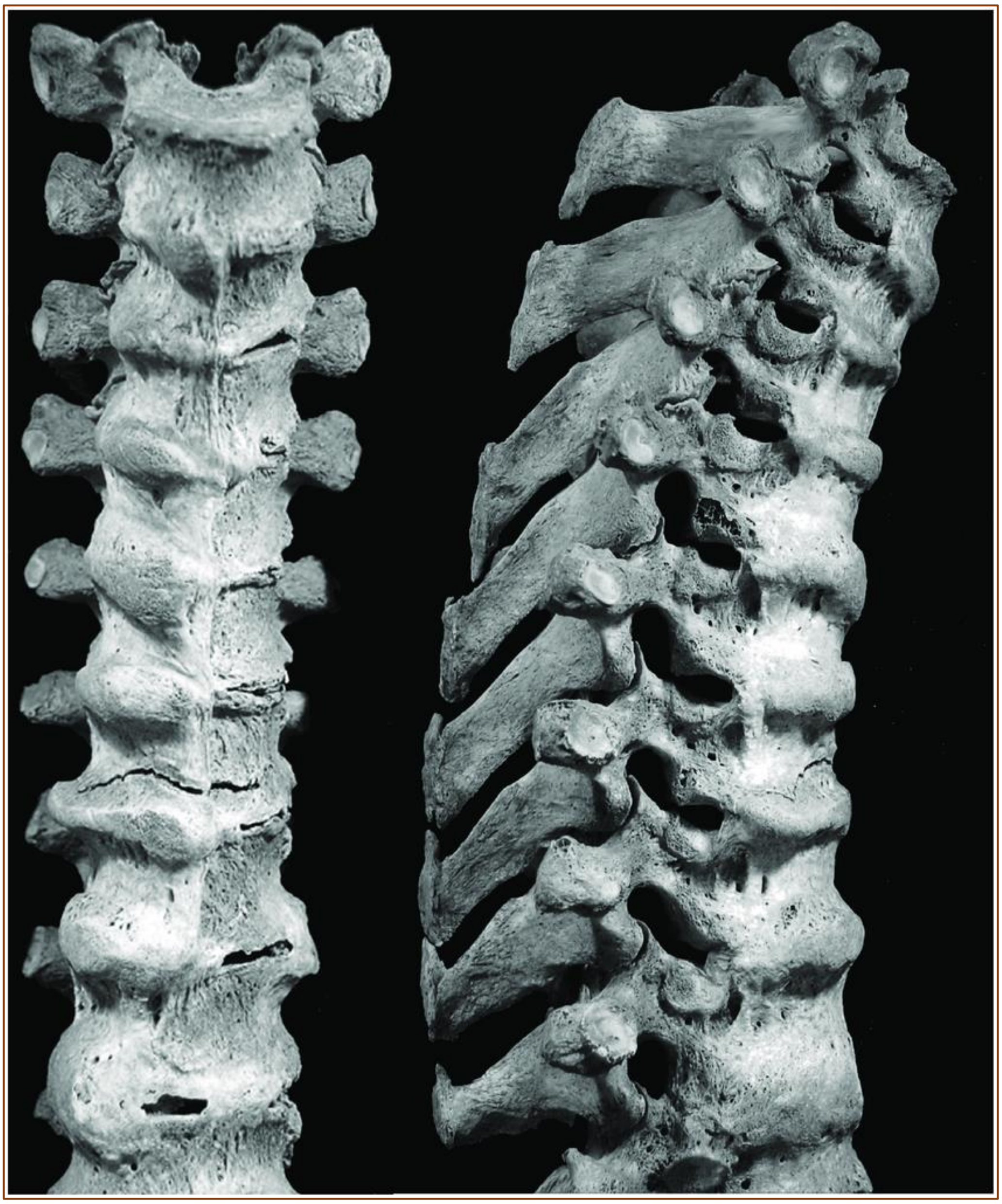
The Link between DISH and diet: On the prevalence of DISH in populations from Medieval and Post-Medieval London.

Bosch, Anouschka

The Link between Diet and DISH

On the prevalence of DISH in populations from Medieval and Post-Medieval London



Nouschka Bosch

Cover image: Vertebrae from a male, 81 years old, with the distinctive DISH ossification resembling candlewax. From Milner, G. R., J. L. Boldsen, S. Ousley, S. M. Getz, S. Weise, P. Tarp and D. W. Steadman, 2018. Selective mortality in middle-aged American women with Diffuse Idiopathic Skeletal Hyperostosis (DISH). PLoS ONE 13(8), 1-14. https://doi.org/10.1371/journal.pone.0202283

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1. Introduction

This thesis will look at the prevalence of Diffuse Idiopathic Skeletal Hyperostosis in medieval and post-medieval London populations in order to identify a pattern or trend in the prevalence. Patterns and trends can be linked to socioeconomic status and provide new insights for the lifestyle of past populations. These insights can also be used in modern research to understand the link between DISH and lifestyle better.

Diffuse Idiopathic Skeletal Hyperostosis, sometimes also referred to as Forestier's disease and often abbreviated to DISH, is a systemic noninflammatory disease which is characterized by ossification/calcification (i.e., soft tissue turning into bone) of tendon ligament and capsule insertions (called entheses), therefore clearly visible in the skeleton. DISH is asymptomatic in most of the affected individuals, although numerous recorded symptoms include the obvious joint aches, limited motion range, susceptibility to fractures and more severe symptoms such as difficulty swallowing and obstruction of the airway (Mader *et al*. 2009, 1478; Nascimento *et al.* 2014, 123). In clinical settings, DISH is treated with a combination of anti-inflammatory and muscle-relaxing medication, appropriate diet and exercise therapy (Al-Herz *et al*. 2008, 210). Patients suffering from more severe symptoms, such as airway obstruction and dysphagia (i.e., problems with swallowing and breathing) and where previous treatment has failed, may be subjected to surgery to remove the bone obstructions (Nascimento *et al.* 2014,125). DISH occurs mainly in older adults, and the incidence increases with age. Males also develop DISH more often than females. Many researchers believe DISH emerges in later years of life and can take several years to develop fully (Kim *et al.* 2018, 43).

It was first assumed the disease only occurred in the vertebrae, but DISH can occur wherever connective tissue between tendon, ligament and bone are present (Mader *et al.* 2009, 1478; Nascimento *et al*. 2014, 122). DISH is commonly identified using three criteria, based on the suggestions of Resnick and Niwayama: at least four sequent thoracic vertebral segments should exhibit bone formations on the side, the intervertebral disc space should be unaffected, and no joint degeneration changes should be occurring. These criteria should help distinguish DISH from other pathological diseases affecting the bone tissue (Nascimento *et al.* 2014, 124-125). DISH often occurs alongside obesity, hypertension, diabetes type II, hyperinsulinemia and other similar conditions. All these conditions are often related to an individual's lifestyle.

It is no surprise that the aforementioned conditions are often treated with a combination of medication and improved lifestyle (Al-Herz *et al.* 2008, 210). Based on these comorbidities of DISH, a careful drawn conclusion could be that the risk for developing DISH is increased with an increased calorie, sugar and salt intake. Following that reasoning, DISH should be more prevalent among individuals of a higher socioeconomic status because they are generally considered excessively nourished (Pillai and Littlejohn 2014, 117). Various studies have been linking the prevalence of DISH to diet and lifestyle and in turn socioeconomic status. An individual's lifestyle (diet is a critical part of lifestyle) can serve as a proxy for identifying an individual's social status (i.e., a nobleman had a different diet compared to a poor countryside farmer). This makes DISH a valuable factor in comparative research on the diet and lifestyle of past populations based on skeletal samples (Merwe *et al.* 2012, 202; Rogers and Waldron 2001, 360).

DISH is quite easily identified in the archaeological record (Merwe *et al.* 2012, 202-214). The main symptom of DISH is fusion of several vertebrae and other joints by the bone formations. The disease has been found across the world and through different ages. The earliest case known is that of a Neanderthal from 35000-45000 years ago, and plenty of cases have been reported in ancient societies across the world, from Peru to the Netherlands.

1.2 Research Problem

While the disease is commonly observed clinically and archaeologically, a lot is unclear about the nature and cause of DISH and what factors could increase or decrease the risk for someone to develop this disease. Through years of research, no clear answer has emerged. The current assumption is that DISH is caused by a combination of mechanical, genetic and external factors; they could positively contribute to the formation of bone ridges on specific sites (Couto *et al.* 2017, 5-6; Nascimento *et al.* 2014, 123; Tsukahara *et al.* 2005, 2323). Although the exact prevalence and incidence remains undetermined, incidence increase with age and DISH seems relatively more common in males than in females. (cite)

Pillai and Littlejohn (2014) summarize several clinical studies on DISH and find that there is a significant difference in the occurrence of DISH between groups of varying socio-economic status.

Obesity is strongly linked to DISH, and patients with DISH are more likely to suffer from diabetes type 2. It is likely insulin and vitamin A also play a significant role in the development of DISH, although how remains unclear (Pillai and Littlejohn 2014, 125-126). While we find out more things about DISH with every new research, a lot of questions remain. The exact processes behind the emergence of DISH are unknown, as is the role of genetics. More research is required to find out more about DISH and its causes. The current generally accepted hypothesis that DISH is caused by a combination of genetics and various metabolic factors, such as diet. But this hypothesis needs more work, more evidence and more support to strengthen itself.

By looking at DISH in skeletal samples from various medieval and post-medieval London sites, new insights could be about the lifestyle of past communities. Additionally, it may provide new insights for modern, clinical studies on the relationship of DISH and diet. This thesis utilizes data from populations from medieval and post-medieval London. The data encompasses different sites with varying socioeconomic statuses. Similar archaeological studies have been conducted in the past, but they often focus on fewer distinct communities and/or smaller populations, in addition to outlying communities (i.e., monastic populations). This study focuses on a large group of people, divided in sub-populations, but all inhabiting the same geographical region. The focus is on the regular population, with ranging socioeconomic statuses instead of a single socioeconomic status or kind of population.

1.3 Research questions

To investigate the link between the prevalence of DISH and socioeconomic status, a decision was made to study the frequency of DISH in different socioeconomic groups from the same time and in the same region (in this case, London). Following this reasoning, the main research question of this thesis will be as follows:

"What is the prevalence of DISH in medieval and post-medieval London society and to what extent is it influenced by socioeconomic status?"

To answer the main research question, several sub questions will be answered which should, together, answer the main question. They will tackle different aspects of the main research question. These questions are:

- *How does the prevalence of DISH differ between males and females?*
- *How does the prevalence of DISH differ between adult age groups?*
- *How does the prevalence of DISH differ between different status groups?*

1.4 Approach

To find answers to the research questions, previously recorded, collected and published data will be used. This data comes from the archaeological collections of the Museum of London (UK). All data is freely available online on their website (museumoflondon.org.uk). This data includes several cemetery sites dating from Roman to post-medieval London. Of all the available sites, six sites and their data will be used in this thesis. These sites date to the medieval and post-medieval period and have varying socioeconomic status.

The medieval sites are St. Mary Graces, which is not directly associated with a certain socioeconomic status, Merton Priory, which is partly monastic, and Bermondsey Abbey, an order of monks. The inclusion of monastic populations can provide interesting results regarding differences in diet. The three post-medieval sites are Chelsea Old Church, St. Bride's Lower and St. Benet Sherehog. They include low, middle and high-status individuals of society, respectively.

The prevalence of DISH is studies per site and linked to biological sex, age and socioeconomic status in order to identify any patterns and trends occurring in the prevalence of the disease in these six populations. Identifying possible patterns and trends can contribute to understanding the disease and its causes better and the link that is clearly present between DISH and lifestyle, but which remains poorly understood until this day.

1.5 Thesis outline

This introduction chapter will be followed by a chapter on the background of this thesis. That chapter will provide more information on DISH and discuss archaeological studies on the prevalence of DISH in ancient populations.

The third chapter is on the materials. It will first provide a historical context of medieval and post-medieval England and London, and then go over the archaeological sites from which the samples are taken and provide information on them.

The methods chapter discusses the methods used by the MoLAS to classify their materials and identify sex, age-at-death and DISH in archaeological context. The statistical methods used in this thesis will be discussed as well.

The results chapter shows the results of the analyses, which will be discussed in the following discussion chapter. The results of this research will be placed in a broader context in the field and compared to modern, often clinical data.
Naturally, the last chapter is the conclusion. Here, an attempt will be made to give an answer to the research questions posed in this thesis, starting with the sub-questions and ending with the main research question. The conclusion will summarizeon all previously covered information to provide a solid overview of the thesis. It will finish with suggestions for follow-up and future research in the same field and the same topic.

2. Background

This chapter will provide background information on the disease Diffuse Idiopathic Skeletal Hyperostosis. It will go over a brief history of the disease, how it is identified and possible causes. Archaeological studies involving DISH will be discussed to provide examples of how DISH can contribute to the reconstruction of historic lifestyle.

2.1 Diffuse Idiopathic Skeletal Hyperostosis: a brief history

It was not until 1950 that Diffuse Idiopathic Skeletal Hyperostosis was properly identified. J. Forestier and J. Rotes-Querol set this disease apart from similar conditions such as arthritis and ankylosing spondylitis (long-term inflammation of the joints of the spine with occasional fusion of the vertebrae). They created guidelines to diagnose and differentiate this disease from similar ones and named it 'senile ankylosing hyperostosis of the spine'. According to them, it is characterized by flowing ossifications occurring mainly in the thoracic vertebrae (see fig. 1), little to no spinal stiffness and pain and the sacro-illiac joints (i.e., the connection between the sacrum and pelvis) being unaffected. Forestier and Rotes-Querol noted the prevalence of this disease mainly among older individuals and males. Possible named causes of the bone formations were fibers and ligaments producing bone or simply turning to bone or possible influences of the prostate on the vertebral region. It is worth nothing here all the patients from the sample used were male (Forestier and Rotes-Querol 1950, 321-329; Holgate and Steyn 2016, 870). Assumed is that DISH was described in cases dating back to the 19th century, and many patients and skeletal remains may have been misdiagnosed (Holgate and Steyn 2016, 874; Kuperus *et al.* 2017, 1124). After this first proper description in 1950, more research was conducted. The guidelines by Forestier and Rotes-Querol were expanded upon, with various authors developing criteria to diagnose DISH in clinical and paleopathological context (Holgate and Steyn 2016; 870-871). Currently, DISH is found in 2.9 % up to 25 % of a population (prevalence differs per genetic population). Patients have a high mean age at around 60 (Verlaan *et al.* 2008, 148). Patients are more often male than female and suffer from obesity, type 2 diabetes and other morbidity-related conditions, which may explain the high mortality rate of the disease when compared to other ankylosing spinal disorders (Verlaan *et al.* 2008, 152).

Figure 1 (left): DISH on the spine of a 50–60-year-old male. Note the flowing, 'candle-wax' like appearance of the bony formations. Picture by Erika Molner, retrieved from: researchgate.net/figure/Diffuse-idiopathic-skeletal-hyperostosis-DISH-of-the-spine-grave-290-male-50-60-yrs_fig3_257919633.

2.2 The causes of DISH

The problem with all these researchers developing their own guidelines to identify DISH, is that ageneral lack of consensus on which criteria to use, in both clinical and paleopathological context, emerged (Kuperus *et al.* 2017, 1124). In current literature, the criteria described by Resnick and Niwaya see the most use. The criteria consist of a flowing ossification (candle wax like appearance) affecting at least four vertebrae, the preservation of intervertebral disc space and the absence of inflammations in the sacro-illiac joint. The downside of these criteria is that they fail at identifying the disease in preceding stages and it lacks standardized descriptions and measurements (Kuperus *et al.* 2017, 1124). Many authors have proposed new criteria to improve upon those of Resnick and Niwaya, and as a result, studies use different sets of criteria. This gives different results (Holgate and Steyn 2016, 874) and complicates comparative research. Most criteria also seem to lack a way to identify DISH in earlier stages, seeing how DISH is a gradual build-up of bone formations and not a sudden appearance. The stage in which at least four vertebrae are affected by flowing ossifications (as described by Resnick and Niwaya) is considered a relatively late stage (Kuperus *et al*. 2017, 1124-1125). It is currently assumed that DISH is caused by a combination of mechanical, genetic and external factors. Mechanical factors refer to the positions and morphologies of anatomical features. The term 'genetic' refers to genes and external factors include environmental exposure, diet and medication intake (Nascimento *et al.* 2014, 123).

2.2.1 Mechanical factors

Among the possible mechanical factors associated with DISH, the location of the aorta is possibly a major influence on the formation of the ossifications. Generally, the bone formations predominantly grow on the right lateral aspect of the vertebrae, with left sided and posterior bone deposition being rare. The aorta is located to the left lateral aspect of the vertebrae and it is hypothesized that its pulsating may prevent the emergence of ossifications (Resnick *et al.* 1978, 161). This is supported by several cases have been reported on patients with *viscerum inversus*, a condition in which an individual's organs, including the aorta, are mirrored. In these individuals, ossifications associated with DISH emerged on the left lateral aspect instead of the right. Since their aorta was located on the right lateral aspect, the pulsating prevented bone formations on the right aspect, resulting in a 'mirrored' case of DISH (Kuperus *et al.* 2020, 7).
Ever since DISH was first described, authors have suggested that the anterior longitudinal ligament (ALL) was the possible source of bone formations, or that the ligament itself was ossifying. The anterior longitudinal ligament is a narrow band that runs the entire length of the spine (see fig. 2) (Kuperus *et al.* 2018, 2491). However, since the ALL is located on the frontal plane, and DISH occurs mainly on the lateral plane, that hypothesis seems difficult to prove. Closer research by Kuperus *et al.* (2018) proved this wrong, while also finding an explanation for previous observations and conclusions drawn. In some cases, the ALL was reported present in a different position or simply absent. But a closer look revealed the ALL to be either covered by bone formations or it being dislocated by those formations. Additionally, the bone formations did not follow the course of the ALL nor did formations seem to start at or emerge from the ALL. DISH may contribute to the degradation of the ALL, which can lead to the misinterpretations mentioned previously. Unfortunately, Kuperus *et al.* (2018) were not able to determine what factors are behind the bone formations instead (Kuperus *et al.* 2018, 2494).

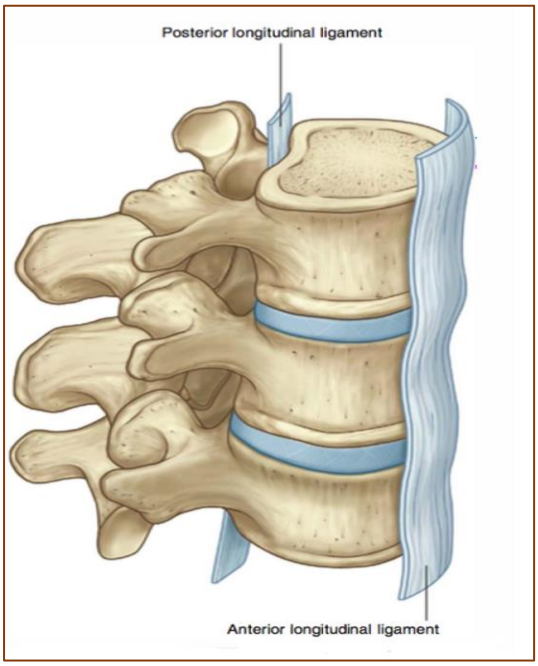

Figure 2 (left): The location of the anterior longitudinal ligament (ALL) and the posterior longitudinal ligament (PLL). From Krames et al. *2009, 436.*

2.2.2 Genetic factors

Genetic factors in relation to DISH seem more complicated. Several independent studies have been trying to link certain genes or gene defects to an increased risk of developing DISH, but none have been able to give a solid answer. DISH is commonly associated with similar conditions which turn tissue into bone or cause the emergence of bone formations, with the disease being more common in patients with other spinal disorders (Toyoda *et al.* 2017, 63). Various studies have tried to prove a link between DISH and diseases which can be linked to genetic mutations and defects, of which two are discussed here.

One of these conditions is chondrocalcinosis (CC), in which a build-up of calcium salts in joints causes inflammations. Despite being poorly understood in a similar manner as DISH, a great number of susceptibility genes have been reported (Couto *et al.* 2017, 1). The study by Couto *et al.* (2017) found a common occurrence between DISH and CC, which suggests a shared pathogenetic mechanism at work. Researchers were able to isolate a few genes which may influence the rate at which bone forms in CC/DISH. Variants of these genes found in different families may explain the increased frequency of CC/DISH. The authors note that future research is needed to unearth the exact processes and identify the exact relevance of these genetic variations in the context of CC and DISH (Couto *et al.* 2017, 5-6).

Another related disorder is OPLL, the ossification of the posterior longitudinal ligament (see fig. 2), in which the posterior longitudinal ligament becomes thicker which leads to various neurological symptoms. Interestingly, OPLL seems more common in Asian populations. Extensive studies have been conducted trying to link the prevalence of OPLL to genetic variations (Tsukahara *et al.* 2005, 2321). Tsukahara *et al.* find an association between DISH and OPLL in a Japanese population, but not in other populations. They also could not identify a specific genetic variation that causes this. More similar research should be conducted to further investigate not only the role of these specific genetic variations, but genetics in DISH (Tsukahara *et al.* 2005, 2323).

Some other studies support the influence of genetic factors in the prevalence of DISH. A study on a population of patients from the American Midwest region (USA), combined with previous literature studies, found possible evidence for this. 2364 patients of both sexes and ranging from 51 to 90 years old were studied (Weinfield *et al.* 1997, 223). From this sample, black patients were found to have a lower prevalence of DISH, as did a group of patients from Asian origin. Patients labelled as 'native indians' showed a lower prevalence as well, but patients of Mexican origin had a higher-than-expected prevalence. Also noteworthy is the overall difference in prevalence among the biological sexes, with DISH being more common among men, which only diverges more as the patients age. The authors see these occurrences as an indication for some sort of genetic predisposition, but do not take factors such as differences in lifestyle into account. More similar research should be done, but this study can be seen as a step in the right direction and a start for more population-based studies on this subject (Weinfield *et al.* 1997, 225).

2.2.3 External factors

External factors that seem to greatly influence whether an individual develops DISH include diet and environmental exposure, but also medication intake (Nascimento *et al.* 2014,123; Pallai and Littlejohn 2014, 116). Several studies, both clinical and paleopathological, pointed out the increased prevalence of DISH among those with a unhealthy lifestyle and high calorie intake (e.g., overweight, high sugar and salt intake). A clinical study by Kiss *et al.* (2007) focused on determining risk factors associated with DISH in a population of men and women. The study used a case-control design, using individuals with degenerative intervertebral discs disease as a control group (Kiss *et al.*

2007, 27). In a population of 635 patients, researchers recorded anthropometric factors (height and weight at different age, BMI) and lifestyle factors such as the weekly intake of dairy, alcohol and smoking (Kiss *et al.* 2007, 28). Subjects with DISH were generally overweight both at present age, as well as earlier years, and had a history of diabetes mellitus. These factors were present in a higher frequency in DISH patients compared to the other group. This suggests obesity (as well as at a younger age) may greatly increase the risk of developing DISH (Kiss *et al.* 2007, 29).
A similar clinical study by Mader and Lavi (2008) also reported a significantly higher prevalence of obesity, diabetes mellitus and hypertension among DISH patients compared to their control group (Mader and Lavi 2008, 826). Mader and Lavi also suggest that, based on their data, the assumption can be made that DISH often starts developing in the fourth decade of life. They assume it takes at least ten years for the pathological process to evolve completely (Mader and Lavi 2008, 826).

Mader and Lavi also note the higher prevalence of DISH among male patients (Mader and Lavi 2008, 826). Although the exact prevalence and incidence remains undetermined, it is well known that DISH is more frequent in men, and the incidence increases with age. This seems to be the case in both clinical and archaeological context (Nascimento *et al.* 2014, 123). Interestingly, similar diseases such as osteoarthritis seem to lack the increased frequency in the male sex, suggesting different pathogenetic factors are at play here (Mader 2003, 507).

2.3 DISH in the archaeological record

DISH is identified using the same criteria as in a clinical setting: flowing ossification affecting at least four vertebrae, the preservation of intervertebral disc space and the absence of inflammations in the sacro-illiac joint. Issues with identifying the disease in earlier stages remain, as they can easily be confused with similar conditions such as arthritis and ankylosing spondylitis or just natural degeneration associated with age (Holgate and Steyn 2016, 874).
DISH is a disease with an ancient lineage, having already been described in a skeleton of a Neanderthal (Shanidar 1) from the Middle Paleolithic (Crubézy and Trinkaus 1992, 417). Paleopathological studies focusing on DISH try to link the prevalence of the condition to lifestyle and different social groups.

Several studies, which will be discussed in detail below, shed light on the prevalence of DISH in various contexts, such as lay and monastic populations.

For example, Rogers and Waldron (2001) examined skeletons and the prevalence of DISH in three medieval sites in England: Merton Priory, Wells Cathedral and Royal Mint. Merton Priory and Wells Cathedral are monastic sites, while Royal Mint contains both important lay people and the 'general population'. Sites that contained both monastic populations and the 'general population' exhibited a large difference in the prevalence when compared with each other. This was the case in both Merton Priory and Wells Cathedral (Waldron 1985, 1763; Rogers and Waldron 2001, 360-361). The Royal Mint site has burial grounds associated with the abbey and a separate burial pit for victims of the Black Death. Among the Black Death victims, consisting mainly of the 'general population', not a single case of DISH was found. The abbey burials had a significantly higher prevalence. The authors link this difference to the monastic way of life (Rogers and Waldron 2001, 361-362).

Verlaan *et al.* (2007) examined 51 skeletons excavated from the *Onze Lieve Vrouwe Kerk* in Maastricht, the Netherlands. The population consisted of clergymen and patrons associated with the church. The skeletons were buried in the abbey court and were from between 275 and 1795 CE. (Verlaan *et al.* 2007, 113). Of the 51 skeletons used in the analysis, 17 were diagnosed with DISH, making the prevalence of the disease in this site a staggering 40.4 % (Verlaan *et al.* 2001, 113).
The authors link this trend to the analyses Rogers and Waldron (2001) discussed previously and the lifestyle of the clergymen: sedentary work, a steady supply and abundance of food, alcohol intake and general dietary composition; the so-called 'monastic way of life' (Verlaan *et al.* 2001, 1134).

Jankauskas (2003) evaluated the prevalence of DISH in Iron Age, Medieval and Early Modern period skeletal samples from Lithuania. The remains of 458 adults were categorized based on sex, age estimate and estimated socioeconomic status (Jankauskas 2003, 291). The results suggest DISH is significantly associated with the male sex, advanced age and high socioeconomic status. These results confirm the assumption that DISH is more likely found in sedentary populations with complex social hierarchies, especially among the 'elite' (which had better access to high calorie diets) (Jankauskas 2003, 291-292).

Quintelier *et al.* (2014) used stable isotope ratios from human burial remains from the Post-Medieval Carmalite friary in Aalst (Belgium) to reconstruct dietary patterns of 39 adult individuals. The population was a mix between monastic and lay, reflecting groups with different socioeconomic status (Quintelier *et al.* 2014, 203). The results suggested a difference in diet in the population, with the monastic and wealthier part of the lay group enjoying a richer diet. The diet of the females in this site was less varied and included fewer animal products when compared to the males (Quintelier *et al.* 2014, 209-211). The authors tried to identify a link between the prevalence of DISH and the monastic way of life, but no statistically significant result was found. However, the data does not contradict the hypothesis, and further research is required (Quintelier *et al.* 2014, 211).

In a case study of an extreme example, Giuffra *et al.* (2009) discuss DISH in two members of the Medici family, buried in the Basilica of San Lorenzo (Florence, Italy). Grand Dukes Cosimo I (1519-1574) and his son Ferdinand I (1549-1609) both suffered from DISH (Giuffra *et al.* 2009, 103). Historical documents and depictions provided insight in the lifestyle of these men and described them as corpulent and enjoying a rich diet with a lot of meat, which isotope analyses confirm (Giuffra *et al.* 2009, 106). The high prevalence of DISH in the higher social class, such as the Medici family, is noteworthy and supports the link between diet and the risk of developing DISH. Despite the small sample size, this family and similar samples provide excellent opportunities to test this link (Giuffra *et al.* 2009, 106).

Interestingly, DISH is also observed in populations from different areas with very different lifestyles. For example, Arriaza (1993) studied various ancient South American populations to test the hypothesis that DISH is an ancient disease (Arriaza 1993, 263-264). The samples include 504 specimens from an archaeological context. The samples span around 8,500 years, ranging from 7000 BC to 1500 AD, and come from different cultural phases which relied on different ways of life, of which most had a very low prevalence of DISH (Arriaza 1993, 270-271).

The lower average life expectancy associated with these cultural phases may be to blame for the low prevalence of DISH. Most people would not live long enough for DISH to develop and reach more severe levels. The composition of diet commonly found among ancient Andean populations may also decrease the frequency of DISH. Combining those two factors with what is known about DISH in clinical context, the lower frequency of DISH occurring among ancient South American populations may simply be explained by their lifestyle (Arriaza 1993, 275). Later populations in the sample (~1100-1400 AD) start showing a higher prevalence of DISH. These populations are characterized by complex agro-pastoral socio-economic organizations. That means that had a different diet and a higher life expectancy (Arriaza 1993, 275).

These studies all note the presence of the trend: DISH has a higher frequency among populations with a way of life linked to a longer life expectancy and a diet that involves a higher average calorie intake. Most studies mainly look at the prevalence of DISH among 'extreme' populations such as monks and individuals of higher socio-economic status, but seldom the people of lower socioeconomic statuses. This study focuses more on the 'regular population' instead of extreme outliers. It uses materials from different socials groups from the same geographical region (London, England) and the same historic periods (medieval and post-medieval age), making it stand out in that regard. This will make an important contribution to current research, both in the medical and the archaeological field.

3. Materials

3.1 Medieval and Post-Medieval London

The medieval age in England runs from the fifth century CE to about 1500. The range of the post-medieval period is somewhat vague. It runs from the end of the medieval period to either just before the industrial revolution around 1750 (archaeologydataservice.ac.uk) or just before the industrialization of the 20th century, around 1900 (spma.org.uk). For the purpose of this thesis, the city of London and its developments will be discussed in two time frames: the medieval age, from the 5th century AD to 1500, and the post-medieval age, from 1500 to around 1850. Because none of the sites used in this thesis date to after 1850, including information on London beyond that period would be redundant. The specific sites and their samples used in this thesis will be discussed in-depth at the end of this chapter.

3.1.1 Medieval England and London

London was established around 50 AD by the Romans as *Londinium*. Its location near the river Thames allowed for the construction of a crossing, quick communications inland and downstream access to the great trade network of the North Sea and the Channel coasts. This new pattern led to London emerging as a centre of trade and transport in the Roman period, and for ages to follow (Keene 1989, 100).

The collapse of the Roman Empire in the early 5th century marks the beginning of the Medieval Age for England. The years 1100 to 1500 AD are characterized by the development of towns and countryside, rapid population growth, crises (such as the plague) and the decline and rise of towns and cities, such as the city of London. London became the primary centre of inland trade. The city dominated nearby towns and settlements in the region to an exceptional degree because of the low urbanization (Keene 1989, 101; Schofield and Vince 2013, 27). In the late medieval period, the largest part of overseas trade was in English hands. But English towns fell into decline after industries migrated. Larger cities continued to grow, but smaller communities fell into decay or even vanished, unable to compete with the large settlements or the changes of the industry (Schofield and Vince 2003, 29).

3.1.2 Post-medieval England and London

The beginning of the Tudor dynasty in 1485 is often used as the end date for the medieval age in Britain. The Tudors would reign until the 15th and 16th centuries are often characterized by the Renaissance. 17th century England is often associated with the triumph of Protestantism and parliamentary sovereignty, law being placed over monarchs and the Counter-Reformation (or Catholic Revival), the Anglo-Dutch naval war and the English Civil War (1642-1651). England became one of the centres of European growth regarding economy and innovations (Peck 2005, 2).

The post-medieval period was characterized by immense economic growth, along with an increase in population in Great Britain, but especially in London. The city became a true centre for overseas trade, and many young folks moved to the city to make a living, as well as rich aristocrats looking to spend their money on foreign wares and entertainment. By the end of the 18th century, London had a population of nearly one million and people continued to move to the city, drawn in by the rapid industrialization (www.bl.uk).

3.1.3 Medieval and post-medieval London society

Medieval English society is often described as feudal in which a ruler who owns land allows vassals to use that land in his stead in return for services (Darby 1977, 8). Large parts of land were held by a minority. Most of the English population were the peasants; a poor layer of society who worked on the tracts of lands and paid tribute to their lords (Crick and van Houts 2011, 15-16). This means it is to be expected that the largest portion of the Medieval London population is too from the lower layers of society.

London has been a magnet for people all over the British Isles and places beyond for ages. People of all kinds and trades came to the city to seek employment, business and perhaps excitement. At all times, medieval London contained the largest population of individuals born overseas (Keene 1989, 103). Whereas the lower layers of society found themselves living in the centre of the city, wealthy Londoners moved to the outer side of the city or the surrounding countryside, where they found both space and close ties to the city (Keene 1989, 105). London society thus contained individuals from all layers of society, different occupations and communities and a large population of immigrants.

3.2 Skeletal collections: medieval and post-medieval cemeteries

To test the hypothesis, six sites from medieval and post-medieval London were selected. The sites are all from roughly the same area (see fig. 3 and fig. 4). The six sites were selected based on historic period, number of individuals included in the sample and the (assumed) socioeconomic status. There are three medieval and three post-medieval sites. Two of the three medieval sites contain individuals from a monastic community. This was done to provide an extra comparison between 'regular' people and monastic people in the medieval period. See table 1 for an overview of the selected sites.

Table 1: A condensed overview of the six sites used. The general history, composition and other details of the site are discussed in-depth below.

Site name	***Site Code***	***Period***	***Sample Size***	***Presumed socioeconomic status***	***Other***
St. Mary Graces	*MIN86*	*Medieval*	*389*	*Middle*	
Merton Priory	*MPY86*	*Medieval*	*738*	*High*	*Monastic community*
Bermondsey Abbey	*BA84*	*Medieval*	*201*	*High*	*Monastic community*
Chelsea Old Church	*OCUoo*	*Post-Medieval*	*198*	*High*	
St. Bride's Lower	*FAO90*	*Post-Medieval*	*544*	*Low*	
St. Benet Sherehog	*ONE94*	*Post-Medieval*	*231*	*Middle*	

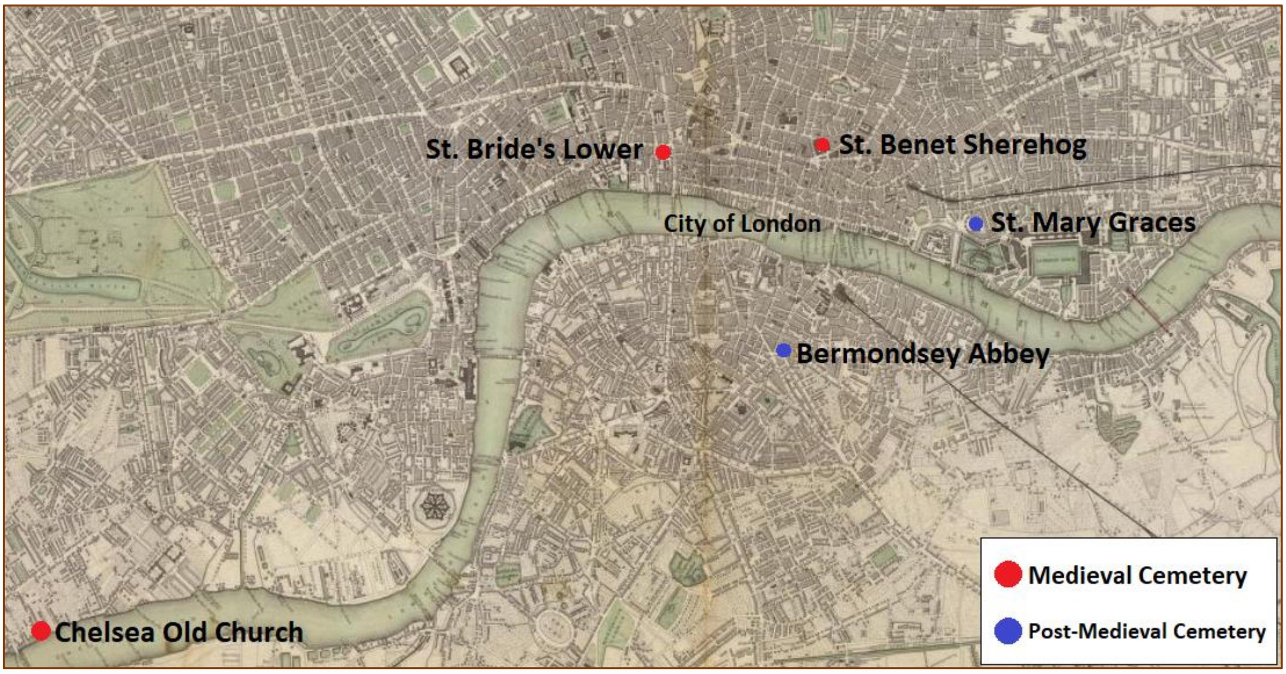

Figure 3: A map of London in 1844 (post-medieval). Added labels indicate the site location and time period. Note that Merton Priory is missing (see figure below). Original source map: http://www.davidrumsey.com/maps3872.html

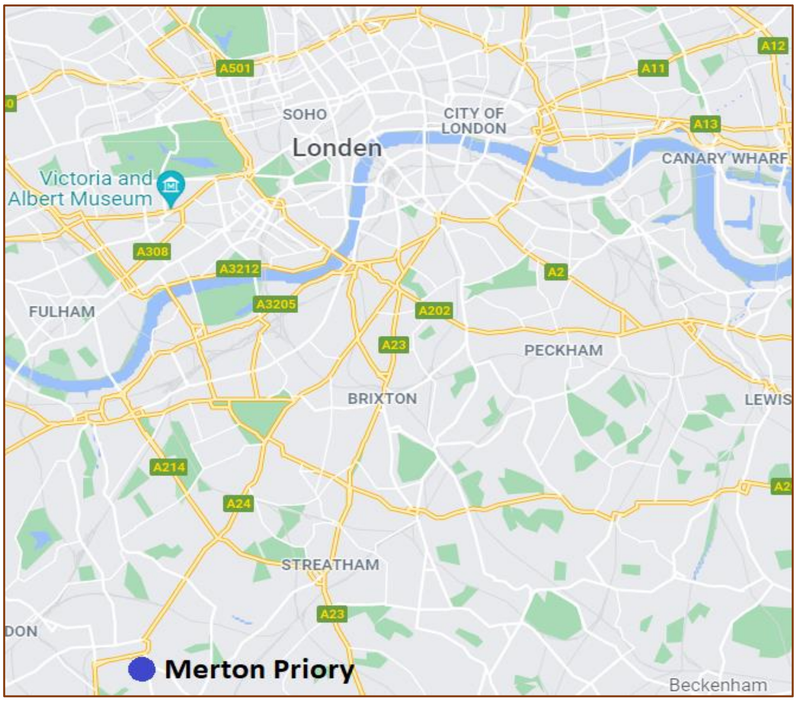

Figure 4: The location of Merton Priory, a Post-Medieval Site, in relation to modern-day London. Screenshot taken from Google Maps.

3.2.1 Medieval cemeteries

St. Mary Graces

St. Mary Graces was established in 1350 by the order of King Edward III and closed in 1540. Despite royal favour declining in the 15th century, the abbey continued to be backed by wealthy individuals (Krakowa 2017, 57).

This site has two separate burial phases: burials associated with the abbey, both intramural and extramural, and burials for victims of the Black Death. Status most likely played a part in the location of the burials, with individuals with a higher social status being buried inside the abbey building (Krakowa 2017, 56-57; museumoflondon.org.uk). Documentation sheds light on the identities of those buried intramural. These people were often from the upper layers of society. Less information is available on the extramural burials, but the medieval burial practices indicate a degree of wealth and social status, but less so than those buried inside (Krakowa 2017, 57). The other burial site, for victims of the Black Plague, is believed to be an extension of nearby plague cemeteries. Unfortunately, no information is available to determine who was buried here, and evidence to estimate social status from skeletal remains is lacking (Krakowa 2017, 57). Krakowa (2017) hypothesizes that the individuals from the plague cemetery may have been from the lower layers of society. The author bases this on the location of the cemetery and it being associated with other cemeteries, and wealthier people fleeing London to more rural areas during the plague (Krakowa 2017, 57).

Because this means this site contains individuals from all layers of society and it was not possible to separate the populations based on burial locations, the socioeconomic status 'middle' was given to the site.

A total of 389 individuals were used for in-depth analysis. The overall male to female ratio was 2:1. The population, using all three burial phases, is quite varied and well-represented. Preservation was generally not very good (museumoflondon.org.uk).

Merton Priory

This site is that of the Augustinian Priory of St. Mary Merton. The priory was formally established in 1117 AD and surrendered to the crown in 1538 during the Dissolution of Henry VIII. Most buildings were then demolished, although some remained to provide for foundations of things that came after (mertonpriory.org; museumoflondon.org.uk).

The collection from the Museum of London that is used here is a monastic collection divided up in four phases that date to between 1117 and 1538 AD.

The site yielded 738 burials total, of which the majority belongs to the monastic population and was buried in the standard late-medieval style. Preservation was generally good (museumoflondon.org.uk).
The age and sex profile fit the expectations of a monastic site well. Most of the individuals were adults, and over 90% of the sexed adults are estimated to be male. The few non-adult present are estimated to have been adolescents, with no non-adults below 1 year old. The presence of non-adults and females in this monastic site may be evidence of some sort of integrated community (museumoflondon.org.uk).
The socioeconomic status of this site is determined to be ‘high’ based on the presence of stone coffins and grave goods such as a pendant lamp, copper alloy buckle and a thread spinner with golden thread (museumoflondon.org.uk).

Bermondsey Abbey

The Bermondsey Abbey is located almost straight across the Tower of London. The abbey was established in 1089 and was in use until the Dissolution of the monasteries in 1538. The site was most likely established on the sites of an earlier monastery based on burials (museumoflondong.org.uk), but further information on that is lacking.
The abbey was home to an order of monks known as the Cluniac order. This order is centered around the monastery of Cluny, France. A few years after the abbey was established, monks from the house St. Mary in Charité-sur-Loire (France) arrived to occupy their new home (Malden 1967, 64). The abbey was quick to gain wealth and influence, and acquired properties is nearby areas. The abbey was eventually granted a market and annual fair. By 1535, the abbey’s annual income was valued at £474, equivalent to over £7 million today (bermondseysquare.net).
As expected with an abbey site, the burials indicate the population is heavily tilted towards male adult individuals. Of the 201 individuals analysed, only one was a non-adult. 147 individuals were estimated to be male, whereas preservation for the remainder was too poor to estimate sex. No individual was estimated to be female. Overall preservation was very good (museumoflondong.org.uk). The socioeconomic status of this site is labelled as high due to the high wealth flowing through the abbey and its role in the surrounding areas.

3.2.2 Post-medieval cemeteries

Chelsea Old Church

This site has a long history of occupation, going back into the prehistory (Cowie *et al.* 2008, 5-7). Through the ages, the village of Chelsea transformed from a 'riverside resort to London suburbs'. Available descriptions of Chelsea suggesting that it was a relatively healthy and prosperous part of London (Cowie *et al.* 2008, 13).
The churchyard of Chelsea Old Church is one of eight known burial grounds in this area. It is unknown when the church was established. The graveyard housed anyone, rich or poor, until a new cemetery opened in 1736 (Cowie *et al.* 2008, 21). After this date, it seemed like varying status was still present among the burials (Cowie *et al.* 2008, 21), but leaning more towards individuals of higher social status (museumoflondon.org.uk).
Of the 290 excavated skeletons, 198 individuals were analysed. The presence of biographical information and inscribed coffin plates allowed for the identification of 26 individuals, with name and sometimes even date of death and burial. The coffin plates date the burials of the cemetery between 1712 and 1842 (Cowie *et al.* 2008, 21; museumoflondon.org.uk).
Of the 198 analysed individuals, 165 (83.3%) were adults and 33 (16.7%) non-adults. Adults were nearly equally divided among sex. Interestingly, the adults were often placed in the older category (≥46 years old) (Cowie *et al.* 2008, 42), which may be reflectant of a higher social status. The preservation of the site was overall quite good (museumoflondon.org.uk). This site has a high socioeconomic status, has indicated by the presence of stone coffins, coffin plates and brick lined graves.

St. Bride's Lower

St. Bride's Lower cemetery is a site connected to St. Bride's Church on Fleet Street, believed to date mainly to the 17th- and 18th-century (museumoflondon.org.uk).
The cemetery most likely contained individuals from a nearby workhouse and prison. The population was well documented, allowing one to identify their age, occupation and cause of death. Based on this information, it seems that the cemetery housed mainly individuals of lower socio-economic status. The crypt of the church was excavated in 1958 and uncovered the remains of those buried inside the church and vaults. Since this excavation is not associated with the Museum of London, individuals from this excavation are not included in the data (museumoflondon.org.uk).

With 606 excavated individuals, St. Bride's Lower is one of the largest post-medieval populations. 544 individuals were used for analysis. 65.5% of the population had at least one pathological condition. It also has a high mortality rate: 32% of the population did not survive into adulthood. The general preservation of the skeletal remains is excellent (museumoflondon.org.uk).

St. Benet Sherehog

The site of St. Benet Sherehog is also known as '1 Poultry'. The church of St. Benet Sherehog was likely constructed somewhere in the 11th century. However, it burned down in 1666 during the great fire of London. The church was never rebuilt, but the land was used as a cemetery until 1853 (museumoflondon.org.uk).
274 individuals were recorded during excavations carried out by the Museum of London. Of those individuals, 235 were post-medieval, and of these remains, 231 were used for further analyses. They date primarily to the 16th and 17th century. The group had a much higher male to female ratio and the largest age group was the 36-45 category. Among the population were also 64 non-adult adults and of those, 28 individuals were children under 5 years old. Based on parish records, the population encompasses individuals from all layers of society in urban 16th- and 17th-century London, thus the socioeconomic status 'middle' is given to the site. Preservation of the remains was generally quite good (museumoflondon.org.uk).

3.2.3 Selection criteria

Before any data analyses were conducted, the data was carefully considered. Since DISH is a disease only found in adults, all non-adults were excluded from the sample. To increase the sample size for this thesis, probable males were grouped together with the males and probable females with the females. Intermediate and undetermined/unobservable were left as is. This brings the total sample to 1827 individuals. Demographic details per site, including age categories and sex distribution, will be discussed in chapter 5.

4. Methods

This chapter will go over the methods used by the Museum of London and the methods used in this research specifically. The methodology used by MoLAS will be discussed first, and then the analyses conducted for this thesis will be discussed.

4.1 The dataset

Data used for this thesis is retrieved from The Oracle Wellcome Osteological Research Database (WORD). This database was designed to record the vast amount of human remains and to simplify querying for research purposes (museumoflondon.org.uk).
Data recorded in this database was analysed in accordance with the Human Osteology Method Statement (Powers 2012), published in 2008 and revised in 2012.
This method statement was developed 'to standardise the recording of all metric and morphological variability expressed in the human skeleton' (Powers 2012, 8).
The MoLAS had used many different methods and sources in the past, but these new guidelines were also designed to be used on any skeleton, regardless of age at death (Powers 2012, 8).
The profile recorded by the MoLAS for each individual skeleton includes a whole list of characteristics. The methods involved with each characteristic are discussed in-depth in Powers 2012, and often are a combination of several methods and references (Powers 2012, 8). The characteristics used by the MoLAS are as follows, in no particular order:

- Skeletal preservation
- Archaeological data (such as samples)
- Skeletal completeness
- Age at death estimation
- Sex estimation
- Ancestry
- Metric Data
- Non-metric skeletal traits
- Dental Pathology
- Skeletal Pathology

For this thesis, only the characteristics 'age at death estimation', 'sex estimation' and 'skeletal pathology' (specifically DISH) are relevant. In the following paragraphs, the MoLAS methodology for these characteristics will be discussed in-depth.

4.1.1 Age at death estimation

The MoLAS divides individuals in two main age categories when it comes to estimating their age-at-death. The first group are the 'non-adults', which include individuals below 18 years old, and 'adults' which naturally includes all individuals above 18 years old. The adult category includes broader age groups because it is more difficult to estimate age in adults (Powers 2012, 14). As this study only focuses on adults, the non-adults will not be discussed any further. See table 2 for an overview of the age groups MoLAS uses.

Table 2: The age groups used by the MoLAS. After Powers 2012, 13-14.

Adults	
Age group	**Age**
Young adult	18-25 years
Early middle adult	26-35 years
Later middle adult	36-45 years
Mature adult	≥46 years
Adult	>18 years
Subadult	<18 years

Adult age at death was estimated using a combination of methods, including pubic symphysis degeneration, auricular surface degeneration, sternal rib morphology and dental attrition data (tooth wear) (Powers 2012, 14). When remains were fragmentary and/or incomplete, adulthood was estimated by the eruption of the third permanent molar and the complete fusion of the epiphyses, with the exception of the fusion of the *os coxa* and medial clavicle. MoLAS uses a so-called 'best fit' approach which involves selecting the most appropriate method to estimate an individual's age and place them in an age group (Powers 2012, 14).

For this thesis, the sample of adults is divided into two age groups: younger adults and older adults. The younger adults include the individuals between ages 18 and 35, and the older adults are individuals equal to or older than 38 years. Unclassified adults are excluded from these groups.

4.1.2 Biological sex estimation

A biological sex estimation was only attempted for adult individuals. The estimation is based on 14 macroscopic features of the skull and the pelvis (Powers 2012, 15). When observable, each feature was graded on a five-point scale (table 2). When an element was not observable, it was graded as a '9', meaning not observable/undetermined sex. An overall estimation of the biological sex is derived from a combination of the data and grading. More weight was given to the grading of the pelvis as it is considered to be more reliable. (Powers 2012, 15).

Table 3: The five-point scale used by MoLAS to grade the features and estimate biological sex. After Powers 2012, 15.

Grade	Estimated biological sex
1	Male
2	Probable Male
3	Intermediate
4	Probable Female
5	Female
9	Undetermined/not observable

4.1.3 Pathology: Diffuse Idiopathic Skeletal Hyperostosis

For recording purposes, DISH is classified as a joint disease in the method statement. Diagnoses are made following the methods by Aufderheide and Rodríguez-Martín (1998) and Resnick (2002). MoLAS had diagnosed DISH based on the ankylosis of vertebral bodies and the excessive bone formations at the muscle attachments of the joints. Intervertebral disc space and apophyseal joints must be unaffected.

MoLAS only diagnoses an individual with DISH if at least four vertebrae are affected by these features and the bony fusions are present on the right anterolateral aspect of the vertebral bodies, which makes for the characteristic 'dripping candle wax' look of DISH (see fig. 5) (Powers 2012, 50). In their database, MoLAS does comment on possible earlier cases of DISH present.

Figure 5 (left): DISH on an individual from context 252 in the site of Chelsea Old Church. Figure displays the left lateral view (left) and right lateral view (right). Note the difference between left and right lateral view, the flowing formations and 'candle wax' look. Intervertebral disc space is preserved. Image by MoLAS, source: https://www.museumoflondon.org.uk/collections/other-collection-databases-and-libraries/centre-human-bioarchaeology/osteological-database/post-medieval-cemeteries/chelsea-old-church-photographs.

4.2 Data analysis

All necessary data for each site was entered in Microsoft Excel. Each individual had their estimated sex, age, pathology and comments recorded in tables. An individual was confirmed to be suffering from DISH based on the comments of MoLAS under the section 'pathology' and 'comments'. In cases where MoLAS commented on a possible early case of DISH, the case was considered and often selected to include in the sample to increase the sample size.

The age groups were categorized as ordinal data, whereas the sex, age and site are nominal data. The data was analysed using IBM SPSS 27. The results of the statistical tests are displayed in tables. Asides from the N, n and %, the tables also include the chi-square test result (X^2), the degree of variability (df) and the significance (p).

Statistical significance was accepted when the analyses indicated $p<0.05$, meaning a 5% or less chance that the frequencies occurred coincidentally. A tendency towards statistical significance was considered when $0.1<p<0.05$.
In order to find out if the prevalence of DISH is statistically significant for certain variables (such as sex, age at death and site) two non-parametric tests were used. When a test uses two or more categorical variables, a chi-square test of independence was used to determine whether the involved variables are related or independent.
If one or more of the expected frequencies did not exceed five individuals, a Fisher's Exact test was used. In the case that there were three or more categories present, but one or more did not exceed five expected individuals, a Fisher-Freeman-Halton Exact test was used instead of a Fisher's Exact test. Asterisks under a table indicate a case where a Fisher's Exact test or a Fisher-Freeman-Halton Exact test was used instead of a chi-square test.

The statistical tests are used to identify the prevalence of DISH among the sexes and age groups within the different sites. Additionally, the prevalence of DISH is compared between the different sites, using the aforementioned variables. The sites are divided into different groups according to their socioeconomic status (low, middle and high, see table 1) and their historic period (medieval or post-medieval, see table 1). The prevalence of DISH is tested between medieval monastic and non-monastic sites, medieval and post-medieval sites and all the males and females, regardless of site, historic period and socioeconomic status.

5. Results

This chapter of the thesis will provide the results of the data analyses conducted. The demographic aspects of the sample are presented first to give a good overview of the sex and age distributions of the different sites. Secondly, the prevalence of DISH is shown per site. The prevalence is calculated for each site's overall numbers, the sexes and adult age groups. The prevalence of DISH is then compared between sites by using two groups: medieval monastic versus non-monastic groups and all the socioeconomic status (low, middle and high) of their associated time period. Socioeconomic status is not compared between medieval and post-medieval sites.

5.1 Demographic composition – Medieval Sites

5.1.1 St. Mary Graces

The medieval site of St. Mary Graces yielded 283 adult individuals for analysis. Most adults belong to the age category ‘unclassified adult’ (22%), followed by 36-45 years (18%) and 26-35 years (15%) (fig. 6). Sex estimation demonstrated that there were 136 males, 68 females and 79 individuals of unassigned sex in the sample. Male to female ratio is therefore 2:1 (fig. 7). However, is it possible more females are present within the group of individuals with unassigned sex.

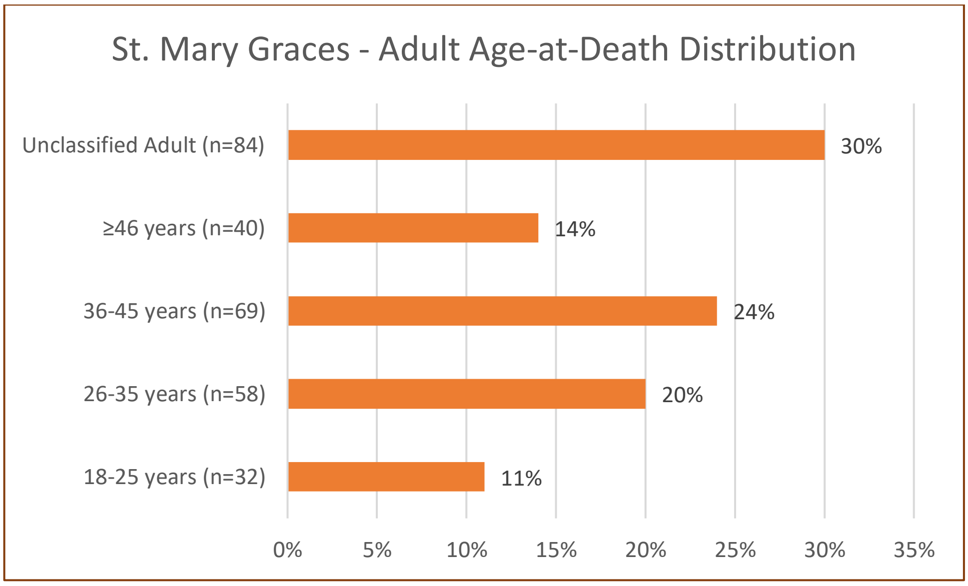

Figure 6: Adult Age-at-Death distribution in the population of St. Mary Graces (n=283).

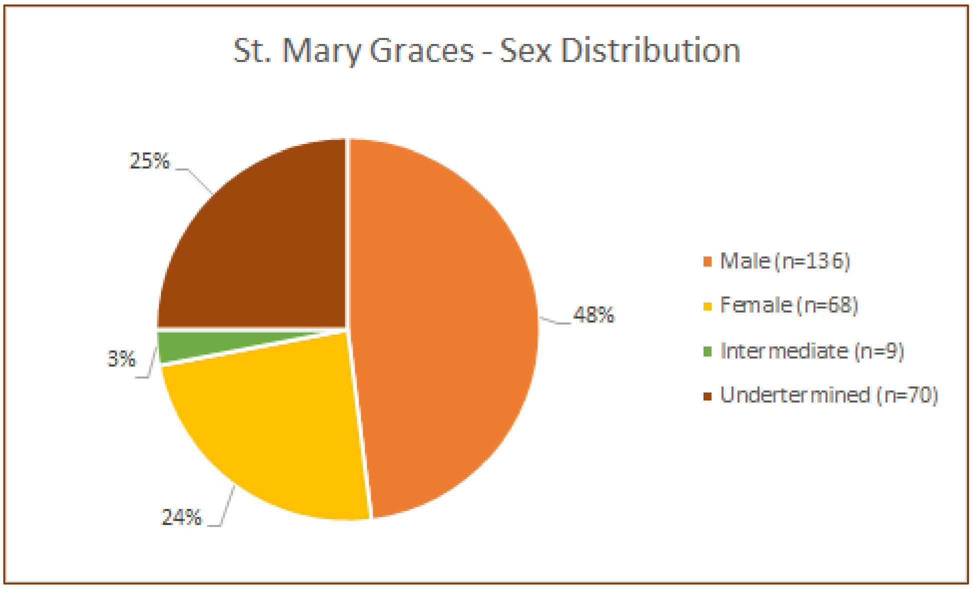

Figure 7: Adult biological sex distribution in the population of St. Mary Graces (n=283).

5.1.2 Merton Priory

This monastic site yielded 643 adult individuals for analysis. Most adults belong to the 36-45 years age category at 41%, followed by unclassified (26%) (fig. 8) Sex estimation demonstrated the sample is composed of 485 males, 53 females, 24 intermediate and 81 individuals of undetermined sex (see fig. 9). Male to female ratio is nearly 9:1, a ratio expected in a monastic population.

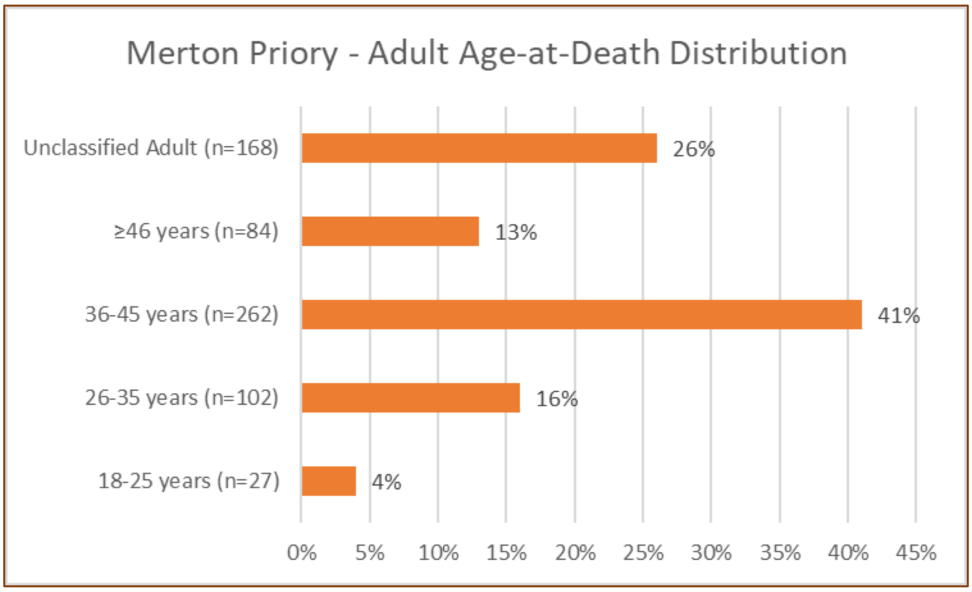

Figure 8: Adult Age-at-Death Distribution in the population of Merton Priory (n=643).

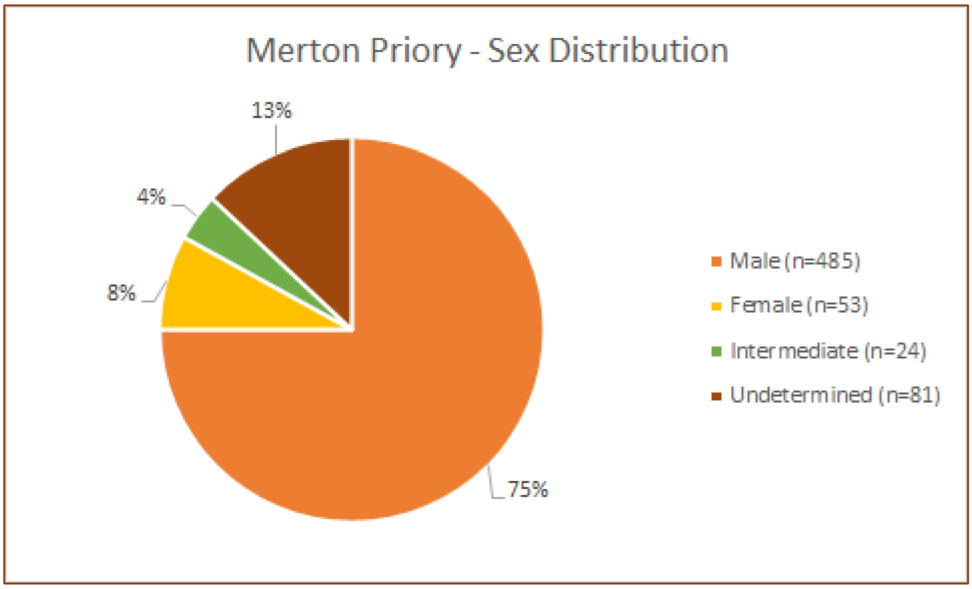

Figure 9: Adult biological sex distribution in the population of Merton Priory (n=643).

5.1.3 Bermondsey Abbey

This monastic site provided 200 adult individuals for analysis. Most adults belong to the unclassified adult category at 35%, followed by the 36-45 years at 25% (fig. 10). In this sample, not a single individual was estimated to be female. 147 are marked as male, 2 as intermediate and 51 as undetermined. The male to female ratio shows a heavy bias, but one expected in monastic sites (fig. 11).

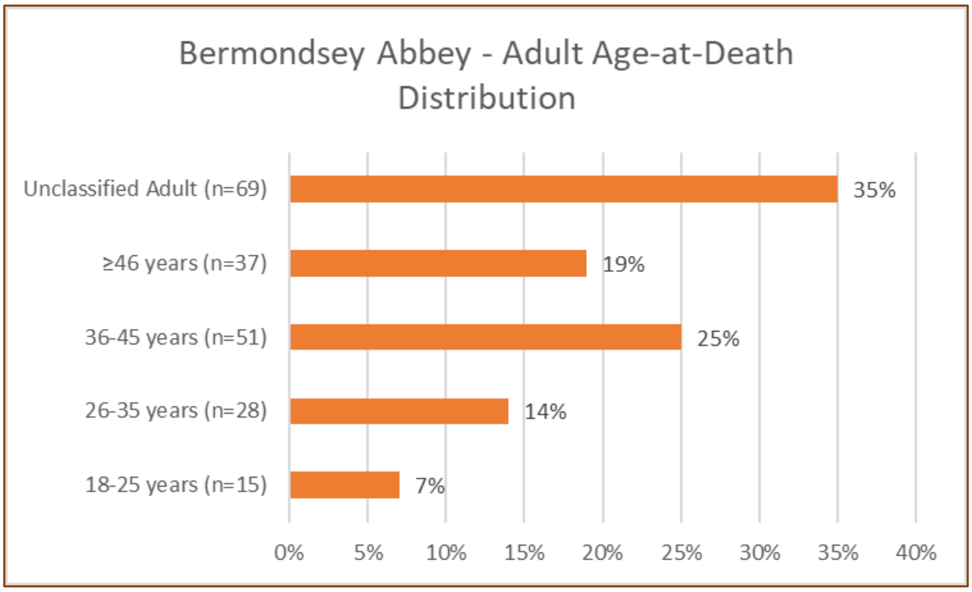

Figure 10: Adult Age-at-Death Distribution in the population of Bermondsey Abbey (n=200).

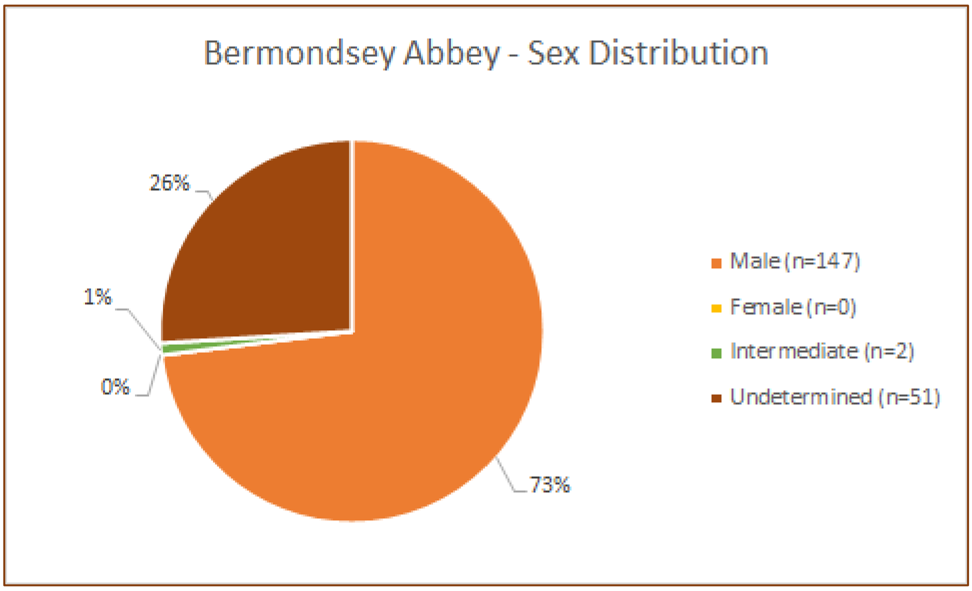

Figure 11: Adult biological sex distribution in the population of Bermondsey Abbey (n=200).

5.2 Demographic Composition - Post-medieval sites

5.2.1 Chelsea Old Church

This sample population contains 165 adult individuals. Most adults belong to the ≥46 years category at 44% (fig. 12). Sex estimation demonstrates 74 individuals to be male, 78 to be female, 5 to be intermediate and 8 to be of undetermined sex. Male to female ratio is 1:1 (fig. 13).

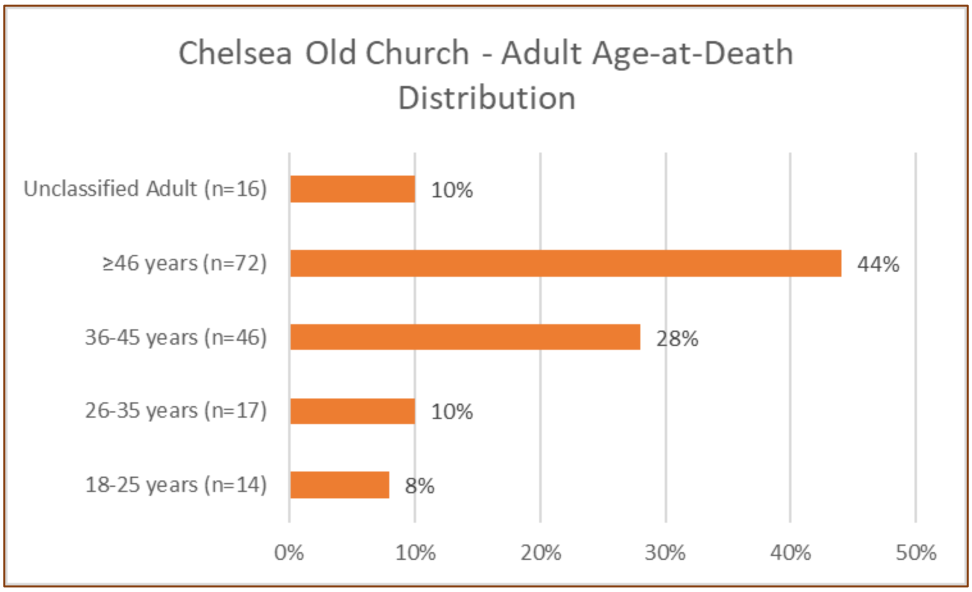

Figure 12: Adult Age-at-Death Distribution in the population of Chelsea Old Church (n=165).

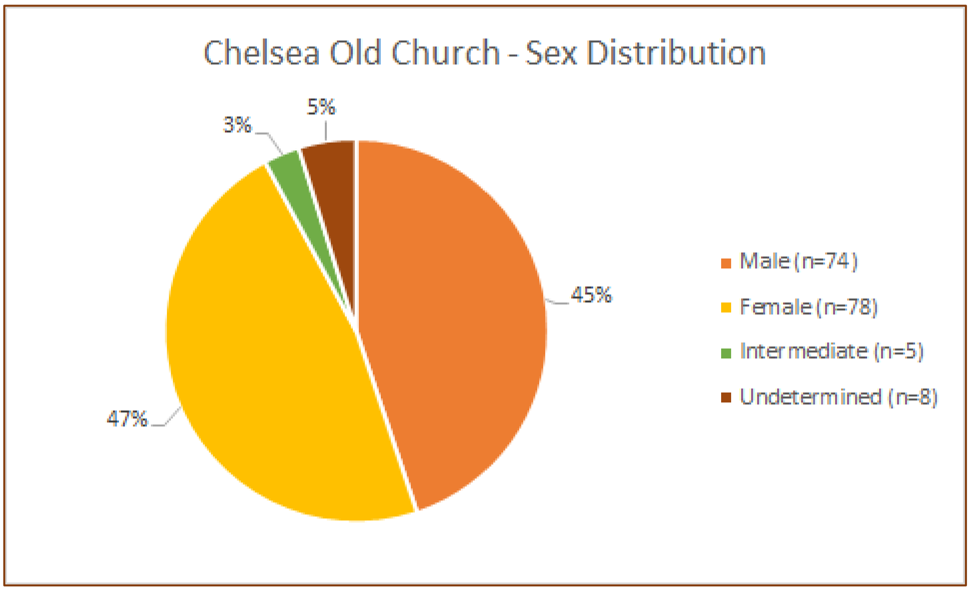

Figure 13: Adult biological sex distribution in the population of Chelsea Old Church (n=165).

5.2.2 St. Bride's Lower

This sample contains 369 adult individuals. Here, the ≥46 years category is most represented at 44% (fig. 14). Sex was estimated for the 369 adults. This portion is comprised of 194 males, 125 females, 14 intermediate and 36 undetermined. The male to female ratio is unequal at 1:1,5 (fig. 15).

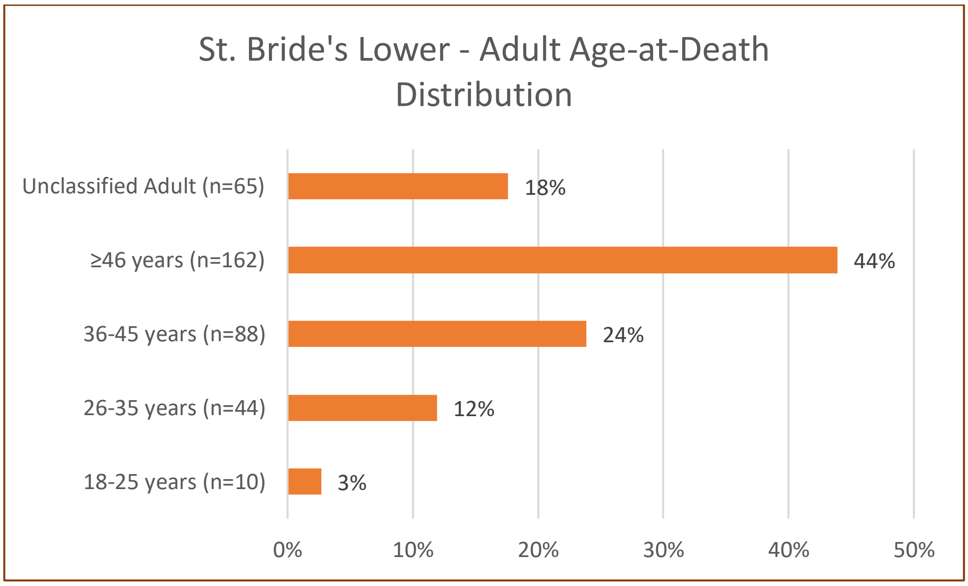

Figure 14: Adult Age-at-Death Distribution in the population of St. Bride's Lower (n=369).

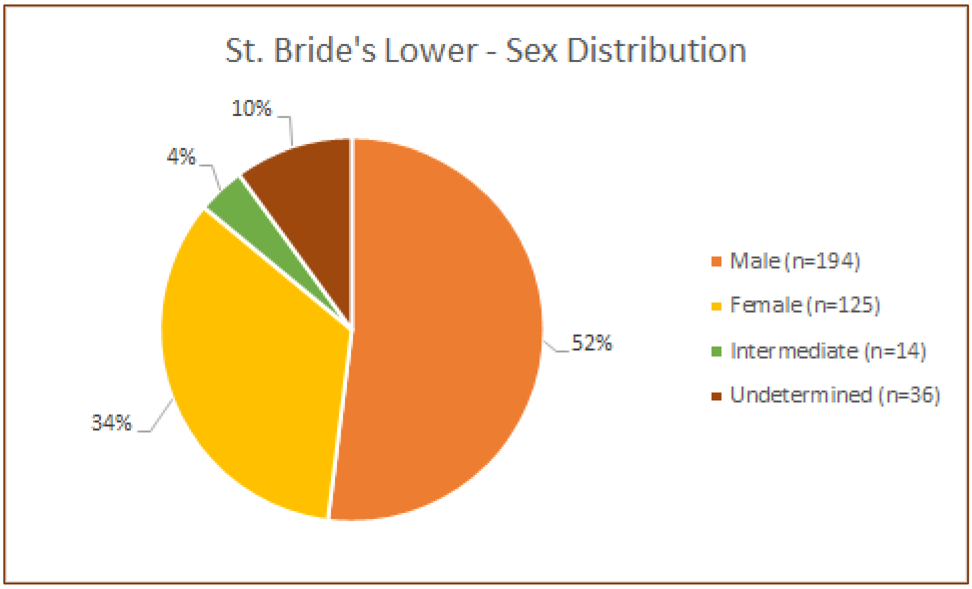

Figure 15: Adult biological sex distribution in the population of St. Bride's Lower (n=369).

5.2.3 St. Benet Sherehog

The sample from this site contains 167 adult individuals. Most adults belong to the 36-45 years age category at 30%, followed by unclassified at 26% (fig. 16). Of the 167 adults, 81 are estimated to be male, 46 female, 3 intermediate and for 37 it was not possible to estimate sex. Male to female sex ratio is unequal at 2:1 (fig. 17).

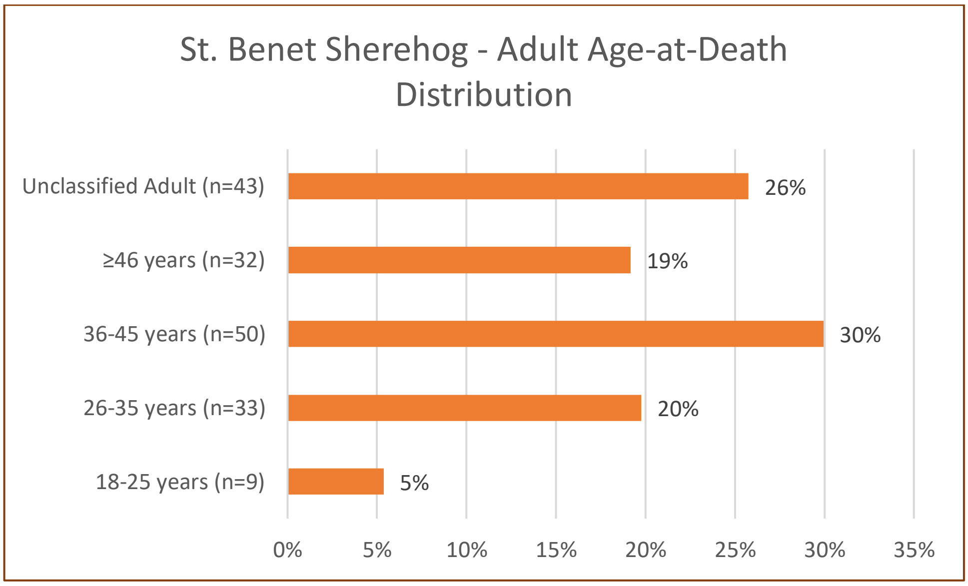

Figure 16: Adult Age-at-Death Distribution in the population of St. Benet Sherehog (n=167).

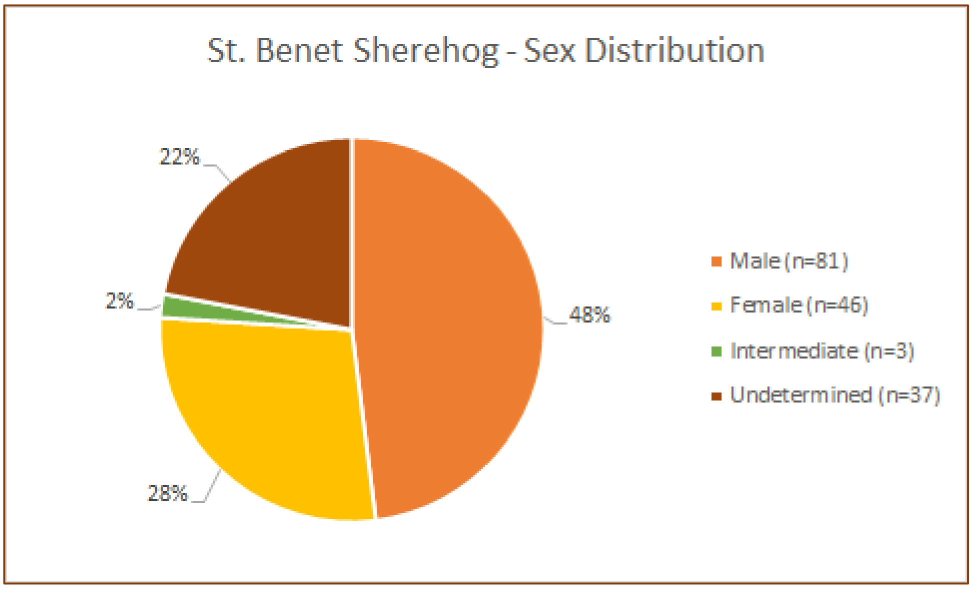

Figure 17: Adult biological sex distribution in the population of St. Benet Sherehog (n=167).

5.3 Site comparisons: Demographic composition

The following figures show an overall comparison between the six sites used in this thesis. Comparisons are made between age-at-death and sex distribution. For the sake of clarity and providing a reasonable overview, the age-at-death distributions have been split in comparisons between medieval and post-medieval sites. For the biological sex distribution, all the six sites are included in the same figure.

5.3.1 Adult Age at Death Distribution

Figure 18 and figure 19 show the adult age-at-death distributions of all six sites. Figure 18 contains data from the medieval sites, whereas figure 19 covers the post-medieval sites. Age categories are overall well represented. Among the sites, the largest number of adult individuals have an estimated age at death between 36-45 years. However, looking at the post-medieval sites, the age at death of individuals seems slightly increased, with a larger percentage of individuals having reached ≥46 years. Older adult individuals (≥36 years) are more prevalent than younger adult individuals (18-35 years). There is a visible jump in numbers between the 18-25 and 26-35 age categories across all sites.

The numbers of Chelsea Old Church stand out. The age-at-death distribution of this site is tailored towards the higher end. 36% of individuals of this site have an estimated age at death of ≥46 years, and 23% of 36-45 years. Among the medieval sites, Merton Priory houses many older individuals. Here, 39% have an estimated age at death of 36-45 years.

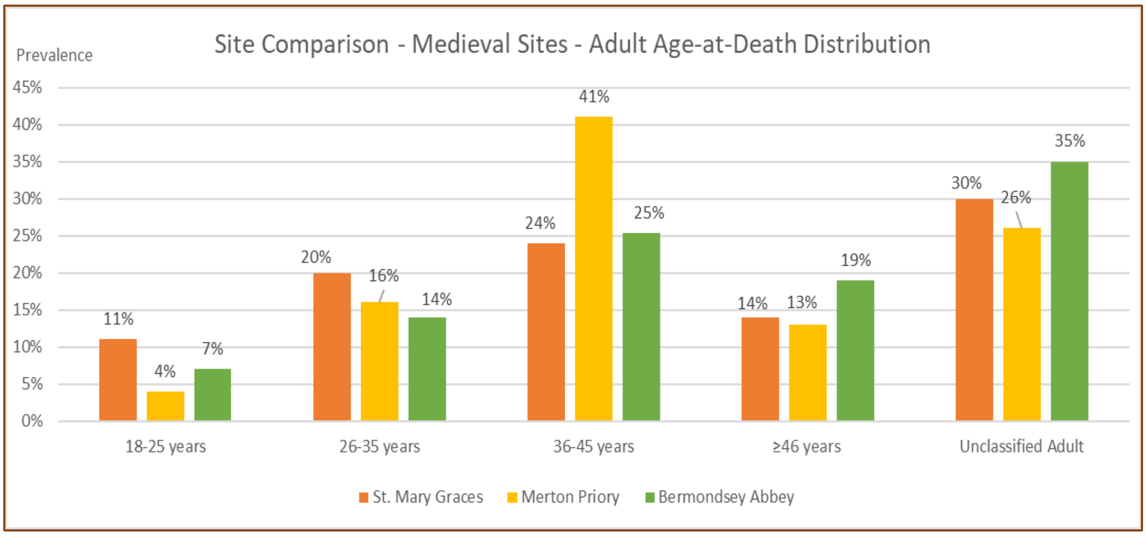

Figure 18: The age-at-death distribution among all the medieval sites used in the sample.

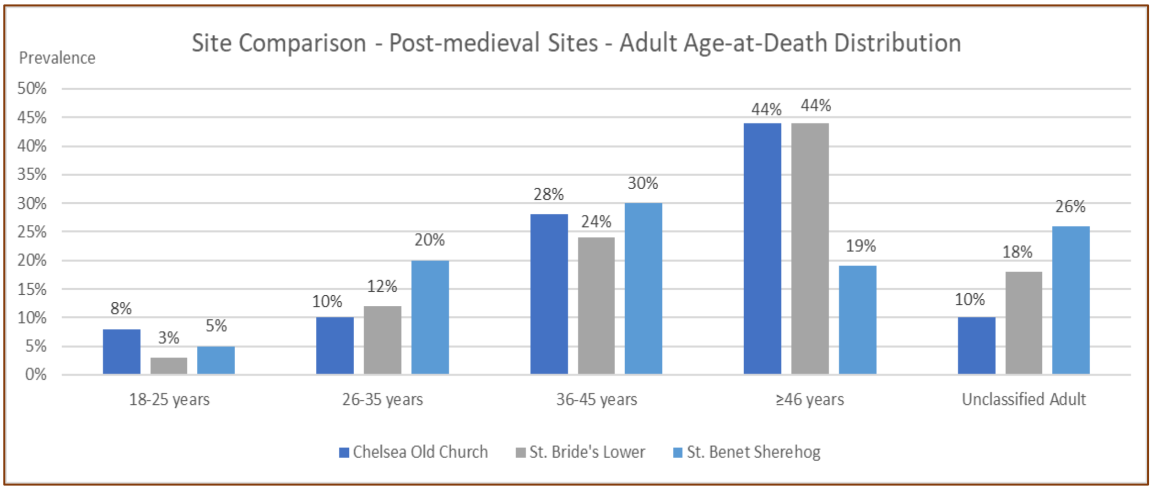

Figure 19: The age-at-death distribution among all the post-medieval sites used in the sample.

5.3.2 Biological sex

Figure 20 represents the adult biological sex distribution among all the sites. Males are abundant at most sites. Chelsea Old Church is the only site where the male to female ratio is relatively equal. Extreme outliers are the monastic sites of Merton Priory and Bermondsey Abbey, where the prevalence of females is 8% and 0%, respectively.

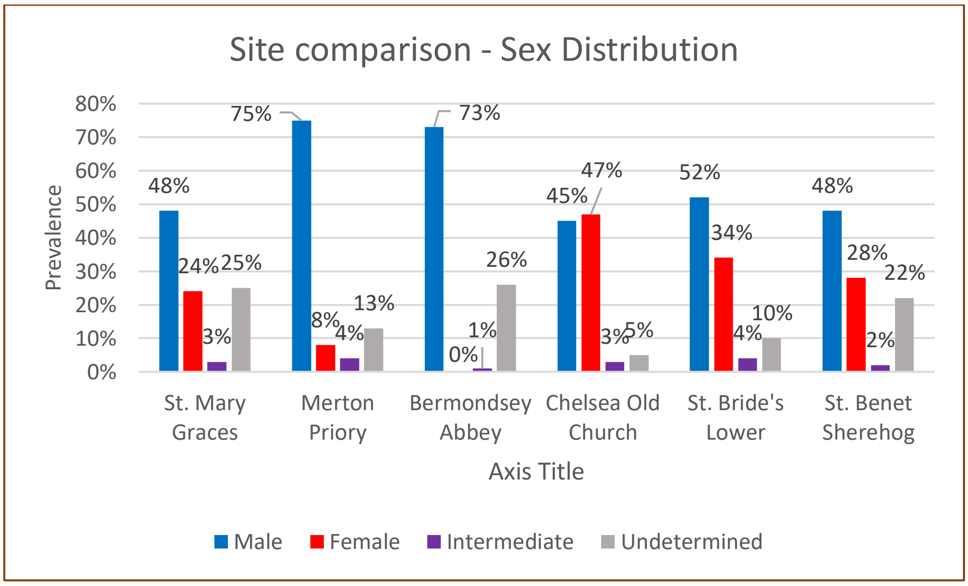

Figure 20: The biological sex distribution of all the sites used in the sample.

5.4 The prevalence of DISH – Medieval Sites

This section covers the prevalence of Diffuse Idiopathic Skeletal Hyperostosis across all the six sites used in the sample. Medieval sites are covered first, followed by post-medieval sites (section 5.5). The data for each site is presented in a table that covers the adult age categories and the number of individuals per group category (N), the number of DISH cases (n) per category and the prevalence in percentages per age category and sex (%). After the relative numbers of each category have been discerned, statistical tests were conducted. Prevalences were compared between males and females and younger and older adults. The results to these tests are displayed in a separate table.

5.4.1 St. Mary Graces

One case of DISH was deselected in this population. The overall prevalence of DISH in this population is 1.8% (n=5). All individuals with DISH are estimated to be male. The age group with the highest prevalence of DISH is 36-45 years, at 2.9% (table 4).

Table 5 displays the results of the statistical tests on the prevalence of DISH. None of these cases yielded a statistically significant result, which may be due to the smaller sample size.

Table 4: The prevalence of DISH among the population of St. Mary graces.

St. Mary Graces – Prevalence of DISH			
Category	**Number of Individuals**	**DISH**	
	N	**n**	**%**
Total	283	5	1.8
Male	136	5	3.7
Female	68	-	-
Intermediate	9	-	-
Undetermined	70	-	-
18-25 years	32	-	-
26-35 years	58	1	1.7
36-45 years	69	2	2.9
≥46 years	40	1	2.5
Unclassified Adult	84	1	1.2

Table 5: The results of the statistical tests conducted on the population of St. Mary Graces.

St. Mary Graces – Statistical Analysis						
Group	**Total number of individuals**	**DISH**		**Statistical Analysis**		
	N	**n**	**%**	**X^2**	**df**	**p**
Total	389	5	1.3	-	-	-
Male	136	5	3.7	-	-	0.172*
Female	68	0	0			
Younger adults	90	1	1.1	-	-	0.628*
Older adults	109	3	2.8			

* Fisher's Exact Test

5.4.2 Merton Priory

The overall prevalence of DISH in this population is 4.8% (n=31). Thirty of these individuals are estimated to be male, and 1 is of undetermined sex. Sixteen of 31 cases are from the 36-45 years age group. This group also has the highest prevalence of DISH in this population (6.1%) (table 6). Table 7 shows the results of the statistical tests. In this population, the prevalence of DISH among older adults as compared to younger adults is statistically significant at p=0.009, suggesting the incidence increases with age. The prevalence of DISH among males and females is not statistically significant but this is likely to the absence of females with DISH in this population, making this data less suitable for statistical analysis.

Table 6: The prevalence of DISH among the population of Merton Priory.

Merton Priory – Prevalence of DISH			
Category	***Number of Individuals***	***DISH***	
	N	***n***	***%***
Total	*643*	*31*	*4.8*
Male	*485*	*30*	*6.1*
Female	*53*	*-*	*-*
Intermediate	*24*	*-*	*-*
Undetermined	*81*	*1*	*1.2*
18-25 years	*27*	*-*	*-*
26-35 years	*102*	*1*	*1*
36-45 years	*262*	*16*	*6.1*
≥46 years	*84*	*7*	*8.3*
Unclassified Adult	*168*	*7*	*4.2*

Table 7: The results of the statistical tests conducted on the population of Merton Priory.

Merton Priory – Statistical Analysis						
Group	***Total number of individuals***	***DISH***		***Statistical Analysis***		
	N	***n***	***%***	***X^2***	***df***	***p***
Total	*738*	*31*	*4.2*	*-*	*-*	*-*
Male	*485*	*30*	*6.1*	*-*	*-*	*0.061**
Female	*53*	*0*	*0*			
Younger adults	*129*	*1*	*0.8*	*6.754*	*1*	***0.009***
Older adults	*346*	*23*	*6.6*			

** Fisher's Exact test*

5.4.3 Bermondsey Abbey

The overall prevalence of DISH in this population is 4% (n=8). All cases are estimated to be male. The age group 36-45 years has the highest prevalence at 9.8% (n=5) (table 8). Table 9 displays the results of the statistical tests. Due to the absence of females in this population, the significance for the prevalence of DISH between the biological sexes could not be tested, but it is clear there is a trend. The prevalence of DISH among older adults can be considered to have a tendency towards statistical significance (p=0.052), but this may be due to the small sample.

Table 8: The prevalence of DISH among the population of Bermondsey Abbey.

Bermondsey Abbey – Prevalence of DISH			
Category	**Number of Individuals**	**DISH**	
	N	**n**	**%**
Total	200	8	4
Male	147	8	3.9
Female	0	-	-
Intermediate	2	-	-
Undetermined	51	-	-
18-25 years	15	-	-
26-35 years	28	-	-
36-45 years	51	5	9.8
≥46 years	37	3	8.1
Unclassified Adult	69	-	-

Table 9: The results of the statistical tests conducted on the adult population of Bermondsey Abbey.

Bermondsey Abbey – Statistical Analysis						
Group	**Total number of individuals**	**DISH**		**Statistical Analysis**		
	N	**n**	**%**	**X^2**	**df**	**p**
Total	201	8	3.9	-	-	-
Male	147	8	3.9	-	-	-
Female	0	0	0			
Younger adults	43	0	0	-	-	0.052*
Older adults	88	8	9.1			

** Fisher's Exact test*

5.5. The prevalence of DISH – Post-medieval Sites

5.5.1 Chelsea Old Church

The overall prevalence of DISH in this population is 6.7% (n=11). Ten of these are estimated to be male, one is estimated to be female. The ≥46 years age group has the highest prevalence at 12.5% (n=9) (table 10). Table 11 shows the results of the statistical tests conducted on this population. As expected, the prevalence of DISH among males is statistically significant in this population. While the other test did not yield a statistically significant result, which may be due to the fact that no cases of DISH are present among the younger adults, the prevalence of DISH among older adult individuals indicates a tendency towards significance (p=0.069).

Table 10: The prevalence of DISH among the population of Chelsea Old Church.

Chelsea Old Church – Prevalence of DISH			
Category	**Number of Individuals**	**DISH**	
	N	**n**	**%**
Total	165	11	6.7
Male	74	10	13.5
Female	78	1	1.3
Intermediate	5	-	-
Undetermined	8	-	-
18-25 years	14	-	-
26-35 years	17	-	-
36-45 years	46	2	4.3
≥46 years	72	9	12.5
Unclassified Adult	16	-	-

Table 11: The results of the statistical tests conducted on the population of Chelsea Old Church.

Chelsea Old Church – Statistical Analysis						
Group	**Total number of individuals**	**DISH**		**Statistical Analysis**		
	N	**n**	**%**	**X^2**	**df**	**p**
Total	198	11	5.5	-	-	-
Male	74	10	13.5	8.463	1	**0.004**
Female	78	1	1.3			
Younger adults	31	0	0	-	-	0.069*
Older adults	118	11	9.3			

** Fisher's Exact Test*

5.5.2 St. Bride's Lower

The overall prevalence of DISH in this population is 2.2% (n=8). Seven cases are estimated to be male, and one is of undetermined sex. The age group with the highest prevalence is ≥46 years with 4.3% (n=7). The one other case is from the 36-45 years age group (table 12). Table 13 shows the results of the statistical tests. The prevalence among males yielded a statistically significant result (p=0.045).

Table 12: The prevalence of DISH among the population of St. Bride's Lower.

St. Bride's Lower – Prevalence of DISH			
Category	**Number of Individuals**	**DISH**	
	N	**n**	**%**
Total	369	8	2.2
Male	194	7	3.6
Female	125	-	-
Intermediate	14	-	-
Undetermined	36	1	2.7
18-25 years	10	-	-
26-35 years	44	-	-
36-45 years	88	1	1.1
≥46 years	162	7	4.3
Unclassified Adult	65	-	-

Table 13: The results of the statistical tests conducted on the population of St. Bride's Lower.

St. Bride's Lower – Statistical Analysis						
Group	**Total number of individuals**	**DISH**		**Statistical Analysis**		
	N	**n**	**%**	**X^2**	**df**	**p**
Total	544	8	1.5	-	-	-
Male	194	7	3.6	-	-	**0.045***
Female	125	0	0			
Younger adults	54	0	0	-	-	0.360*
Older adults	250	7	3.2			

* Fisher's Exact test

5.5.3 St. Benet Sherehog

The overall prevalence of DISH in this population is 1.8% (n=3). All cases are estimated to be male. Two of the cases are from the 36-45 years age group which makes for a prevalence of 4%. The other case is from the ≥46 years group (table 14).

Table 15 shows the results of the statistical tests. None of the tests yielded a statistically significant result, or a tendency towards. This data suggests the prevalence of DISH increases with age and/or is mostly prevalent among older adults.

Table 14: The prevalence of DISH among the population of St. Benet Sherehog.

St. Benet Sherehog– Prevalence of DISH			
Category	Number of Individuals	DISH	
	N	n	%
Total	167	3	1.8
Male	81	3	3.7
Female	46	-	-
Intermediate	3	-	-
Undetermined	37	-	-
18-25 years	9	-	-
26-35 years	33	-	-
36-45 years	50	2	4
≥46 years	32	1	3.2
Unclassified Adult	43	-	-

Table 15: The results of the statistical tests conducted on the population of St. benet Sherehog.

St. Benet Sherehog – Statistical Analysis						
Group	Total number of individuals	DISH		Statistical Analysis		
	N	n	%	X^2	df	p
Total	231	3	1.3	-	-	-
Male	81	3	3.7	-	-	0.553*
Female	46	0	0			
Younger adults	42	0	0	-	-	0.558*
Older adults	82	3	3.7			

** Fisher's Exact test*

5.6 Site comparisons: The prevalence of DISH

5.6.1 Overall prevalence

Figure 21 shows the overall prevalence of DISH among the six sites used in this sample. The post-medieval site Chelsea Old Church has the highest prevalence of DISH overall, followed by the medieval monastic sites Merton Priory (4.8%) and Bermondsey Abbey (4%). The monastic sites have a high prevalence when compared to the non-monastic site of St. Mary Graces, which has a prevalence of 1.8%. The high prevalence of DISH in Chelsea Old Church is interesting, given how the site contains the fewest individuals and adults of the post-medieval sites. It also has the highest number of individuals suffering from DISH (n=11) of the post-medieval sites.

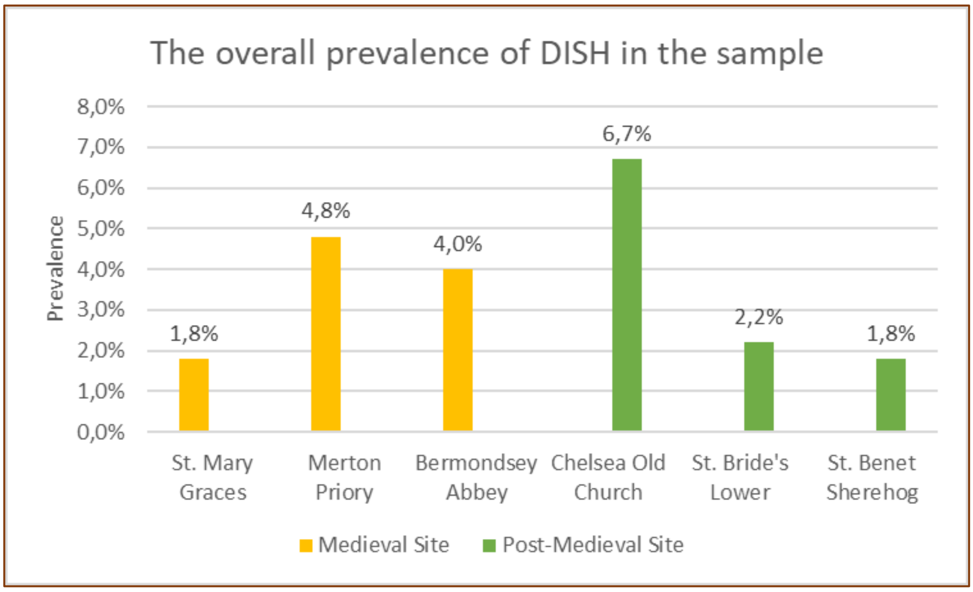

Figure 21: The overall prevalence of DISH among the six sites used in the sample.

5.6.2 Prevalence among the biological sexes

Figures 22 and 23 display the prevalence of DISH among the biological sexes in the medieval and post-medieval sites, respectively. This data has been split into two separate figures to increase readability and overview. Overall, DISH is clearly more prevalent among males. Prevalence among the other groups (female, intermediate and undetermined) is very small. Chelsea Old Church is the only population that has a case of DISH among females.

This occurrence may be explained by the lower number of females included in the overall sample. Chelsea Old Church has the highest overall prevalence among males at 13.5%.

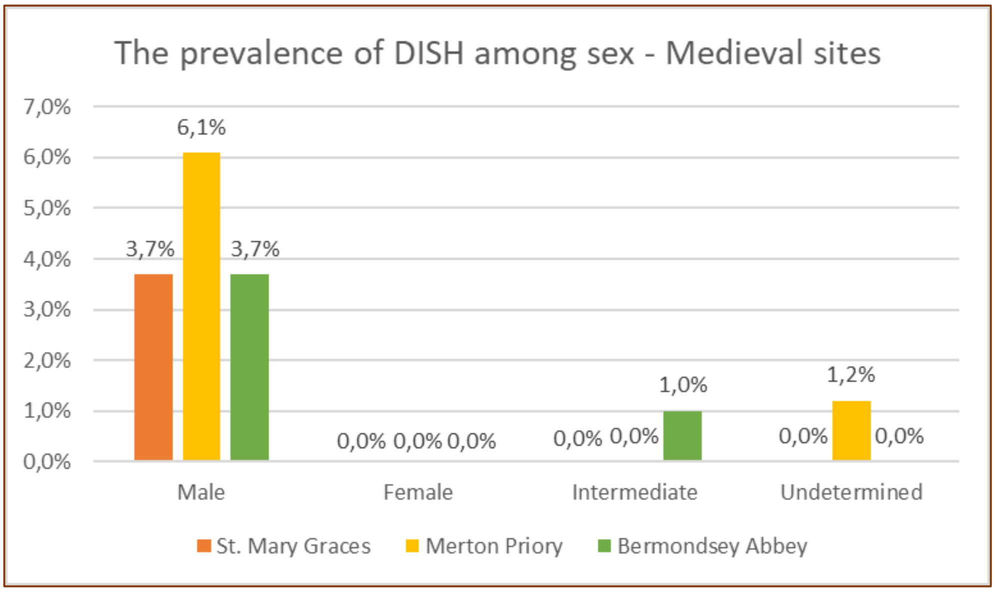

Figure 22: The prevalence of DISH among sex in the medieval sites of the sample.

Among medieval sites, Merton Priory exhibits the highest prevalence among males at 6.1%, followed by a tie between the two other sites (both at 3.7%) (see figure 21). Among post-medieval sites, the prevalence of DISH among males is highest in Chelsea Old Church, followed by St. Benet Sherehog (3.7%) (see figure 22). The prevalence among males of Chelsea Old Church is much higher than the other two post-medieval sites. St. Benet Sherehog and St. Bride's Lower are very close together in that regard.

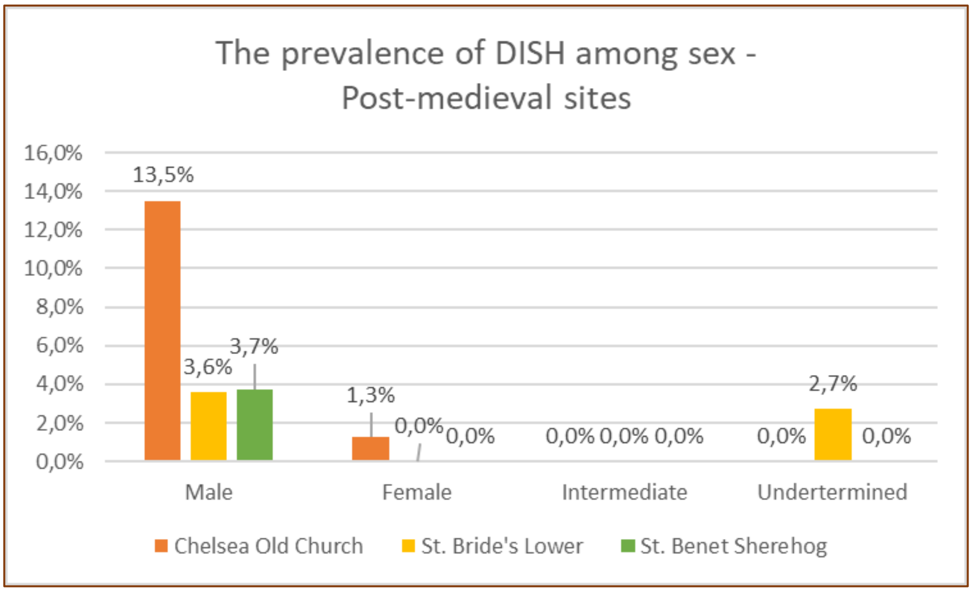

Figure 23: The prevalence of DISH among sex in the post-medieval sites of the sample.

Table 16 displays the results of a statistical test conducted on the overall prevalence of DISH among the biological sexes. This test excluded all intermediate and undetermined cases. The result is highly significant at p=0.001, suggesting this pattern could not have occurred coincidentally.

The prevalence of DISH between males and females						
Group	***Total number of individuals***	***DISH***		***Statistical analysis***		
	N	***n***	***%***	***X^2***	***df***	***p***
Total	*1487*	*44*	*3.9*	-	-	-
Males	*1117*	*63*	*5.6*	*19.458*	*1*	***0.001***
Females	*370*	*1*	*0.3*			

Table 16: The results of the statistical tests conducted on the prevalence of DISH among the sexes.

5.6.3 Prevalence among different socioeconomic statuses

To test if there is any significance to the prevalence of DISH among sites of different socioeconomic status (see table 1 for the statuses of the sites), the data was split into two groups: medieval sites and post-medieval sites.

Table 17displays the results of the tests for the medieval sites. The prevalence of DISH among individuals of a high status (p=0.033) and high-status older adults (p=0.091) are statistically significant. The prevalence among females of different status could not be tested because not a single female in this part of the sample had DISH. This test can also double for statistical tests regarding the prevalence of DISH among monastic and non-monastic sites of the sample. The monastic sites have a high socioeconomic status, while the non-monastic site of St. Mary Graces has the middle status. Based on these results, DISH is more prevalent among monastic sites, which may also be due to the fact that the monastic population is larger than the non-monastic population.

Table 18 displays the results of the tests for the post-medieval sites. Since there is one site for each social status, all tests in table 18 can also double for a test comparing the overall prevalence between sites. In this case, high status stands for Chelsea Old Church, middle status for St. Benet Sherehog and low status for St. Bride's Lower. The prevalence among females was tested here but was not statistically significant. This result also provides little contribution, since it only deals with one individual. The prevalence of DISH among all individuals of high status is statistically significant when compared to lower statuses at p=0.012. Among males of high status, the significance is p=0.010 and among older adults of high status this is p=0.050. Three out of four tests on the prevalence of DISH among post-medieval sites suggest that the prevalence is significant among populations with a higher socioeconomic status.

Table 17: The results of the statistical tests conducted on the prevalence of DISH among the different socioeconomic statuses of the medieval sites.

The prevalence of DISH between different socioeconomic status – Medieval sites						
Group	***Total number of individuals***	***DISH***		***Statistical analysis***		
	N	***n***	***%***	***X^2***	***df***	***p***
Total	*1126*	*44*	*3.9*	-	-	-
High status	*843*	*39*	*4.6*	-	-	***0.033****
Middle status	*283*	*5*	*1.8*			
High status males	*632*	*38*	*6*	*1.156*	*1*	*0.282*
Middle status males	*136*	*5*	*3.7*			
High status females	*53*	-	-	-	-	-
Middle status females	*68*	-	-			
High status older adults	*434*	*31*	*7.1*	*2.861*	*1*	***0.091***
Middle status older adults	*109*	*3*	*2.8*			

* *Fisher's Exact test*

Table 18: The results of the statistical tests conducted on the prevalence of DISH among the different socioeconomic statuses of the post-medieval sites.

The prevalence of DISH between different socioeconomic status – Post medieval sites						
Group	***Total number of individuals***	***DISH***		***Statistical analysis***		
	N	***n***	***%***	***X^2***	***df***	***p***
Total	*701*	*22*	*3.1*	-	-	-
High status	*165*	*11*	*6.7*	*8.831*	*2*	***0.012***
Middle status	*167*	*3*	*1.8*			
Low status	*367*	*8*	*2.2*			
High status males	*74*	*10*	*13.5*	-	-	***0.010*****
Middle status males	*81*	*3*	*3.7*			
Low status males	*194*	*7*	*3.6*			
High status females	*78*	*1*	*1.3*	-	-	*0.498***
Middle status females	*46*	-	-			
Low status females	*125*	-	-			
High status older adults	*118*	*11*	*9.3*	-	-	***0.050*****
Middle status older adults	*82*	*3*	*3.7*			
Low status older adults	*250*	*8*	*3.2*			

** *Fisher-Freeman-Halton Exact test*

5.7 Chapter summary

This chapter analysed the prevalence of DISH in the six sample populations of St. Mary Graces, Bermondsey Abbey, Merton Priory, Chelsea Old Church, St. Bride's Lower and St. Benet Sherehog. Prevalence rates are compared between age categories, sexes and socioeconomic status.

The prevalence of DISH is highest among the population of Chelsea Old Church and lowest among the populations of St. Bride's Lower and St. Benet Sherehog. In the overall prevalence, there is a clear trend visible. DISH is more prevalent among populations of higher socioeconomic status and less among populations of low socioeconomic status, which is the case for both the medieval and post-medieval collections. Among the medieval populations, the monastic sites have a higher prevalence than the non-monastic site. DISH is abundantly more prevalent among males in this sample. The disease is observed only once in females.

6. Discussion

This chapter aims to identify possible patterns in the prevalence of DISH in biological sex, age and socioeconomic status among medieval and post-medieval London populations. It will first proceed by discussing the osteological parados and the limitations and biases of this study. Then, the prevalence of DISH among biological sexes, age groups, medieval and post-medieval populations, socioeconomic status and medieval monastic and non-monastic populations will be discussed and interpreted. After this has been discussed and interpreted, the results are placed in a broader context by comparing them to the results of Jankauskas (2003), Rogers and Waldron (2001), and Verlaan *et al.* (2007). Comparisons are also made with modern clinical data. Altogether, these interpretations will be used to provide an answer to the main research question and the sub-questions.

5.5 Osteological data and sample limitations

5.5.1 The Osteological Paradox

Studies such as this thesis are valuable tools in understanding past populations. Where most interpretations of paleodemographic and paleopathological data assumes a straightforward relationship between the prevalence of a certain pathology among a population, Wood *et al.* (1992) suggest that those relationships may be more complex than anticipated. To combat this pitfall, Wood *et al.* suggest that three factors – demographic nonstationarity, selective mortality and hidden heterogeneity in risk – are the main problems in making assumptions about past populations (Wood *et al.* 1992, 344),

Demographic nonstationarity refers to the constant changes in mortality, fertility and migration. In a nonstationary population (almost all populations are nonstationary), age-at-death is incredibly sensitive to fertility, but less to mortality. This creates a paradox were the life expectancy or mean age-at-death of a population actually represents the fertility, and not the mortality of a population (Wood *et al.* 1992, 344).

Selective mortality is a concept that assumes that the mortality of a past population never truly encompasses the risks of contracting/developing a disease and dying from it. Since all the individuals with a certain disease are already dead and/or have died from that disease, we can never know the full number of people at risk, but who did not develop or die from that disease. As a result, such research may overrepresent the actual prevalence of a certain disease in a population (Wood *et al.* 1992, 344).

Hidden heterogeneity in risks is closely related to selective mortality. This concept emphasizes that individuals in a population all have their own susceptibility to disease and death. These variations may be explained by genetic causes, socioeconomic differences, microenvironmental differences and trends in health (Wood *et al.* 1992, 345). Skeletal assemblages represent accumulations of all these risks over longer periods of time, making it impossible to interpret aggregate-level and age-specific mortality rates (Wood *et al.* 1992, 345).

These problems reflect two undeniable facts: it is impossible to obtain direct estimates of demographic or epidemiological rates from archaeological populations, and although health is a characteristic of an individual, conclusions about it must be drawn based on aggregate- or population-based statistics. This means that reports on the characteristics of a single individual are worthless to make a conclusion about past populations (Wood *et al.* 1992, 345). An example provided by Wood *et al.* (1992) to illustrate these problems: there is a population comprised of three sub-populations, all of which are potentially exposed to stress. This stress increases the risk of death and produces distinct skeletal lesions in survivors. Sub-population one is never exposed to this stress, thus shows no sign of skeletal lesions. Sub-population two is moderately exposed to this stress, sufficient for a wide-spread sickness lasting long enough to develop bony lesions, but with few deaths. Sub-population three is heavily exposed to this stress, resulting in numerous deaths soon after onset (thus before any bony lesions develop), meaning few bony lesions are present in the assemblage. Now, based on what we know, we could group these populations from healthiest to least healthy. But based solely on the skeletal assemblages, there appear to be only two groups: healthy (no bony lesions) and unhealthy (bony lesions). The groups experiencing the least amount of stress and the most amount of stress appear the same in the assemblages, despite clearly not being the same in terms of health (Wood *et al.* 345).

The osteological paradox is very relevant to this thesis. Firstly, the populations used in the sample are very likely to have undergone changes in mortality, fertility and migration. All the sample populations are from London and surrounding areas, meaning they likely have undergone drastic changes over the years. But using sites from the same geographical area reduces the risk and influence of changes having occurred in mortality, fertility and migration. The sites used to compare the results of this thesis with, in the Netherlands (Verlaan *et al.* 2007) and England (Rogers and Waldron 2001), are of the same historic periods and located in roughly the same latitude within northwestern Europe. The comparisons to the data of Jankauskas (2003) may not be from the same geographical region or distinct historic period, but such an interesting comparison can offer new insights.

Selective mortality and hidden heterogeneity in risks are also very relevant here. DISH is one of many diseases that does not immediately affect a skeleton; the bony formations undergo a gradual build-up which can take years to fully develop and be visible in the skeleton (Kuperus *et al*. 2017, 1124-1125). This means an unhealthy population (with a lower mean age-at-death) may exhibit less lesions, simply because there isn't enough time for them to develop fully. The same argument can be made for DISH in a historic population, as is done by Arriaza (1993) (see chapter 2).

5.5.2 Limitations of this research and possible bias

This research includes only individuals with DISH based on the guidelines provided by MoLAS (Powers 2012, 50) (see chapter 4). The largest downside from this is that earlier and underdeveloped cases of DISH may be missed or misdiagnosed, reducing the sample size. Fortunately, comments in the databases of MoLAS note the possible presence of early DISH and the reasoning behind that conclusion, allowing for a more liberate selection of the data.

The fact that DISH is still often misdiagnosed in earlier stages (Holgate and Steyn 2016, 874) and the preservation of skeletal remains also contributes to the possibility that the prevalence of DISH in this sample is underrepresented. For example, the preservation of remains was very good in Chelsea Old Church, since individuals could afford better quality coffins (Cowie *et al.* 2008, 6). Preservation in St. Mary Graces was not very good. The site contained large pits for mass burials of victims of the plague (Krakowa 2017, 57), which does not help for preservation. Naturally, DISH is more likely to be identified among the well-preserved individuals of Chelsea Old Church than the plague victims in the mass grave of St. Mary Graces.

Methodologic differences will need to be considered when comparing this data to that of Rogers and Waldron (2001) and Verlaan *et al.* (2001). Prevalence may differ based on the methods they used, preservation of the remains and type of population. Despite all the sample populations being from the same region, not all of them are from medieval and/or post-medieval London. The site used by Verlaan *et al.* (2001) is from Maastricht, the Netherlands, while the sites used by this thesis and Rogers and Waldron (2001) are from London and surroundings. These differences offer interesting comparisons.

The sample of this thesis comes with possible biases. The first one is based on the demographic composition of the sites. The overall number of females present in the sample is very low compared to the number of males (1117 and 370, respectively) which may have influenced the representativeness of the sample.

5.6 Interpretation of the results

5.6.1 DISH among biological sex

An extremely high prevalence of DISH is observed among all the males when compared to the females of all the sites of the sample. Only one site has an equal male-to-female ratio, another site even lacks females altogether. Despite the observation that DISH is more prevalent among males (Weinfield *et al.* 1997, 225) and the results supporting this, the low number of females in this sample may skew the data and create a larger gap between the prevalence of DISH among the sexes. This gap in prevalence can be accounted for by the overall low number of females in the sample, thus them being underrepresented (see table 15). The inclusion of male-dominated monastic sites (with Bermondsey Abbey as extreme example) might further enlarge the gap in prevalence. Yet, even when this is taken into account, the differences between the sexes is striking. This increased prevalence of DISH among males is in line with modern, clinical data on the prevalence.

In a preliminary clinical study by Kim *et al.* (2018), the authors scanned 164 patients of different age categories for DISH and compared their data to three similar clinical studies (Kim *et al.* 2018, 42). The DISH prevalence in this population is 24.4 %. The prevalence in males is 31.7 %, and 15.8 % among females (Kim *et al.* 2018, 44). Kim *et al.* (2018) note that the prevalence increases with age but is also double as high among males than females. And indeed, when compared to the three other studies (Hirasawa *et al.* (2016), Mori *et al.* (2017) and Oudkerk *et al.* (2017)), a trend is present. The three other studies demonstrate that the prevalence of DISH among males is at least twice as high than among females (Kim *et al.* 2018, 45). The study by Hirasawa *et al.* (2016) also compares the prevalence of DISH among their sample of 558 Japanese patients with six similar studies. This study uses an x-ray and CT scan in combination with the guidelines by Resnick and Niwayama to identify DISH (Hirasawa *et al.* 2018, 288). The overall prevalence of DISH based on CT in this sample is 27.2 %. The prevalence among males is 38.7 %, and 13.9 % among females. This gap between prevalence only grew bigger the older the patients were (Hirasawa *et al.* 2016, 289) (see figure 21).

Again, this is an observable trend when comparing the prevalence in the sample to other studies. The six other studies this data is being compared to (Resnick (1976), Cassim (1990), Weinfield (1997), Kim (2004), Westerveld (2008) and Kagotani (2014)), all show this trend. The six other studies used different methods, patients of different races and other sample sizes, but all found a significantly higher prevalence of DISH among males (Hirasawa *et al.* 2016, 288). We see the same patterns and trends present in historic populations, such as the one presented in this study, even though our lifestyle has changed drastically. This large sex difference present now and in the past may be explained by the fact that DISH likely develops different in the sexes. Westerveld *et al.* (2008) speculate, based on clinical observations, that DISH is more prevalent among men but also develops faster and is more expressed. DISH would develop slower in females, and less often reach fully developed DISH (Westerveld *et al.* 2008, 1637). This does relate to the osteological paradox, because the low prevalence of DISH in females may be explained by the fact that DISH needs longer to develop. Alternatively, it has been hypothesized that there were marked lifestyle differences between the sexes (DeWitte 2012, 292-293) causing the difference in prevalence, but modern clinical data suggests this gap still exists. If anything, this phenomenon is most likely explained to be a possible combination of several factors with a possible genetic predisposition and not a drastic difference in lifestyle between the sexes.

5.6.2 DISH among different age groups

In some sites, the prevalence increases among older individuals. This is the case in Merton Priory, Chelsea Old Church and St. Bride's Lower. This trend suggests that DISH develops in a person's later years of life and can take a long time to develop fully. In this sample, the prevalence of DISH among older adults is significantly higher than the prevalence among younger adults (18-35 years). Referring to the concepts of selective mortality and hidden heterogeneity in risks (Wood *et al.* 1992, 344), it likely that young adults simply died too early to develop DISH, despite possibly having had a high risk of developing the bone formations. Individuals may already have developed DISH at an earlier age, but died while older, thus leading to a significantly higher prevalence of DISH among older adults.

Referring to the study of Kim *et al.* (2018). They found no patients with DISH in their thirties, which suggests DISH starts developing end-thirties the earliest. The prevalence increased as age did, and the percentile indices positively correlated with the age of the patients (Kim *et al.* 2018, 43). The same phenomenon occurred in the study by Hirasawa *et al.* (2016).

The prevalence of DISH progressively rose with increasing age but came to a halt in females in their eighties (Hirasawa *et al.* 2016, 489). Figure 24 shows the increasing prevalence with age and the difference among the sexes in this study.

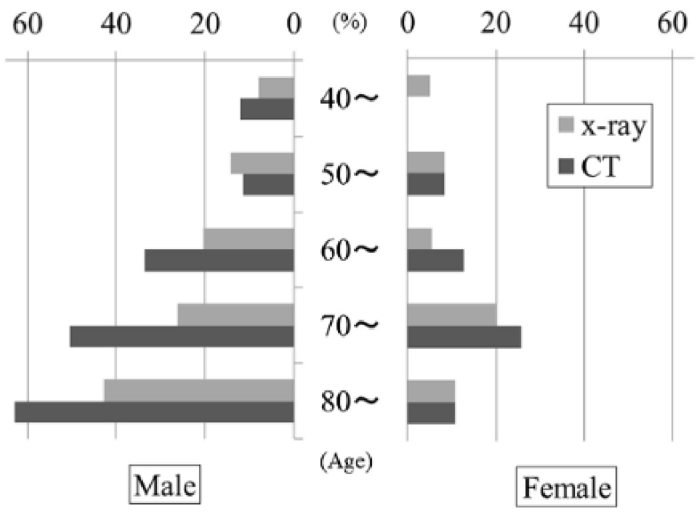

Figure 24: The prevalence of DISH between the sexes in the study by Hirasawa et al. (2016).

The prevalence of DISH in this population is thus in line with modern, clinical numbers. The same trend is visible in historic populations, especially when populations reach higher ages which may be due to a change in lifestyle or because of socioeconomic status (see Arriaza 1993). This suggests the emergence and development may be positively linked to age meaning that a population capable of reaching higher ages has a higher risk to develop DISH.

5.6.3 DISH among different socioeconomic statuses

Statistical tests on the prevalence of DISH among sites of different socioeconomic statuses resulted in a statistically significant results for the overall prevalence in high-status sites (see table 17 and 18). This all suggests that next to sex and age, socioeconomic status plays a role in the risk of developing DISH. The higher the socioeconomic status, the higher the risk seems to be. The prevalence among all females is not statistically significant, but this probably has to do with the sample containing few females, and only one case of DISH among females being present. Refer to table 1 for an overview of what sites belong to what socioeconomic status. The overall prevalence is significantly higher among sites of high socioeconomic status (at 6.7%) versus sites with a middle or low status (1.8% and 2.2%, respectively).

This gap between the prevalence may be further widened by the presence of monastic sites in the sample. As other authors have shown, the prevalence of DISH among monastic sites is often much higher when compared to 'regular' populations. The explanation for this significant result is simple, but not so much straight forward: lifestyle. Rogers and Waldron (2001) point out that research may be inclined to over-diagnose DISH when dealing with monastic sites, further reinforcing the relationship between high-status and monastic sites and DISH (Rogers and Waldron 2001, 362). A lot of studies have been done on this exact relationship, not so much on the 'regular' people. By looking at the regular population, this relationship can be better understood. Following the clinical study by Kiss *et al.* (2002) and Mader and Lavi (2008), individuals with a less-healthy lifestyle, meaning an increased calorie intake and consumption of alcohol and a smoking habit, had a higher frequency of DISH compared to the control group. The group with the unhealthy lifestyle also had a higher prevalence of associated conditions such as obesity and diabetes type II (Kiss *et al.* 2002, 28-29; Mader and Lavi 2008, 826). This may also have been the case in the sites of Chelsea Old Church, Merton Priory and Bermondsey Abbey. The increased calorie intake and excessive consumption of dairy and alcohol may have increased the prevalence of obesity and diabetes, thus also DISH. This excessive intake may have been worse at the monastic sites. Assumed is that the individuals of these sites lived a 'monastic way of life'. Their diet would have consisted of an abundance of meat and fish, which was washed down with a steady supply of wine or ale (Rogers and Waldron 2001, 362). It is very unlikely that individuals with increased risk for developing DISH selected themselves to be monks or that monks were selected from a different gene pool, so the answer lies in the differences in lifestyle. Given what we know about DISH and the observations of clinical studies, diet seems to be the only factor to strongly relate to the increased prevalence of DISH among monastic communities (Rogers and Waldron 2001, 361). Age may also play a part here, referencing the osteological paradox. DISH is mainly prevalent among older adults (Mader and Lavi 2008, 826). Knowing that, a population containing more older individuals is more likely to exhibit a higher prevalence of DISH. Such populations are Chelsea Old Church and Merton Priory, where relatively more individuals reached an older age compared to sites such as St. Mary Graces and St. Bride's Lower, which are sites of middle and lower socioeconomic status, respectively. Higher socioeconomic status may positively correlate with an individual's life expectancy, thus the risk of developing DISH. This trend supports the notion that the development of DISH positively correlates with age (as shown by Hirasawa *et al.* 2016).

5.6.4 In a broader context: DISH in medieval and post-medieval London versus other studies

Other studies on this topic are presented here as evidence to support the relationship between the prevalence of DISH and socioeconomic status of populations, both in the UK and elsewhere. Three such studies are those by Rogers and Waldron (2001), Verlaan *et al.* (2007) and Jankauskas (2003). They will be discussed in-depth here and comparisons will be made with the data and results used in this study to identify similar trends.

Rogers and Waldron were among the first to coin the term 'monastic way of life', which links the prevalence of DISH to a royal lifestyle often associated with monasteries. In a previous study, they looked at the prevalence of DISH in the population of Merton Priory (see Waldron 1985) and for the follow-up study, they looked at two more sites, one of which is Wells Cathedral (Wells, England). This site dates between the 13th and 16th century and yielded the skeletal remains of 205 adults for analysis. The population was retrieved from three different cemeteries: a lay cemetery, the Lady chapel and the Stillington's chapel. The lay cemetery was for the 'regular' people while the chapel burials were those of priests and lay benefactors (i.e., individuals of a higher socioeconomic status). The prevalence in the lay cemetery is 6.5%, in the Lady Chapel 13.3% and 23.1% in Stillington's chapel (table 19). Despite this difference not being statistically significant, the visible trend is highly curious and suggestive (Rogers and Waldron 2001, 360).

Table 19: The prevalence of DISH at Wells Cathedral's different burial sites. After Rogers and Waldron (2001), 360.

Site	***Number of males***	***Number with DISH***	***Prevalence (%)***
Wells Cathedral – Lay cemetery	*93*	*6*	*6.5*
Wells Cathedral – Lady chapel	*15*	*2*	*13.3*
Wells Cathedral – Stillington's chapel	*13*	*3*	*23.1*

Verlaan *et al.* (2007) analysed 51 individuals excavated from a cemetery associated with the *Onze Lieve Vrouwe Kerk* in Maastricht, the Netherlands. The prevalence of DISH was 40% in this population. Individuals with DISH were often male older adults (mean age 49.5 years), although this population contained five females with DISH (Verlaan *et al.* 2007, 1131), way higher than this thesis and the research by Rogers and Waldron (2001). Verlaan *et al.* (2007) blame the monastic way of life for this high prevalence (Verlaan *et al.* 2007, 1134). The prevalence of DISH in the population of the Onze Lieve Vrouwe Kerk (OLVK) in Maastricht is unusually high at 40%, even when compared to similar studies and modern clinical data (Verlaan *et al.* 2007, 1133-1134). The monastic sites used in this study have a high prevalence of DISH, especially when compared to the sites with lower socioeconomic status, although not as extreme as the case of the *Onze Lieve Vrouwe Kerk*. These trends suggest that DISH is indeed positively associated with age and lifestyle and occurs more frequently in men. Just as Verlaan *et al.* (2007) attribute this high prevalence to the monastic way of life, the same can be said about the monastic and high-status sites used in this study.

Jankauskas (2003) studied the prevalence of DISH in Iron Age, Medieval and Early Modern sites in Lithuania. Their data shows a trend that DISH is positively associated with age and social status; the higher the age and status, the higher the prevalence. A rather extreme difference between the sexes is also observed (Jankauskas 2003, 291) (see table 20). Their data on the prevalence in age groups also supports the notion that DISH starts developing later in life, as argued by Hirasawa *et al.* (2016).

Table 20: The prevalence of DISH in the sample used by Jankauskas (2003). After Jankauskas (2003), 291.

Sample	***Social Status***	***Subsample***	***Number of cases***	***%***
Males and females	*Rich*	*70*	*19*	*27.1*
	Middle	*177*	*21*	*11.9*
	Poor	*154*	*11*	*7.1*
Males	*Rich*	*50*	*18*	*36*
	Middle	*112*	*19*	*16.9*
	Poor	*92*	*11*	*11.9*
Females	*Rich*	*20*	*1*	*5*
	Middle	*64*	*2*	*3.1*
	Poor	*61*	*1*	*1.6*

The study by Jankauskas (2003) is more unique in the regard that it includes sites with varying socioeconomic statuses, not only high status or monastic populations. Many similarities are shared between the data of that study and this study, namely that the prevalence of DISH is highly associated with sex, age and socioeconomic status (see table 16 and 17). This suggests that, despite the geographical and historical differences, a clear trend is always present. Our lifestyle changed drastically compared to past ages, and yet the prevalence of DISH in ancient times is sort of in line with modern data: males have a higher risk to develop DISH, the incidence increases with age and individuals with an unhealthy lifestyle have a greater risk to develop DISH.

7. Conclusion

The aim of this thesis was to figure out how biological sex, age at death and socioeconomic status influence the prevalence of DISH in six medieval and post-medieval sites, of which two were monastic sites. Materials were provided by the Museum of London Archaeology Service and were retrieved from the medieval sites of St. Mary Graces, Merton Priory and Bermondsey Abbey and the post-medieval sites of Chelsea Old Church, St. Bride's Lower and St. Benet Sherehog. Results were then compared to the similar studies by Rogers and Waldron (2001), Verlaan *et al.* (2007) and Jankauskas (2003). Additionally, while doing so, an attempt was made to support the current clinical hypothesis that developing DISH is highly dependent on one's lifestyle, even in ancient times. This was all done to answer the main research question of this thesis. This main question was divided in three sub questions covering biological sex, age-at-death, socioeconomic status. The answers to these four sub questions together form an answer to the main question.

7.1 Sub-question 1: DISH among biological sex

"How does the prevalence of DISH differ between biological sex?"

There is a statistically significant difference in the prevalence of DISH between the biological sexes in the sample used in this thesis. The prevalence is significantly higher among individuals of the male sex. This is in line with other, similar studies and modern clinical data. This suggests that biological sex is a major factor in the risk of developing DISH. The exact causes of this phenomenon are unknown but are suggested to be genetic. It is also assumed that DISH develops differently and longer in females and reaches more severe stages less frequent compared to males.

The data used for this study may be flawed and further widens the gap in the prevalence. The sample used fewer females altogether, and male-tilted monastic sites where a higher prevalence was expected. But even when these limitations are taken into account, the difference is striking and highly suggestive. Other studies, namely those by Rogers and Waldron (2001), Verlaan *et al.* (2007) and Jankauskas (2003), noticed a similar trend, further reinforcing the assumption that DISH is more prevalent among males.

7.2 Sub-question 2: DISH among age groups

"How does the prevalence of DISH differ between age groups?"

DISH is only present among adults, and most common among older adults in this sample. Although there is only one site where this difference is statistically significant (Merton Priory, see table 6), this may be due to the low number of cases among younger adults. Even when this is considered, the numbers are highly suggestive. Similar studies by Rogers and Waldron (2001) and Jankauskas (2003) identified the same trend in their sample. This trend is in line with modern clinical studies, which state that the prevalence of DISH increases with age and can take 10 years to develop fully.

However, the osteological paradox must be kept in mind. The age-at-death is on average higher in sites of high socioeconomic status when compared to populations of middle or low socioeconomic status. Adults of middle-to-low socioeconomic status may simply not have reached the age sufficient for developing DISH. Earlier cases of DISH are often missed or misidentified, further lowering the prevalence.

7.3 Sub-question 3: DISH among socioeconomic status

"How does the prevalence of DISH differ between socioeconomic statuses?"

When looking at the prevalence of DISH among the socioeconomic statuses of this sample, a clear trend emerges. DISH is more prevalent among sites of high socioeconomic status (which includes monastic sites) when compared to sites of middle and lower status. Similar trends are shown by Rogers and Waldron (2001) and Jankauskas (2003).

The explanation to this phenomenon is lifestyle. Individuals of high socioeconomic would have had an unhealthier diet consisting of more meat, sugar, salt and alcohol intake. This may even have been more extreme in monastic sites. Another factor to consider is age. Individuals of high socioeconomic status reached higher ages when compared to 'lower' groups. Since DISH emerges later in life and can take up to 10 years to develop, these groups would have had a higher prevalence based only on age.

As shown in clinical studies, patients with DISH often had other conditions associated with an unhealthy lifestyle (such as obesity and diabetes type II). Even when taking other factors into account, such as sex, genetics and medication intake, the connection is clearly there.

7.4 Answering the main research question

"What is the prevalence of DISH in medieval and post-medieval London society and to what extent is it influenced by socioeconomic status?"

Socioeconomic status seems to greatly influence the risk of developing Diffuse Idiopathic Skeletal Hyperostosis in an individual. In this study and other comparable studies, in particular Rogers and Waldron (2001), Verlaan *et al.* (2007) and Jankauskas (2003), the prevalence of DISH is higher among groups of higher socioeconomic status when compared to groups of lower statuses. The main factor that set different statuses apart, especially in historic context, is lifestyle. Rogers and Waldron (2001) came up with the concept of 'the monastic way of life' and blame this lifestyle for the high prevalence of obesity-related conditions and diseases such as DISH. Individuals with a high socioeconomic status are also more likely to reach older ages, thus increasing the risk of developing DISH.

These trends are all in line with modern, clinical data. Several discussed clinical studies (Harasawa *et al.* 2016, Kim *et al.* 2018 and Mader and Lavi 2008) have identified a trend in the prevalence of DISH among sex, age and lifestyle. DISH emerges later in life and is more prevalent among males and individuals with an unhealthy lifestyle. The fact that past and present trends in the development of DISH are still the same even though our lifestyle has changed drastically, means that an unhealthy lifestyle plays a big part in the risk of developing DISH.

7.5 Recommendations for future research

The largest limitation of this thesis was the little available information and similar studies on the prevalence of DISH in non-monastic historical populations. This particular aspect of the historical prevalence of DISH remains understudied. Studies seem to favour populations with variables that greatly affect the prevalence of DISH, as does the monastic way of life. By studying such exceptions, the assumption that lifestyle greatly influences DISH is further reinforced. Although this hypothesis is supported by modern, clinical data, studies on the prevalence of DISH in historical non-monastic sites could contribute to this assumption. Studies could also do more by comparing their data, even if it concerned a monastic population, to other non-monastic populations.

The materials themselves offer the opportunity to do so on a regional scale (London) in the same historical period. These materials could be used to make comparisons on larger scales with other, similar populations. Comparisons could be made with other settlements in the United Kingdom or in other European regions. The site of Bermondsey Abbey offers additional opportunities. Since the site contains individuals from France, this population is particularly interesting to compare with other local populations or different French populations.

But the largest problem DISH, not this thesis, faces is the lack of universal guidelines to identify the disease by. Various authors coming up with their own guidelines or a combination of existing ones leads to different methods being used, thus different results being produced. This leads to inconsistencies, misunderstandings and a general lack of consensus. It would do all modern research, whether clinical or historical, good to reach an agreement over which guidelines to use in identifying the disease. But to reach a consensus, one must understand the causes and mechanics behind the disease. Although many factors have been named as to blame, current research lacks a conclusion about what exactly is (or makes up) the cause of DISH.

This thesis aims to identify what factors in an individual's life significantly increase the risk of developing DISH. By successfully identifying that lifestyle plays a major role in this, even in historical populations, it reinforces the hypothesis that the prevalence DISH is influenced by lifestyle.

Abstract

The aim of this thesis is to understand how biological sex and socioeconomic status affect the prevalence of Diffuse Idiopathic Skeletal Hyperostosis in six populations from medieval and post-medieval London. The populations come from the high status and monastic sites of Chelsea Old Church, Merton Priory and Bermondsey Abbey, from the middle status sites of St. Mary Graces and St. Benet Sherehog and the low status site of St. Bride's Lower. Materials were analysed by the Museum of London Archaeology Service. Since DISH is a disease that only occurs in adults, non-adults were excluded from this study.

The prevalence of DISH is statistically compared between younger adults and older adults, males and females and socioeconomic statuses. The six sites were grouped in three separate groups corresponding with their assumed socioeconomic status and the prevalence was statistically compared between these groups. The results of the tests were then compared to studies on the prevalence of DISH by Rogers and Waldron (2001), Verlaan *et al.* (2007) and Jankauskas (2003).

During statistical analysis, several trends were identified. Firstly, males had a much higher recorded prevalence of DISH than females. DISH was significantly more prevalent among older adults and individuals of high socioeconomic status, as well as in monastic populations. As age and socioeconomic status increased, so did the prevalence of DISH. The sample has some flaws in the overall number of females and the inclusion of monastic sites, but even when these limitations are considered, the present trends are striking and highly suggestive. These trends are in line with modern, clinical data. These suggest DISH develops later in life and is more prevalent in males and people with an unhealthy lifestyle.

The important takeaway from this study is that sex and lifestyle are significant risk factors for developing DISH in medieval and post-medieval London. But these trends are on par with modern data, which suggests that despite the drastic changes in lifestyle over the ages, the main risk factor in developing DISH winds down to an individual sex but most importantly, lifestyle.

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