 109).

From the hospital's assorted cemetery, 17 individuals were selected for stable isotope analysis of whom 15 have an estimated sex. Samples were primarily taken from ribs, but where no ribs were present the samples were taken from long bones (Müldner and Richards 2005, 43). Two of these individuals have been identified as priests, and the rest is presumably inmates of the hospital (Müldner and Richards 2005, 41). Sex estimation was done on the basis of skull and pelvic morphology, and where possible, long bone measurements were taken into account (Cardwell *et al.* 1995, 216).

3.1.3. The Augustinian Friary in Warrington

The Augustinian Friary is located in the town of Warrington, situated between Liverpool and Manchester in England. The Friary can be dated back to the mid-13th century, and like most other religious institutions in England, it discontinued after the reformation of the English church in the first half of the 16th century (Müldner and Richards 2005, 41). Augustinian Friars were part of a religious movement that swore to absolute poverty and were devoted to religious spread as they settled in town to preach (Müldner and Richards 2005, 41-42). They were however quickly absorbed into the Christian establishment where wealth became more important, and burials in friaries became popular very popular to purchase. The church would accept considerable donations from the more fortunate of ordinary people, whom wanted the privilege of being buried inside the friary (Müldner and Richards 2005, 42).

Excavations from inside the Friary revealed multiple burials from both women, men and children, representing benefactors as well as friars. Out of these, eighteen adult individuals with determined sex were chosen for stable isotope analysis (Müldner and Richards 2005, 42). From the research it is unclear how sex determination was done, but it can be assumed it was done on the basis of pelvic and skull morphology, as it is very common in osteological research. Samples were primarily taken from ribs, but where no ribs were present the samples were taken from long bones (Müldner and Richards 2005, 42-43).

3.2. Dental caries case studies

3.2.1. St. Mary Grace cemetery, England

The Cistercian Abbey of St. Mary Graces and its associated cemetery was founded right after the Black Death ended in London in 1350 and was in use until the reformation of the English church in 1538 (DeWitte and Bekvalac 2010, 344). Located northeast of the tower of London, the Abbey's cemetery was used for the general population, and the church and chapels were reserved for monks and important lay people (DeWitte and Bekvalac 2010, 344). Excavations at the site in the 1980s revealed 133 skeletons from the church and chapels and 310 individuals buried in the cemetery. This study on caries includes a total sample of 80 adults, of whom 50 were estimated to be male and 21 females (Walter *et al.* 2016, 34). Unfortunately, no separation between the general population and the church and chapels were made.

Sex in this study was determined using skeletal features of the pelvis and skull, and only adult individuals of assigned sex or probable sex was used (Walter *et al.* 2016, 34). In the study, all observable teeth were scored for caries presence. Caries was recorded in the individual tooth, including position and severity of the caries. If destruction of dental enamel could be observed caries was scored as "present" in the tooth (Walter *et al.* 2016, 35). In this study the presence of at least one carious tooth would be recorded, however, the study only use data on tooth and caries presence from maxillary molars as a result of trying to minimize caries overestimation due to the criteria for caries presence. The choice to use maxillary molars only was also to maximize the size of the sample for statistical analysis (Walter *et al.* 2016, 35).

3.2.2. St. Mary Spital, England

St. Mary Spital was a priory as well as a hospital, and used to be one of England's largest hospitals during the medieval period. Located close to St. Mary Grace, it was founded during the 12th century, and the associated cemetery was in use from the 12th to the 16th century (Sidell *et al.* 2007, 593; Walter *et al.* 2016, 33-34). Founded on the outskirts of London, it was charged with caring for pilgrims and the sick, as well as providing care for pregnant women and children of those who died in childbirth (Walter *et al.* 2016, 33-34)

Despite the site being legally protected, pressure for redevelopment in the area prompted extensive excavations in 1991. During excavations, the cemetery belonging to the leys revealed around 10,500 buried individuals (Sidell *et al.* 2007, 594). Out of the excavated collection, 167 males and 124 females dating to between 1120-1539 AD were used for dental caries examination and are considered in this study. The period between 1250-1400 was excluded from the study due to an increased mortality due to the Black Death and the possibility of misrepresentative patterns in caries prevalence (Walter *et al.* 2016, 33-34).

This study was carried out by Walter *et al.* 2016. which was also responsible for the research on St. Mary Grace. Consequently, sex estimation as well as dental caries recording done at both sites was carried out similarly. This thesis will therefore refer to information about sex estimation and dental caries recordings as mentioned under St. Mary Grace for St. Mary Spital as well. Results from St. Mary Grace and St. Mary Spital will be combined in the next chapter, as sites are located closely and is expected to have little variation between them.

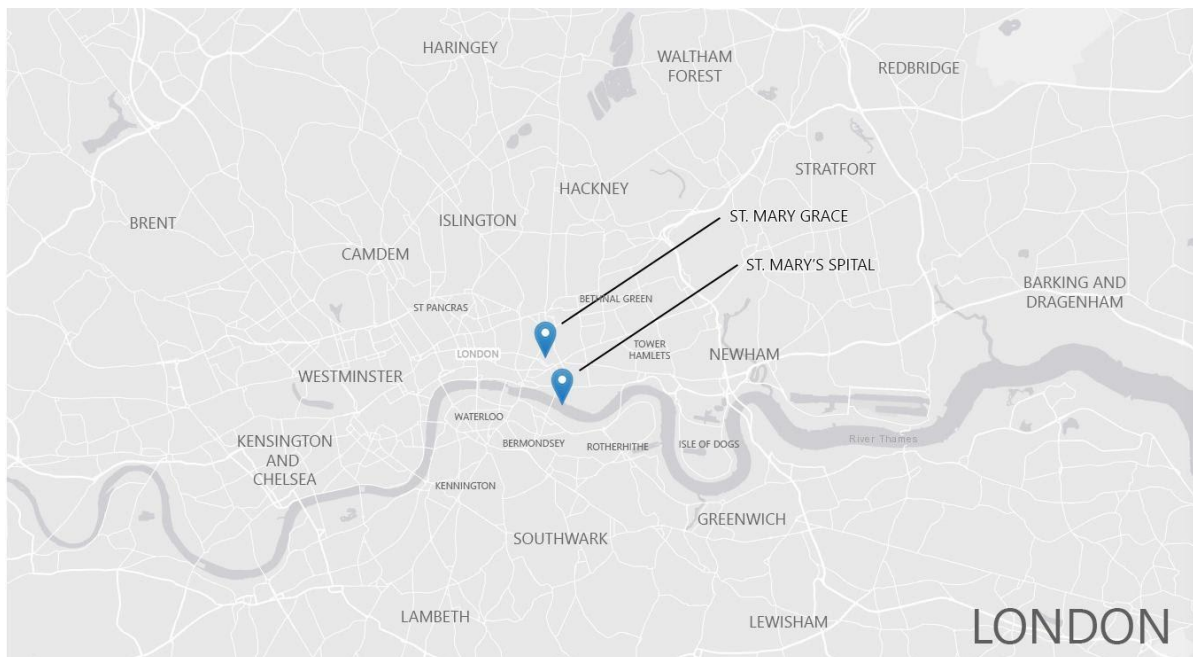


Figure 8: Location of St. Mary Grace and St. Mary Spital, London (Eidissen 2020).

3.2.3. Klaaskinderkerke, the Netherlands

Located on the island of Schouwen-Duiveland in the southwest part of the Netherlands, in what is today the province of Zeeland, was the medieval village of Klaaskinderkerke (Schats 2016, 24). The village was located on a naturally elevated ridge in the landscape and was first mentioned in historical texts in 1286. The village had a church that was built after 1286, and its associated cemetery was taken in use a few years after (Schats 2016, 24). The village seems to have been abandoned in 1570 due to a storm that flooded the entire island of Schouwen (Schats 2016, 24)

The area, susceptible to flooding, flooded again in 1953. The flood which affected large parts of Zeeland removed the topsoil of the associated cemetery of Klaaskinderkerke, exposing the buried human remains (Schats 2016, 26). As a result, it was decided to excavate the area, and by 1959 the cemetery had been completely excavated by the Dutch Cultural Heritage Agency (Schats 2016, 26).

In this study sex estimation was done on the basis of morphological features of the cranium, mandible and the pelvis. Individuals were placed into five categories of male, probable male, indeterminate, probable female and female (Schats 2016, 56). Dental caries was scored as present per tooth, and the location of lesions was recorded. Caries prevalence as well as caries frequency was also calculated (Schats 2016, 76).

3.2.4. The medieval cemetery of Vilarnau d'Amont, southwest France

Vilarnau was a medieval village located at the border between continental Europe and the Iberian Peninsula, close to Perpignan, the main city of Roussillon. It was a small village which had a castle, a church and an associated cemetery (Esclassan *et al.* 2009, 288). The cemetery in this rural parish was first used taken into use during the 9th century, and was used until the middle of the 15th century. During the Black Death in 1348, the village experienced a decline, and the village was more or less deserted. The period between the 12th and 14th century was rich in economic and rural development in Roussillon (Esclassan *et al.* 2009, 288).

Sex in this study was determined by researchers using Bruzek's method, which is a method that bases sex estimation on characteristics of the human pelvis. From this

study, 58 individuals were selected on the basis of sex, paired maxilla and mandible, as well as at least six teeth on each dental arch. Caries frequency was investigated macroscopically. Discolouring in the enamel was not considered to indicate caries, unless there was clear cavitation underneath the discolouring. Lesions were only considered carious if the cavity was a clear defect in the tooth tissue. Number of cavities were recorded, as well as where they were located on the tooth (Esclassan et al. 2009, 288-290).

3.3. Case studies where both methods have been applied

3.3.1. Alkmaar, The Netherlands

Alkmaar is located in the province of North-Holland, in the north-western part of The Netherlands. Habitation can be traced back to the Early Bronze age, and settlement continued until the fall of Rome in the West. Habitation can be observed again in early medieval times, but archaeological evidence for this period is limited (Schats 2016, 27). In 1254 Alkmaar received city status, and during the 13th and 14th centuries Alkmaar developed substantially when the city increased in size (Schats 2016, 27-28).

In the northern part of the town, in a location known as Het Heilighe Velt, or The Holy Field in English, a Franciscan monastery was founded in 1448 (Schats 2016, 28). While the majority of people were buried in the larger parish church or its associated cemetery, some people decided to be buried with the Franciscans (Schats 2016, 28). Both the wealthy and poor were buried at the Franciscan monastery, and the monastery was in use up until 1572 when large parts of the monastery was destroyed as a consequence of the Eighty Years War (Schats 2016, 29). In 2005 the monastery area was excavated by the Dutch archaeological company Hollandia Archeologen due to development in the area. In 2010, the cemetery was excavated by the same company, where 189 inhumations were uncovered (Schats 2016, 30).

In this study, sex estimation was done on the basis of morphological features of the cranium, mandible and the pelvis. Individuals were placed into five categories of male, probable male, indeterminate, probable female and female (Schats 2016, 56). Stable carbon and nitrogen isotope samples were extracted from bone collagen from ribs of 26 individuals (van Hattum 2014, 44). Dental caries investigations in Klaaskinderkerke and

Alkmaar was done by the same researcher, and was consequently scored the same way. In Alkmaar, a total of 60 females and 45 males were studied for dental caries (Schatz 2016, 122).

3.3.2. Holbæk, Denmark

Holbæk, located in the north-eastern part of the region Sjælland the country of Denmark (Turner 2013, 34). In a period between 1985 and 1986 excavations was carried out by the Museum of Holbæk in the associated cemetery of St. Nicolai (Turner 2013, 33). The cemetery was first in use in the 12th century AD, and both the church and the cemetery was abandoned in AD 1573 due to the reformation of the Danish church (Turner 2013, 34). The individuals whom were excavated at Holbæk is believed to represent the general public (Turner 2013, 38).

The Holbæk skeletal collection is housed at the University of Copenhagen, and while it is unclear from the publication how sex estimation was done, it was most likely done on the basis of pelvic and skull morphology, as it is very common in osteological research. From the collection, data on dental caries and stable isotopes from a total of 44 skeletons were extracted to fit the aims of this thesis (Turner 2013, 43). The stable isotope samples from this study were collected from the trabecular rib bone of the individuals (Turner 2013, 43-44). Dental caries was scored according to Buikstra and Ubelaker where the total number of caries per individual was recorded (Turner 2013, 40-41).

3.3.3. Sigtuna, Sweden

Sigtuna was founded in the second half of the 10th century in a rural area, connected to a royal manor (Kjellström *et al.* 2009, 2689). The town is situated in eastern central Sweden, 35 km south of Gamla Uppsala, and 35 km north of Birka (Kjellström *et al.* 2005, 87). The city was founded by the king to operate as a stronghold in his quest for power in the area, but the town soon developed into a true urban centre with a hierarchic society, several religious institutions and a social stratification unique for Sweden at the time (Kjellström *et al.* 2009, 2689). The urbanization of Sigtuna was so immediate that it made the town comparable to other contemporary large settlements

in western Europe (Kjellström *et al.* 2005, 87). During the end of the 13th century a slow stagnation of the town took place, most likely due to the foundation of Stockholm.

For Sigtuna, both stable carbon/nitrogen analysis and caries investigations have been done. For the stable isotope analysis, burials from the St. Laurence churchyard and Church 1, phase 1, is of relevance, and data was extracted accordingly to fit the aims of this thesis. The churchyard and the burials associated with it dates to 1300-1500 AD, which was the period when St. Laurence was the church of the town parish. Because of this it is believed that the people who were buried here were general citizens in Sigtuna (Kjellström *et al.* 2009, 2691-2693). In this study, samples for the stable isotope analysis was collected from human long bones, primarily the femur, and a total of 35 males and females were analysed (Kjellström *et al.* 2009, 2692).

Dental caries investigations were carried out slightly differently. Sigtuna had multiple churches and churchyards through its medieval occupation from where this study collected samples from. Relevant for this thesis is a phase between the 12th to the 14th century (phase 1), and a phase between the 14th century to the Swedish reformation in 1527 (phase 2) (Kjellström *et al.* 2005, 90-92). Caries frequency was recorded as one or more present caries lesions (Kjellström *et al.* 2005, 98). In phase 1, 26 females and 54 males were looked at for caries lesions, and in phase 2, six females and 12 males were also investigated (Kjellström *et al.* 2005, 104)

Sex estimation for Sigtuna was done on the basis of pelvic and skull morphology, and only adults were included in this study (Kjellström *et al.* 2005, 96)

3.4. Summary

In order to give a better overview of the materials and samples used for this thesis the following table was made (Tab. 1). The table consists of all studies in alphabetical order, their dates and the number of females and males used in the study. The studies are also sorted by the type of methods used to analyse the material.

From the Stable isotope studies, we can see that 16 females and 24 males were tested. Females are slightly underrepresented here, and the sample pool is somewhat skewed towards England. In the caries studies a total of 179 females and 270 males were analysed. Females are also underrepresented here, and also here the sample pool is

slightly skewed towards England. In the studies that investigated both methods, a total of 101 females and 126 males were investigated for dental caries, and a total of 45 females and 60 males were sampled for isotope analysis. The sample pool for the studies using both methods is diverse, including mid-and south Scandinavia, as well as the lowlands represented by the Netherlands. In the remaining chapters of this thesis, the dental caries and the isotopic studies will be discussed separately.

Table 1: Studies used indicated by applied methods, date and number of individuals.

| | Site | Date | Females | Males | |
|-------------------------|-------------------------|-----------------------|---------------|-------|----|
| Stable Isotopes | Petriplatz | 1250-1400 AD | 3 | 4 | |
| | St. Giles | 12th- 15th century AD | 4 | 11 | |
| | Warrington | 13th century- 1539 AD | 9 | 9 | |
| Dental Caries | St. Mary Grace | 1350-1538 AD | 21 | 59 | |
| | St. Mary Spital | c. 1120-1539 AD | 124 | 167 | |
| | Klaaskinderkerke | 1286-1573 AD | 5 | 15 | |
| | Vilarnau d'Amont | 12th-14th century AD | 29 | 29 | |
| Methods combined | Alkmaar | | Stable | | |
| | | 1448-1572 AD | isotopes | 12 | 13 |
| | | | Dental Caries | 60 | 45 |
| | Holbæk | | Stable | | |
| | | 1200-1573 AD | isotopes | 20 | 24 |
| | | | Dental Caries | 20 | 24 |
| Sigtuna | | Stable | | | |
| | 1300-1500 AD | isotopes | 13 | 22 | |
| | | Dental caries | 32 | 66 | |

4. Results

In this chapter, this thesis will present the results from the stable carbon/nitrogen studies and the dental caries analysis. It will briefly explain the results, give average values, and determine if these values have differences that are statistically significant. If the results and statistical results are directly used from the corresponding studies, sources are cited. If no sources are cited the analysis were ran separately by the author of this thesis. To improve readability of this chapter, results from all stable isotope studies and dental caries studies will be addressed separately, with sites presented in alphabetical order.

4.1. Stable isotope results

4.1.1. Alkmaar

From Alkmaar, the data from 12 females and 13 males sampled for isotope analysis were collected from van Hattum 2014. The average $\delta^{13}\text{C}$ values record at -20.1‰ for the males, and at -20.4‰ for the females. For males, the average $\delta^{15}\text{N}$ value is recorded at 13.6‰ , and for the females at 12.8‰ . A t-test was run to see if the recorded values from the samples differed significantly between males and females. $\delta^{13}\text{C}$ values held no significant difference between males and females ($t=1.092$, $p=0.286$, $n=25$). $\delta^{15}\text{N}$ values compared did have statistical significance ($t=2.699$, $p=0.013$, $n=25$) (van Hattum 2014, 78). In this regard, males had higher $\delta^{15}\text{N}$ values than females with statistical significance which suggests that males ate more animal protein, or consumed different types of animals with higher trophic level.

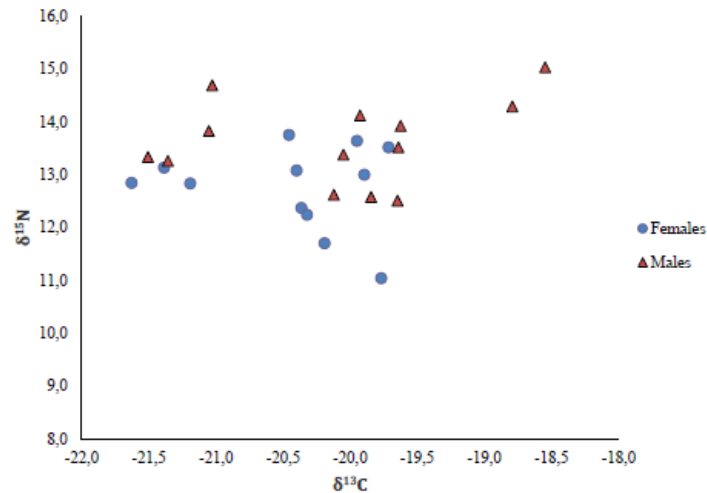
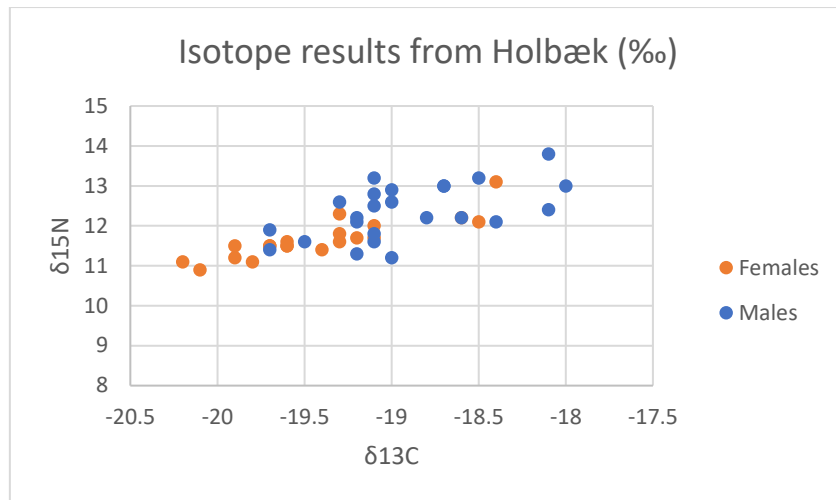


Figure 9: Isotope results from Alkmaar of males and females plotted (van Hattum 2014, 78).

4.1.2. Holbæk

From Holbæk 20 females and 24 males were sampled for isotope analysis. The data was extracted from Turner 2013 to make suitable data for this thesis considering the age of the individuals, and with the new data a t-test was run by the author of this thesis. The average $\delta^{13}\text{C}$ value for males recorded at -18.92‰ , and the females average $\delta^{13}\text{C}$ value was recorded at -19.4‰ . The average $\delta^{15}\text{N}$ value for men records at 12.3‰ , and for females 11.6‰ . A t-test was run to see if the recorded values from the samples differed significantly between males and females. $\delta^{13}\text{C}$ values held significant difference between males and females ($t=-3.359$, $p=0.002$, $n=44$). $\delta^{15}\text{N}$ values did also have differences with statistical significance between males and females ($t=-3.789$, $p=0.000$, $n=44$). In this collection there is difference with statistical significance in both the $\delta^{13}\text{C}$ values and $\delta^{15}\text{N}$ values between males and females, where females have higher $\delta^{13}\text{C}$ values- and lower $\delta^{15}\text{N}$ values than males. These results indicate that males and females consumed different types of animal protein and that males perhaps consumed more protein than females.



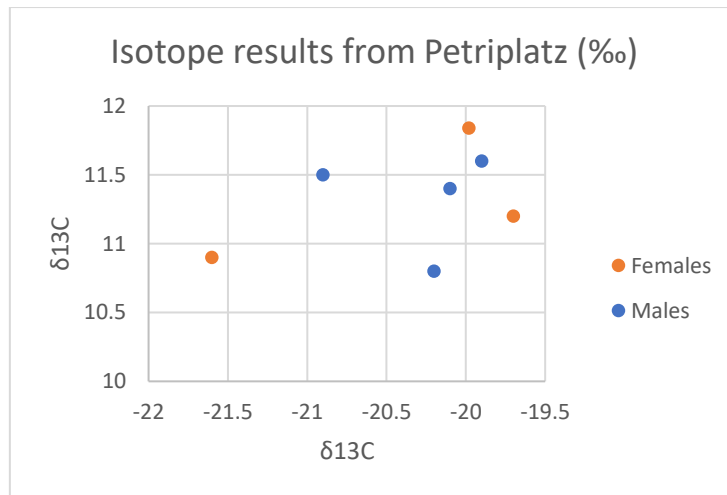


Figure 11: Isotope results from Petriplatz, Berlin, with males and females plotted (after Zechini 2017, 39-41).

4.1.4. Sigtuna

From Sigtuna, 13 females and 22 males were sampled for isotope analysis. The data was extracted on the basis of burial phases from Kjellström *et al.* 2009, to make the data suitable for this thesis. With the new data a t-test was run by the author of this thesis. In this study, the average $\delta^{13}\text{C}$ values for the male individuals lie at -21.14, and for the women the average was recorded at -21.03‰. The average $\delta^{15}\text{N}$ value for the male individuals is 13.34‰, and for the females 12.57‰. After running a t-test, it was found that differences in $\delta^{13}\text{C}$ values were not statistically significant between males and females ($t=0.475$, $p=0.638$, $n=35$). There was no statistical significance in the differences in $\delta^{15}\text{N}$ values either ($t=1.861$, $p=0.072$, $n=35$). In this regard there is no statistically significant difference between males and females in regards to $\delta^{13}\text{C}$ values and $\delta^{15}\text{N}$ values, which suggests that they had similar diets.

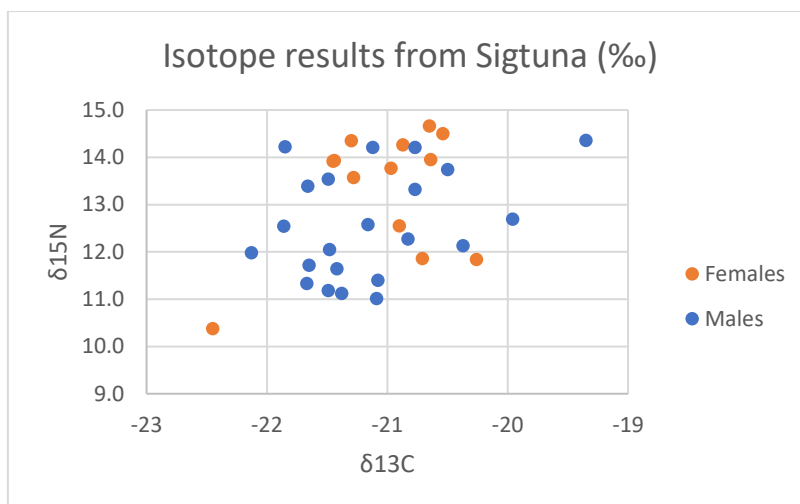


Figure 12: Isotope results from Sigtuna with males and females plotted (after Kjellström *et al.* 2009, 2697-2698).

4.1.5. St. Giles, England

From St. Giles in England, four females and 11 males were sampled for stable carbon/nitrogen analysis. The data was extracted from Müldner and Richards 2005, and with the data a t-test was run by the author of this thesis in order to test the statistical significance in the results. The females $\delta^{13}\text{C}$ values average at -19.32‰ , and the $\delta^{15}\text{N}$ values average at 11.97‰ . Males have slightly higher carbon and nitrogen values, where the $\delta^{13}\text{C}$ value average at -18.92‰ and the $\delta^{15}\text{N}$ value at 12.89‰ . Average differences between males and females can be observed with a less negative $\delta^{13}\text{C}$ value, and a more positive $\delta^{15}\text{N}$ value in males rather than females. After testing the statistical significance of the differences, it was found that $\delta^{13}\text{C}$ values held no significant difference between males and females ($t=-1.397$, $p=0.186$, $n=15$). No statistical significance in the differences in $\delta^{15}\text{N}$ values could be recorded either ($t=-2.572$; $p=0.023$, $n=15$). In this regard there is no difference with statistical significance between males and females in regards to $\delta^{13}\text{C}$ values and $\delta^{15}\text{N}$ values, suggesting that they had similar diets.

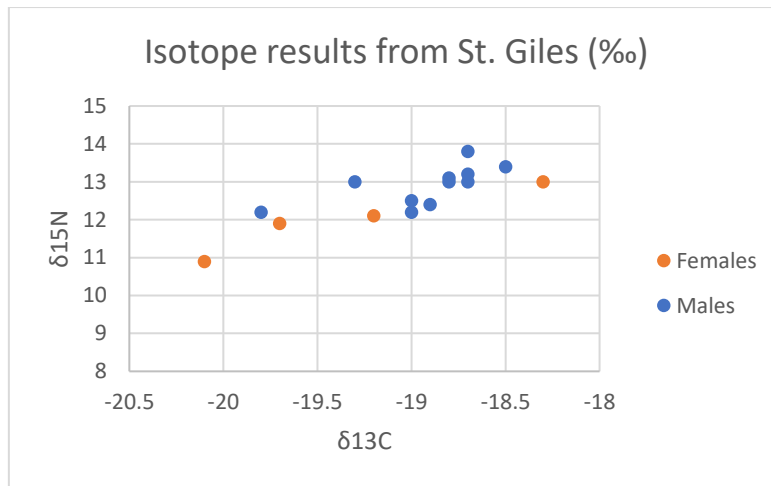


Figure 13: Isotope results from St. Giles, England, with males and females plotted (after Müldner and Richards 2005, 43).

4.1.6. Warrington, England

From Warrington in England, nine females and nine males were sampled for isotope analysis. The data was extracted from Müldner and Richards 2005, and with the data a t-test was run by the author of this thesis. In this study the females $\delta^{13}\text{C}$ values average at -19.96‰ and the $\delta^{15}\text{N}$ value average at 11.46‰ . The males are similar to the females $\delta^{13}\text{C}$ values with -19.72‰ , but differ in the $\delta^{15}\text{N}$ values, where the male samples average at 12.43‰ . After running a t-test, it was found that $\delta^{13}\text{C}$ values were not significantly different between males and females ($t=0.584$, $p=0.345$, $n=18$). A statistical significance in the differences in $\delta^{15}\text{N}$ values between males and females was however recorded ($t=-2.291$, $p=0.036$, $n=18$). In this collection there is no statistically significant difference between males and females in regard to $\delta^{13}\text{C}$ values, but a difference with statistical significance was recorded in the $\delta^{15}\text{N}$ values. The male individuals generally have higher $\delta^{15}\text{N}$ values, suggesting that they consumed more protein and/or consumed different animals with higher trophic level, than females.

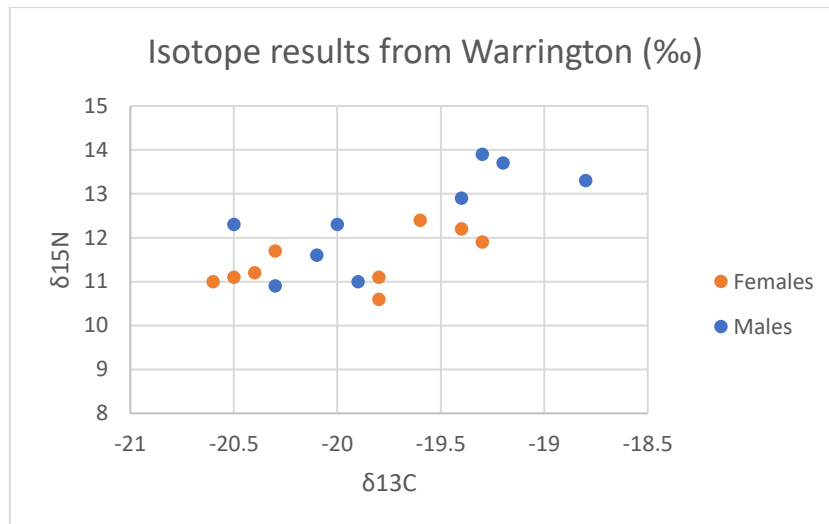


Figure 14: Isotope results from Warrington, England, with males and females plotted (after Müldner and Richards 2005, 43).

4.2 Dental caries studies

4.2.1. Alkmaar

From Alkmaar a sample pool of 60 females and 45 males were studied for dental caries, and the results are displayed in prevalence and frequency. From this collection the females display caries prevalence of 81.7%, and the males 80% (Fig. 15). The caries frequency of females records at 16.7%, and the males had a caries frequency of 16.8% (Fig. 16). Clearly there is no remarkable difference between males and females in this regard ($p=0.974$, $n=105$) (Schats 2016, 118). These results indicate that males and females were probably equally reliant on foods rich in carbohydrates.

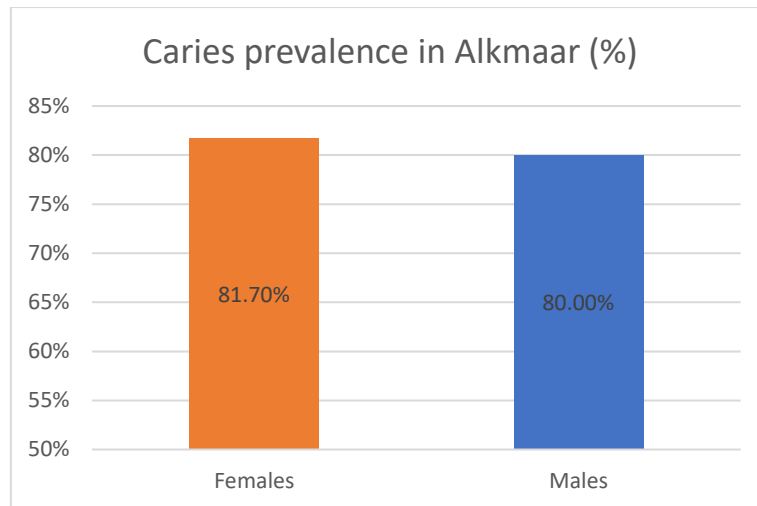


Figure 15: Sex differences in dental caries prevalence at Alkmaar (after Schats 2016, 118).

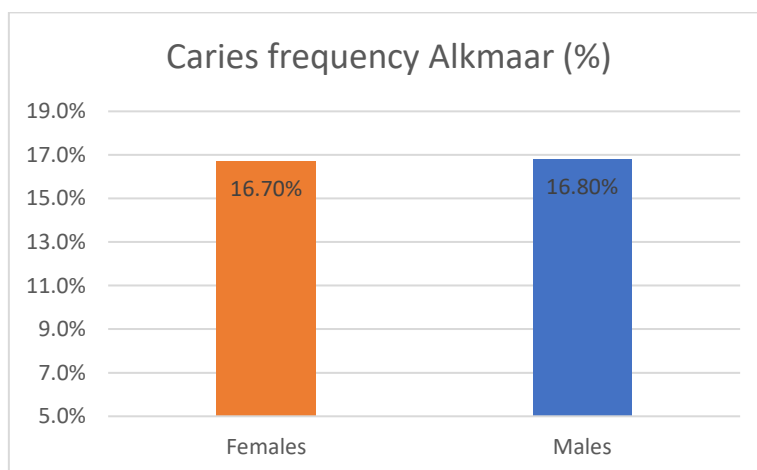


Figure 16: Sex differences in dental caries frequency at Alkmaar (after Schats 2016, 118).

4.2.2. Holbæk

From Holbæk in Denmark 20 females and 24 males were analysed for dental caries. The data was, with consideration of age groups, extracted from Turner 2012 in order to make suitable data for this research, and with the new data a Chi-square test was run by the author of this thesis. In this study, the total number of caries was recorded per individual, making it possible to create a caries prevalence diagram (Fig. 17). In the caries prevalence diagram, females score at 55% and males at 58%. In this study, males

had an average of 1.29 lesions and the females 1.05 (Turner 2013, 92). Although some differences can be observed, the Chi-square test proved that there is no significant difference in number of caries per individual between males and females ($p=0.679$, $n=44$). These results indicate that males and females were similarly affected by caries when considering number of caries per individual.

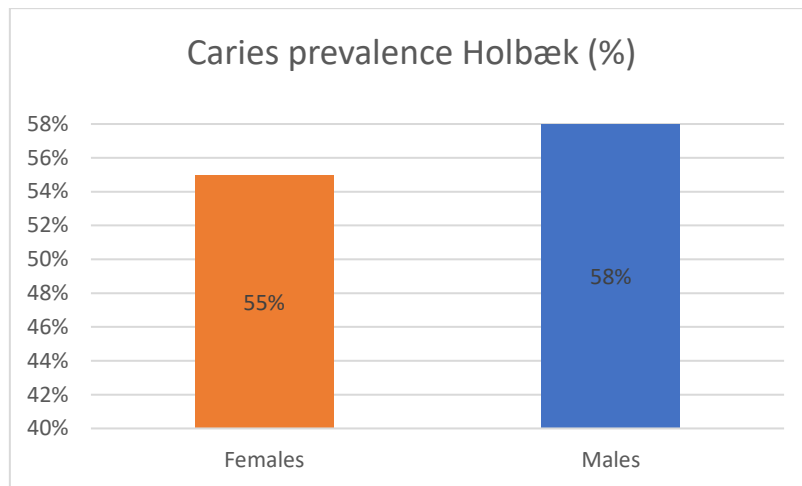


Figure 17: Sex differences in caries prevalence from individuals in Holbæk (after Turner 2013, 92).

4.2.3. Sigtuna

Dental caries was investigated in 32 females and 66 males from Sigtuna. The data was extracted from Kjellström *et al.* 2005 in order to make suitable data for this thesis considering burial phases. Caries was recorded as one or more lesion present per individual, and as a result, the data is only presented in prevalence. 40.9% of the male individuals showed one or more lesions present within the teeth, and for the females it was recorded to 46.8% (Fig. 18; Kjellström *et al.* 2005, 104). There was no statistical data available from this study, and it is not possible to do statistical analysis because the original data is not available. However, when only looking at caries prevalence there is a tendency towards higher caries prevalence in females, indicating that they might have had different diets.

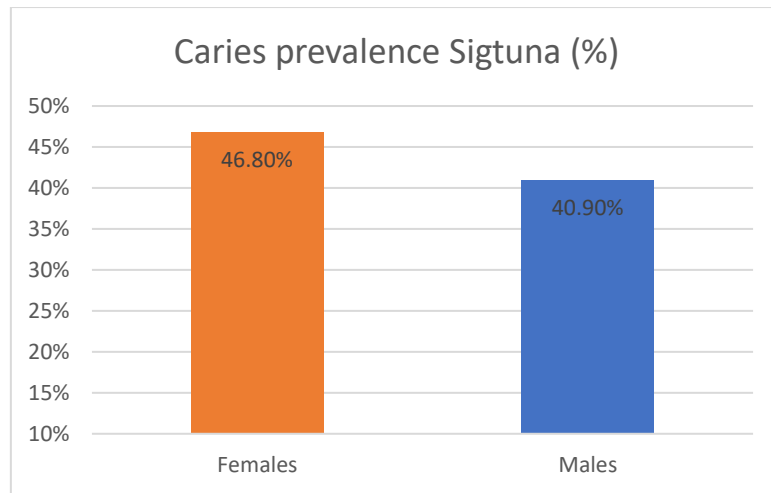


Figure 18: Sex differences in dental caries prevalence at Sigtuna (after Kjellström *et al.* 2005, 104).

4.2.4 St. Mary Grace & St. Mary Spital

St. Mary grace and St. Mary Spital combined have a total of 145 females and 226 males that were investigated for dental caries. The results are displayed in prevalence, but there is no information on caries frequency (Fig. 19). From the male individuals, 126 had caries presence, making the caries prevalence in males 56%. This stands in contrast to the females, where 107 individuals had caries present, making the caries prevalence 74% (Walter *et al.* 2016, 36). A Chi-square test was used to assess possible differences between sexes with statistical significance. Results from the test indicate that there is a significant difference ($p=0.01$, $n=371$) between males and females (Walter *et al.* 2016, 36). This indicates that females had higher caries prevalence than males, and were perhaps more reliant on foods rich in carbohydrates than males.

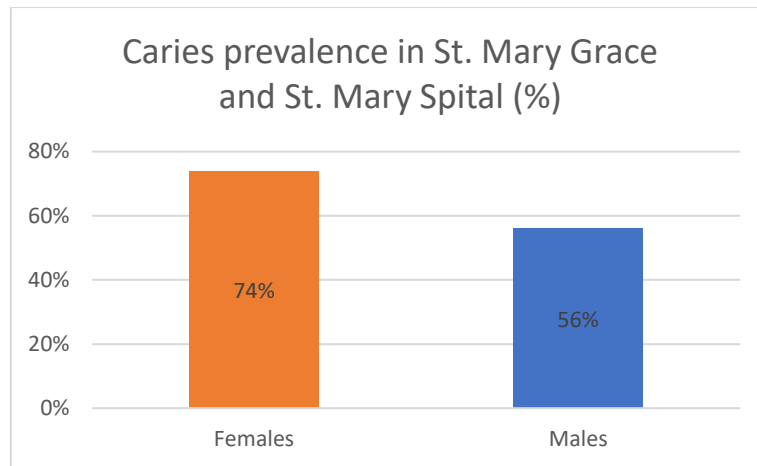


Figure 19: Dental caries prevalence in St. Mary Grace and St. Mary Spital with males and females indicated (after Walter *et al.* 2016, 36).

4.2.5. Klaaskinderkerke, The Netherlands

From Klaaskinderkerke a total of five females and fifteen males were investigated for dental caries (Schats 2016, 117). It was recorded that the male individuals have a caries prevalence of 71.4%, and the females 55.6% (Fig. 20). The total number of teeth and carious teeth in males and females was also recorded, which show that females have a caries frequency of 7.4% and males a frequency of 8.8% (Fig. 21). Generally, there is no significant difference between males and females in caries frequency ($p=0.596$, $n=20$) (Schats 2016, 117). This indicates that females and males were probably equally reliant on foods rich in carbohydrates.

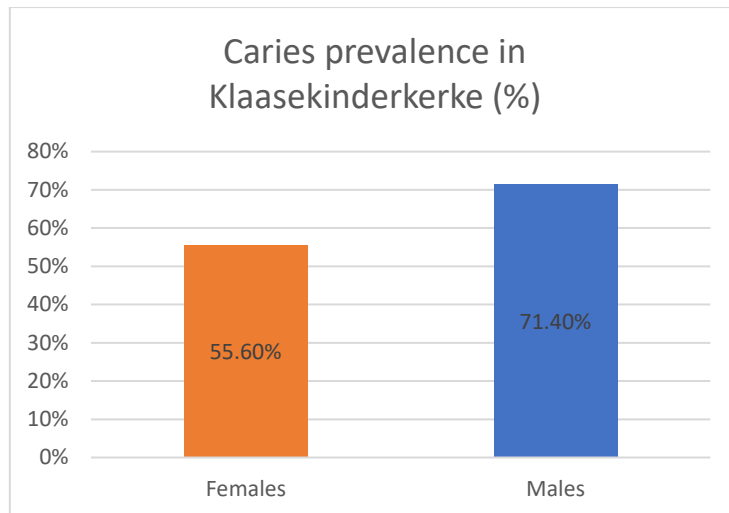


Figure 20: Caries prevalence in Klaaskinderkerke (after Schats 2016, 117).

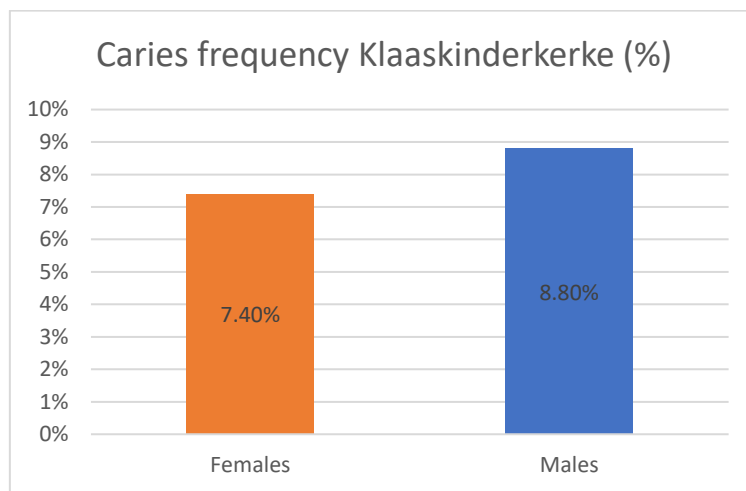


Figure 21: Sex differences in dental caries frequency at Klaaskinderkerke (after Schats 2016, 117).

4.2.6. Vilarnau d'Amont

In Esclassan *et al.* 2009, from Vilarnau d'Amont, a total of 29 males and 29 females were analysed for dental caries. While information on caries prevalence was not present in the study, data on caries frequency was available. The caries frequency for the male individuals is recorded at 21.9%, and the females had a caries frequency at 14% (Fig. 22; Esclassan *et al.* 2009, 290). The male individuals display a higher caries frequency than the females but this difference is not statistically significant ($P < 0.05$) (Esclassan *et al.*

2009, 293). This indicates that despite higher caries frequency in males, males and females were probably equally reliant on foods rich in carbohydrates.

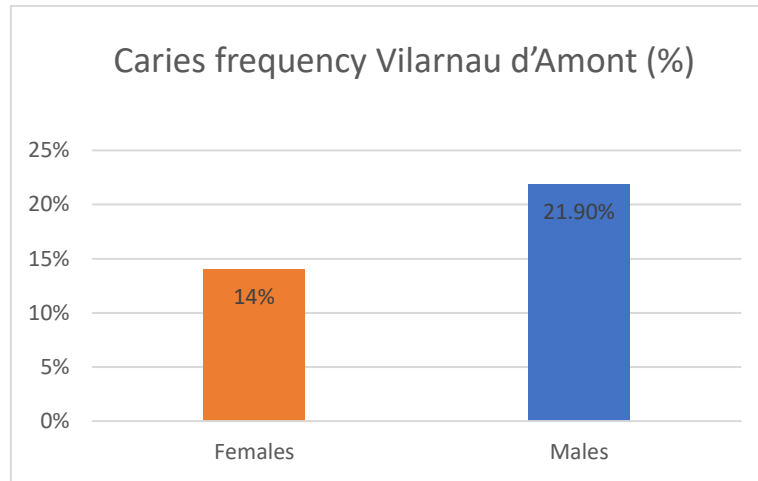


Figure 22: Sex differences in dental caries frequency at Vilarnau d'Amont (after Esclassan *et al.* 2009, 290).

5. Discussion

This chapter is dedicated to discussing the results from the stable isotope and dental caries studies. First, a short summary of the previous chapter will be provided, and then an interpretation of the observed results will be made. Differences in diet between sexes will also be discussed, and historical data will be added to both the interpretation of diet and the interpretation of dietary differences between males and females in north-western Europe. For the isotope studies, information about the animal baseline, what it is, and how it relates to interpreting the human isotope results will be explained. Possible limitations to this study will be briefly mentioned. To improve readability of this chapter, results from all stable isotope studies and dental caries studies will be addressed separately, with sites presented in alphabetical order.

5.1. Diet and isotopes

From the results chapter it was recorded that individuals from Petriplatz, Sigtuna and St. Giles showed no difference with statistical significance in regards to isotopes between males and females, indicating that they had similar diets. However, from Alkmaar, Holbæk and Warrington differences in diet with statistical significance could be observed. Generally, in these sites, males displayed higher $\delta^{15}\text{N}$ values than females, and in Holbæk differences in $\delta^{13}\text{C}$ values could also be observed where females displayed higher values than males. This indicates that males and females had different diets, where different sources of animal protein were consumed between the groups, and/or that males consumed higher amounts of animal protein. In order to interpret late medieval diet for males and females based on stable carbon/nitrogen isotopes, a comparison between human isotopes and isotope samples from local fauna is necessary.

5.1.1. Interpretation of stable isotopes and late medieval diet

As already discussed in chapter 2 of this thesis, the higher up the food chain an organism is, the higher $\delta^{15}\text{N}$ values can be observed. However, since trophic level is relative, comparing isotope values between humans and local fauna is needed in order to determine the human trophic level and dietary source. For example, humans having a vegetarian diet will display isotope values 1-2‰ closer to herbivores such as sheep,

cows or goats, and if humans had an omnivorous diet, they would have an increased trophic level and therefore display higher $\delta^{15}\text{N}$ values than local herbivores (Zechini 2017, 42).

When using local fauna to compare human isotope samples with, it is beneficial to have samples from herbivores, omnivores, carnivores, freshwater fish and saltwater fish. This is because trophic level is relative, and by comparing samples with these groups of animals, one can better understand how humans fit in on the food chain. Between the isotope studies of this thesis the animal baseline is similar, but some variation can be observed. What is similar for all sites is that samples from cow, sheep/goat, pig and domesticated fowl were used (van Hattum 2014, 91; Kjellström *et al.* 2009, 2691; Müldner and Richards 2005, 42; Yodler 2012, 1189; Zechini 2017, 42). Samples from carnivores like dog and cat were also included for the sites, with Holbæk as an exception. Freshwater fish samples were included in the animal baseline for Alkmaar, Holbæk, St. Giles, Sigtuna and Warrington, and is represented by flatfish, cyprinid, eel, bream and pike. Alkmaar and Holbæk also included samples of saltwater fish like codfish, haddock, herring and ling (van Hattum 2014, 91; Kjellström *et al.* 2009, 2691; Müldner and Richards 2005, 42; Yodler 2012, 1189; Zechini 2017, 42). When comparing human isotope values to local fauna in order to see their relative trophic level, a correction of 0-2‰ for carbon can be expected, and a correction of 3-6‰ for nitrogen (Zechini 2017, 42).

Due to differences in ecology between sites it is preferable to use reference samples which are extracted from local fauna (Kjellström *et al.* 2009, 2691). However, for many sites this is not possible due to lack of local data. In the case of Alkmaar faunal samples were collected from the site itself, but the fish samples came from Oldenzaal, east of Alkmaar. It is noteworthy that Oldenzaal is located inland, and saltwater fish found at this site must have been transported from the coastline of The Netherlands (van Hattum 2014, 91). An animal baseline was not reported in the case study of Holbæk, so an attempt to interpret the human isotope results will be done by comparing the data to an animal baseline which was used to interpret human isotope results in another medieval site in Denmark, namely Øm kloster (Yoder 2012, 1189). Faunal data from Petriplatz was not collected from the site itself either, but from a medieval cemetery located 500km south of Petriplatz (Zechini 2017, 42). In the case of St. Giles and Warrington, the faunal samples originate from St. Giles and the medieval rural village Wharram Percy. The fish samples for St. Giles and Warrington came from the Dominican Priory at Beverley in

Eastern Yorkshire (Müldner and Richards 2005, 42). Lastly, in the case of Sigtuna, an animal baseline was collected from a nearby settlement named Birka which is, like Sigtuna, also located on the Lake Mälaren. The carnivore sample to compare human isotopes from Sigtuna with was collected from Öland in Sweden, and the freshwater fish sample was collected from the Bothnian Bay area, from the coast of Latvia (Kjellström *et al.* 2009, 2691).

When interpreting diet based on stable carbon/nitrogen isotopes, it is beneficial to first look at the carbon component of the diet in order to determine the reliance on C₃ and C₄ plants. Looking at the carbon component of the isotope results in this study it can be seen that all sites express similar $\delta^{13}\text{C}$ values, which suggests a C₃ plant-based diet. As discussed in chapter 2 of this thesis, C₃ plants represents grasses, trees, tubers etc., and they include cereal grains such as wheat, barley and oats. These are not surprising results as all sites are located within temperate regions, and not in a hot and dry climate as would be expected with C₄ plants. (van Hattum 2014, 101; Kjellström *et al.* 2009, 2694; Müldner and Richards 2005, 42; Zechini 2017, 43).

As the plant component of the diet has been determined, it is possible to look at the nitrogen component of the diet. In Alkmaar it was found that the $\delta^{15}\text{N}$ values were too enriched for the human diet to be based mainly on cow, dairy, sheep and/or goat, and that meat from omnivores such as pig must have been consumed as well (van Hattum 2014, 97). The observed large differences between the human isotopes and isotopes from freshwater fish, as well as saltwater fish, suggests that diet in Alkmaar was not primarily based on freshwater and saltwater fish (van Hattum 2014, 97). The $\delta^{15}\text{N}$ values from individuals in Alkmaar is however too enriched to be explained with a terrestrial diet alone, and although the values are greatly lower than those of the saltwater fish and freshwater fish, historical documents mention marine fishing along the coast of the Netherlands, and also extensive fishing for eel. The combination of freshwater fish with low $\delta^{15}\text{N}$ values, as well as saltwater fish in a diet can be an explanation for the $\delta^{15}\text{N}$ values seen in individuals from Alkmaar (van Hattum 2014, 101).

When looking at the herbivore and omnivore $\delta^{15}\text{N}$ values used to interpret human isotopes from Holbæk, it is noticeable that most values are lower than the human samples from this site, indicating that pig, chicken, sheep/goat and cow were probably an important part of diet (Turner 2013, 95-96; Yodler 2012, 1189). The ling and pike express higher $\delta^{15}\text{N}$ values than humans, and was therefore probably not important in

people's diet. Freshwater fish such as pike and trench also have lower $\delta^{15}\text{N}$ values than humans, and are likely to have been part of diet (Turner 2013, 95-96; Yodler 2012, 1189). Most of what is known about medieval diet though historical documents in Europe comes from England, and while some variation between European countries is to be expected, the overall character of medieval diet may be generalized from these sources (Yodler 2012, 1184). These sources indicate that dairy products, fruits and meats were available on a limited basis for the majority of the population, and that peasants were more reliant on produce from gardens, and that the wealthier ate less vegetables and more meat (Yodler 2012, 1184).

At Petriplatz, high levels of nitrogen and relatively low levels of carbon indicate that individuals had a diet based on terrestrial animals, but also freshwater fish. This is not surprising as the site is located on the banks of Spree River (Zechini 2017, 48). This is supported by historical documents from Germany in the form of a 14th century cookbook, which lists recipes for, amongst other things, dishes that include freshwater fish such as perch. Other historical documents from Germany also state that individuals of higher social class ate white bread and drank wine, while poor people ate bran bread. While there are differences in class, many people from Germany ate cheese soup, perch and different fruit dishes (Zechini 2017, 16).

In England the situation was similar in regards to diet. Both St. Giles and Warrington display high levels of nitrogen and low levels of carbon, and the available faunal data suggests a diet consisting of terrestrial animal protein, as well as freshwater and marine protein (Müldner and Richards 2005, 45). Historical documents from England supports this, and states that diet was mainly based on cereals with varying amounts of meat and fish. However, it is important to mention dietary differences between social classes. Meat was more commonly consumed by the wealthy, and the lower class was more reliant on eggs, milk and cheese as a protein source (Müldner and Richards 2005, 40-41). Marine fish seems to have been an important part of diet, while freshwater fish was more limited to wealthy people (Müldner and Richards 2005, 41).

When comparing the human isotope samples to the animal baseline it was found that the diet individuals at Sigtuna had was predominantly terrestrial in origin. However, the $\delta^{15}\text{N}$ values from Sigtuna may have been affected by an intake of leguminous or nonlegumes vegetables, dairy products, suckling animals, migrating birds and also different types of meat or freshwater fish (Kjellström *et al.* 2009, 2692). This correspond

with other studies on medieval diet in Sweden (Kjellström *et al.* 2009, 2694). Some is known about medieval diet in Sigtuna through historical sources and will be covered in the dental caries part of this chapter. However, it should be noted that historical records from Sweden talk about the importance of meat in the diet, and how it was seen as the most nutritious food where its consumption was associated with masculinity, strength, power and virility (Sundman 2018, 95)

5.1.2. Stable isotopes and differences in diet based on sex

When looking at medieval diet through the lens of stable carbon/nitrogen isotope analysis in North-Western Europe, different results emerge. In the isotope studies, isotopes from males and females from Petriplatz showed very similar averages, and when a t-test was run, no difference with statistical significance could be observed. In this regard males and females from Petriplatz had similar diets, but it should be noted that in the case of Petriplatz, the dataset had few individuals and may not represent a general trend. Males and females from St. Giles in England had different isotope averages where males had a more positive $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. However, when a t-test was run, no difference with statistical significance was found. It is important to mention here that St. Giles was a low-status religious hospital, and that the burial grounds would have consisted of patients from the hospital, namely the sick elderly and poor. It could be that in communities like these, where people already have little, that there was less difference between people. It is also noteworthy that a rather few number of females were sampled, which might also affect the results. When looking at the isotope values from Sigtuna it can be observed that the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from males and females had little differences. This was also supported by the t-test which concluded that there was no difference with statistical significance.

There is however a trend towards difference in diets between males and females. In Alkmaar, the average $\delta^{13}\text{C}$ values from males in females are similar and display no statistically significant difference either. However, the average $\delta^{15}\text{N}$ values are different between sexes, where males have a more positive average. This difference between males and females also holds statistical significance through statistical analysis. Differences can also be observed in Holbæk, where the average $\delta^{13}\text{C}$ values between males and females are different, and females show a more negative $\delta^{13}\text{C}$ value than

males. This difference also held statistical significance. At Holbæk, the $\delta^{15}\text{N}$ averages were different, where females had a more negative $\delta^{15}\text{N}$ value than males. This difference too held statistical significance. In England and the Augustinian Friary in Warrington, differences between males and females was also observed. While the average $\delta^{13}\text{C}$ values from both groups were similar, the average $\delta^{15}\text{N}$ values were different as males displayed a more positive $\delta^{15}\text{N}$ value than the females. This difference was also proven significant.

Differences in diet between males and females may be explained with differences in gender related daily activities, divisions in labour, and also ideologies (van Hattum 2014, 109-111). In medieval times, women were often preoccupied with the household, and working women would often be employed as servants, caring for children, working the garden, cooking meals, or selling food at the market. Assuming that women were not allowed to eat from the expensive meat in the household they were working in, it can be assumed that they ate a lot of vegetables due to often being involved in food-preparatory activities (van Hattum 2014, 109-111). Males were not restricted to the household, kitchen or market in the same way as females, and would not have the same availability to vegetables. It is possible that the lack of restrictions in employment and daily activities allowed males the liberty to have a meal at the local tavern, where meat would be served (van Hattum 2014, 109).

Social rank and ideologies might have also played a role to the observed differences between males and females. Historical texts, such as cook books and other documents, imply that meat was considered to be more appropriate served to males rather than females because it was believed to be an aphrodisiac (van Hattum 2014, 110-111).

5.2. Dental caries and diet

In the results chapter it was observed that males and females from Alkmaar, Holbæk, Klaaskinderkerke and Vilarnau d'Amont had no difference with statistical significance in regards to dental caries prevalence and frequency. This suggests that males and females from these sites had an equal reliance on foods rich in carbohydrates. Results from Sigtuna show that that there is a trend towards higher caries prevalence in females, however, determining the statistical significance of this difference is not possible due to lack of statistical and raw data. Males and females from St. Mary Spital and St. Mary

Grace did show differences with statistical significance in caries prevalence, where females had higher caries prevalence than males, indicating that they did have different diets. To best understand late medieval diet based on dental caries in north-western Europe as a whole, results will be compared where data is expressed similarly.

5.2.1. Interpreting diet based on dental caries

Alkmaar, Holbæk, Sigtuna, Klaaskinderkerke, St. Mary Grace and St. Mary Spital all had their data expressed in caries prevalence, giving information on the proportions of individuals in a population with dental caries. In this regard, individuals from Alkmaar displayed the highest caries prevalence amongst the studied sites, and the caries prevalence was almost twice the amount of what was recorded in individuals from Sigtuna. Both Sigtuna and Alkmaar are urban sites, but the difference in caries prevalence is noticeable, and might be explained with access to different kinds of foods. While citizens in both cities were dependent on agricultural produce and livestock, it seems as if inhabitants in Sigtuna had a more varied diet with greater reliance on animal and fish protein. Historical literature mentions the consumption of beans, turnip, peas, onions, cabbage, apples, flax and a variety of other plants in Sigtuna. It can also be assumed that a variety of roots, herbs, fruits, mushrooms, nuts and berries were consumed on a regular basis (Kjellström *et al.* 2009, 2690). This is similar in medieval Holland, where next to livestock, grain-based foods and dairy, people consumed cabbage, turnips, parsnip, peas, beans, onions, as well as garlic. The lack of meat was probably supplemented with eggs and fish among common people, and the nobility could enjoy dishes with poultry and game (van Hattum 2014, 35). In Sigtuna however, archaeological evidence suggests that next to livestock and crops, there was a great reliance on wild birds and freshwater fish, indicating that these sources of protein would have been available for most people (Kjellström *et al.* 2009, 2690). Because of a higher reliance on animal and fish protein, it is possible that individuals from Sigtuna had a lower reliance on foods rich in carbohydrates compared to Alkmaar, which might explain the difference in caries prevalence between the two sites.

Caries prevalence in individuals from St. Mary Grace & St. Mary Spital, and Klaaskinderkerke is similar, with males in St. Mary Grace and St. Mary Spital scoring similarly to females in Klaaskinderkerke, and vice versa. While the data from St. Mary

Grace and St. Mary Spital represent the general population of an urban society, individuals from Klaaskinderkerke represent a rural population. Differences in diet between urban and rural societies is to be expected due to the fact that urban societies are more market dependent, and rural societies often produce some of their own food (Schats 2016, 178; Walter *et al.* 2016, 33). However, the similarities between St. Mary Grace, St. Mary Spital, and Klaaskinderkerke might be explained by a couple of factors. Firstly, while it is known through historical, archaeological and faunal data that individuals from London had a rather diverse diet with access to local and exotic foods, the diet people had was very much class based. People of lower status would have a so-called rural or peasant diet, with little to no animal or fish protein consumption and would rely more on vegetables and cereal based foods such as stews (Walter *et al.* 2016, 33). It could be that the majority of the general population in late medieval London were low-status individuals, and would therefore have a diet similar to rural Klaaskinderkerke. Another thing to consider is that while an increase in caries prevalence can be observed with access to a market and foods containing sugar, sugar was not commonly consumed in England (Schats 2016, 178; Walter *et al.* 2016, 36). To conclude, despite the fact that individuals from St. Mary Grace & St. Mary Spital represent an urban population they must have had a similar reliance on foods rich in carbohydrates as rural Klaaskinderkerke.

Caries prevalence in individuals from Holbæk is somewhat higher than in individuals from Sigtuna. It is also generally lower than the caries prevalence as observed in Klaaskinderkerke and St. Mary Grace and St. Mary Spital, except that females in Holbæk and Klaaskinderkerke score similarly. Historical documents indicate that social status played a role in what people ate. People of lower stand would mostly eat dark bread and porridge made from barley and oats, which is reaffirmed by isotope analysis, confirming that diet was mainly based on cereals and fish. Peasants would often keep their own gardens, and kale, turnips, onions, mustards, cabbage, beets, legumes, hops and other root fruits were also consumed (Turner 2013, 16). Vegetables was not considered to be an upper-class food, but bread made of wheat, meat and fish was consumed regularly (Turner 2013, 16).

While caries prevalence provides information on the proportions of individuals in a population with dental caries, it is important to mention that caries prevalence does not take post mortem processes such as tooth loss into account, and that by studying dental caries using prevalence, one might not fully understand to which degree groups of

individuals are affected by dental caries. A more preferable way of studying to what extent a group of individuals are affected by dental caries is by looking at the caries frequency. When looking at caries frequency the number of affected teeth is compared to the number of observed teeth, giving information on the rate of occurrence of dental caries. In this regard, Alkmaar, Klaaskinderkerke and Vilarnau d'Amont had their data expressed in frequency, making comparisons between sites possible.

When looking at the results, Alkmaar and Vilarnau d'Amont express similar caries frequencies. While Alkmaar is an urban site, Vilarnau d'Amont is much more rural, so similarities in caries frequencies may not be explained with an urban/rural diet. In understanding the similarities in caries frequency between the two sites it is important to mention that Alkmaar and Vilarnau d'Amont is located in rather different environments, meaning that they may have had differences in access to food. From historical texts it can be seen that the central European medieval diet was simple and consisted mainly of cereals and meat, while fruits and vegetables were considered lesser foods. Beans and cabbage on the other hand was seen as evil foods (Schats 2016, 174). The market played an important role in urban sites, where citizens would have had an increased access to products containing sugar, which might in turn explain the dental caries frequency in Alkmaar (Schats 2016, 174). While it is unknown what access villagers in Vilarnau d'Amont had to the market, it is known through historical texts that food production in the region based mostly on farm animals and agriculture (Esclassan *et al.* 2009, 294). Medieval crops in the Mediterranean consisted of cereals and pulses, as well as fruits such as figs, olives, plums, peaches, corn, almonds and grapes (Esclassan *et al.* 2009, 288). While the central European and Mediterranean diet is seemingly different, access to a market and imported goods, as well as foods containing sugar in Alkmaar might explain the similarities in caries prevalence between the two sites, as fruit was an important part of diet in Vilarnau d'Amont.

A comparison between Alkmaar and Klaaskinderkerke is interesting because both are situated in The Netherlands. Alkmaar display a much higher caries frequency than Klaaskinderkerke, and this might be explained with the fact that Alkmaar is an urban site and Klaaskinderkerke is rural. While both rural and urban sites in the late medieval period would have had access to urban markets, it is possible that urban people may have had more access, and also a higher dependency on the market than people living in rural areas (Schats 2016, 178). While some townspeople might have had access to gardens, agriculture was not common for urban citizens, and in rural areas, despite

commercialization and the presence of a market, villagers most likely still produced their own food and kept livestock. Because of this it is possible that villagers in the rural area limited their carbohydrate intake, and that townspeople in urban areas has increased opportunity to buy products containing sugar (Schats 2016, 178).

5.2.2. Dental caries and differences in diet based on sex

From all of the studied sites, individuals from St. Mary Grace and St. Mary Spital were the only ones that displayed differences between males and females with statistical significance concerning dental caries prevalence. These differences may be attached to complex behavioural and biological differences between males and females that existed in medieval Europe. As discussed previously in this chapter, the first thing is linked to gender roles, where a division in labour based on sex may have contributed to a higher caries prevalence in females. In some cultures, males are responsible for acquiring meat and therefore less exposed to foods rich in carbohydrates, while females spend a lot of time working with cariogenic plants (Walter *et al.* 2016, 33). While it is unlikely that the rural and urban males of late medieval Europe were responsible for acquiring meat, they were probably working outside of the home, rather than working within the household. Females would stay at home and be, amongst other things, responsible for cooking, giving them access to foods rich in carbohydrates. Additionally, females experience pregnancy which is known to increase cravings and snacking throughout the day. It is also known that saliva type and quality, as well as higher oestrogen levels and hormonal fluctuation have been associated to have a negative effect on female oral health, which in turn affect the prevalence of dental caries (Walter *et al.* 2016, 33). Permanent teeth in girls also erupt earlier than boys, leaving the tooth exposed for a longer time to the oral environment (Schats 2016, 175). Considering these social and biological differences between males and females, they might explain the higher caries prevalence in females, and also explain why males are not equally affected.

When considering that biological differences between males and females might explain a higher dental caries prevalence in females, the absence of differences in dental caries between males and females in the other studied sites might point to differences in diet between the sites. Females in the sites which proved to have no difference between sexes were probably eating more animal protein, such as eggs, fish and milk products

(Schats 2016, 175-176). If females had an increased consumption of animal protein it might explain the similarities in caries prevalence and frequency between males and females in the studied sites.

6. Conclusion

The aim of this thesis was to understand to what extent dietary differences can be seen between males and females in late medieval North-Western Europe, and debate the possible explanations for the dietary differences. With that, this thesis aimed to answer the question if dietary differences between these two groups could be seen when looking at stable carbon/nitrogen isotope results, and if differences could be seen when investigating dental caries between the groups. Both these aims were met, and comments were made on the differences in data and how they were presented.

6.1. Can differences be seen between males and females in late medieval North-Western Europe when looking at stable nitrogen/carbon isotope analysis?

It was observed that while at some sites stable carbon/nitrogen isotope results between males and females were similar, other sites gave results that testify to a significant difference. In Petriplatz, St. Giles and Sigtuna no difference was found between the two groups in either $\delta^{15}\text{N}$ or $\delta^{13}\text{C}$ values, but in Warrington, Alkmaar and Holbæk differences with statistical significance could be observed. Isotope values from Petriplatz and St. Giles had few sampled individuals, and might not represent general population. For the studies that provided differences between males and females with statistical significance it could for the most part be observed that males have higher $\delta^{15}\text{N}$ values than females, indicating that males perhaps had higher consumption of animal protein and/or consumed different kinds of protein, such as fish. At Holbæk in Denmark differences between males and females with statistical significance could be observed in both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values, indicating that females not only consumed less protein, but also perhaps got their protein from different sources, such as legumes etc. While some sites provided evidence that testified to no difference in isotope values, in the studies that did show a difference in stable isotope values, males always display a higher $\delta^{15}\text{N}$ value than the females.

6.2. Can differences be seen in diet between males and females in late medieval North-Western Europe when investigating dental caries?

Differences in diet when looking at dental caries in the research area as a whole is difficult to determine. No difference could be observed in Alkmaar, Holbæk, Sigtuna, Klaaskinderkerke and Vilarnau d'Amont when looking at caries prevalence and caries frequency. In Sigtuna the caries prevalence seemed to be higher in females, but this difference was not proven significant. Similarly, the caries frequency in males from Vilarnau d'Amont seemed to be higher than females, but this was also proven not significant. Individuals that proved to have differences with significance came from St. Mary Grace and St. Mary Spital, where females displayed a higher caries prevalence than males.

6.3. To what extent can dietary differences be seen between males and females in late medieval North-Western Europe, and what are the possible explanations for these dietary differences?

Dietary differences between males and females in North-Western Europe is mainly seen in differences in stable isotope values, and especially in $\delta^{15}\text{N}$ values. The significant differences in $\delta^{15}\text{N}$ values as observed for half of the isotope studies indicate that males generally might have either consumed higher amounts of protein than females, or that males and females consumed different types of proteins, such as fish. Looking at diet based on dental caries differences in diet become less clear. While males and females from St. Mary Grace and St. Mary Spital did show significant differences where females had higher caries prevalence than males, the rest of the dental caries studies used in this thesis recorded no significant difference in either dental caries prevalence or frequency. Considering that the vast majority of dental caries studies used by this thesis provided no evidence for differences between sexes, when talking about late medieval diet in north-west Europe as a whole, it is possible to infer that males and females generally had an equal reliance on foods rich in carbohydrates.

Possible explanations for the observed differences in diet have been briefly touched upon in the introduction, and more extensively in the discussion chapter. Here, it was

found that differences in diet can be tied to complex biological and behavioural differences between males and females. The biological aspect refers to differences in tooth eruption, hormones and hormone levels, as well as hormone fluctuation, and saliva type and quality, which is known to have a negative effect on the female oral health. This might explain the differences in dental caries prevalence as observed in St. Mary Grace and St. Mary Spital. A large number of females also experience pregnancy, which is known to increase cravings and snacking throughout the day. The behavioural differences mostly refer to differences in labour between males and females, giving males and females different access to different foods. The differences in diet between males and females as observed in this thesis might also be attached to social rank and ideology. Historical documents imply that meat was more appropriately served to males rather than females because it was believed to be an aphrodisiac, and also associated with masculinity, strength, power and virility.

As the biological differences between males and females mainly point to differences in oral health, it can be assumed that the differences in diet between males and females in north-western Europe is mostly attached to behavioural differences and possibly social rank and ideology. The aspect of pregnancy cravings should however not be ignored, and the combination of division in labour, pregnancy, social rank and ideology may explain the differences in diet between males and females which is observed in north-western Europe.

6.4. Future research

Even though this research has shown that there are in fact dietary differences between males and females in north-western Europe, improvements can be made. Firstly, it is always beneficial to increase the sample size of studied individuals, and also having a more equal number of males and females studied. In doing this, the knowledge of dietary differences between males and females would improve. Similarly, by expanding upon the number of studied sites in the research area, our understanding of late medieval diet as whole would increase. It would also be interesting to use more sites that combine isotope analysis and dental caries in order to study the relation between protein consumption and reliance on foods rich in carbohydrates. Secondly, in this research, data on dental caries were presented in prevalence and frequency, and while

this is not necessarily problematic due to the availability of data expressed similarly, only using data presented in frequency would improve this research due to the data taking post-mortem processes such as tooth loss into account. Lastly, as mentioned previously, it is preferable to use an animal baseline to compare the human isotopes with which are collected locally. This is due to differences in ecology between sites. However, this is not necessarily a big problem in this thesis as the animal baselines had often been collected from sites located nearby, but the interpretation of the human isotopes would improve by using an animal baseline collected from the same site.

7. Abstract

In this study a selection of articles on dental caries, stable carbon/nitrogen isotope analysis, and articles applying both methods were chosen to investigate dietary differences between males and females in north-western Europe. It was found that few differences could be seen in the dental caries studies throughout the studied region, but differences with statistical significance ($P < 0.05$) could be seen for half of the isotope studies where males displayed higher $\delta^{15}\text{N}$ values than females. The results suggest that males and females in late medieval Europe generally had an equal reliance on foods rich in carbohydrates, but that males in half of the case consumed more animal protein than females. Low sample sizes and lack of available data encourage further research into dietary differences between males and females in north-western Europe.

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