Bones & Body Mass: A Correlation Study

Donker, Charmax

BONES & BODY MASS

A correlation study

C.J.V. Donker
s. 148 43 54

Figure 1 - Cover Figure - Anterior view of the right femur head.

Traditional Anatomical Drawings and Artwork (Hinman, n.d.).

Bones & Body Mass

A correlation study between body mass and the effect thereof on the human skeleton.

Based on the Post Medieval Chelsea Old Church skeletal cemetery assemblage derived from the archaeological services of the Museum of London.

Author	Charmax Johanna Vera Donker s. 148 43 54
Course	Bachelor Thesis 1083VBTHEY
Supervisor	Dr. R. Schats
Leiden University	Faculty of Archaeology
Amsterdam, 23-08-2023	Version 2.0 Final Version

Table of Contents

Chapter 1

Introduction

This paper will research whether a correlation between body mass and excess body mass (per example: obesity) associated pathologies can be established within the, London based, post-medieval Chelsea Old Church graveyard population.

1.1 Post-medieval London

The period before the post-medieval era was the Middle Ages during which the housing of the population majorly shifted from rural to urban. The developments of towns, urbanization, brought forth numerous health implications as the people began to live closer to each other and settlements became more densely populated while less ventilated and hygienic. In contrast, the countryside stayed rural and its population was on the lower end (Roberts & Manchester, 1995/2010, p. 17; Mant & Roberts, 2014, p. 190).

The (English) post-medieval period was an era of ever-changing living circumstances as it began after the urbanization of the Middle Ages and experienced the Industrial Revolution. As a result of the drastic social and economic change that occurred due to the Industrial Revolution, new substantial health risks dawned upon the English population in the 18th century (Mant & Roberts, 2014, p. 189). With the Industrial Revolution, the agriculture progressed and food was commercialized. It impacting the British diet of the Post Medieval population as quantity was prioritized over quality. In addition, the production of refined and pure flour was developed which resulted in white bread becoming favoured over rye and barley bread post 1750 CE (Mant & Roberts, 2014, p. 189-191).

The post-medieval Londoner's diet staples consisted out of this white bread in addition to potatoes and tea. For those who could afford it, the base diet was further supplemented with eggs, milk, meat, fruit, and vegetables. This was generally the case for those who had a social status equal to higher than upper middle class, as the food expenses were raised even though the nutritional quality of the food diminished during the post-medieval time. This was also the case for those who lived in the countryside as, in contrast to London's urban distract, the food expenses were lower and meat was more accessible in rural areas. For the 'elite' group of the post-medieval London society, their diets were further complemented with luxury foods such as chocolate, sweets, and cream. Overall, the industrial revolution, with its surge in white bread and decrease of food quality, has resulted in a diet that, although nutritious, is fairly high in calories. Especially so for those who lived in the countryside and who were of a social status of upper middle class or higher (Mant & Roberts, 2014, p. 190-191).

1.2 The Consequences of High Body Mass (Obesity)

A high calorie diet, similar to the one that was practiced by certain portion of the post-medieval London (the upper middle class and above), may result in excess body mass which may eventually lead to obesity. Obesity is a complex disease which is neither limited to age or sex, and it occurs when an individual's body mass is higher than what's considered the healthy norm for that individuals height. The excess gain of body mass is influenced by several factors, such as: genetics, diet, physical activity, and lack of sleep. There's also a social influence that's determinant for an individual's choice of living (Centers for Disease Control and Prevention, 2022).

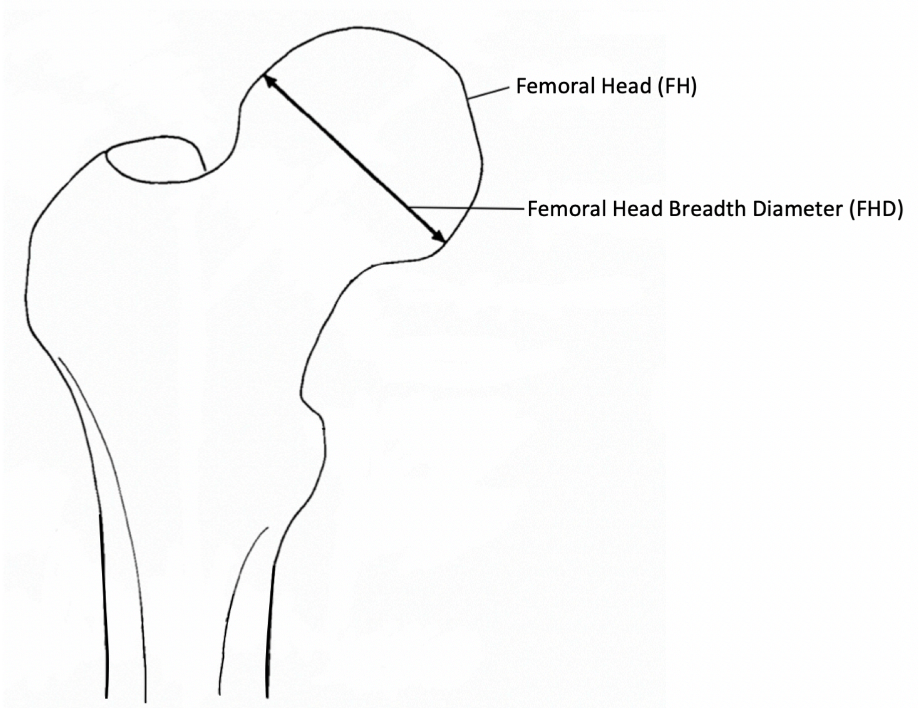

Figure 2 - Proximal femoral head breadths (Ruff et al., 1991, p. 400; edited by C.J.V. Donker, 2023).

In present day, the connections between high body mass (obesity) and the skeletal body has been extensively researched. It's known that bone is a living tissue with metabolic functions and the health of bones gets affected by a variety of mechanism, such as: body weight, fat volume, and bone formation\resorption (Hou *et al*., 2020, p. 1). Through an individual's lifetime, the bone reshapes and models itself to ensure skeletal structure and integrity. It has been found that the skeletal body response to mechanical loading is the reformation of the diaphyseal cross-sectional size of the femoral head breadth (figure 2) (Hou *et al*., 2020, p. 1; Ruff *et al*. 1991, p. 397). However, according to Iwaniec and Turner, the skeletal response to such loading is not fully understood (2016, p. 115). Aside of remodeling, as mentioned earlier, the bone health is influenced by diet and body mass. Several pathologies have been linked to high body mass (e.g. obesity) and diet. Osteoarthritis for instance is the most common known degenerative joint disease that has been connected to (aside of age, sex and trauma) obesity. It has been estimated that individuals with a higher than average body mass are 10 times more likely to develop the disease within the lower appendicular skeleton (the pelvic girdle, legs, knees, and feet). Although it may also manifest in an individual's hands (Centers for Disease Control and Prevention (CDC), 2020; Felson, 1996, p. 430; Hou *et al*., 2020, p. 6-7). Research based on the effect of body mass on bones have also indicated a correlation between body weight, diet, gout, and diffuse idiopathic skeletal hyperostosis (DISH) (Aune *et al.,* 2014; Choi *et al*., 2005; Denko & Malemud, 2005; Felson, 1996; Hou *et al*., 2020; Johns Hopkins Arthritis Center, 2022; Pini *et al.,* 2020). Further elaboration about the effects of body mass on the skeletal body, in regard of functional bone adaptation, osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH), can be found in the background chapter (chapter 2) of this paper.

1.3 The What and Why of the Research

A connection between the consequences of high body mass (e.g. obesity) and their associated health risks has been confirmed in present time (§1.2 & chapter 2). Additionally, it is known that traces of body mass\diet associated diseases, such as osteoarthritis, gout, and DISH, have been found in historical human remains of the past (Waldron, 2008). However, no link has been established between said diseases and body mass in historical context through osteoarchaeological research. As such, it is not yet acknowledged that people of the past may have had these pathologies due to body mass. Research about a correlation between body mass and associated conditions in historical context may provide deeper understanding about the effects of (excess) body mass in relation to skeletal health. Consequently, such a study may open a two-way path to further research possibilities such as the influence of social environment on diet and body and through that skeletal health in regard of diseases that are associated to a high body mass, and the other way around: to reconstruct past social settings due to discovered body mass associated lesions. Therefore, this thesis will research whether a correlation between body mass and excess body mass (per example: obesity) associated pathologies can be established within the, London based, post-medieval Chelsea Old Church graveyard population. It will do so by answering the following research question:

To what extent is there a correlation between obesity associated conditions and a higher body mass in Post Medieval London?

This question will be answered through the following subsidiary questions that focus on the main components of interest of this research: sex and high body mass (obesity) associated diseases (osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH)). The sub-research questions are as follows:

1. To what extent does osteoarthritis correlate with body mass and are there any differences between the sexes?

2. To what extent does gout correlate with body mass and are there any differences between the sexes?

3. To what extent does diffuse idiopathic skeletal hyperostosis (DISH) correlate with body mass and are there any differences between the sexes?

1.4 Research Approach

In the subsidiary questions it can be noted that, per researched pathology, sex too is a topic of research as it is important to see whether there is a difference between the two sexes in regard of how body mass may affect the skeletal health. However, the focus mainly lays on whether a correlation between the above-mentioned pathologies and body mass can be established in historical context, specifically the one of post-medieval London. This will be done by researching the population of the post-medieval Chelsea Old Church site that has been studied by the Museum of London Archaeological Services (aka MoLAS) (Museum of London Archaeological Services, 2009).

1.4.1 Materials: Chelsea Old Church

Chelsea Old Church is located 2-4 Old Church Street, Chelsea, SW3, London, United Kingdom. It is a post-medieval site that was excavated in 2000 by the Museum of London Archaeological Services and contains a population of 290 individuals. The osteological data of 198 of these 290 individuals was shared online by MoLAS as an opensource database (Museum of London Archaeological Services, 2009). In chapter 3, paragraph §3.1, the site's information and its database will be discussed further.

This particular site was chosen as the site was found to be well-preserved and it was established by MoLAS that the population was of upper middle to higher social standing. In addition, during the post-medieval period it was located in the rural area of London (figure 3). The combination of lower food expenses, high meat accessibility, and upper middle to higher social standing raises the likeliness that the Chelsea Old Church population enjoyed an abundant and calorie rich diet, albeit nutritious (Mant & Roberts, 2014, p. 189-191; Museum of London Archaeological Services, 2009). Therefore, the chance rises of them having existed with a higher body mass and the associated pathologies. Making it a for this study fitting research assemblage.

*Figure 3 - Location of Chelsea Old Church, indicated by a cross in an oval, London 1800 (*Norman B. Leventhal Map & Education Center. (n.d.)).

1.4.2 Methods: Body Mass Estimation & Data Analysis

In order to work and analyse the Chelsea Old Church database of the Museum of London Archaeological Services, it first needs to be sorted to fit the research criteria of this thesis. The criteria are based on the (to be) implemented body mass estimation method.

Although body mass estimation from skeletal remains has been less studied than other osteological methods (such as stature or age estimation), there are several existing formulas through which body mass may be estimated from human bones. In general, these methods can be divided into two different kind of approaches: the mechanical approach and the morphometric approach (Auerbach & Ruff, 2004, p. 331; Ruff *et al.*, 2012, p. 602). The mechanical approach focusses on body mass and the mechanical support of that mass through a singular skeletal element. For this approach the dimension of femoral head breadth (figure 2) is the most customary skeletal element used to estimate body mass. In contrast, the morphometric approach estimates body mass by combining the maximum pelvic breadth (the biiliac) with stature. Through this it attempts to reconstruct the size and shape of an individual's body from its preserved skeletal elements. However, as this latter method requires a complete pelvis (or one that can be reconstructed) as well as skeletal elements needed to estimate stature, it was opted to use a mechanical approach to this study of body mass and associated conditions. What further strengthened the choice for the mechanical approach is that the femoral head is frequently available in osteoarchaeological assemblages (Auerbach & Ruff, 2004, p. 331; Ruff *et al.*, 2012, p. 602).

The Mechanical approach encompasses three different estimation equations based on the dimensions of the femoral head breadth. Although none of these equations are specific to European population, they do include Euro-American data points in their calculations (Auerbach & Ruff, 2004, p. 331; Ruff *et al.*, 2012, p. 602). The three mechanical approach body mass estimation methods are:

- Grine *et al.* (1995): based on a sample of 10 sex-specific means of large-bodied individuals of African American, European American, and Native American origin. As it is based on a mean, it does **not** differ between sex (as cited in Auerbach & Ruff, 2004, p. 334).

- McHenry (1992): based on the mean of a sample grouping of four, consisting out of individuals of North American, African Pygmies, and Khoisan origin. As it is based on a mean, it does **not** differ between sex (as cited in Auerbach & Ruff, 2004, p. 334).

- Ruff *et al.* (1991): a sex specific equation based on the data of 80 individuals from the Baltimore (Maryland, United States of America) population. As it is sex specific, it **differs** between sex (as cited in Auerbach & Ruff, 2004, p. 334; Ruff *et al.*, 2012, p. 608-611). In 2012 the Ruff *et al.* equation of 1991 was reviewed and update to a more accurate version after studying 1145 European Holocene adult skeletal samples (Ruff *et al.*, 2012, p. 603-611).

Since this study focusses on sex in addition to the high body mass (obesity) associated conditions, the methods of Grine *et al.* (1995) and McHenry (1992) have been omitted from this research as they do not differ between sex. Instead, the male and female specific body mass estimation equation of Ruff *et al.* (1991-2012) will be applied to this thesis. However, this method is only applicable to adult individuals of who the metric data of at least one femoral head breadth is available (Auerbach & Ruff, 2004, p. 334; Ruff *et al*., 1991, p. 397; Ruff *et al.*, 2012, p. 608-611). Therefore, the 198 individuals of the Chelsea Old Church database will be divided into non-adults and adults, of which the non-adults will be discarded from this research. Then the adults without metric data of either of the femoral heads will be discarded. Chapter 3 (materials & methodology), as mentioned in §1.4.1, will further elaborate on how the materials will be handled within this research. Including the application of the Ruff *et al.* (2012) formula and the data analysis of the sorted materials.

1.5 Thesis Outline

In order to reach a sound conclusion, this thesis will begin (post introduction, chapter 1) with a background chapter about functional bone adaptation to body mass and the pathological conditions that are associated with a higher body mass due to obesity and\or diet (chapter 2, background). The chapter (chapter 3, materials & methodology) thereafter will elaborate about the materials (the by MoLAS created Chelsea Old Church osteological database) used for this research as well as the methodology applied to this material: the skeletal analysis of MoLAS, the body mass estimation equation of Ruff *et al.* (1991), and statistical data analysis. The results of the data analysis will be presented in chapter 4 (results), further interpreted and discussed in chapter 5 (discussion), and eventually concluded in chapter 6 (conclusion) by answering the main research question of this thesis through the subsidiary questions.

Chapter 2

Background Chapter

This thesis researches whether a link can be established between high body mass associated pathological conditions and the estimated body mass of the remains of adult individuals of the post-medieval Chelsea Old Church population. A correlation between body mass and certain health risk of having a higher body mass (obesity) and an abundant calorie rich diet has been established in present time, but has yet to be connected in historical context (Centers for Disease Control and Prevention, 2022; Hou *et al*., 2020; Waldron, 2008). Due to the Museum of London Archaeological Services, and the known historical context of the site's living environment, it is known that the population of the post-medieval Chelsea Old Church graveyard site consists out of individuals who enjoyed an abundant high calorie diet while including individuals who depict pathological lesions that indicate high body mass associated diseases, such as: osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH) (Mant & Roberts, 2014, p. 190-191; Museum of London Archaeological Services, 2009; Museum of London Archaeological Services, n.d.). Therefore, the Chelsea Old Chursh osteological assemblage is a for this thesis fitting database material in order to study whether there's a correlation between the two elements of this research (body mass and associated conditions). To do so, it's needed to first comprehend the effect of mechanical loading (body mass) on the skeletal body and health in addition to how this is visible in the osteological record of human remains.

2.1 Functional Bone Adaptation & Body Mass

Throughout an individual's lifetime, their skeletal body (their bones) continuously adapts and remodels itself to ensure skeletal structure and integrity in order to optimize its bone functionality such as the bearing of the mechanical loading of the body. This process is known as functionally adaptive (re)modelling and is dependent on the environmental circumstances of an individual (Hou *et al*., 2020, p. 1; Mosley, 2000, p. 189-190; Ruff *et al*. 1991, p. 397).

2.1.1 Body Mass & Skeletal Body

The bones within the human body combine into an individual's skeletal body and consists out of living and adaptive tissue. As it adapts to optimize its functionality to the living circumstances of an individual, it represents the most direct biological evidence of how someone may have lived in the past (Larsen, 2002, p. 119). Bone tissue response to mechanical stimulation is self-remodeling. For instance, the tissue multiplies to strengthen the bone in skeletal areas that are subjected to high levels of mechanical loading. As a result, it is possible to deduce the levels of physical activities or the amount of body mass related mechanical loading that an individual may have had during their lifetime. This can be done by measuring the external dimensions of long bones found in the arms and legs (Larsen, 2002, p. 134-135).

2.1.2 Estimation of Body Mass based on Femoral Head Breadth

Although it's an imprecise method of estimating bone strength, the thumb of rule goes: long bones that are more robust and larger in dimension indicate greater bone strength due to the mechanical loading and physical activities it endured during an individual's life than smaller and less robust long bones. In order to more precisely study the effect of certain lifestyles on the morphology of the skeletal body, physical anthropologists have applied engineering theories to their research. As is the case for the study of Ruff *et al.* (1991, 2004, & 2012) in regard of the response to body mass related mechanical loading on the femoral head (the head of the femur, depicted in figure 2) (Larsen, 2002, p. 135; Ruff *et al*., 1991, p. 397).

The body mass estimation equations are commonly based on the femoral head breadth measurements (Auerbach & Ruff, 2004, p. 331; Ruff *et al.*, 2012, p. 602-605). In figure 2 (chapter 1) it is visible that the femoral head is the most proximal end of the femur (upper leg long bone\thighbone), it's also known as the 'ball' of the femur and in the skeletal body it is lodged in the acetabulum (socket) of the pelvis (the hip bone). One of the functions of the femur is carrying the weight of an individual. However, the initial loading falls upon the femoral head due to which the functional bone adaptation that may occur due to this body mass related mechanical loading is most apparent in the femoral head. According to Ruff *et al.* (1991, p. 397), the functional bone adaptation, due to loading, occurs only in the diaphyseal cross-sectional size of the femoral head (Ruff *et al*., 1991, p. 397; White & Folkens, 2005, p. 255).

In 1991 Ruff *et al.* first publishes a study about how body mass can be estimated from skeletal remains through a mechanical approach by using the metric measurement of the diaphyseal cross-section of the femoral head (Ruff *et al*., 1991, p. 397; Ruff *et al*., 2012, p. 602). In 2004 Ruff *et al.* presented an elaboration on their research and in 2012 Ruff *et al.* presented with a more accurate version of their previous body mass prediction equation. Therefore, within chapter 3 of this thesis, the most resent Ruff *et al.* (2012) formula will be applied to the Chelsea Old Church database. The exact formula of this equation and the manner of application within this research will be further discussed in chapter 3 (materials & methodology), paragraph §4.2.2 (body mass estimation).

2.2 Body Mass & Pathology

As stated earlier, the skeletal body consists out of living bone tissue, with its own metabolic functions, that responds to the living environment and stressors (e.g. activity, mechanical loading, diet) of an individual (Hou *et al*., 2020, p. 1). A manner of response to such mechanism is bone activation, resorption, reversal, and formation. Which are phases of the remodelling cycle that bone go through. Initially bone remodelling may be a response to strain or initiated to repair cracks or other small defects in the bone. However, as far known, bone remodelling may also occur at random and may also occur as a response to a disease (Hou *et al*., 2020, p. 1; Waldron, 2008, p. 17-19). When bone remodelling occurs as a reaction to a disease, it commonly tends to express itself in rapid overgrowth (proliferative) or erosion (Waldron, 2008, p. 19-20). There are several pathological conditions that may impact the skeletal health of an individual and which have been associated by a heavy loading of body mass (e.g. obesity) and\or an abundant and calorie rich diet (which often correlated with a higher body mass). The most known body mass associated condition is arthritis (joint inflammation). Especially osteoarthritis is often linked to a higher mechanical loading due to excess body mass (obesity). Nonetheless, other types of arthritis such as gout and diffuse idiopathic skeletal hyperostosis (DISH) have also been linked to excess body mass (Aune *et al.,* 2014; Choi *et al*., 2005; Denko & Malemud, 2005; Felson, 1996; Hou *et al*., 2020; Johns Hopkins Arthritis Center, 2022; Pini *et al.,* 2020)

2.2.1 Osteoarthritis

Osteoarthritis translates to bone (osteo) joint inflammation (arthritis). Theoretically, arthritis can occur wherever any of two bones meet (the joint area). There are several types of arthritis, osteoarthritis is the most common form of it (Centers for Disease Control and Prevention (CDC), 2020; Felson, 1996, p. 430; National Institute of Arthritis and Musculoskeletal and Skin Diseases, 2022). Osteoarthritis is, aside of dental disease, also the most common condition found in the skeletal body. It's known as the degenerative joint disease that may affect singular or multiple joint, it most frequently occurs in the pelvic girdle (hip bones), knees, and hands (Centers for Disease Control and Prevention (CDC), 2020; Felson, 1996, p. 430; Waldron, 2008, p. 26-30).

*Figure 4 - Osteoarthritis in the knee (patello-femoral compartment) with marginal osteophyte (bone growth), eburnation containing directional scoring, and joint surface pitting (*Waldron, 2008, p. 32).

When an individual has osteoarthritis, the cartilage within a joint begins to deteriorate. There are three stages to the progress of the disease: breakdown of the cartilage matrix (first stage: enzymatic erosion), splitting of cartilage bone tissue (second stage: vertical and horizontal fibrillation), and bone production response as the bone tissue attempts to repair (third stage: bone response). This results in changing the structure of the underlaying bone, including: new bone formation around joint margins (marginal osteophyte), new bone formation on joint surface, pitting (small indentations) in the joint surface, alteration of the original joint's contour (in general widening and flatting), and a distinguished high polished joint surface area (eburnation) with possible scoring in the direction of movement (figure 4). Eburnation is the most recognisable lesion type of osteoarthritis and is therefore pathognomonic for the disease. Creating the rule of thumb for palaeopathologist and osteoarchaeologists: if there's eburnation than that indicates osteoarthritis (Centers for Disease Control and Prevention (CDC), 2020; Waldron, 2008, p. 27-28).

Although the cause for osteoarthritis is unknown, it has been linked to factors such as age, genetics, sex (it affect women more than men), race, and obesity. The mechanism of how excess weight may cause osteoarthritis is unknown, previous population-based studies have concluded that being overweight is a risk factor that may contribute to developing osteoarthritis, especially in the knee (Felson, 1996, p. 430; Johns Hopkins Arthritis Center, 2022). It's estimated that individuals with an excess of body weight due to fat mass have up to 10 times more risk of gaining knee osteoarthritis. There's also the possibility that such an individual may develop osteoarthritis in the pelvic gridle and hands (Felson, 1996, p. 430; Hou *et al*., 2020, p. 6-7).

During the lifetime of an individual with osteoarthritis, the changes within their skeletal body due to osteoarthritis is slow but continuous. However, the changes are regarded as irreversible and may induce pain, swelling, and stiffness. In the worst-case scenario, it can reduce an individual’s functionality, resulting in disability (Centers for Disease Control and Prevention (CDC), 2020; Waldron, 2008, p. 29-31).

2.2.2 Gout

Gout is one of the oldest recorded diseases in medical literature and was common affliction during the 18th century (post-medieval period). In 1799 it was depicted in a cartoon by James Gilray as a devil attacking the big toe, where the disease is most common to occur. However, rather than the cause of devilry, it is an asymmetric erosive joint disease, and a type of arthritis, that's caused by disorder in the uric acid metabolism: i.e. increase of uric acid production or decrease if the acids excretion through the kidneys. The disorder in the uric

acid metabolism (hyperuricemia) results in an increase of urid acid in the blood (Centers for Disease Control and Prevention (CDC), 2023; Waldron, 2008, p. 67-70).
Uric acid is a normal body waste product that is produced to break down purines (a natural chemical that is found in the body and diet). Normally the level of uric acid is balanced by the kidneys; but, when an individual carries excess body mass, the kidneys work less efficient. Due to this, uric acid builds up in the blood stream causing crystallization of the acid into monosodium urate which builds-up in joints, fluids, and (other) bodily tissues. Aside of the influence of excess body mass and fat on the kidneys, gout correlates with diet as purine can be found in a wide variety of ingredients (Arthritis Foundation, n.d.; Aune *et al.,* 2014, p. 1591; Centers for Disease Control and Prevention (CDC), 2023; Waldron, 2008, p. 67-68).

Gout is a common form of arthritis that usually affects one joint at the time, commonly the first metatarsal-phalange (big toe) joint. The disease begins with an acute self-limiting attack followed by a period of months to years without symptoms of inflammation. Half of the individuals that experience gout end up with chronic (recurring) gout. Also known as gouty arthritis. The disease is not always cause by hyperuricemia (about 20% with disorder in the uric acid metabolism). Other causes for gout include: enzyme abnormalities, genetics, and sex as gout is more common in males than females (Centers for Disease Control and Prevention (CDC), 2023; Waldron, 2008, p. 67-68).

*Figure 5 - Radiograph of ankle, depicting a Martel Hook (indicated with arrow) (*Waldron, 2008, p. 69).

Diagnosing gout from skeletal remains relies on discovering signs of erosions within or around joints. The operational definition for gout is: asymmetric erosions in or around articular tissues with a Martel hook (an overhanging margin) (figure 5). In very rare and lucky occasions, urid acid crystals may still be present in a lesion (Waldron, 2008, p. 69-70).

2.2.3 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Diffuse idiopathic skeletal hyperostosis, commonly known by its abbreviation: DISH, is a disease that represents the extreme end of bone forming. It is characterized by abundant bone production in the vertebra (spine), resulting in calcification and\or ossification of connection points between the spine and anterior longitudinal ligaments (extra-spinal entheses). Although DISH is regarded as a type of arthritis, it is known as a non-inflammatory rheumatic musculoskeletal disorder that primarily affects the spine. Nevertheless, it is possible for DISH to occur throughout the body (Resnick *et al.*, 1975, as cited in Denko & Malemud, 2005, p. 292; Pini *et al.*, 2020, p. 1521; Waldron, 2008, p. 73).

*Figure 6 - Thoracic spine of the last Anglo-Saxon Bishop of Wells showing extensive fusion and right-sided bone growth (osteophyte formation) (*Waldron, 2008, p. 74).

The ligament ossification may result in abnormal enthesophytes (bone spurs). In its final stage, the ossification may even resemble candle wax on the anterior (front) side of the vertebrae (spine). As mentioned earlier, DISH does not discriminate between areas of the skeletal body although it commonly involves the spine. Nevertheless, DISH induced changes in the thoracic region of the spine (the part below the neck and above the lower back) (figure 6) are unique as they follow the descending aorta (largest artery of the body). Therefore, in the thoracic region the bone formation generally occurs only on the right-hand side of the vertebral bodies unless the individual has situs inversus. In which case the aorta lies on the right side of the vertebra bodies instead of left and thus the bone formation occurs on the left side (Behring, 2021; Waldron, 2008, p. 73).

The calcification\ossification in tendons and ligaments occurs when there's a build-up of calcium salts in the body. The cause for a calcium salt build-up is unknown, but it is likely that it occurs due to a combination of factors such as: environment, genetics, and metabolism. Usually those who have DISH are of middle age or older (it rarely occurs below the age of 40), and the commonness of the disease increases with age. Similar to gout, DISH is more prevalent in men than women and has been associated with obesity and late onset of type 2 diabetes. It has also been associated with abnormal vitamin A metabolism. The link between DISH and obesity, diabetes, and vitamin A has especially been noted in studies of modern populations (Behring, 2021; Denko & Malemud, 2005, p. 296; Waldron, 2008, p. 72-74).

2.3 Summary

To recap: the skeletal body attempts to ensure structure and integrity to optimize bone functionality through functional bone adaptation by reacting to environmental triggers. The remodelling of bone may occur due to changes in mechanical loading, but also due to pathological conditions such as osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH). These conditions are all different types of arthritis (joint inflammation) that have been linked to excess body mass and diet; nevertheless, they each depict specific lesions. For instance:

- Osteoarthritis is often found in the pelvic girdle, knees, and hands. Eburnation is pathognomonic for the disease and is its most recognisable lesion.

- Gout is generally found in the first metatarsal-phalange joint (the big toe) and often accompanied by a Martel hook.

- DISH is commonly located in the spine and shows fusion of the vertebra and may depict a candlewax resembling ossification on the anterior side of the vertebrae at its most florid form.

Aside of the pathological lesions, through the aftereffect of bone remodelling in the femoral head due to mechanical loading, it is possible to estimate the body mass of an individual by measuring the femoral head breadth and implementing it in the Ruff *et al.* (2012) equation.

Chapter 3

Materials & Methodology

As noted in the introduction, this research paper is based on the available data of the post-medieval cemetery site: Chelsea Old Church, retrieved from the open source osteological research database of the Museum of London (Museum of London Archaeological Services, n.d.). This chapter will elaborate about the Chelsea Old Church site (§3.1) and in which methods (§3.2) have been applied to the site's database in order to answer the research questions.

3.1 Materials

3.1.1 The Site: Chelsea Old Church

The Chelsea Old Church site is a graveyard site that is located in Chelsea, 2-4 Old Church Street (figure 3). Originally, during the 18th century, Chelsea was a popular riverside town, a resort of some sorts for the elite, on the outskirts and rural part of London. Today is has become a suburb of modern London (United Kingdom) (Cowie *et al.*, 2008, p. 13).

The site dates back to the post-medieval era (18-19th century; 1712-1842) and contains a population that consists out individuals from an upper middle class to higher social status. The population's social status has been based on the location, the historic information of individuals that could be identified, and the biographical data of the site (Cowie *et al.*, 2008, p. 10-40). Regardless, it should be noted that post-medieval Chelsea was not solely inhabited by those of higher social and economic standing. Additionally, to housing those of common to lower class (tavern owners, artisans, farmers, fishermen), the Old Church cemetery originally housed parishioners of the Saint Luke's parish until 1736. Hence it should be kept in mind that the assemblage contains a mixture of social status, though the majority of the Chelsea Old Church individuals leans in favor towards being of high status (Cowie *et al.*, 2008, p. 10-21). Therefore, regardless of a possible slight deviation, the population of this site will be regarded as one of upper middle to higher social status. Hence, it is still assumed that the Chelsea Old Church population enjoyed an abundant a calorie rich diet during their lifetimes that went beyond the staples of the post medieval London diet. The pathological indication of excessive diet and metabolic disorders present in the site's skeletal assemblage supports this likeliness (Cowie *et al.*, 2008; Mant & Roberts, 2014, p. 190-191).

3.1.2 MoLAS: Chelsea Old Church Excavation

Before the Museum of London Archaeological Services (MoLAS) began their excavation of the Chelsea Old Church graveyard in 2000, the site was disturbed on two occasions: by bombing during the second world war (WWO-II), and restorative exhumation and reburial of the churchyard during the 1950-1960s in lieu of said bombings. Regardless, when MoLAS excavated the post medieval site throughout the year 2000, the site was found to have been well preserved (Cowie *et al.*, 2008, p. 1-2; Museum of London Archaeological Services, 2009).

During the excavation, MoLAS discovered a variety of features and material artefacts that date back to the prehistoric, Roman, Saxon, Middle Ages, and post-medieval period. In addition, 290 post-medieval burials were found of which a small number (25) contained coffin plates through which the individuals could be identified. From the 290 excavated burials, only 198 were analysed and recorded MoLAS in in WORD, a digitalized public database that can be found on the Museum of London website under the 'Collections - Archaeology at the Museum of London' page (Cowie *et al*. 2008, 5-40; Museum of London Archaeological Services, n.d.) It is unclear for what reason the remaining 92 individuals were not included.

3.1.3 Site Demographics

From the 290 excavated individuals of the Chelsea Old Church site, 198 skeletal remains have been analysed by MoLAS. What happened to the osteological data of the remaining 92 individuals is unknown (Cowie *et al.*, 2008, p. 40).

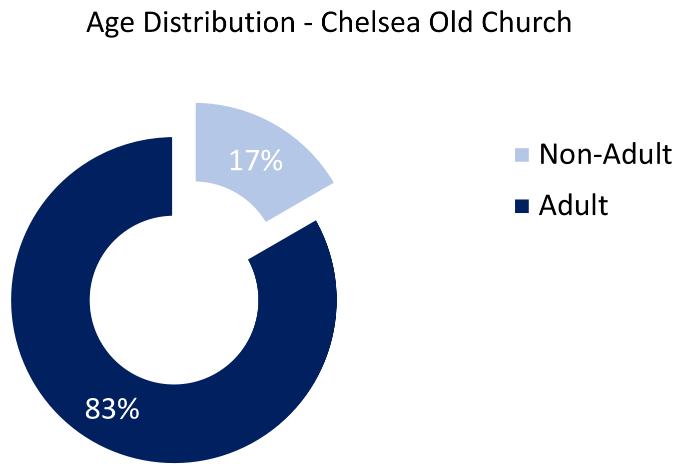

Figure 7 - Age Distribution of the Chelsea Old Church post-medieval graveyard population.

In figure 7 the age distribution depicts that the majority (165 individuals, 83%) of the Chelsea Old Church population reached adulthood. Combining that knowledge with figure 8 leads to realising that the sex distribution among adult individuals is fairly equal: 39% male, 37% female, and 7 % intermediate or undeterminable. Since the sex of non-adult individuals cannot be estimated, the sex-based data is of adult individuals only by default.

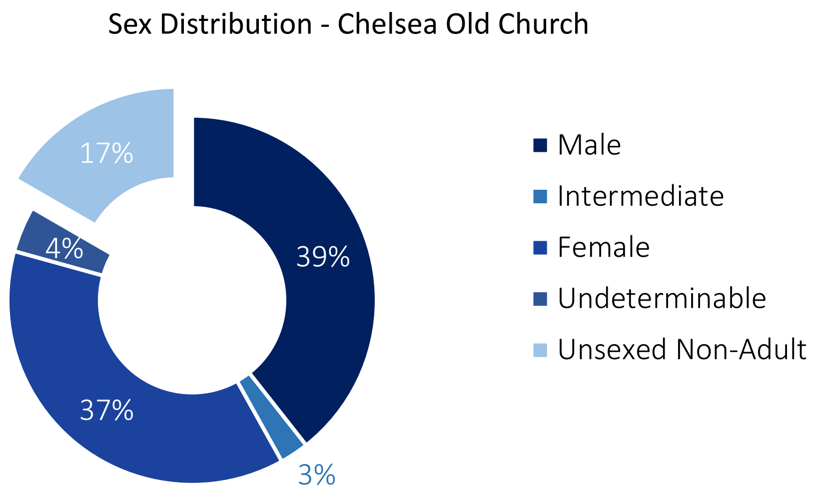

Figure 8 - Sex Distribution of the Chelsea Old Church post-medieval graveyard population.

Not all of the 198 by MoLAS documented individuals will be used within this thesis as they do not all meet the necessary requirements to calculate body mass. The criteria and final sample selection overview will be further discussed in §3.2.2 (methodology - body mass estimation).

3.2 Methodology

3.2.1 MoLAS Skeletal Analysis

The osteological data of the Chelsea Old Church graveyard site used in this study has been taken from the publicly available database of the Museum of London Archaeological Services (MoLAS). The specialists of MoLAS have analysed 198 of 290 excavated human burials in line with the Human osteology method statement of the museum (Cowie *et al.*, 2008, p. 40; Museum of London Archaeological Services, 2009). Preservation, completeness, age at death estimation, sex estimation, measurement of metric data, non-metric skeletal traits, dental pathology, and skeletal pathology were recorded in order to create osteobiographies for the exhumed individuals of the Chelsea Old Church cemetery (Powers, 2012). For this research the age, sex, femoral head breadth metric data, and the pathology of osteoarchaeology, gout, and diffuse idiopathic skeletal hyperostosis (DISH) are what's required to know in order to answer the research questions. Therefore, the methods of MoLAS related to these subjects will be discussed below.

3.2.1.1 Age-at-Death Estimation

There are different methods of age-at-death estimations depending on whether an individual is regarded as a non-adult or adult. Age estimation of non-adults was done through multiple methods. For foetal and new-born (neonatal) individuals the Scheuer and Black (2000) method was applied which is based on the diaphyseal (shaft) length (in millimetres) of (complete) long bones. For non-adults that were likely over the age of two months the diaphyseal length-based method of Maresh (1970) was applied in combination with the maximum dimensions of the ilium (upper part of pelvis) and the basilar part of the occipital (most posterior cranial bone, the 'base' of the skull). In addition to these methods, dental eruption-based estimation according to the Gustafson and Koch (1974) method and epiphyseal (growth plate) fusion assessment (Connell and Rauxloh 2003, with reference to Scheuer and Black 2000; Buikstra and Ubelaker, 1994, 41) has been utilised to further asses the age-of-death of non-adult individuals. It ought to be noted that age estimation through dental eruption has been found to be the most in line with chronological age (Powers, 2012, 12-13).

Age-at-death estimation of adult individuals was done through a combination of pubic symphysis (anterior side of the pelvis, where the pubic bones of the hip meet) degeneration (per the methods of Brooks and Suchey (1990) & Buikstra and Ubelaker (1994)), auricular surface (articulation point of the ilium (upper pelvis part) with the sacrum) degeneration (Lovejoy *et al.* (1985) method), sternal rib (true ribs, rib 1-7) morphology (Iscan *et al* (1984-1985) method), and dental attrition (loss of tooth structure) data (per the Brothwell method (1981)). In contrast to the non-adult age estimation, dental morphology has been deemed as the least reliable method of adult age-of-death estimation (Powers, 2012, 14).

In the case of a burial consisting out of fragmentary or incomplete remains of an individual, then the state of adult or non-adult was based on the level of fusion of the epiphyses and eruption of the permanent third molar. The higher the level of fusion the likeliness of adulthood. Similar to that, the complete eruption of the third molar signifies adulthood (Powers, 2012, 14).

Following the age-of-death analysis of MoLAS, individuals were categorised in main categories of adult and non-adult and further categorised into sub-groups such as: Non-Adult Perinatal, Non-Adult 1-6 Months, Non-Adult 7-11 Months, Non-Adult 1-5 Years, Non-Adult 6-11 Years, Non-Adult 12-17 Years, Unclassified Non-Adult, Adult 18-25 Years, Adult 26-35 Years, Adult 36-45 Years, Adult > 46 Years, and Unclassified Adult (Museum of London Archaeological Services, n.d.; Powers, 2012, 12-14).

3.2.1.2 Sex Estimation

It is only possible to estimate sex for adult individuals. MoLAS estimated the sex of the adult Chelsea Old Church population on macroscopic assessment of features of the skull (including the mandible (jaw)) and the pelvis (hip). The assessment of the skull features excluding the mandible followed the methodology of Brothwell (1981), Bass (1987), and Ferembach et al. (1980). The Brothwell (1981) method was also applied to assess the features of the mandible. As for the pelvis features assessment, the methods of Phenice (1969) and Bass (1987) were implemented by MoLAS (Powers, 2012, 15).

The assessed features were graded with the use of a five-point scale depicted in table 1. When a feature could not be observed, it was assigned the code '9'. An overall final sex estimation was based on the combination of feature grades with the emphasis on the pelvis features as they are deemed more significant that the skull features (Powers, 2012, 15).

CODE	1	2	3	4	5	9
SEX	Male	Probable Male	Intermediate	Probable Female	Female	Undeterminable

Table 1 - MoLAS Adult Sex Estimation Scale.

3.2.1.3 Metric Measurement FHB

MoLAS took numerous measurements of and individual's skeletal elements (e.g. cranial, dental, post-cranial) following the metric system. All of the measurements were, depending on what's most fitting, taken in millimetres or degrees. The measurement of the femoral head breadth is a post-cranial measurement which has been abbreviated by MoLAS to FeHD. The measurement of the FeHD (femur head vertical diameter) was done according to the Buikstra and Ubelaker (1994) method. It was taken in millimetres (mm) by using a sliding calliper (Powers, 2012, 17 & 19).

3.2.1.4 Pathology Criteria

Although there are many pathologies that MoLAS assessed in their research of the Chelsea Old Church population, only the pathological criteria of the diseases significant to this thesis will be discussed in table 2. All lesions have been macroscopically examined by MoLAS, following the step-by-step diagnosis procedure of Roberts and Connell (2004) (Powers, 2012, 27).

Skeletal Pathology - Joint Disease	
Disease	**Diagnostic Criteria**
Osteoarthritis	Eburnation (figure 4) is regarded as a diagnostic requirement for this disease, as per Rogers and Waldron (1995). In addition, using a presence\absence system, degenerative joint changes were recorded for each joint surface and catalogued by the severity of marginal osteophyte formation and pitting. The breakdown of cartilage in osteoarthritis may cause sub-chondral cysting, which has been indicated by the presence of micro and macro porosity (Powers, 2012, 48).
Gout	The principal of diagnosing gout is the observation and description of sharply defined lytic lesions, such as the Martel Hook (figure 5), of the para-articular joint surfaces of the first metatarsal, with unilateral joint involvement. This follows the diagnostic method Aufderheide and Rodríguez-Martín (1998) (Powers, 2012, 49).
Diffuse idiopathic skeletal hyperostosis (DISH)	The disease is indicated by excessive bone formation at the joint entheses (were a tendon or ligament meets the bone) and ankylosis (abnormal stiffing and immobility) of the spine ligaments with no intervertebral disc involvement, or apophyseal (facet joints, where the posterior and inferior vertebra meet) fusion. However, following the diagnostic criteria of Aufderheide and Rodríguez-Martín (1998) and Resnick (2002), DISH can only be diagnosed if at least four contiguous vertebrae (individual spine bone) are fused in a candle wax resembling manner ('dripping candle wax'-bony fusion with bony bridges rooted from the anterolateral aspect of the vertebral bodies on the right side of the vertebrae) (Powers, 2012, 50).

Table 2 - MoLAS Skeletal Pathology - Joint Disease.

3.2.2 Body Mass Estimation

3.2.2.1 Sample Criteria

As mentioned earlier, not all of the by MoLAS provided and available osteological data of the Chelsea Old Church is useable within this study. In order to research whether there's a correlation between body mass and obesity associated conditions, and whether there is a difference between sexes, it is of necessity to establish sample criteria that match the research questions. The main components of this research are: age, sex, availability of metric data of the femoral head breadth (FHB), and the pathological diagnosis of osteoarthritis, gout, and\or diffuse idiopathic skeletal hyperostosis (DISH).

Age is the first criteria of this research. This is because the femoral head breadth equation of Ruff *et al.* (2012) is only applicable to the skeletal remains of adult individuals. In addition, sex can only be estimated through macroscopic analysis when the skeletal remains of an individual are those of an adult. As was visualised in figure 7, 83% of the original assemblage is adult (165 of the 198 individuals).

Sex is the second criteria as this thesis will research whether there's a difference between sex in relation to the pathologies. In table 1 it is noted that MoLAS uses six grouping of sex: male, probable male, intermediate, probable female, female, undeterminable. For this research [probable male] and [male] have been grouped together as [male], as have [probable female] and [female] been combined to [female]. Whereas those who were estimated by MoLAS as intermediate or undeterminable have been discarded from the research as they are neither male or female. In figure 8 it can be seen that this entails 76% from the complete original data set (39% male (78 individuals) & 37% female (74 individuals). This further downsizes the sample size to 152 individuals of the original 198.

The third criteria is whether the metric data of the femoral head breadth diameter is available of these 152 individuals. This data is of absolute necessity in order to calculate the body mass of those who match the criteria of this thesis. Within the database provided by MoLAS it became clear that this data was not available for every individual. Of the 78 adult male individuals, 59 matched the third criteria. As did 58 of the 74 adult female individuals. This gives a relative balanced sample selection as there's little differentiation in the number of male and female individuals. The third criteria brings the final sample size to 117 individuals (59% of the original 198 individuals) (figure 9). Of these 117 individuals that met all the necessary criteria for this research it was further established with whether they were diagnosed by MoLAS with osteoarthritis, gout, and\or diffuse idiopathic skeletal hyperostosis (DISH). A complete overview of this final sample selection will be given in table 3.

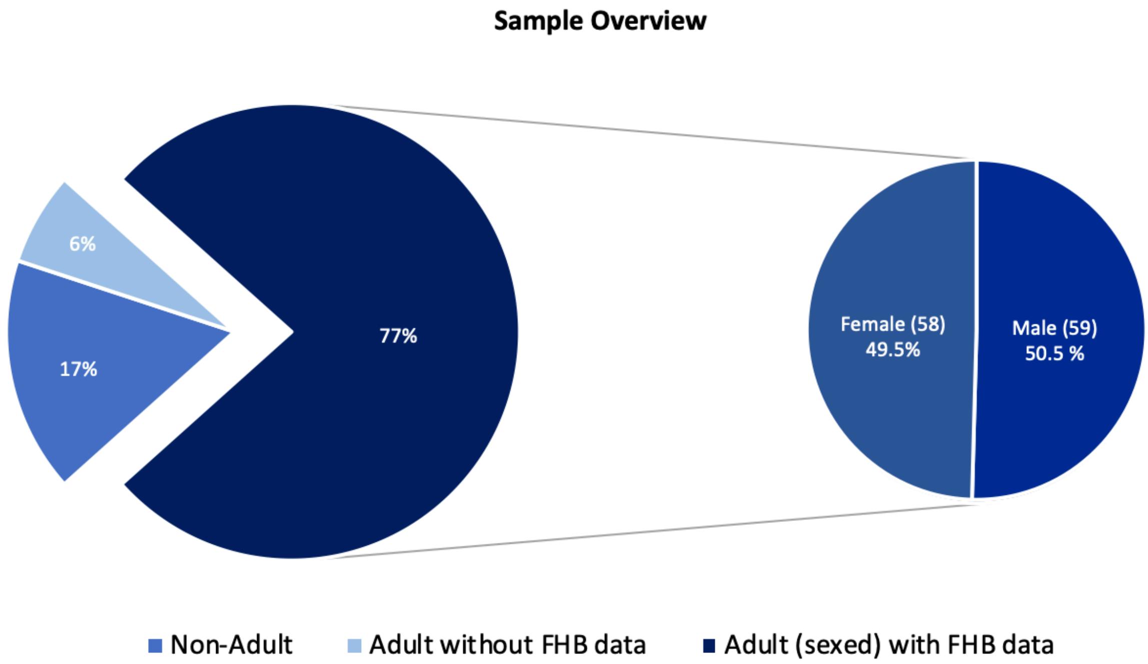

Figure 9 - Final Sample Selection Overview.

Sex	FHB Data	Osteoarthritis	Gout	DISH
Male	59	18	2	5
Female	58	19	1	1
Total Count	117	37	3	6

Table 3 - Final sample selection overview, including pathologies.

In figure 10 and 11 the sex (male and female respectively) will visualise the percentage of pathologies within the sexes. In preparation to the data analysis, and the addition of the femoral head breadth equation, the data of these individuals were implemented into an excel table of which an example is given in table 4. An overview of used abbreviations can be found in appendix 1.

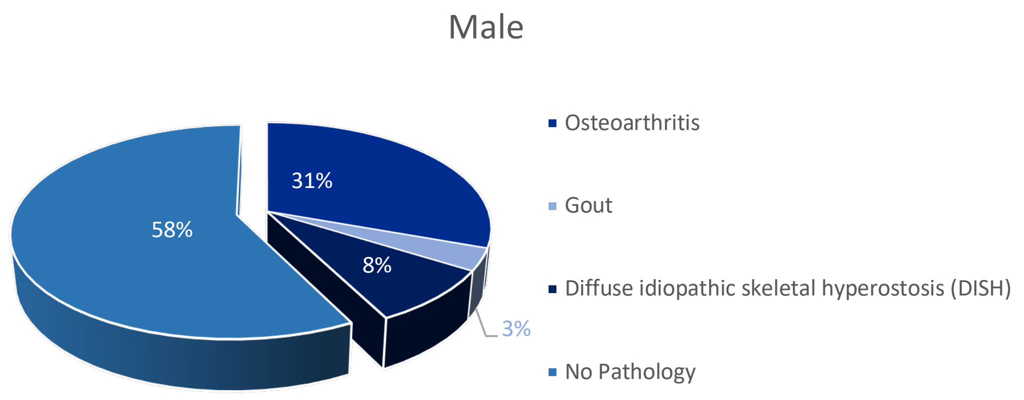

Figure 10 - Male sample selection and their percentage of pathologies.

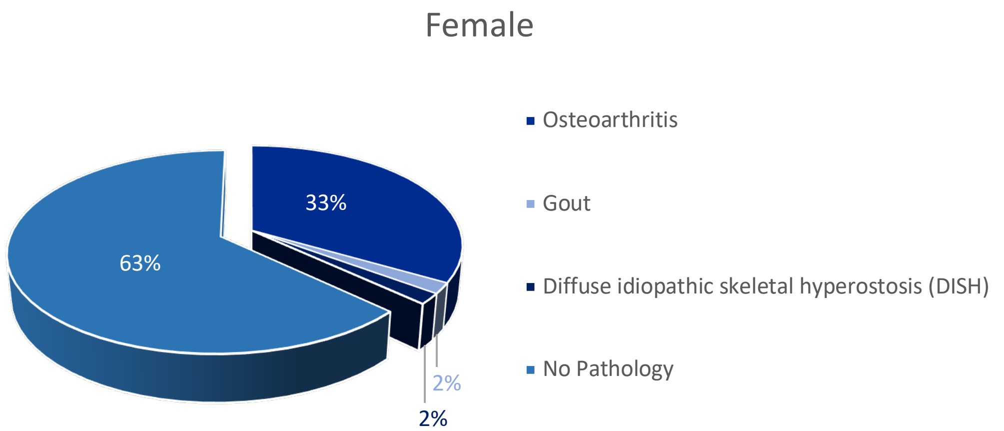

Figure 11 - Female sample selection and their percentage of pathologies.

Context	Sex	FHB-L (mm)	FHB-R (mm)	FHB-M (mm)	BM (kg)	OA	GOUT	DISH
###	Male\Female	#	#	#	#	Yes\No	Yes\No	Yes\No

Table 4 - Example of excel table layout of how the sample selected data set will be implemented. Context is a code that is given to the individual by MoLAS, rest of the abbreviations can be found in appendix 1.

3.2.2.2 Femoral Head Breadth Equation (Ruff et al. 2012)

The femoral head breadth equation of Ruff *et al.* was first published in 1991 and later updated in 2012. The original equation of 1991 was based on a research data of 80 living individuals that were restricted to Baltimore, Maryland, United States. This body mass estimation equation is subject to a number of limitations, such as a possible mismatch of body proportions. It exhibits a bias when applied to European (Holocene) populations (Ruff *et al.*, 2012, p. 601-609). In 2012, Ruff *et al.* revised their 1991 formula based on their study of 1145 European Holocene adult skeletal remains. As a result, a new body mass estimation equation was created that is more fitting for European skeletal remains that fall within the current geological epoch (the Holocene) (Ruff *et al*., 2012, p. 603-615). Both Ruff *et al.* equations are based on the metric measurement of the femoral head diameter in millimetre. The location of where this ought to be measured has been clarified in figure 2 (chapter 1). The revised equation is as follows:

$$BM = 2.80 \times FHB - 66.70\ (\text{♂} - \text{males})$$

$$BM = 2.18 \times FHB - 35.81\ (\text{♀} - \text{females})$$

$$BM = 2.30 \times FHB - 41.72\ (\text{⚥} - \text{combination of sex})$$

$BM = Body\ Mass\ in\ kilogram\ (kg);$
$FHB = Femoral\ Head\ Breadth\ diameter\ in\ \text{millimetre}\ (mm)$
(Derived from Ruff *et al.*, 2012, p. 611)

In order to apply the Ruff *et al.* (2012) formula to the sample selection of this thesis, the available metric data of the femoral head breadth diameter (FHB) have been taken from the original MoLAS osteological database of the Chelsea Old Church and implemented into the excel sheet\table that has been created for this thesis.

Not all individuals that made the sample selection had the metric data for both of their femoral heads. As can be seen in table 4, the available metric data of an individual would be implemented into the table in millimetres. If the metric data was only available for the left femoral head, it would be notated below FHB-L (left femoral head breadth diameter in mm); if the metric data was only available for the right femoral head, it would be notated below FHB-R (right femoral head breadth diameter in mm). As no mean could be calculated, this data would be repeated below FHB-M (mean of femoral head breadth diameter). When the data was available for both of the femoral head than these would be notated below their designated row (FHB-L and\or FHB-R) and the mean would be calculated and notated below FHB-M. To clarify:

$$FHB - L\ (mm) + \ [unknown] = FHB - L\ (mm) = \ FHB - M\ (mm)$$

$$[unknown]\ +\ FHB\ -\ R\ (mm) = FHB - R\ (mm) = \ FHB - M\ (mm)$$

$$\frac{\big(FHB - L\ (mm) + FHB - R\ (mm)\big)}{2} = FHB - M\ (mm)$$

The body mass of the individuals within the sample selection was then calculated by implementing the FHB-M into the Ruff *et al.* (2012) equation. The combined sex formula of Ruff *et al.* (2012) has been omitted as this thesis only focusses on adult individuals with a definite estimated sex (male or female). Therefore, formulas that were applied to the sample selection data set (in excel) were:

$$BM = 2.80\ \times\ [FHB - M]\ -\ 66.70\ (\text{♂}\ -\ \text{males})$$

$$BM = 2.18\ \times\ [FHB - M]\ -\ 35.81\ (\text{♀}\ -\ \text{females})$$

The final results can be found in appendix 2 and 3. As the sample selection data set was too large to fit on a single page, it has been split and divided over two appendixes. Appendix 2 will depict the first half of the data set, providing a data overview of the adult male individuals; while appendix 3 will depict the second half of the data set, providing an overview of the female individuals.

3.2.3 Data Analysis

The discussed data (spread over appendix 2 & 3) will be analysed through a number of statistical tests using the SPSS program. However, in order to know which test can be applied to the data, the data first needed to undergo a test of normality in order to understand whether the sample data is normally distributed or not. If the normality test depicts a bell-curve histogram than the data has a normal distribution and it will be possible to do parametric testing (McDonald, 2014, p. 102-103 & 133-136). However, parametric testing is only possible when the sample size is larger than 5 (>5). When one of the to be tested variable has a sample size that's less than 5 (<5), a non-parametric test needs to be applied. Non-parametric test does not rely on whether the data is normally distributed or not. It can also be used for small sample sizes (<5). On the other hand, it is more likely to accept the null hypothesis (H_0) even when H_0 isn't true. In contrast, parametric tests are less likely to faultily accept H_0; however, the data needs to be normally distributed and the sample size cannot be too small (>5) (McDonald, 2014, p. 135-136).

Through probability testing (the testing of the data that's done after the normality test) it is possible to test for statistical significance of the research. Statistical significance will clarify the probability of whether the found relationship within the data is established by random chance. Test results are statistically significant when the alpha level (α; arbitrary threshold) is below 5% (0.05). The calculated probability, P-value, ought to be $p < \alpha$ (= $p < 0.05$) for the results to be statistically significant.

For the normality test the body mass [BM (kg)] was noted as the dependent while [Sex] was set as the factor. Through this test, as noted in the results (chapter 4), it can be seen that the data is normally distributed and thus it is possible to make use of parametric testing. An overview of what will be further tested in order to research the subsidiary questions, and in which type of statistical tests these will be, has been created in table 5 (osteoarthritis), 6 (gout), and 7 (diffuse idiopathic skeletal hyperostosis (DISH)). The main question will be answered through the results of the subsidiary questions.

Osteoarthritis (OA)					
Correlation between BM (kg) and OA					
Sex	Variables		Sample Size		Test Type
Male	BM (kg): Metric Numeral	OA: Nominal Categorical	BM (kg): 59 > 5	OA: 18 > 5	Parametric test: *Independent two-sample t–test*; This test whether the mean values of the measurement variable are the same in two groups (McDonald, 2014, p. 297).
Female			BM (kg): 58 > 5	OA: 19 > 5	

Table 5 - Statistical data analyse testing overview - Osteoarthritis.

Gout					
Correlation between BM (kg) and Gout					
Sex	Variables		Sample Size		Test Type
Male	BM (kg): Metric Numeral	Gout: Nominal Categorical	BM (kg): 59 > 5	Gout: 2 < 5	Non-parametric test: *Mann-Whitney U-test*; non-parametric alternative to the two-sample t–test (McDonald, 2014, p. 126-130).
Female			BM (kg): 58 > 5	Gout: 1 < 5	*No Test Possible*

Table 6 - Statistical data analyse testing overview - Gout.

Diffuse Idiopathic Skeletal Hyperostosis (DISH)					
Correlation between BM (kg) and DISH					
Sex	Variables		Sample Size		Test Type
Male	BM (kg): Metric Numeral	DISH: Nominal Categorical	BM (kg): 59 > 5	DISH: 5 > 5	Parametric test: *Independent two-sample t–test*; This test whether the mean values of the measurement variable are the same in two groups (McDonald, 2014, p. 297).
Female			BM (kg): 58 > 5	DISH: 1 < 5	*No Test Possible*

Table 7 - Statistical data analyse testing overview - DISH.

As can be seen in table 5, 6, and 7: parametric testing has been chosen for those who had a sample size larger than 5. However, for those with a sample size smaller than 5 a non-parametric equivalent has been chosen. In table 6, and table 3 (§3.2.2), it is apparent that among the female individuals there's but one case of gout and one case of DISH. This means that it isn't possible to statistically test whether there's a correlation between body mass and gout or DISH for the female individuals of the sample selection. This is because it is not possible to do a statistical correlation test, whether pragmatic or non-pragmatic, when one of the test sample sizes exists out of a singular case since it tests the mean value and there's no mean value in 1. Additionally, a singular case has a standard deviation of 0 as there's no deviation possible.

Chapter 4

Results

From the sample selection, derived from the by MoLAS provided osteological database of the Chelsea Old Church, overview (figure 9 and table 3, §3.2.2) it can be observed that the sample assemblage is relatively balanced as there's little discrepancy between values. It is also visible that the male individuals of the group have a higher percentage of individuals diagnosed with the discussed pathologies (osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH)) than the female individuals. This is also evident in figure 10 and 11 (§3.2.2) which depict that 42% of the male individuals, and 37% of the female individuals, have pathological lesions. Which creates an overall small difference of 5%. Another observation that can be derived from table 3 and figures 10 & 11 is that the female individuals have a higher percentage rating of osteoarthritis than the male individuals (33% versus 31% respectively), while in contrast the male individuals have a higher percentage rating in gout (3% versus 2%) and DISH (8% versus 2%). That gout and DISH appear more prevalent among the male individuals is within expectation as contemporary studies have shown that men have a higher risk of developing these diseases (see chapter 2) (Behring, 2021; Centers for Disease Control and Prevention (CDC), 2023; Denko & Malemud, 2005, p. 296; Waldron, 2008, p. 67-68 & 72-74).

4.1 Normality Test: Body Mass & Sex

As mentioned in §3.2.3, before a correlation between body mass and the pathologies of interest (osteoarthritis, gout, and DISH) can be tested, a normality taste needs to be done to research whether the available data is distributed normally or not. This is done through the SPSS program by exploring body mass (BM (kg) - the dependent) and sex (the factor), the results of the test of normality can be found in table 8. Two types of normality tests are depicted in this table (8), the Kolmogorov-Smirnov test and the Shapiro-Wilk test. Generally, the latter is used for sample sizes below 50 while Kolmogorov-Smirnov is often used for larger sample sizes. However, Shapiro-Wilk test is also perfectly applicable for larger sample sizes. Both tests depict a normal distribution as their significance (Sig.) is above 5% (0.05), this is emphasized by the bell curve which is visible in figure 12 (histogram of body mass and male individuals) and figure 13 (histogram of body mass and female individuals). The tests statistics indicate that standardized sample quantiles fit the standard normal quantiles. For the Shapiro-Wilt test the statistic value lays between 0 and 1 with 1 being a perfect match. As is visible in table 8, the Shapiro-Wilt statistics are fairly near perfect. The same principle goes for the Kolmogorov-Smirnov test (King & Eckersley, 2019, p. 149-156).

Test of Normality							
BM (kg)	Sex	Kolmogorov-Smirnov Test			Shapiro-Wilk Test		
		Statistic	df*	Sig.	Statistic	df*	Sig.
	Male	0.108	59	0.084	0.979	59	0.395
	Female	0.081	59	0.200**	0.975	58	0.263

*. 'df' Stands for 'degree of freedom', it is the sample size minus the number of restrictions. In this case the df is equal to the sample size of the sexes as there are no restrictions.
**. Lower bound of the true significance

Table 8 - Normality Test.

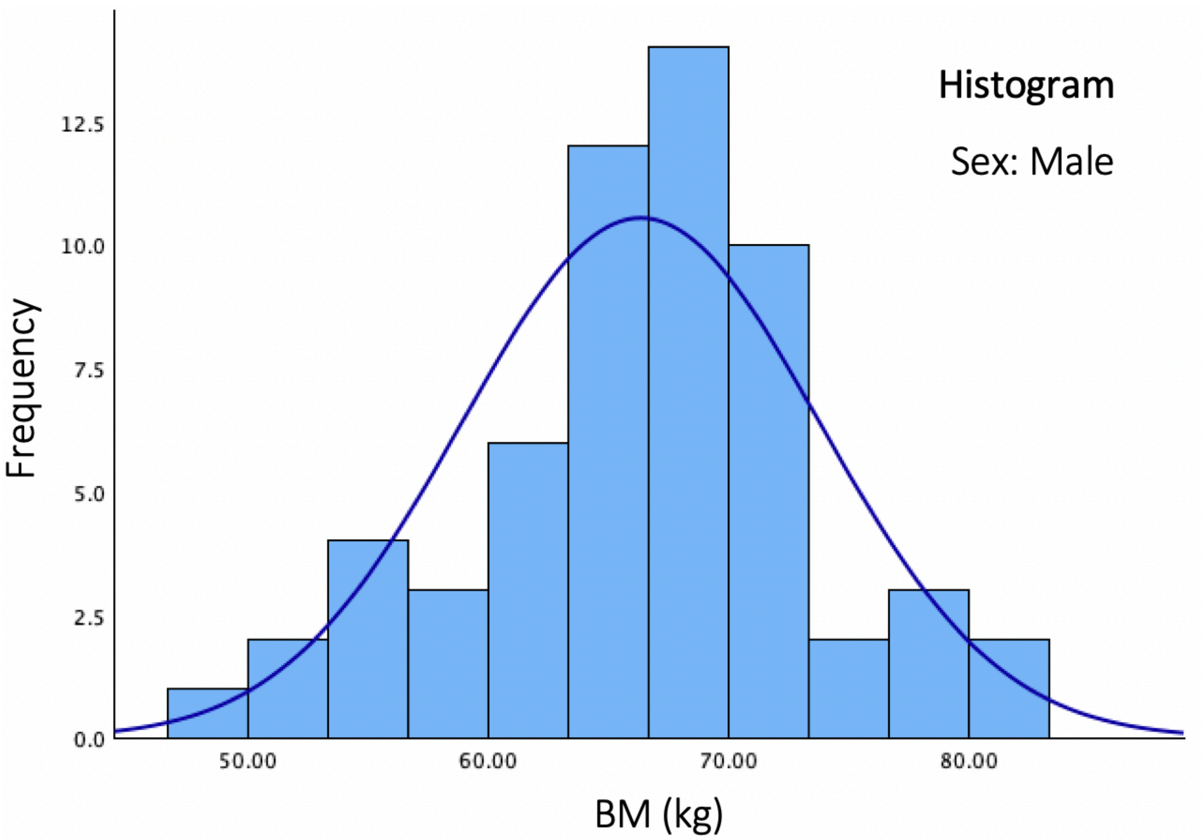

Figure 12 - Normality test histogram - male individuals.

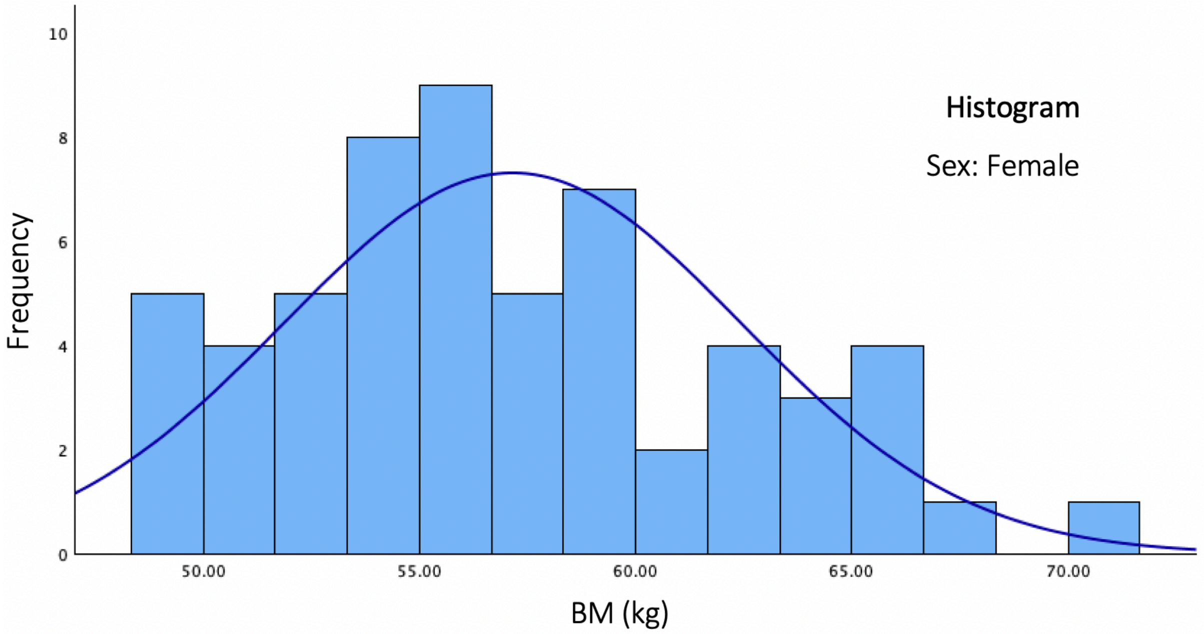

Figure 13 - Normality test histogram - female individuals.

4.2 Body Mass & Pathologies

From the normality test it has become clear that the data is normally distributed. That means, as stated in chapter 3 (§3.2.3), that it is possible to apply parametric testing as long as both test sample sizes are larger than 5 (> 5). As soon as one of the sample sizes is smaller than 5 (< 5), a non-parametric equivalent will be used.

In order to test whether there's a correlation between a pathology and body mass while considering whether there's a sex-based difference, it is needed to test the male and female individuals separately. Otherwise a general overview without sex specific statistics will come to be from which it would not be possible to discern between sexes.

4.2.1 Osteoarthritis

As noted in table 3 (§3.2.2) and table 5 (§3.2.3), both test sample sizes are larger than 5. As the data is normally distributed, a parametric independent two-sample t-test has been run separately for both male and female individuals. The result of this can be found in table 9.

Correlation between BM (kg) and OA									
	Sex	OA	N	Mean	SD	Levene's Test	Independent two-sample T–test		
						Sig.	t	df	Sig.
BM (kg)	Male	No	41	65.24	7.29	0.541	-1.707	57	0.093
		Yes	18	68.77	7.39				
	Female	No	39	57.14	5.07	0.262	-0.175	56	0.862
		Yes	19	57.40	5.82				

Table 9 - T-test result of osteoarthritis.

To clarify: 'N' stands for sample size which are the number of individuals who do or do not have a certain pathology. This would be osteoarthritis in table 9, gout in table 10, and DISH in table 11. Furthermore, 'Mean' stands for the average body mass in kilograms and 'SD' stands for standard deviation of said mean. These abbreviations will be upheld throughout this thesis.

From the SPSS generated independent two sample T-test it becomes apparent that there's no statistical significance for either of the sexes. This is first noticed through the Levene's test for equality of variances (Levene's test), which gives a significance of 0.541 for the male individuals and 0.252 for the female individuals. This means that for both sexes the assumption is that the variances are equal. In other words, the null hypothesis (H_0: there's no correlation between body mass and osteoarthritis) has been accepted rather than rejected as both 0.541 and 0.252 are (far) higher than the arbitrary threshold and probability of 0.05. This is further underlined by the actual T-test results which depict a significance of 0.093 for the male individual-based data and 0.826 for the female individuals.

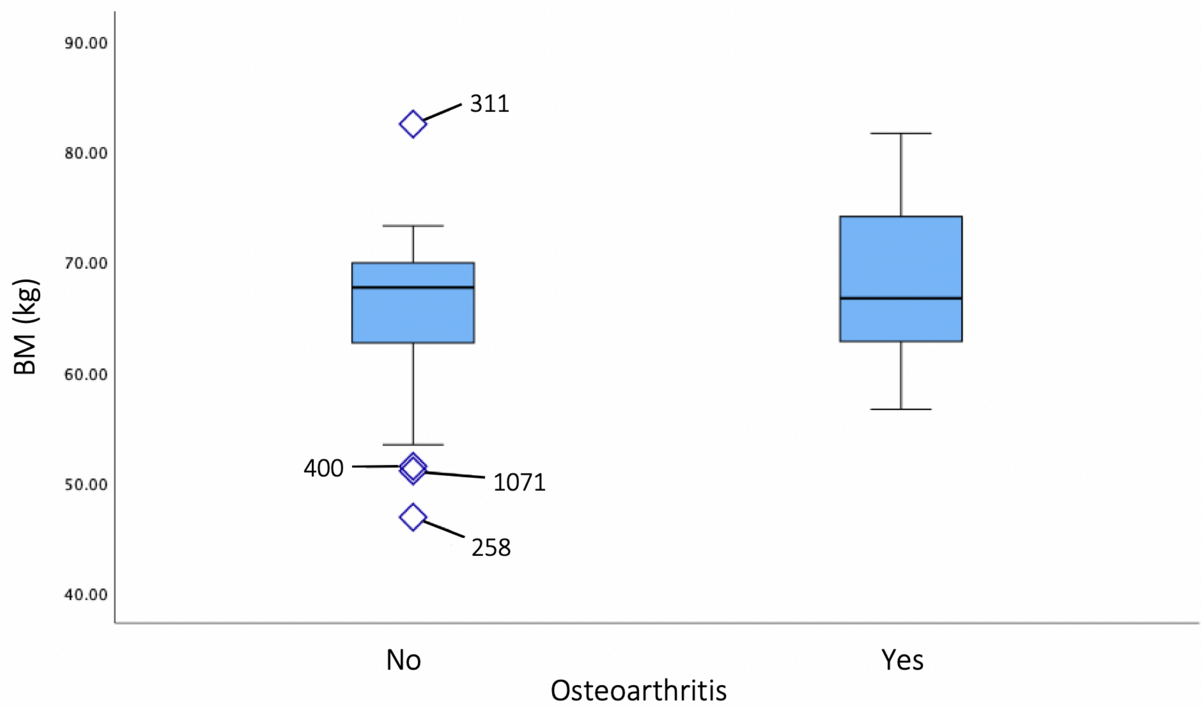

Figure 14 - Boxplot: BM (kg) and osteoarthritis - male individuals.

In figure 14 (male individual) and figure 15 (female individual) a box-plot visualisation has been depicted of the tested sample selection for the osteoarthritis pathology. In the one of the male individuals (figure 14) it can be seen that there are several outliers, two can be regarded as mild (case 400 and 1071) while the other two can be regarded as relative extreme outlier (case 258 and 311). These outliers are restricted to the 'No' group of the assemblage. It should also be noted that the medians of both the 'No' and 'Yes' group are nearly on the same level, but there's a clear difference between the minimum and maximum value of the boxplots. Both the minimum and the maximum body mass value of the group without osteoarthritis (the 'No' group) is lower that the 'Yes' group (with osteoarthritis). Another difference is that the interquartile range of the 'No' group is smaller and the range of the first and third quartile of the 'No' group is the opposite of the 'Yes' group. There's less of a stark difference among the female individuals (figure 15). Similar to figure 14, figure 15 depicts a median that's similar to both the 'No' and 'Yes' group and the interquartile range of the 'No' group is also smaller than the 'Yes' group (although less extreme than in figure 14). However, there's nearly no difference between the minimum values of either of the groups and the range of the first quartile appears to be quite equal to each other. Regardless, the 'Yes' group does depict a larger third quartile range and a slightly higher maximum value.

Figure 15 also depicts a singular semi-extreme outlier (case 980) in the 'No' group. Neither the boxplots in figure 14 or 15 depict outliers in the 'Yes' group.

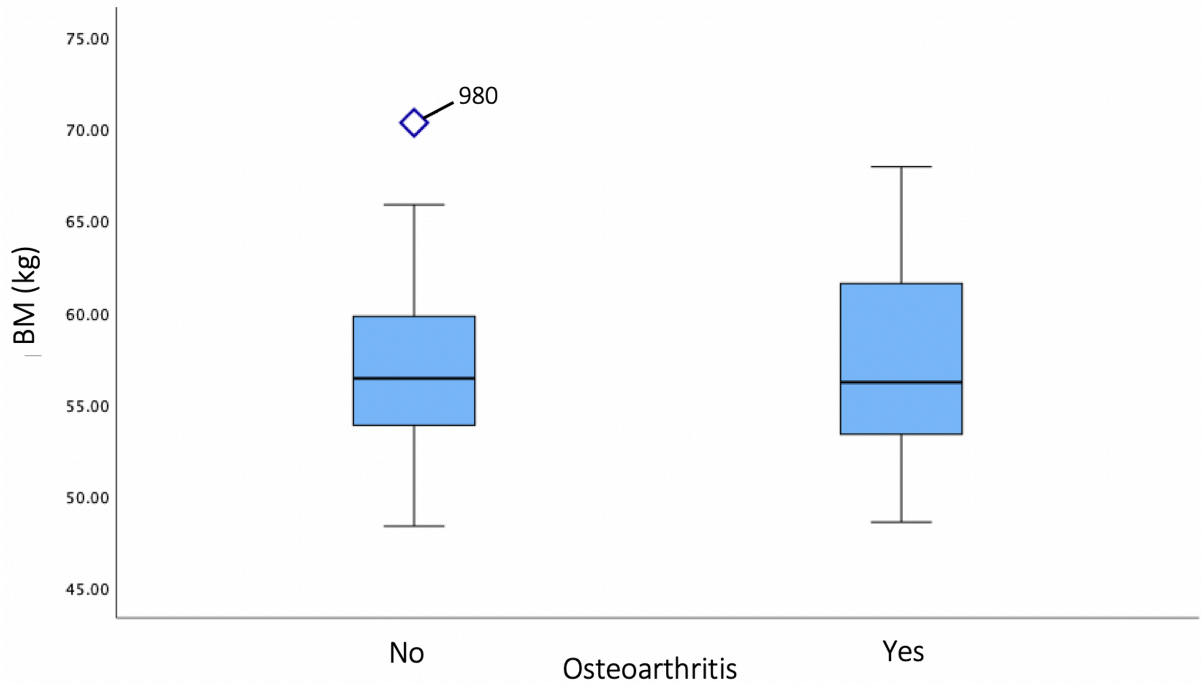

Figure 15 - Boxplot: BM (kg) and osteoarthritis - female individuals.

4.2.2 Gout

Due to the limited number of individuals diagnosed with gout, it wasn't possible to execute an independent two sample t-test. For the men who had a total of 2 individuals with gout it was possible to execute a Mann-Whitney U-test (table 10) The U-test is a non-parametric test, which could mean that the null hypothesis may become wrongfully accepted. Regardless, the significance of the U-test depicts a result of 0.867 which is far higher than the arbitrary threshold and probability of 0.05. Therefore, with 0.867 > 0.05, the null hypotheses of the gout pathology (H_0: there's no correlation between body mass and gout) has been accepted for the male individuals of the sample assemblage and thus the results are not statistically significant.

Correlation between BM (kg) and Gout							
	Sex	Gout	N	Mean	SD	Mann-Whitney U-test	
						U	Sig.
BM (kg)	Male	No	57	66.32	7.44	53.00	0.867
		Yes	2	67.14	7.62		
	Female	No	57	*Testing not possible*			
		Yes	1				

Table 10 - U-test result gout.

For the female sex it wasn't possible to run a statistic test as there was but 1 case with gout throughout the whole sample selection assemblage. Therefore, it wasn't possible either to create a boxplot visualization. At most it can be noted that gout is more frequent within this database among male individuals. However, as mentioned above, this is not statistically significant. It was possible to create a boxplot visualisation of the male individuals (figure 16). In here it is visible that, similar to the osteoarthritis 'No' group, the 'No' group has several mild outliers (case 258, 311, and 400). It can also be seen that the interquartile range of 'No' group is smaller than the 'Yes' group and that, in contrast to the 'Yes' group, the 'No' group depicts a clear minimum and maximum value. Nevertheless, it should be kept in mind that the 'Yes' group consists out of only two individuals, in contrast to the 57 individuals of the 'No' group. Thus, it isn't possible for the 'Yes' group to have a minimum (60.28 kg) or maximum (74.00 kg) value beyond the interquartile range of the group. As in figure 14 and 15, the median of both groups is nearly equal to one each other.

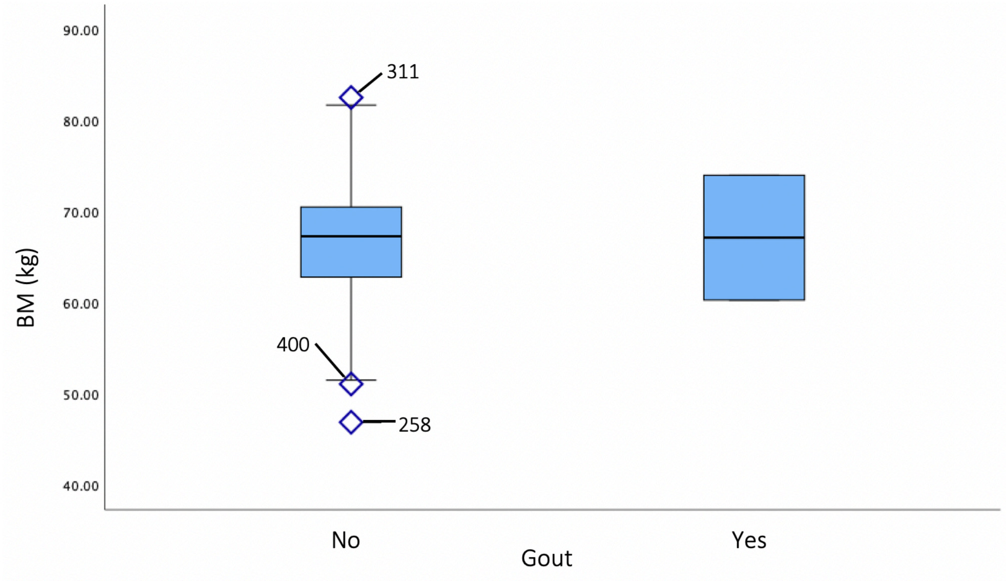

Figure 16 - Boxplot: BM (kg) and gout - male individuals.

4.2.3 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Comparable to gout, there's a limited number of individuals that have been diagnosed with DISH. There's but one recorded female case (of the 58 available individual) of DISH. Hence, much alike the situation of gout, it is not possible to statistically test the significance of the female-based data nor is it possible to visualise it in a boxplot.

As for the male individuals: there are five cases of male individuals with DISH. Therefore, the method of testing balances between parametric (sample size > 5) and non-parametric (sample size < 5) testing. As non-parametric testing favours the acceptance of the null hypothesis, the parametric independent two sample T-test has been chosen to apply to the DISH male sample selection. Regardless, in table 11 it becomes clear that both the significance of the Levene's test (0.652) as well as the significance of the T-test (0.290) are both far beyond the arbitrary threshold and probability of 0.05 (0.652 > 0.05 and 0.290 > 0.05). Thus, there's no statistical significance and has the null hypothesis (H_0: there's no correlation between body mass and DISH) been accepted.

Correlation between BM (kg) and OA									
	Sex	OA	N	Mean	SD	Levene's Test	Independent two-sample T–test		
						Sig.	t	df	Sig.
BM (kg)	Male	No	54	66.00	7.52	0.652	-1.069	57	0.290
		Yes	5	69.72	6.10				
	Female	No	57	*Testing not possible*					
		Yes	1						

Table 11 - T-test result DISH.

Figure 17 depicts a boxplot visualization of the male individuals who did (the 'Yes' group) and didn't (the 'No' group) have the DISH diagnosis. Similar to the previous boxplots (figure 14, 15, and 16), it only depicts (mild) outliers (case 258 and 311) in the 'No' group. The median and maximum value are quite similar between the 'No' and 'Yes' groups while the minimum value of the 'No' group is far lower than the 'Yes' group. The interquartile range of both groups is also rather similar. Though, in contrast to the 'No' group, the first quartile is nearly non-existent within the 'Yes' group. Similar as to the 'gout' situation, it should be kept in mind that the 'Yes' group (5 individuals) is significantly smaller than the 'No' group (54 individuals).

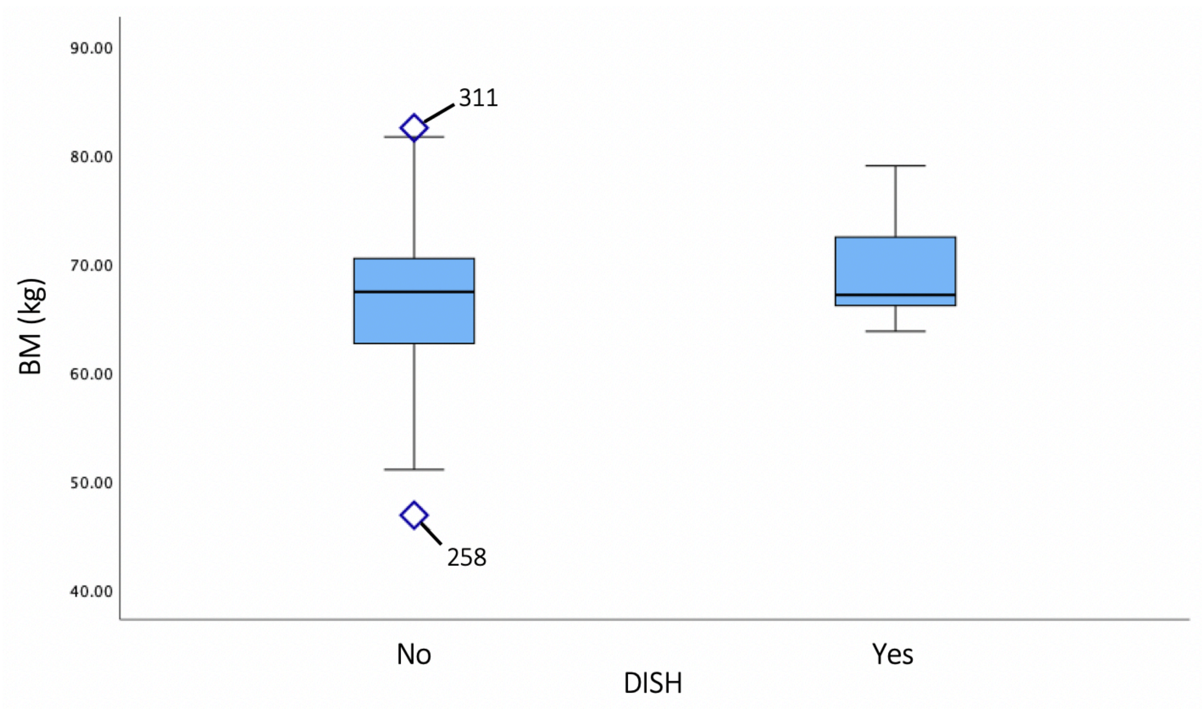

Figure 17 - Boxplot: BM (kg) and DISH - male individuals

4.3 Summary

Results Summary	
Initial Observation	☠ The sample selection is relatively balanced. ☠ 42% Of the male individuals have pathological lesions, it's 37% for the female individuals (5% less). ☠ 33% Of the female individuals with lesions have osteoarthritis, this is 31% for the male individuals. ☠ Male individuals are found to have a higher percentage of gout (3% versus 2%) and DISH (8% versus 2%) than female individuals. This is in line with what's expected.
Normality Test	☠ Both the Kolmogorov-Smirnov normality test and the Shapiro-Wilk normality test depict that the data is normally distributed. Therefore, parametric testing is possible as long as the tested sample size is > 5. ☠ Both normality test also indicate that the standardized sample quantiles fit the standard normal quantiles.
Osteoarthritis	☠ The mean BM (kg) is higher for those who have OA then who do not. Though this is most apparent among the male individuals and the difference is nearly nullable among the female individuals. This is emphasized in the boxplots of figure 14. It is also slightly visible in figure 15, though less extreme. ☠ Both sexes have been tested through the parametric independent two sample T-tests. ☠ Levene's test for equality of variances (male): 0.541 > 0.05 ☠ Levene's test for equality of variances (female): 0.262 > 0.05 ☠ T-test (male): 0.093 > 0.05; T-test (female): 0.862 > 0.05 ☠ Therefore, there's no statistical significance, H_0 accepted.

Gout	☠ The mean BM (kg) is slightly higher among the males who have gout than the male individuals who do not. ☠ The interquartile range of those with gout is clearly larger than those without; however, the sample size (2) is far smaller (versus 57) (figure 16). ☠ The male sex has been statistically tested through the non-parametric Mann-Whitney U-test. ☠ U-test: 0.867 > 0.05; no statistical significance. H_0 accepted. ☠ As there's but 1 female case of gout, it could not be tested nor visualized.
Diffuse Idiopathic Skeletal Hyperostosis (DISH)	☠ The mean BM (kg) is higher for the male individuals with DISH than for the males who do not. ☠ There's nearly no first quartile in the boxplot (figure 17) for those with DISH, in contrast with those who do not have DISH. ☠ As there's but 1 female case of DISH, it could not be tested nor visualized. ☠ The male sex has been statistically tested through the parametric independent two sample T-tests. ☠ Levene's test for equality of variances: 0.652 > 0.05 ☠ T-test: 0.290 > 0.05 ☠ Therefore, there's no statistical significance, H_0 accepted.

Table 12 - Summarization of the results.

Chapter 5

Discussion

The aim of this thesis is to research whether a correlation between obesity associated conditions and body mass can be established based on the by MoLAS provided osteological database of the post-medieval Chelsea Old Church graveyard site. This had become a topic of interest due to the realisation that osteoarchaeological research has diagnosed numerous skeletal remains with diseases that are associated with a high boy mass (obesity) (Waldron, 2008); however, so far, no direct link has been established between the diseases and body mass in historical context. In present time, a connection has been made between pathologies such as osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH) as possible consequences of a calorie rich diet and high body mass (e.g. obesity) (Aune *et al.,* 2014; Centers for Disease Control and Prevention (CDC), 2020; Centers for Disease Control and Prevention, 2022; Choi *et al*., 2005; Denko & Malemud, 2005; Felson, 1996, p. 430; Hou *et al*., 2020, p. 1-7; Johns Hopkins Arthritis Center, 2022; Pini *et al.,* 2020). Regardless, the results depicted in the previous chapter (chapter 4) depict statistical insignificance.

5.1 Interpretation of the Results

In table 3 (§3.2.2) an overview can be found about the final sample selection derived from the originally available Chelsea Old Church database, while in table 12 (§4.3) a bullet point overview of the results has been provided. Combined with figure 9, 10, and 11 it becomes clear that the sample selection is relatively balanced and that, for both male and female, osteoarthritis is by far the most commonly diagnosed pathology within the assemblage.

The results provided by the data analysis will be discussed down below per researched pathology.

5.1.1 Osteoarthritis

When looking at the sample selection that focusses on osteoarthritis it becomes apparent that, in contrast to gout and DISH, there are more female individuals who have been diagnosed with osteoarthritis than male individuals. Nonetheless, this falls within expectations as present studies indicate that women are more likely to get osteoarthritis than men (Centres for Disease Control and Prevention (CDC), 2020; Felson, 1996, p. 430; Johns Hopkins Arthritis Center, 2022; Hou *et al*., 2020, p. 6-7). Although osteoarthritis is more common among the female individuals, there's nearly no difference in weight between females who have or don't have osteoarthritis (figure 15). However, body mass is evidently higher among males with osteoarthritis than among male individuals without osteoarthritis (figure 14). Which could mean that there may indeed be a connection between osteoarthritis and body mass, as contemporary studies stipulate, at least in regard to men. If it wasn't for the statistical insignificance that became evident in the data analyse (§4.2.1) due to which the null hypothesis (H_0: there's no correlation between body mass and osteoarthritis) has been accepted rather than rejected.

A possible reason for the statistical insignificance may be due to the grouping of ages into adult and non-adult. Through this, the by MoLAS created original grouping of age has been disregarded and combined into a broad group of 18 years and older (> 46). However, both the Ruff *et al.* (1991) formula and the revised Ruff *et* al. (2012) formula give the most accurate results when applied to the skeletal remains of individuals of below the age of 36 (young adults). Thus, there may be a slight standard deviation error within the body mass estimations of this assemblage. In contrast, osteoarthritis increases in occurrence and severity with age (Centres for Disease Control and Prevention (CDC), 2020; Felson, 1996, p. 430). Additionally, it is not fully researched whether the remodelling the femoral head breadth correlates with the actual weight-at-death or whether it is a snapshot of the heaviest ante-mortem period of an individual.

5.1.2 Gout

There were very few individuals within the final sample selection that have been diagnosed with gout. Since gout has been frequently linked to a calorie rich diet and the thereby added concerns of a high body mass, the lack of gout diagnoses came as a surprise (Centres for Disease Control and Prevention (CDC), 2023; Waldron, 2008, p. 67-68). Perhaps, due to being generally located in the big toe (first metatarsal), it may have either been missed or it may not have been possible to diagnose due to the possibility of missing toes within the assemblage. Perhaps the presence of toes should have been included into the sample selection. Regardless, due to the limited number of individuals diagnosed with gout, the statistical test had to be changed from parametric to non-parametric despite the normal data distribution. Among the female individuals there was but a single case of gout and therefore it was not possible to test, nor visualise, for a correlation between gout and body mass in regard to the female sex. The male based sample selection was tested with a non-parametric statistical test: the Mann-Whitney U-test. It resulted in no statistical significance. Non-parametric tests favour the acceptance of the null hypothesis; however, when taking the results in consideration of the other pathologies, it is highly unlikely that the null hypothesis (H_0: there's no correlation between body mass and gout) was accepted due to chance or the non-parametric tests favour towards H_0.

The result of statistical insignificance in regard to gout, though also applicable on osteoarthritis and DISH, may be due to the focus of this thesis being on body mass rather than the affect that fat may have on an individual's health. Especially since fat is a known biochemical component that's in relation to diet and of which is known for being an active influence in the lipid metabolism and bone health (Shapses & Wang, 2017). Although there's currently no known method of realizing this through an osteoarchaeological manner of research.

5.1.3 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Similar to gout, there was but one female individual who was diagnosed with DISH within the sample selection. As such, it wasn't possible to execute a statistical test or visualisation in order to research whether there may be a correlation between DISH and body mass in relation to the female sex. Despite the low number of diagnosed individuals, it was still possible to run a parametric independent two-sample T-test (although barely) for the male individuals of the selection. Though this too, akin to osteoarthritis and gout, resulted in statistical insignificance.

DISH primarily affects the spine; but, although rare, it can occur throughout the body (Resnick *et al.*, 1975, as cited in Denko & Malemud, 2005, p. 292; Pini *et al.*, 2020, p. 1521; Waldron, 2008, p. 73). Which means that there's a very slight chance of underdiagnosing DISH within the Chelsea Old Church assemblage. Especially when considering that MoLAS only diagnosed an individual with DISH if they had found at least 4 continuous vertebrae fused together in a candlewax resembling manner (Powers, 2012, 50). That said, the extreme fusion of the vertebrae impacts the mobility of an individual on a much higher level than osteoarthritis and gout. Which may influence the body mass of an individual, depending on their diet as well, when the movement of an individual becomes restricted.

There may also be a small discrepancy within the study due to not knowing whether the remodelling of the femur correlates with the actual weight at death or if it only dictates the heaviest ante-mortem period of an individual. It's possible that the change in bone occurred over a long term of time and that weight loss may not have been able to rectify the change. Which may lead to researching whether the remodelling of the femoral head breadth truly depicts the weight-at-death or a more general long term 'heaviest' ante-mortem period of an individual. The result of such a study may impact how lifestyle and diet are viewed in regard to both past and contemporary living situations.

5.2 Concluding Remarks

There were remarkable few, and less than expected, female individuals who were diagnosed with gout or DISH. Due to the limited number of individuals diagnosed with gout and\or DISH, the study of osteoarthritis has become the most decisive even though all statistic tests indicate that there's no statistical significance. Hence, it's very likely that none of the pathologies depict a correlation with body mass. Nor does there appear to be a significant difference between sexes in this regard. Regardless, there are some observational correlations in regard of body mass and pathologies, such as the body mass mean (kg) being generally higher for those with pathologies than those without. However, aside of osteoarthritis, this could not be compared between sexes. Additionally, when compared to the sample selection, the diseases do depict an expected of being more prevalent in a certain sex: gout and DISH occur more often in male individuals while osteoarthritis occurs more often in female individuals.

Nevertheless, although this research has proven itself to be statistically insignificant, it does open up many future research possibilities. Which will be elaborated upon in the following chapter: the conclusion (chapter 6).

Chapter 6

Conclusion

"*To what extent is there a correlation between obesity associated conditions and a higher body mass in Post Medieval London?*"

The aim of this thesis was to research whether a correlation could be established between body mass and obesity associated conditions. For this the, by MoLAS created and shared, osteological database of the post-medieval Chelsea Old Church graveyard site has been analysed in regard of body mass and the diseases: osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH). In addition, it has been attempted to study whether a sex-based difference could be established within such a correlation. Accordingly, three subsidiary questions have been created to answer the main research topic.

6.1 Bones & Body Mass

The three subsidiary questions are created to study to what extent a certain obesity associated pathology correlate with body mass and whether there are any differences between the sexes. Based on their result, an all-encompassing conclusion will be drawn in § 6.1.4.

6.1.1 Osteoarthritis

While researching osteoarthritis it was discovered that the mean body mass (kg) was higher in men who were diagnosed with the disease than those who weren't. What's peculiar is how it was a difference that was apparent among the male individuals, but nearly negligible among the female individuals. In addition, the disease followed suit to its pattern of being more common among female individuals. Hence the curiosity for there being such a difference between male individuals who do or do not have arthritis in regard to body mass, yet so little difference among the female individuals themselves. Regardless, the data analyses resulted in accepting the null hypothesis. Therefore, it can be assumed that there's no correlation between body mass and osteoarthritis as there's no statistical significance.

6.1.2 Gout

Similar to osteoarthritis, it was found that the mean of the body mass (kg) was higher among the male individuals who were diagnosed with gout than those who weren't. Due to the lack of female gout cases, it was not possible to research whether there was a sex-based difference in this regard.

Akin to osteoarthritis, it can be assumed that there's no correlation between body mass and gout as there's no statistical significance.

6.1.3 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Much alike osteoarthritis and gout, the mean of the body mass (kg) is observed to be higher among the male individuals who were diagnosed with DISH than the ones who weren't diagnosed with DISH. Though, in the case of DISH, the body mass may be related due to the extreme jeopardy if movement which is less evident in the skeletal outing of osteoarthritis and gout.

Matching to osteoarthritis and gout, there's no statistical significance and thus it may be assumed that there's no correlation between body mass and DISH.

6.1.4 In Conclusion

Regardless of the statistical insignificance, all three pathologies have been observed to follow suit in regard of their expected occurrence within a specific sex. Within the male population of the sample selection it can also be observed that those who have a pathology have a higher body mass mean (kg) than those who do not. Though it is not possible to call it a statistical correlation as there are too many factors that may cause individual to gain weight. Nor was it possible to properly research whether there was a sex difference due to the lack of female gout and DISH cases. Due to the limited number of individuals diagnosed with gout and\or DISH, the study of osteoarthritis has become the most decisive. Regardless, the data analysis of each pathology resulted in no statistical significance. For that reason, based on the research of the post-medieval site of Chelsea Old Church, it is likely that there's no direct correlation between obesity associated conditions and a higher body mass. Though it does lead to further future research.

6.2 Proposal for Future Research

Though statistically insignificant, or perhaps precisely due to this thesis lack of significant statistics, this research generates many questions in regard of lifestyle related physical and skeletal health. Hence, these proposals for future research:

As noted in the results (chapter 4) and discussion (chapter 5), there's a clear body mass increase among male individuals with osteoarthritis in contrast to those without. This contrast seems to be only apparent in the male based sample selection. Although the statistical analyse indicated that there's no statistical significance within this study, it may still be interesting to study whether there's a higher influence of body mass in men in correlation to health risks that may (also) lead to osteoarthritis and in contrast to women who appear to be more susceptible for osteoarthritis regardless of weight.

There may also be a small discrepancy within the study, as mentioned in the discussion (§5.1.1), due to not knowing whether the remodelling of the femur correlates with the actual weight at death or if it only dictates the heaviest ante-mortem period of an individual. It's possible that the change in bone occurred over a long term of time and that weight loss may not have been able to rectify the change. Which may lead to researching whether the remodelling of the femoral head breadth truly depicts the weight-at-death or a more general long term 'heaviest' ante-mortem period of an individual. The result of such a study may impact how lifestyle and diet are viewed in regard to both past and contemporary living situations.

Due to the statistical insignificance of this research it is proposed that it may perhaps indicate the need for a more in-depth study about the cause for high body mass\obesity associated diseases and whether overweight has become a common characteristic of contemporary society rather than a plausible cause for diseases such as osteoarthritis, gout, and\or diffuse idiopathic skeletal hyperostosis (DISH).

Abstract

This thesis studies the, by the Museum of London Archaeological Services (MoLAS) analyzed and shared, open source osteological database of the Chelsea Old Church cemetery site OCUoo. Based on this data set, the study aims to research whether there is a correlation between obesity associated diseases, such as: osteoarthritis, gout, and diffuse idiopathic skeletal hyperostosis (DISH), and body mass. In addition, it attempts to research whether there's a sex-based difference that may influence such a correlation.

It does so by creating three subsidiary question that are meant to lead to answering the main question. Subsequently, a sample selection according to the criteria required for this study (adult, sex determined, availability of femoral head breadth metric data). This sample selection will be further tailored by implementing the revised Ruff *et al.* (2012) body mass estimation equation, before it will undergo statistical data analysis with the use of the SPSS statistics program.

The result depicts a data set that's relatively balanced and has a normal distribution. It may be noted that the mean of the body mass (kg) of those with pathological diagnoses lies higher than for those without. As well as that the pathologies follow suit as expected in regard of their prevalence in a certain sex. Osteoarthritis is more common among female individuals while gout and DISH are more common among male individuals. These notions could indicate that there may be a correlation; however, the statistical analyses resulted in the acceptance of the null hypothesis as there's no statistical significance. Therefore, against expectations and contemporary studies, it can be assumed that there's no correlation between obesity associated diseases and body mass.

Bibliography

Arthritis Foundation. (n.d.). *How Fat Affects Gout.* https://www.arthritis.org/health-wellness/about-arthritis/related-conditions/other-diseases/how-fat-affects-gout

Auerbach, B. M., & Ruff, C. B. (2004). Human body mass estimation: A comparison of "morphometric" and "mechanical" methods. *American Journal of Physical Anthropology*, *125*(4), 331–342. https://doi.org/10.1002/ajpa.20032

Aune, D., Norat, T., & Vatten, L. J. (2014). Body mass index and the risk of gout: a systematic review and dose–response meta-analysis of prospective studies. *European Journal of Nutrition*, *53*(8), 1591–1601. https://doi.org/10.1007/s00394-014-0766-0

Behring, S. (2021, October 6). *Understanding DISH Disease*. Healthline. https://www.healthline.com/health/arthritis/dish-disease#outlook

Bhandari, P. (2023, June 22). *An easy introduction to statistical significance (With examples)*. Scribbr. https://www.scribbr.com/statistics/statistical-significance/ - :~:text=Significance is usually denoted by,time under the null hypothesis

Centers for Disease Control and Prevention (CDC). (2022, March 21). *Causes of Obesity*. https://www.cdc.gov/obesity/basics/causes.html#:~:text=Obesity%20is%20a%20complex%20disease,activity%20levels%2C%20and%20sleep%20routines

Centers for Disease Control and Prevention (CDC). (2023, June 12). *Gout*. https://www.cdc.gov/arthritis/basics/gout.html

Centers for Disease Control and Prevention (CDC). (2020, July 27). *Osteoarthritis (OA)*. https://www.cdc.gov/arthritis/basics/osteoarthritis.htm#:~:text=Osteoarthritis%20(OA)%20is%20the%20most,underlying%20bone%20begins%20to%20change

Choi, H. K., Atkinson, K., Karlson, E. W., & Curhan, G. C. (2005). Obesity, weight change, hypertension, diuretic use, and risk of gout in men: The Health Professionals Follow-up Study. *Archives of Internal Medicine*, *165*(7), 742–748. https://doi.org/10.1001/archinte.165.7.742

Cowie, R., Bekvalac, J., & Kausmally, T. (2008). Late 17th- to 19th-century burial and earlier occupation at All Saints, Chelsea Old Church, Royal Borough of Kensington and Chelsea. *MoLAS Archaeology Studies Series*, *18*, 1–67. https://doi.org/10.1002/oa.1073

Denko, C. W., & Malemud, C. J. (2005). Body Mass Index and Blood Glucose: correlations with serum insulin, growth hormone, and insulin-like growth factor-1 levels in patients with diffuse idiopathic skeletal hyperostosis (DISH). *Rheumatology International*, *26*(4), 292–297. https://doi.org/10.1007/s00296-005-0588-8

Felson, D. T. (1996). Weight and Osteoarthritis. *The American Journal of Clinical Nutrition*, *63*(3), 430–432. https://doi.org/10.1093/ajcn/63.3.430

Felson, D. T., Zhang, Y., Hannan, M. T., & Anderson, J. J. (2009). Effects of weight and body mass index on bone mineral density in men and women: The framingham study. *Journal of Bone and Mineral Research*, *8*(5), 567–573. https://doi.org/10.1002/jbmr.5650080507

Hou, J., He, C., He, W., Yang, M., Luo, X., & Li, C. (2020). Obesity and Bone Health: A Complex Link. *Frontiers in cell and developmental biology*, *600181* (8), 1-16. https://doi.org/10.3389/fcell.2020.600181

Iwaniec, U. T., & Turner, R. T. (2016). Influence of body weight on bone mass, architecture and turnover. *Journal of Endocrinology*, *230*(3), 115–130. https://doi.org/10.1530/joe-16-0089

Johns Hopkins Arthritis Center. (2022, August 1). *Osteoarthritis: Role of body weight in osteoarthritis - Weight management*. https://www.hopkinsarthritis.org/patient-corner/disease-management/role-of-body-weight-in-osteoarthritis/#:~:text=Overweight%20women%20have%20nearly%204,or%20obesity%20and%20knee%20OA.

King, A. P., & Eckersley, R. J. (2019). Inferential Statistics IV: choosing a hypothesis test. In *Statistics for Biomedical Engineers and Scientists* (p. 147–171). Academic Press. https://doi.org/10.1016/b978-0-08-102939-8.00016-5

Larsen, C. S. (2002). Bioarchaeology: The Lives and Lifestyles of Past People. *Journal of Archaeological Research*, 10(2), 119–166. https://doi.org/10.1023/a:1015267705803

Lewis, M. E. (2002). Impact of industrialization: Comparative study of child health in four sites from medieval and postmedieval England (A.D. 850-1859). *American Journal of Physical Anthropology*, *119*(3), 211–223. https://doi.org/10.1002/ajpa.10126

Mant, M., & Roberts, C. A. (2014). Diet and Dental Caries in Post-Medieval London. *International Journal of Historical Archaeology*, *19*(1), 188–207. https://doi.org/10.1007/s10761-014-0286-x

McDonald, J. H. (2014). *Handbook of Biological Statistics (3rd ed.).* Sparky House Publishing. https://www.biostathandbook.com

Mosley, J. (2000). Osteoporosis and bone functional adaptation: Mechanobiological regulation of bone architecture in growing and adult bone, a review. *Journal of Rehabilitation Research and Development*, 37(2), 189–199. https://pubmed.ncbi.nlm.nih.gov/10850825

Museum of London Archaeological Services. (2009, 20 February). *Chelsea Old Church (post-medieval) cemetery summary.* Museum of London. https://www.museumoflondon.org.uk/collections/other-collection-databases-and-libraries/centre-human-bioarchaeology/osteological-database/post-medieval-cemeteries/chelsea-old-church-post-medieval

Museum of London Archaeological Services. (n.d.). *Post-medieval cemetery data - Chelsea Old Church.* Museum of London. https://www.museumoflondon.org.uk/collections/other-collection-databases-and-libraries/centre-human-bioarchaeology/osteological-database/post-medieval-cemeteries/post-medieval-cemetery-data

National Institute of Arthritis and Musculoskeletal and Skin Diseases. (2022, November). *Arthritis.* U.S. Department of Health and Human Services, National Institutes of Health. https://www.niams.nih.gov/health-topics/arthritis#:~:text=%22Arthritis%22%20literally%20means%20joint%20inflammation,skin%2C%20can%20also%20be%20affected.

Nielson, C. M., Srikanth, P., & Orwoll, E. S. (2011). Obesity and fracture in men and women: An epidemiologic perspective. *Journal of Bone and Mineral Research*, *27*(1), 1–10. https://doi.org/10.1002/jbmr.1486

Norman B. Leventhal Map & Education Center. (n.d.). *Fairburn's map of the country twelve miles round London*. Boston Public Library. https://collections.leventhalmap.org/search/commonwealth:q524n379w

Pini, S. F., Sgaramella, G. A., Pariente-Rodrigo, E., Ramos-Barron, M. A., Olmos-Martínez, J. M., & Hernández-Hernández, J. L. (2020). Trabecular bone score and bone turnover markers in men with DISH: Data from the Camargo Cohort study. *Seminars in Arthritis and Rheumatism*, *50*(6), 1521–1524. https://doi.org/10.1016/j.semarthrit.2020.01.008

Pomeroy, E., Macintosh, A. A., Wells, J. C. K., Cole, T. J., & Stock, J. T. (2017). Relationship between body mass, lean mass, fat mass, and limb bone cross-sectional geometry: Implications for estimating body mass and physique from the skeleton. *American Journal of Physical Anthropology*, *166*(1), 56–69. https://doi.org/10.1002/ajpa.23398

Powers, N. (ed), 2012. *Human osteology method statement*. London: Museum of London, 1-64.

Roberts, C. A., & Manchester, K. L. (2010). *The Archaeology of Disease* (3rd ed.). The History Press. http://ci.nii.ac.jp/ncid/BA47103474 (Original work published 1995)

Ruff, C. B., Scott, W. K., & Liu, A. Y. (1991). Articular and diaphyseal remodeling of the proximal femur with changes in body mass in adults. *American Journal of Physical Anthropology*, *86*(3), 397–413. https://doi.org/10.1002/ajpa.1330860306

Ruff, C. B., Holt, B., Niskanen, M., Sládek, V., Berner, M., Garofalo, E., Garvin, H. M., Hora, M., Maijanen, H., Niinimäki, S., Salo, K., Schuplerová, E., & Tompkins, D. (2012). Stature and body mass estimation from skeletal remains in the European Holocene. *American Journal of Physical Anthropology*, 148(4), 601–617. https://doi.org/10.1002/ajpa.22087

Shapses, S. A., Pop, L. C., & Wang, Y. (2017). Obesity is a concern for bone health with aging. *Nutrition Research*, *39*, 1–13. https://doi.org/10.1016/j.nutres.2016.12.010

Traditional Anatomical Drawings and Artwork — Artista Medico/ Medical Artist. (n.d.). Artista Medico/ Medical Artist. Retrieved May 13, 2022, from https://www.artistamedico.com/anatomicalart-louisehinman-brighton-london-barcelona

Waldron, T. (2008). *Palaeopathology.* Cambridge University Press. https://doi.org/10.1017/cbo9780511812569

White, T. D., & Folkens, P. A. (2005a). Chapter 15: Leg: Femur, Patella, Tibia, & Fibula. In *The Human Bone Manual* (pp. 255–286). Elsevier Academic Press. https://doi.org/10.1016/c2009-0-00102-0

List of Tables

List of Figures

Appendices

Appendix 1 The Data Set Abbreviation Explanation

As mentioned in §3.1 (Chelsea Old Church): this data set has been derived from the MoLAS opensource available data set that contains the data of the skeletal population of the Post Medieval site: Chelsea Old Church (Bekvalac & Kausmally, 2009).

Abbreviation\Heading	Explanation of Indication
Context	Contextual code of the individual, coded by Museum of Archaeology Archaeological Services (MoLAS) (Bekvalac & Kausmally, 2009).
Sex	The sex of the individual of context #, as estimated by MoLAS (Bekvalac & Kausmally, 2009).
FHB-L (mm)	Left Femoral Head Breadth in millimeters, measured by MoLAS (Bekvalac & Kausmally, 2009).
FHB-R (mm)	Right Femoral Head Breadth in millimeters, measured by MoLAS (Bekvalac & Kausmally, 2009).
FHB-M (mm)	Femoral Head Breadth used for the final equation, in millimeters. It either entails the mean (for when the metric data of the left and right femur were available) or the measurement of the singular available side. Based on the metric measurements of MoLAS (Bekvalac & Kausmally, 2009).
BM (kg)	Body Mass calculated from FHB-M by using the sex specific Ruff et al. (2012) Formula, in kilogram.
OA	Osteoarthritis - pathology derived from the MoLAS data set (Bekvalac & Kausmally, 2009).
GOUT	Gout - pathology derived from the MoLAS data set (Bekvalac & Kausmally, 2009).
DISH	Diffuse Idiopathic Skeletal Hyperostosis - pathology derived from the MoLAS data set (Bekvalac & Kausmally, 2009).

Appendix 2 The Data Set - First Half - Male Selection

Context #	SEX	FHB-L (mm)	FHB-R (mm)	FHB-M (mm)	BM (kg)	OA	GOUT	DISH
20	Male	48.3	49.2	48.75	69.80	No	No	No
35	Male	45.0	45.7	45.35	60.28	**Yes**	**Yes**	No
43	Male	47.2	47.5	47.35	65.88	**Yes**	No	No
47	Male	48.0	48.0	48.00	67.70	No	No	No
100	Male	48.2	48.0	48.10	67.98	No	No	No
143	Male	50.3	49.1	49.70	72.46	No	No	**Yes**
147	Male	52.2	53.8	53.00	81.70	**Yes**	No	No
154	Male	46.9	47.1	47.00	64.90	No	No	No
188	Male	52.7	50.3	51.50	77.50	**Yes**	No	No
198	Male	47.9	46.4	47.15	65.32	No	No	No
225	Male	46.7		46.70	64.06	No	No	No
258	Male	40.7	40.4	40.55	46.84	No	No	No
261	Male		48.8	48.80	69.94	No	No	No
281	Male	49.4	48.5	48.95	70.36	No	No	No
285	Male	43.2	43.1	43.15	54.12	No	No	No
311	Male	53.3		53.30	82.54	No	No	No
323	Male	46.5	46.0	46.25	62.80	**Yes**	No	No
339	Male	43.7	45.6	44.65	58.32	No	No	No
343	Male	49.0		49.00	70.50	No	No	No
349	Male		50.0	50.00	73.30	No	No	No
359	Male		49.1	49.10	70.78	No	No	No
400	Male		42.2	42.20	51.46	No	No	No
411	Male		48.3	48.30	68.54	No	No	No
432	Male	47.0	46.3	46.65	63.92	**Yes**	No	No
460	Male	46.4	46.7	46.55	63.64	No	No	No
462	Male		48.3	48.30	68.54	No	No	No
485	Male	52.0		52.00	78.90	**Yes**	No	No
494	Male	49.7	49.7	49.70	72.46	No	No	No
507	Male	50.0	48.7	49.35	71.48	No	No	No
516	Male	50.0	49.4	49.70	72.46	No	No	No
525	Male	46.8	48.1	47.45	66.16	**Yes**	No	**Yes**
527	Male	46.6	46.4	46.50	63.50	**Yes**	No	No
532	Male	42.2	44.0	43.10	53.98	No	No	No
544	Male	47.2		47.20	65.46	No	No	No
593	Male		46.2	46.20	62.66	**Yes**	No	No
635	Male		46.7	46.70	64.06	No	No	No
654	Male	45.4	47.0	46.20	62.66	**Yes**	No	No
668	Male	50.2	50.3	50.25	74.00	**Yes**	**Yes**	No
713	Male	47.2	48.5	47.85	67.28	**Yes**	No	No
734	Male	50.3		50.30	74.14	**Yes**	No	No
744	Male	48.1		48.10	67.98	No	No	No
750	Male		46.6	46.60	63.78	No	No	**Yes**
759	Male	49.2	49.4	49.30	71.34	No	No	No
782	Male	43.6	45.6	44.60	58.18	No	No	No
805	Male	48.7	48.6	48.65	69.52	No	No	No
810	Male		46.2	46.20	62.66	No	No	No
819	Male	46.0	46.0	46.00	62.10	No	No	No
836	Male	48.0		48.00	67.70	No	No	No
856	Male	44.4	43.7	44.05	56.64	**Yes**	No	No
898	Male	50.6	49.4	50.00	73.30	**Yes**	No	No
948	Male	48.3	47.6	47.95	67.56	**Yes**	No	No
951	Male		42.9	42.90	53.42	No	No	No
994	Male	48.9	46.7	47.80	67.14	No	No	**Yes**
1004	Male	42.2	46.4	44.30	57.34	No	No	No
1018	Male	48.4	48.3	48.35	68.68	No	No	No
1021	Male	52.3	51.8	52.05	79.04	**Yes**	No	**Yes**
1068	Male	46.0	47.5	46.75	64.20	No	No	No
1071	Male	42.1	42.0	42.05	51.04	No	No	No
1157	Male		48.4	48.40	68.82	No	No	No

Appendix 3 The Data Set - Second Half - Female Selection

Context #	SEX	FHB-L (mm)	FHB-R (mm)	FHB-M (mm)	BM (kg)	OA	GOUT	DISH
18	Female	39.7	40.2	39.95	51.28	No	No	No
19	Female		41.5	41.50	54.66	**Yes**	No	No
31	Female	42.2	42.0	42.10	55.97	No	No	No
39	Female	40.1	40.6	40.35	52.15	**Yes**	No	No
92	Female	43.9	42.5	43.20	58.37	No	No	No
96	Female		43.5	43.50	59.02	**Yes**	No	No
104	Female	38.8	39.4	39.10	49.43	No	No	No
115	Female	39.4	40.4	39.90	51.17	No	No	No
152	Female	42.9	43.3	43.10	58.15	No	No	No
161	Female	42.6	43.3	42.95	57.82	No	No	No
218	Female	43.2	43.1	43.15	58.26	**Yes**	No	No
232	Female	42.6	42.0	42.30	56.40	No	No	No
248	Female	40.3	40.7	40.50	52.48	No	No	No
274	Female	42.0	42.8	42.40	56.62	No	No	No
301	Female	43.8		43.80	59.67	No	No	No
303	Female	43.9		43.90	59.89	No	No	No
363	Female	39.6	38.7	39.15	49.54	No	No	No
392	Female	40.0	40.5	40.25	51.94	No	No	No
407	Female	41.2	40.8	41.00	53.57	**Yes**	No	No
436	Female	44.0	44.7	44.35	60.87	**Yes**	No	No
446	Female	40.2		40.20	51.83	No	No	No
474	Female	44.0	43.7	43.85	59.78	**Yes**	No	No
483	Female	44.4	44.7	44.55	61.31	No	No	No
523	Female	42.0	42.2	42.10	55.97	No	No	No
552	Female	41.6	41.3	41.45	54.55	No	No	No
565	Female	45.2	45.5	45.35	63.05	No	No	No
583	Female	46.1	47.0	46.55	65.67	**Yes**	No	No
587	Female	41.6	41.3	41.45	54.55	**Yes**	No	No
597	Female		46.0	46.00	64.47	**Yes**	No	No
600	Female	45.0	46.2	45.60	63.60	No	No	No
612	Female	44.6	45.2	44.90	62.07	No	No	No
628	Female	46.6		46.60	65.78	No	No	No
632	Female		39.8	39.80	50.95	No	No	No
638	Female	45.0		45.00	62.29	**Yes**	No	No
697	Female	43.6	43.3	43.45	58.91	No	No	No
716	Female	45.4	47.3	46.35	65.23	**Yes**	No	**Yes**
722	Female	40.5	41.1	40.80	53.13	**Yes**	No	No
730	Female	39.1		39.10	49.43	**Yes**	No	No
754	Female	42.0	42.6	42.30	56.40	No	No	No
790	Female	44.4	46.0	45.20	62.73	No	**Yes**	No
792	Female	40.0	39.6	39.80	50.95	**Yes**	No	No
802	Female	41.6	42.3	41.95	55.64	No	No	No
812	Female	41.0	41.8	41.40	54.44	No	No	No
841	Female	43.1	41.3	42.20	56.19	**Yes**	No	No
885	Female		38.6	38.60	48.34	No	No	No
888	Female	47.6		47.60	67.96	**Yes**	No	No
892	Female		42.1	42.10	55.97	No	No	No
910	Female	41.5	40.7	41.10	53.79	**Yes**	No	No
918	Female	41.9	40.6	41.25	54.12	No	No	No
980	Female	48.7		48.70	70.36	No	No	No
990	Female		42.5	42.50	56.84	No	No	No
1001	Female	46.4	45.3	45.85	64.14	No	No	No
1014	Female	41.0		41.00	53.57	No	No	No
1016	Female	41.9		41.90	55.53	No	No	No
1023	Female	43.6	43.8	43.70	59.46	No	No	No
1126	Female	38.4	39.0	38.70	48.56	**Yes**	No	No
1140	Female	43.1		43.10	58.15	No	No	No
1175	Female	49.7	43.6	46.65	65.89	No	No	No