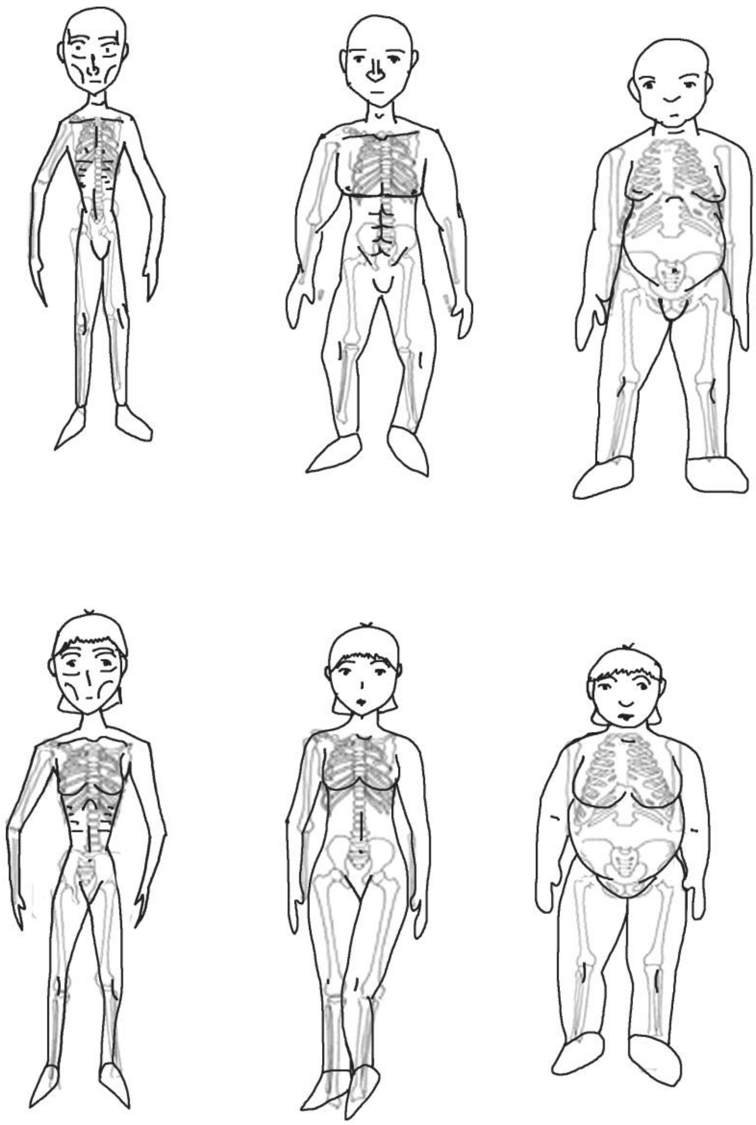
**Body Mass in the 19th Century Skeletal Population of Middenbeemster, The Netherlands**



Kirsten A. Ziesemer BSc

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Kirsten A. Ziesemer BSc

Zuiderweg 175

1461 GJ Zuidoostbeemster

k.ziesemer@hotmail.com

06-55326396

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| Name: | Kirsten Annika Ziesemer BSc |
| Course: | MSc Thesis (1040X3053Y) |
| Student number: | s1264788 |
| Name supervisor(s): | Dr. M.L.P. Hoogland |
| Specialization: | Human Osteology and Funerary Archaeology |
| University: | University of Leiden, Faculty of Archaeology |
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Kirsten

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# Chapter 1. Introduction

The adult human skeleton consists of 206 bones which act as a reservoir of calcium (Sadava *et al.* 2007, 1017). Furthermore, the skeleton provides support for muscles, protects many organs, permits movement and plays a role in blood cell production and endocrine regulation (Sadava *et al.* 2007, 1017). During running, a human loads the bones at the knee joint with a force in excess of five times the weight of the entire body (White and Folkens 2005, 33). Yet, despite its great strength bone is very lightweight material (White and Folkens 2005, 33). Therefore, bones are one of the strongest biological materials in existence, made up of protein (collagen) and mineral (hydroxyapatite) which act as building blocks for the skeleton (White and Folkens 2005, 33).

Every skeleton requires certain building blocks, basic organic molecules, that it cannot synthesize for itself. These building blocks can be derived from the metabolism of almost any food (Sadava *et al.* 2007, 1072). The lack of essential nutrients in the diet produces a state of deficiency called malnutrition, and chronic malnutrition leads to characteristic deficiency diseases (Sadava *et al.* 2007, 1074). Alternatively, the overload of nutrition, which is stored as increased body mass, may lead to obesity. Body mass estimation from adult skeletal remains has received considerable attention, but previous research has failed to account for body mass extremes due to the restraints of research collections (Moore 2009, 2). Therefore the accuracy of estimates for age and sex, among others, are centered around average body mass, disregarding extremes of emaciation and obesity (Moore 2009, 2). The osteological profile, which contains information about the age, sex, stature, and ancestry estimations of a skeleton, would be greatly supplemented by the addition of body mass (Moore 2009, 13).

This research will study the body mass extremes in a skeletal population of an apparently wealthy rural 19$^{th}$ century area in the Netherlands; for a better understanding, the metabolic processes of bone synthesis and absorption will be discussed. Thereafter, body mass extremes will be discussed, which will cover the main aim of this research. Subsequently, pathological lesions associated with emaciation and obesity (such as anemia and vitamin deficiencies for emaciation, and DISH and osteoarthritis for obesity) will be covered. The last section will contain an introduction to the research design and methods, including research questions, used in this research.

## 1.1 Metabolic processes of bone synthesis and absorption

The skeleton appears to be a stable structure, yet bone is a dynamic organ that continuously undergoes a process called remodeling, involving bone absorption by osteoclasts and bone formation by osteoblasts (White and Folkens 2005, 31). This process is balanced, thus an increase in osteoclasts automatically means a decrease in osteoblasts (Novack and Teitelbaum 2008, 2). Bone remodeling is influenced by both mechanical factors and chemical factors (see figure 1).

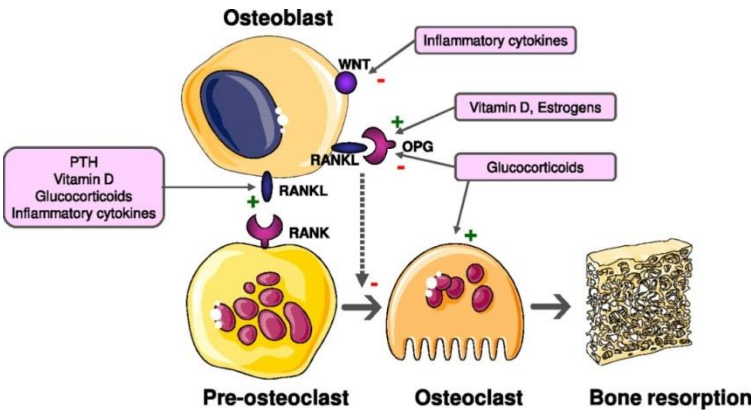


**Figure 1 RANK-RANKL pathway. Influence of chemical factors on bone metabolism. PTH: parathyroid hormone, RANK(L): Nuclear factor-κB (ligand). (After Lehouck *et al.* 2011, 2)**

On their surface, osteoblasts constitutively express the receptor activator of nuclear factor-κB ligand (RANKL). The binding of RANKL to its receptor RANK is required for the formation of osteoclasts (Lehouck *et al.* 2011, 2). Additionally, osteoblasts, but also stromal cells, secrete a soluble decoy receptor, osteoprotegerin (OPG), which blocks the RANK/RANKL interaction, thereby acting as a regulator of bone turnover (Lacey *et al.* 1998, 7). Activation of the Wnt signaling pathway (see figure 1, right side) in the osteoblast, a second pathway influencing the bone cell differentiation, up-regulates OPG, resulting in inhibition of bone absorption.

Bone absorption occurs in a non-uniform manner, even in generalized decreases, as during a space flight, with the distal leg bones experiencing the highest degree of bone loss (Collet *et al.* 1997, 3). Thus when gravity has no influence on the distal legs, or less influence, the distal legs experience the highest amount of bone loss. This can be compared to emaciation, were the distal legs experience less weight and therefore the cell differentiation is in favor of osteoclasts. On the other hand, mechanical loading stimulates bone formation by decreasing apoptosis (cell death) and increasing proliferation and differentiation of osteoblasts through the Wnt pathway (Bonewald and Johnson 2008, 2). This is comparable with obesity in an individual; more mechanical loading is carried out in an overweight individual and therefore osteoblast formation undergoes greater stimulation through the Wnt pathway.

The chemical factors for bone metabolism include hormones from nutrition, adipocyte, and more (Reid 2008, 3-5). In terms of hormones from nutrition, consuming glucose causes an increase in calcitonin and a decrease in parathyroid hormone (PTH). Hence, bone differentiation will be in favor of osteoclasts.

It has been suggested by Elefteriou *et al.* (2004, 5) that serum leptin and adiponectin levels, which are hormones secreted by adipose tissue, are regulators of bone mass. The local effects of leptin are all directed towards skeletal preservation and would be consistent with a need for individuals with a higher fat mass to have a stronger skeleton in order to support the greater weight (Reid 2008, 1). Conversely, when there is a limited amount of fat mass, there is no secretion of leptin and thus no osteoblast activity.

Most of the factors influencing bone metabolism are obtained from nutrition; therefore a deficiency or abundance of certain nutrients can result in changes in bone turnover. The change in bone turnover and the resulting change in osteoclast or –blast formation can be measured from human skeletal remains. The postcranial elements particularly, for example hips and legs, experience the most influence (Auerbach and Ruff 2004, 8-9). The femoral head and the hip body mass estimation formulae have been developed by Ruff *et al*. (1991 and 1997).

### 1.2 Body mass extremes

Although the cells of the body use energy continuously, most organisms do not eat continuously (Sadava *et al.* 2007, 1071). Therefore, they must store fuel molecules that can be released as needed between meals. Fat is the most important form of stored energy, and this energy storage is one of the main component of our body mass (Sadava *et al.* 2007, 1071). Other factors that contribute to our body mass are our skeleton, organs and other components. Body mass can be measured and compared by the Body Mass Index (BMI), which was first described in the 1860s by Adolphe Quetelet (Gropper *et al.* 2009, 279). BMI is considered to indicate body adiposity but does not measure body fat (Gropper *et al.* 2009, 279). It is calculated from a person's height and weight, with weight in kilograms, and height measured in meters and raised to a power of two, as follows:

$$BMI = \frac{Weight}{Height^2}$$

Emaciation, the lower extreme of the BMI, might affect the progression rate of age-related features. Whether BMI does affect age-related features, and the degree of this effect is important to know due to the manner in which it can effect age estimation in archaeological samples. One is considered underweight and thus emaciated when the BMI, does not exceed 18.5 kg/m$^2$ (Gropper *et al.* 2009, 280). One can be underweight due to genetics, metabolism or lack of food. It was suggested in

Roberts and Manchester (2007, 39) that malnutrition during growth may cause growth retardation. This may cause the individual's age to be underestimated.

Not only is it important to know whether emaciation affects the progression rate, it is also important to know how being overweight or even obesity influence the progression rate of age-related features. Over one third (35.7%) of the population of the United States of America is suffering from obesity (see figure 2). An individual is classified as morbidly obese when their BMI, reaches 30 kg/m$^2$ (Gropper *et al.* 2009, 280). With a still increasing number of obese individuals, the representation of obesity in forensic cases will increase as well (Wescott and Drew 2013). Therefore it is important to know whether obesity affects the rate of progression through the age-related stages of pubic symphysis and auricular surface morphology.

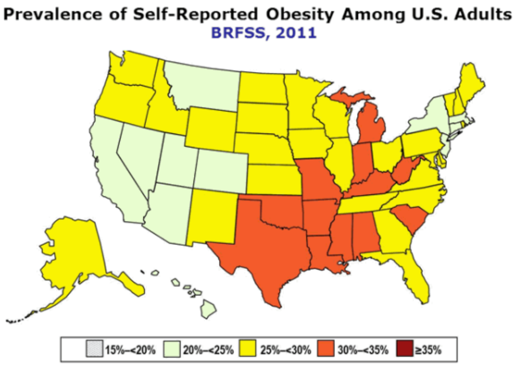


**Figure 2 Prevalence of self-reported obesity among U.S. Adults (2011). Obesity is a widespread problem among U.S. adults and already an average of 35.7% is suffering from obesity. (After Center for Disease Control and Prevention 2011)**

### 1.3 Prevalence of body mass extremes in Middenbeemster

The prevalence of body mass extremes in the Middenbeemster collection will be analyzed to establish what proportion of the skeletal population of Middenbeemster has an extreme body mass. The inhabitants of Middenbeemster possibly suffered from a potato famine, which could have caused malnourishment. However, this was only temporarily and therefore it could be that the resulting metabolic processes had not enough time to influence the skeletons of the affected individuals. Furthermore, it could be expected that older individuals have a higher BMI, possibly in the obese range, since they stopped their labour and may have continued to ingest the same amount of nutrition (personal communication, Dr. M.L.P. Hoogland). Therefore, the influence of an excessive body weight on age-related features is important for past societies, as well as for present societies.

Starvation is still a familiar sight today in the less developed areas of the world, particularly where the rainfall level is critical (Roberts and Manchester 2007, 221). Furthermore, starvation is not merely seen in less developed areas, it can also be seen in the less prosperous individuals of the developed areas, for example drug addicts or in affluent areas in individuals with eating disorders

(Goldstein 2001, 10). However, this research is not only relevant for present societies and forensic implications. It is often assumed that there is a fine line between subsistence and starvation in past societies (Roberts and Manchester 2007, 221). Therefore, this research would be relevant for both archaeological and forensic implications. Research performed by Cowgill *et al*. (2012, 567) showed that nutritionally stressed Kulubnarti infants, compared to other groups, displayed the lowest subadult postcranial robusticity.

### 1.4 Aim and relevance of this research

The aim of this study was firstly to study the prevalence of body mass extremes in the Middenbeemster skeletal population during the late 19$^{th}$ century. Secondly, the aim of this study was to establish the influence of body mass on two age-related features, namely the pubic symphysis and the auricular surface of the same skeletal population. The focus of influence of body mass has been on the body mass extremes. Thirdly, the aim of this study was to test the correlation between pathological lesions caused by diseases known to be associated with either one of the body mass extremes and the body mass of the skeletal population of Middenbeemster.

The body mass of a rural 19$^{th}$ century skeletal population has not been studied before; not in this time period and not in this area. Therefore, this research will be an important contribution to the extensive knowledge about this specific skeletal population. Furthermore, besides the addition to information about this skeletal population, this study will also be a contribution to general knowledge on the influence of body mass on age indicators. The influence of body mass on age indicators is especially relevant for forensic cases, but also for the identification of, for example, soldiers who need to be identified to bring them home to their kin. Obviously, in such cases, proper identification is imperative.

The determination of accuracy and precision of body mass estimation may also be of relevance for other archaeological research regarding body mass, especially that of early hominids, which has been proven to be very difficult to determine. The body mass of early hominids may be indicative of many biological relationships including adaptive, morphological, physiological, and metabolic ones (Porter 2002, 26).

Furthermore, for many analyses, body mass estimation remains the most reasonable 'size' parameter to use in evaluating other characteristics, such as long bone robusticity and relative organ size (Ruff 2000, 508). Body size estimation can also be made in living individuals, thus a large data set of comparative behavioural, physiological, and ecological data relative to body mass is available (Ruff 2000, 508). Finally, because skeletal material is usually fragmentary and the specific elements recovered may vary, use of a single variable (body mass) allows comparisons of body size or relative size between recovered individuals (Ruff 2000, 508).

### 1.5 Pathological lesions associated with emaciation

Body mass affects the skeleton as a continuum from obesity at one extreme and emaciation at the other (Moore 2009, 87). The skeleton continually strives to maintain enough bone to be strong enough for support, but light enough for locomotion (Moore 2009, 87). The reduced load bearing capability associated with emaciation causes bone atrophy and the absorption of minerals. Hence, emaciated individuals will suffer from pathological bone lesions. However, there will be an absence of hypertrophic pathological lesions in conjunction with low bone mineral density.

Previous research has suggested that body mass does influence age-related features; therefore, osteologists could make more accurate osteological profiles when they have been adjusted for body mass. This could be done by looking at the pathological lesions associated with body mass extremes. If present, they would be indicative of an extreme body mass and hence that the age estimation and the entire skeletal profile should be made with care. Furthermore, susceptibility to disease may be enhanced by poor nutrition, a depressed immune status and poor absorption of nutrients (Roberts and Manchester 2007, 39). The following pathological lesions could aid in the recognition of emaciation.

#### *1.5.1 Anemia*

Red blood cells (RBCs) transport oxygen throughout the body. Oxygen is transported by its attachment to the iron molecule of hemoglobin. When the circulating hemoglobin is lower than the standard, a state of anemia is present (Aufderheide and Rodríguez-Martin 1998, 346). Anemia results from three mechanisms: blood loss, as well as a decreased production rate or increased destruction rate of hemoglobin synthesis (Aufderheide and Rodríguez-Martin 1998, 346). Acute blood loss is usually temporary and does not lead to bone changes (Aufderheide and Rodríguez-Martin 1998, 346). However, decreased production and increased destruction rate do lead to bone changes.

Decreased hemoglobin synthesis might occur due to iron insufficiency. The low level of hemoglobin in the blood provides a stimulus to increase RBC production. Therefore individuals suffering from iron-deficient anemia have subnormal blood hemoglobin levels but their marrow is continuously expanding in response to the RBC production stimulus (Aufderheide and Rodríguez-Martin 1998, 347).

Thalassemia is a group of anemias caused by a variety of genetic mutations at sites of the gene encoding for the structure of the hemoglobin. The consequence is that the formation of RBCs will be affected, ranging from severe to mild (Aufderheide and Rodríguez-Martin 1998, 347). The affected RBCs will be recycled for new RBC production, leading to an enormous increase in RBC turnover rate.
Anemias due to increased RBC destruction are, for example, sickle cell anemia and hereditary spherocytosis (Aufderheide and Rodríguez-Martin 1998, 348). The former leads to abnormal RBCs which look like elongated, crescent moons. The latter produces RBCs in the form of rigid spheres. The abnormal RBCs of sickle cell anemia will be recognized and removed, however this leads to an enormous replacement burden since the newly formed cells will still be formed as a sickle cell (Aufderheide and Rodríguez-Martin 1998, 348). Therefore the cells will continue to be replaced and will not enter the bloodstream. The sickle cell RBCs that escape the removal and do enter the bloodstream, cannot penetrate through blood vessels, forming aggregates large enough to block the blood flow (Aufderheide and Rodríguez-Martin 1998, 347). Blocking of the blood flow then causes necrosis (Aufderheide and Rodríguez-Martin 1998, 347).

Symptoms of anemia are, among others, cribra orbitalia and porotic hyperostosis. Porotic hyperostosis is characterized by cranial vault lesions, usually on the frontal and parietal and, to a lesser extent, on the occipital bone (Aufderheide and Rodríguez-Martin 1998, 347). Cribra orbitalia is similar, but smaller and located in the orbital roof (Aufderheide and Rodríguez-Martin 1998, 347).

**Figure 3 Individual 1600613 affected with Cribra Orbitalia, housed at the Osteoarchaeology lab, Leiden (Ziesemer 2013).**

### *1.5.2 Tuberculosis*

Tuberculosis is a chronic infectious disease that is caused by a bacterium, *Mycobacterium tuberculosis*. The result of infection may be bone and joint destruction (White and Folkens 2005, 318). The most commonly affected bones are the vertebrae of the vertebral column, which can collapse, resulting in kyphosis (White and Folkens 2005, 318; see figure 4). However, since tuberculosis spreads to the bone from its original entry into the body through the bloodstream and lymphatic system, it is most likely that there are more bone elements involved than merely the vertebral column (Roberts and Manchester 2007, 187). The changes in the spine are usually found in the lower thoracic and lower lumbar vertebrae; tuberculosis may also be complicated by an abscess in the psoas muscle anterior to the spine.

**Figure 4 Tuberculosis of the spine, also known as Pott's deformity with stabilization by new bone formation due to healing in a modern adult. (After Aufderheide and Rodríguez-Martin 1998, 136)**

The inflammatory cytokines, which help the immune system fight the inflammation, stimulate the RANK-RANKL pathway in favour of osteoclast differentiation. Therefore the major focus of tuberculosis infection will be on bone loss. However, pulmonary conditions may also result in rib lesions and bone formation on the sternal rib ends and shafts (Roberts and Manchester 2007, 191).

In agriculture, the reduced population mobility and increased aggregation provide conditions that promote the spread and maintenance of infectious diseases and the increase in pathogen load in humans (Larsen 1995, 198). More crowded living conditions facilitate greater physical contact between members of a settlement, and permanent occupation can result in decreased sanitation and hygiene. Therefore, more densely settled agricultural societies were more prone to infection than less densely settled agricultural societies (Larsen 1995, 199). Middenbeemster has been known as a dense agricultural settlement and could therefore be prone to infectious diseases.

### *1.5.3 Vitamin deficiencies*

Vitamins are small molecules that are not synthesized by the human body and must be acquired from the diet (Sadava *et al.* 2007, 57). Deficiency of a particular vitamin may lead to symptoms which are diagnostic of malnutrition. These diagnostic markers are still present on the human skeletal remains, since vitamin deficiency might influence the RANK-RANKL pathway. Vitamin D and C deficiencies leave the most apparent markers on bone.

Lack of vitamin D availability may cause skeletal deformations characterized by a metabolic defect in mineralization of bone at sites of endochondral bone formation (Aufderheide and Rodríguez-Martin 1998, 305). In children the effects of vitamin D deficiency are called rickets, and in adults, osteomalacia (Aufderheide and Rodríguez-Martin 1998, 305). Vitamin D works, as seen in figure 6, through the RANKL-RANK pathway in favor of osteoclast differentiation. Furthermore, calcification of the cartilage at sites of endochondral bone ossification is dependent on vitamin D. Therefore the manifestations will be maximal in growing infants and children (Aufderheide and Rodríguez-Martin 1998, 306). The clinical outcomes of vitamin D deficiency are deformed, shortened, and bowed long bones (Aufderheide and Rodríguez-Martin 1998, 307).

**Figure 5 Tibia of individual 5181086 probably affected with a vitamin D deficiency, housed at the osteoarchaeology lab, Leiden (Kerkhoff 2012).**

Scurvy is a condition caused by the lack of vitamin C, resulting in defective collagen synthesis with consequent skeletal growth retardation and hemorrhagic phenomena (Aufderheide and Rodríguez-Martin 1998, 310). Lack of Vitamin C does not affect either one of the bone cells; instead, vitamin C deficiency causes lack of blood vessel wall integrity resulting in hemorrhages (Aufderheide and Rodríguez-Martin 1998, 310). The severely affected individuals will also suffer from anemia (Waldron *et al.* 1998, 310). When the hemorrhage is of substantial size, the bone structure will appear more porous than healthy bone (Aufderheide and Rodríguez-Martin 1998, 311). An example of porous bone is cribra orbitalia, as seen in anemia (figure 4).

### 1.6 Pathological lesions associated with obesity

Emaciation could cause potential hazards for the strength of the bone, while obesity might cause problems with locomotion (Moore 2009, 87). Obesity is recognized as a risk factor for osteoarthritis

(Moore 2009, 8). Furthermore, Diffuse Idiopathic Skeletal Hyperostosis (DISH) is highly correlated with a high protein diet (Moore 2009, 8). The following pathological lesions could aid in the recognition of overweight individuals.

### *1.6.1 Osteoarthritis*

Osteoarthritis (OA) is the most common form of arthritis and results from mechanical and biological events that involve synovial joints (knee, elbow e.g.). With an increase in BMI, the load on the joints increases as well, leading to a higher risk of injury (Ford *et al.* 2005). OA occurs because of repeated injury to the joint capsule, which is often the case in joints that are regularly overloaded by weight and consequently permits bone-to-bone movement (Aufderheide and Rodríguez-Martin 1998, 93). OA of the knees could be a mechanism to create more surface area to increase the compressive strength at the joint leading to knee malignment in overweight individuals (Moore *et al.* 2009, 88). Furthermore, obese individuals are more likely to have hand and wrist OA, because the arms play a major role in locomotion (Holmberg *et al.* 2005; Hough, Jr. 1993; Moskowitz, 1993 and Oliveria *et al.* 1998). An example of the role of upper limbs in locomotion is a sit-to-stand exercise in which an overweight individual would use his/her upper limbs to lift the extreme body mass from the seated position.

Malalignments of the knee, as mentioned above, are common in overweight individuals. The knees can be either knock-kneed (*genua valgus*) or bow-legged (*genua varus*). To compensate for the increased body mass, the knees bend in such a way that the angle from hip to patella exceeds 17°, whereas the normal degree of bending is 10-14° in men and 14-17° in women.

**Figure 6 Individual 2430381 eburnation on the distal end of the ulna indicative of OA of the wrist, housed at the osteoarchaeology lab, Leiden (Silberman 2013).**

### *1.6.2 Diffuse Idiopathic Skeletal Hyperostosis (DISH)*

DISH, also known as Forestier's disease, is a combination of ankylosis of the spine and ossification of muscle attachments throughout the body. The clinical outcome of this pathology on the spine resembles candle wax melting and flows along the right anterior of the spinal column. The left side is only affected when the congenital condition *situs inversus* is present. In this condition the major visceral organs are all or partially reversed or mirrored from their normal position (Sadava et al. 2007, 1051). When *situs inversus* is not present, the right side is affected since the descending aorta is positioned on the left side.

DISH produces ankylosis and is not a true arthropathy because neither cartilage nor synovium are involved (Aufderheide and Rodríguez-Martin 1998, 97). This pathology is rarely detected before 40 years of age and clinical symptoms are rare, although more than half of the autopsies show some degree of the change associated with DISH (Aufderheide and Rodríguez-Martin 1998, 97).

**Figure 7 Individual 3490752 probably affected with DISH, housed at the osteoarcheology lab, Leiden (Ziesemer 2013).**

## 1.7 Research design and methods

### 1.7.1 Research questions

- What is the prevalence of body mass extremes in the Middenbeemster skeletal population of the 19th century?
  - What is the difference in BMI of males and females of the skeletal population of Middenbeemster?
- What is the influence of body mass on the age-related features, pubic symphysis, and auricular surface in the Middenbeemster skeletal population of the 19th century?
- What is the correlation between the diseases known to be associated with body mass extremes and the body mass of the Middenbeemster skeletal population of the 19th century?

### 1.7.2 Research sample

In the summer of 2011, the church of Middenbeemster, the Netherlands needed construction work. In cooperation with a Dutch archaeological company, Hollandia, the laboratory of human osteoarchaeology of the University of Leiden excavated the cemetery, and approximately 450 individuals were found. The research sample consists of a total of 39 identified and 90 unidentified individuals from this 19th century cemetery. The identified skeletal remains were examined for body mass estimation (see chapter 1.6.1.) and age estimation (see chapter 1.6.2.) to study the influence of body mass on two age-related features. The unidentified skeletal remains were also examined to study the prevalence of body mass extremes and the correlation of body mass with diseases known to be associated with body mass extremes.

### 1.7.3 Body mass estimations

At the heart of any attempt to reconstruct behaviour, or in this case body mass from skeletal remains, is the concept that bone is adapted to its environment during life (Katzenberg and Saunders 2008, 183). If bone is not responsive, then its preserved morphology after death will not reflect accurately the particular loadings it was subjected to (Katzenberg and Saunders 2008, 183). The general concept that mechanical loading influences bone structure is often referred to as 'Wolff's law' (Katzenberg and Saunders 2008, 183). Ruff *et al*. (2006, 484) adapted this law in a feedback model, which illustrated bone functional adaptation. It is based on the mechanical deformation, or strain, of bone tissue under mechanical loading. Increased strain, for example, through an increase in body mass stimulates the deposition of new bone tissue, which strengthens the bone and reduces strain to its original level (Ruff *et al.* 2006, 485).

It has been generally agreed that postcranial features, which have a more direct relationship to overall body size, produce the most accurate estimates in body mass (Auerbach and Ruff 2004, 8-9). In this study, the body mass estimation of the identified individuals was measured by both stature/Bi-iliac Breadth (STBIB) and femoral head diameter. STBIB alone works well for both highly active and sedentary normal weight individuals. Nevertheless, STBIB fails to account for body mass extremes (Moore 2009, 2). The unidentified individuals have only been measured by femoral head diameter.

The femoral head diameter is often well-preserved and accurate measurements can be obtained. Three sets of body mass estimation formulae have been available from studies of modern humans with known body masses (Ruff *et al.*, 1991; McHenry, 1992; Grine *et al.*, 1995). The formulae as proposed by Ruff *et al*. (1991) were deemed the most appropriate for this study and have therefore been applied accordingly.

### 1.7.4 Age estimations

The morphological indicators of age are relatively easy to apply, require no special equipment, and are non-destructive (Meindl and Russelll 1998, 384). However, their application requires an understanding of anatomy, development, and physiology of the soft tissues associated with the bony markers in order to understand normal variation in the age-related features and to discriminate outliers, pathologies, and post-mortem damage (Meind and Russel 1998, 384).

Two of the most commonly used approaches for estimating adult age-at-death have been carried out. These approaches consist of examining age-progressive morphological changes in the auricular surface of the ilium (*i.e.,* the iliac side of the ilium-sacrum articulation; Buckberry and Chamberlain 2002) and the symphyseal face of the pubic bone (*i.e.,* the surface of the pubic bones where the two pelvic bones most closely approach each other; Brooks and Suchey 1990). Both anatomical regions are influenced by life history events (*e.g.*, diet, disease, physical activity) and therefore the rate of progression through these stages can vary, especially at the population level (Hoppa 2000, 6).

### 1.7.5 Statistical analysis

Statistical analysis showed whether the expected difference in age estimation and actual age-at-death are significant or not. These analyses were adjusted for sex to retrieve the most accurate significance.

This study has compared three groups: the underweight, normal weight and overweight individuals. The first statistical analysis has been the comparison between the actual age at death and the age-at-death estimated from the pubic symphysis and auricular surface in all three groups. However, there were not any underweight individuals in the research sample. Therefore, the statistical test performed was a paired samples T-test to determine the difference between the true age at death and the estimated age at death for the normal and overweight group only, with the Statistical Package for the Social Sciences (SPSS). The result was recorded as whether or not the estimated age differs significantly from the true age-at-death. The hypothesis was that this analysis would be significant for the underweight group and overweight group and would not be significant for the normal weight group. The paired samples T-test was done before and after correction for BMI to exclude the possibility of difference due to chance.

This study also tested whether the difference among males and females in the Middenbeemster skeletal population has been significant. The test most appropriate was deemed to be the independent samples T-test.

Furthermore, pathological lesions associated with body mass extremes have been studied. Particular attention has been paid to noting whether the pathological lesions known to be associated with body mass extremes are associated with the body mass extremes from the Middenbeemster individuals as well. This was carried out with a Pearson *r* correlation test with SPSS. The result of this test was hypothesized to be closer to 1.0 than to 0.0, because it was expected that there would be a correlation between BMI and diseases known to be associated with certain variations in BMI. Due to the low frequency of the scored pathological lesions, merely the correlation of BMI with DISH and Osteoarthritis have been tested.

Prior to all tests, a Levene's test for equality was performed. This test is indicative of the assumption of equal variances, and normal statistics can only be done when the Levene's test is not significant.

### 1.7.6 Confounding factors

Beforehand, the confounding factors that might interfere with the results of this research have been analysed. The potential biases were primarily centred around the weight and stature estimations. The actual weight information from the skeletal population is unknown. Therefore, the accuracy and precision of the used formulae provided by Ruff *et al*. (1991 and 1997) is a potential confounding factor. Furthermore, for the statistical analysis, merely the mean of all estimations has been used. Therefore the age estimations may produce a distribution reflecting the skeletal reference population upon which the ageing method was based, rather than the age structure of the cemetery being analyzed (Meindl and Russell 1998, 383). Hence, special care had to be taken when interpreting the results.

Although the pathological lesions mentioned are degenerative changes, there should be a difference if the pathology was due to obesity or if it was due to some other activity. For example, runners are known to commonly have heel spurs (Buchbinder 2004). Nevertheless, one would not expect runners, nor people standing all day to have DISH (Moore 2008, 90). Moore (2008, 109) concluded that obesity plays a greater role in the etiology of these degenerative diseases than ageing. Nevertheless, during this research the question may arise whether the observed pathological lesions are due to ageing or to the observed body mass extreme. Therefore, the age estimation has been taken into account with every observed pathological lesion.

## Chapter 2. Materials and methods

This chapter will consist mainly of a literature study about the 19th century population of Middenbeemster which was found interred in a churchyard cemetery. This study will focus on the demographic indicators, diet, and occupation of this population. Furthermore, this chapter contains an explanation of all the methods used, including the morphometric method to estimate body mass, the stature-bi-iliac breadth method, and the biomechanical method that estimates body mass from femoral head diameter. Thereafter, the ageing methods used in this study will be explained. The ageing methods used were the pubic symphysis and the auricular surface. The pathological lesions that have been scored will be discussed after the ageing methods. Lastly, the statistical analysis will be explained.

### 2.1 Research sample

The research sample was composed of 39 identified, Caucasian individuals(see appendices A). This research sample is part of the collection housed at the laboratory for human osteoarchaeology of the University of Leiden. The individuals are identified by archival records from this cemetery and are thus of known age, sex, and sometimes known cause of death but not of known weight. The identified samples consisted of 25 female individuals and 14 male individuals. Beforehand, the skeletal remains were cleaned, sometimes in water, to remove dirt and soil. This method will not have consequences on the outcome of this research.

The unidentified sample, used for the prevalence of body mass extremes and correlation of body mass with disease, was composed of 90 Caucasian individuals, 40 of whom were female and 50 were male. The unidentified sample in this study has solely consisted of individuals with a definite sex determination. For the measurements, sex-specific formulae have been used and probable or indeterminate sex determinations would potentially cause a hiatus in the results. The unidentified sample has been cleaned in a similar way as the identified sample.

Measurements were taken with callipers. Only individuals with fully fused epiphyses on both long bones and the pelvis were measured, to ensure that primary individual growth had stopped (Auerbach and Ruff 2004, 332). Therefore, merely individuals over the age of 18 have been selected for the identified individuals sample. The individuals for the unidentified sample were selected on age estimation. Therefore, it could be that these individuals were under 18 years of age. Nevertheless, these individuals did have fully fused epiphyses and therefore it would not have consequences on the outcome of this research whether the unidentified sample consisted of individuals younger than 18 years of age.

Individuals with signs of disease other than mentioned in the introduction, trauma or other interfering bone gain or loss were removed from the sample. Therefore, two of the selected individuals had to be excluded, because they showed signs of achondrodysplasia (dwarfism).

## 2.2 Bio-cultural background

This section provides information about the inhabitants of Middenbeemster from the onset of habitation of the polder. The demographic indicators and general information (section 2.2.1) state how the Beemster used to be one of the largest lakes of The Netherlands and how it has been dried and divided into a grid. Furthermore, diet and occupation of the 19th century will be discussed in section 2.2.2 and 2.2.3. Lastly, the excavation methods and materials will be discussed in section 2.2.4.

### *2.2.1 Demographic indicators and general information*

Middenbeemster is one of the villages of the Beemster in Noord-Holland, the Netherlands. In the past, it was the largest lake north of the IJ, known as the Beemstermeer, until 1612 (Aten *et al.* 2012, 11). After the polder was created by windmills, the land was divided into geometrical square and rectangular land portions (Aten *et al.* 2012, 26). The Beemster polder was placed on the UNESCO world heritage list in December of 1999, because of its unique design in square plots. The World Heritage Committee presented the Beemster as a masterpiece of creative planning, in which the ideals of antiquity and renaissance were applied to the design of a reclaimed landscape. Aten *et al*. (2012, 12) suggest that the lake was dry in the Middle Ages as well. As a result of the land reclamation and subsequent plowing, the dried land started to become wetter, but how the land turned into this large lake again, until 1612 that is, has yet to be studied (Aten *et al.* 2012, 12).

In 1612, a new elite gradually originated in the Beemster with wealthy farmers (Aten *et al.* 2012, 49). However, the land was, similar to the Middle Ages, too wet for agriculture (Aten *et al.* 2012, 49). Therefore, most farmers started dairy companies or livestock farms (Aten *et al.* 2012, 49). Today, the Beemster is still famous for its Beemster cheese that originated from one of the dairy companies started in the 17th century (Aten *et al.* 2012, 83).

After 1850, a slight population expansion appeared in the Netherlands (Wintle 2000, 7). The cause of this expansion was not an increase in birth rate and neither was it an increase in immigration. It was a decrease in mortality rate (Wintle 2000, 7-27). The mortality rate experienced a free fall, because there was an increase in health status in combination with an increase of availability of better food, medical advances and the upcoming industrialization which, over time, improved personal hygiene (Wintle 2000, 7-27).

Nowadays, the Beemster is divided into four villages, namely: Middenbeemster, Noordbeemster, Westbeemster and Zuidoostbeemster. In addition to the villages, the municipality of Beemster consists of two hamlets (Aten *et al.* 2012, 29).

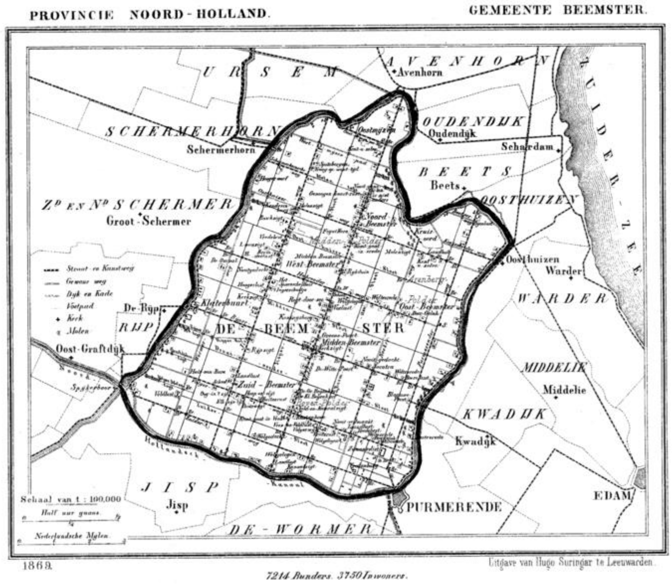


**Figure 8 After the Muncipal Atlas of the Netherlands by J. Kuyper. Historic map of Beemster.**

### *2.2.2 Diet*

The most important source of food came from the Dutch's own supply (Wintle 2000, 54). By the 1720s, the potato was a major element in the dietary intake of the Dutch (Wintle 2000, 59). It has been known that the individuals had a diverse diet, consisting of bread and potatoes and occasionally fruit, vegetables, milk, and fish for the working population (Wintle 2000, 59). However, since the working population ate potatoes three times a day, seven days a week, they potentially suffered from malnutrition, since potatoes do not contain all necessary dietary nutrients (Wintle 2000, 60). Potatoes do contain sufficient vitamin C to prevent scurvy, however, and they constituted a good and cheap pig feed (Bergman 1953, 393). Therefore, many agricultural labourers were able to fatten their animals. Moreover, potatoes provided the raw material for the potato-flour industry and for gin and syrup distilleries (Bergman 1953, 393).

Besides the alcohol-containing drinks, the most common drinks were water, tea, and in the Zaanstreek also hot chocolate. The Zaanstreek is near Middenbeemster(Wintle 2000, 61). Therefore, inhabitants of Middenbeemster could have had this drink as well. Furthermore, it was said by Wintle

(2000, 61) that milk was too valuable for the working population, but a by-product of milk, buttermilk, was very common amongst the working population.

In the period before 1850, the consumption of nutrition was stagnant or even declining (Zanden 1996). After 1850, the weather conditions improved and led to a greater food capacity, as well as the introduction of new crops and artificial fertilizer (Wintle 2000, 54). Knibbe proposes (2007, 71) that in the beginning of the 19th century, the population of the Netherlands was reasonably well fed, and that the calorie intake per person was actually quite high. Nevertheless, in the 1840s, a potato blight potentially caused a decrease in nutrient status of the population, however this has yet to be proven (Knibbe 2007,73).

The inhabitants of the Beemster had a few setbacks over the years that could have influenced their nutrition status. For example, in 1745 their cattle were suffering from a cattle plague epidemic that caused the death of approximately 81% of the cattle (Aten *et al.* 2012, 57). Furthermore, the potato blight in the 1840s was suggested to be the cause of a rise in food prices, a spread of pauperism, and social unrest (Bergman 1953, 390). Potato growing had become so important that most fertile clay areas were used for it and the potato had taken rye's position as primary food source (Bergman 1953, 391). In the Netherlands, the potato blight was halted by a great drought in August and September 1846, which prevented the fungus that caused the blight from penetrating the tubers (Bergman 1953, 394). However, it is not known how the potato blight affected the crops of Middenbeemster. The historical documents only seem to provide information about the main cities in The Netherlands, such as Haarlem, Leiden and The Hague. Therefore, it could be that the crops of the Middenbeemster were not as affected as elsewhere in The Netherlands.

Nevertheless, halfway through the 19th century it was suggested that the farmers were reliving the glory of the 16th century, because Great-Britain allowed food products imported from the Netherlands into their country (Aten *et al.* 2012, 58). This could have led to an elite community with enough nutrition and possibilities to feed every individual.

### *2.2.3 Occupation*

There were three main areas of work: livestock farming, nurseries, and agriculture (Aten *et al.* 2012). The farms that raised domesticated animals in an agricultural setting that produced commodities such as food, clothing, and labour have been known as stock farming. It has been proposed that from the 17th century until the 19th century, the women would tend the home and the men would be working in the field, or in specialized occupations, such as blacksmithing. However, it is not clear whether this happened in Middenbeemster as well. Care should be taken when interpreting the BMI differences among males and females and translating them to occupations.

Degenerative changes in joints result largely from physical demands occurring over the course of an individual's lifetime (Larsen 1995, 199). Their prevalence in the Middenbeemster might therefore provide an important perspective on activity in the living population. However, many researchers have failed to find a definitive pattern relating prevalence and subsistence with regard to specific activities such as haying, milking, etc. (Larsen 1995, 200). Nevertheless, others show distinctive patterns such as bilateral elbow osteoarthritis in some populations, especially in women, which are reflective of physical activities requiring both arms, such as preparation of cereals into flour with grinding stones (Larsen 1995, 201).

Agriculture has long been regarded as an improvement in the human condition. However, in the 19th century, many foreigners noted that the Dutch labourer was physically weak and that he took great quantities of liquor (Bergman 1953, 392). Furthermore, research by Larsen (1995, 185) suggests that the adoption of agriculture involved an overall decline in oral and general health.

Ruff *et al*. (1997, 391) suggest a reduction in sexual dimorphism from hunter-gathering, to agriculture, to industrial subsistence. This trend is indicative of reductions in sexual division of labour, in particular differences of relative mobility of males and females (Ruff 1987, 391). In order to understand the difference in body mass and the possible translation into sexual division of labour, it should first be discussed what the effect of the several occupations on the human body is.

The two methods used in this study focus on the postcranial elements, the femoral head diameter and the bi-iliac breadth, for the estimation of weight. In combination with the estimation of stature, this will be transferred into an estimation of body mass which can be used to compare males to females and individuals of different statures to each other. Therefore, this section will focus on the muscles attached to the femoral head, the iliac blades, and their function.

Agriculture is the cultivation of animals, plants, fungi, and other life forms for food, fuel, and other products. In agriculture, the hours were long and the work was heavy, especially when dealing with clay soils which are present in the Beemster area (Wintle 2000, 66). Agriculture was a major sector in the economy, responsible for the livelihoods of almost half the population at mid-19th century, if one includes the various dependent trades such as rural blacksmiths (Wintle 2000, 68). In the west, farming had by the 1800s reached levels of sophistication which would not be surpassed in most parts of Europe for a century or more. The Dutch agricultural sector has been highly productive and in no way comparable to the peasant-based low productivity farming sector, as was found in southern Europe. The largest farms were to be found on the heavy sea-clay soils where expensive capital equipment was necessary to work them (Wintle 2000, 69).

When muscles grow stronger, the underlying bone adapts by changing its physical shape to bear the increased stress (Ruff 2006,508). Nevertheless, the most affected long bones were probably the bones from the upper limbs, since they had to provide the strength for shoveling, haying and more. The lower limbs did not have specific increase in muscle strength during agriculture.

It has been suggested by Wintle (2000, 66) that women and children had to work alongside men, until the private bill in 1874 stating that child labour could no longer take place. However, this bill has been shown to be ineffective and without sanctions. Therefore, because of the time period of the cemetery (1617 – 1866), it could be suggested that also the females and children of the skeletal population of the Middenbeemster were working alongside men. Nevertheless, this study merely looks at adults and therefore merely at the sexual division in labour. Furthermore, Wintle (2000, 69) conversely suggested that men were superior in every way, in law, money, and in the running of society, whereas a women's place was at home, and her virtues were those of domesticity and motherhood. Therefore, it cannot be suggested with certainty whether female inhabitants of Middenbeemster worked alongside men or had a more domestic occupation.

Besides the main areas of work one could also occupy professions as a baker, blacksmith or caretaker. The caretaker was merely present for the well-being of the poor, who have been in the Middenbeemster since before 1634. In 1634, economic immigrants were not welcome anymore in the Beemster (Aten *et al.* 2012, 253) and the Middenbeemster banned them from their village. Therefore, the less prosperous individuals that were still present after 1634 were supported by the community with gifts of food, fuel, and clothing (Aten *et al.* 2012, 253). When needed, they were able to get medical care as well as a proper funeral (Aten *et al.* 2012, 253). Thus, even the less prosperous individuals only experienced a hard time when unforeseen events happened, such as the cattle plague or disease epidemics such as cholera or diphtheria (Aten *et al.* 2012).

### *2.2.4 Excavation*

In July and August of 2011, the laboratory for human osteoarcheology carried out an excavation on a former cemetery of the Middenbeemster, Noord-Holland, in cooperation with the archaeological company Hollandia. The excavation was planned due to construction and expansion of the church.

Approximately 450 individuals were excavated from the cemetery. The cemetery can be dated between 1617 and 1866. According to the historical documents and archaeological information, most graves can be dated to the late 18th and early 19th century.

**Figure 9 Excavation seen from the church top ('t Gilde 2011).**

Similar to the design of the Beemster, the cemetery was also laid out in a grid design. This square design was recorded on a map, from 1829 until the cemetery was out of use. This map provided the precise date of birth, death, and sex of the individuals buried in the cemetery. Furthermore, from the historical and archaeological data it became clear that when a pit was full the bones were excavated and reburied in an empty space in the cemetery. In 1846, a new cemetery, at the periphery of Middenbeemster was taken into use, which is still in use today (Aten *et al.* 2012). This was a catholic cemetery, and therefore kin of the diseased placed the skeletal remains of the catholic individuals in this second cemetery. Notably, due to a redesign of the cemetery by the municipality, which had obtained the overview of the cemetery from 1829, some of the graves were emptied, and therefore some of the graves consist of the individuals on the archival records, but also of the difficult to remove individuals from before the redesign of the cemetery.  Because of the difficult to remove individuals and redesign of the cemetery the identification process takes time and therefore most skeletal remains have yet to be identified.

## 2.3 Lab procedures

The entire collection will ultimately be analyzed and recorded. The analysis will include an inventory of all skeletal elements, age determination of the auricular surface, pubic symphysis, sternal rib end, ectocranial suture closure, and a dental ageing method. Furthermore, it will be determined what the sex of the skeletal remains could be using the *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994) in combination with *the Workshop of European* *anthropologists* (WEA 1980). Stature will be calculated by several methods, including Trotter (1957), which has been used in this study. Moreover, metric and non-metric data will be recorded using a skeletal recording form available at the laboratory for human osteoarchaeology. The last part of the skeletal recording form includes a differential diagnosis of all the pathological lesions observed. All this data will be entered into a database that would allow future students to run queries and search for the skeletal remains suitable for their thesis or research. Before the osteological profile of each individual has been made, DNA extraction of the teeth has been taken.

### 2.4 Body mass estimations

Bone can, as stated in the introduction, change during growth, development, and ageing, indicating that the shape of a bone will reflect weight-bearing throughout life due to levels of activity and to body mass (Moore 2008). Two general approaches to body mass estimation using postcranial elements have been employed: the mechanical, which relies on the functional association between a weight-bearing skeletal element and body mass, and the morphometric, which attempts to directly reconstruct body size and/or shape from preserved human skeletal remains (Auerbach and Ruff 2004, 331). Both methods have been applied on the identified individuals; on the unidentified individuals solely the femoral head diameter method was used to estimate body mass. The femoral head diameter was the most accessible and quick method and in combination with time restriction the most appropriate method for the 91 unidentified individuals.

The regression equation of stature from Trotter *et al*. (1970, 71) have been used as reference for the stature estimations. The regression equations were derived from the lengths of two or more long limb bones in various combinations. The long limb bone most commonly used is the femur, since this is a postcranial bone, with the smallest standard deviation in males. Furthermore, sex-specific regression equations for white males and white females were used. Females had the smallest standard deviation for the fibula. However, the femur has been used as the long bone in the regression equation for both females and males; since the femur has a better preservation rate this study has based its stature estimations on the femur. The regression equation for males is 2.38 x femur length + 61.41. The regression equation for females is 2.47 x femur length + 54.10. The difference between the standard deviation for the femur and fibula is 20 millimeters..

The formulae used in this study (Trotter 1970, 73) were derived from the Terry collection housed at the National Museum of Natural History, Washington D.C., U.S.A. The Terry collection consists of males and females, both whites and blacks, all born from 1840 to 1924. Breitinger (1937) provided stature formulae from a group of young German males. Although the geographical location of the individuals used from the Breitinger sample is better, the most appropriate formulae remained the sex-specific formulae provided by Trotter *et al*. (1970). It was suggested that for the estimation of stature of older individuals, 0.06 cm has to be subtracted for every year after the age of 30 (Trotter *et al.* 1970, 77). However, since the precise age of the unidentified individuals is not known the subtraction has not been performed. In all stature estimations the right femur has been used, unless the right femur was not available, then the left femur has been used.

Since the 19th century, the average height of the Dutch population has increased dramatically (Maat 2005, 276). Currently, the Dutch are the tallest population in the world, but also among the broadest in the world (Shaw, cited in Saers 2012, 66). Maat (1995, 286) suggested that from the onset of the Dutch Industrial Revolution in the mid- 19th century, more and more resources became available for the general population to spend on food, housing, etc. (Maat 1995, 286). This led to an improvement in health and subsequently an increase in height and potentially an increase in BMI. It has also been suggested that the consumption of dairy and good healthcare might be the cause of this increase (Fredriks *et al.* 2000, 322).

The average result of the femoral head diameter and the standard bi-iliac breadth taken together has been used to measure the estimated body mass of the skeletal remains. This average has been divided by the estimated stature in meters raised to the power of two. This results in a body mass estimation in kilograms per meter$^2$ which is indicative of BMI, also known as the Quetelet’s index. Quetelet, a Belgian mathematician, proposed the measurement for human body shape based on a living population in 1832 (Eknoyan 2008, 49).

Body mass categories of emaciated (BMI<17.9), normal weight (18<BMI<24.9), overweight (25<BMI<29.9), obese (30<BMI<39.9), and morbidly obese (BMI> 40) are designated by the World Health Organization Standards. Questions have been raised concerning the applicability of BMI categories to other populations, owing to the effects of varying body proportions and lean body mass fraction on the index (Ruff 2002, 224). Nevertheless, the Quetelet’s index or BMI has been based on a living population of approximately the same geographical and temporal period as the studied population therefore the proposed BMI measurements and categories of the WHO can be used in this study.

It is important to note that the absence of relief in the area where the skeletal population originates from might have a negative effect on the robusticity of the lower limbs (Jaap Saers 2012, 20). Sparacello and Marchi (2008, 491) made the observation that lower limb robusticity significantly increases when terrain becomes more rugged. This would lead to higher body mass estimations. However, since the Middenbeemster terrain is quite flat, the robusticity and thus the body mass estimation could be lower than it might actually have been. Nevertheless, this will only be noted and not corrected for.

### 2.4.1. Morphometric methods – Stature Bi-iliac Breadth (STBIB)

Morphometric body mass estimation models the human body as a cylinder. The height of the cylinder is stature and the diameter of the cylinder is calculated from the measure of body breadth. Separate equations for males and females could improve this method, by controlling for sex by the width of the pelvis and length of the clavicle (Moore 2009,2). Bi-iliac breadth is done by articulating the pelvis and subsequently accounting for tissue thickness (Ruff 1991; Ruff and Walker 1993; figure 11). This method relies on stature measurement; therefore the use of accurate stature formulae from appropriate reference populations is very important. As stated above, in this study the stature formulae from Trotter *et al.* (1970, 71) have been used.

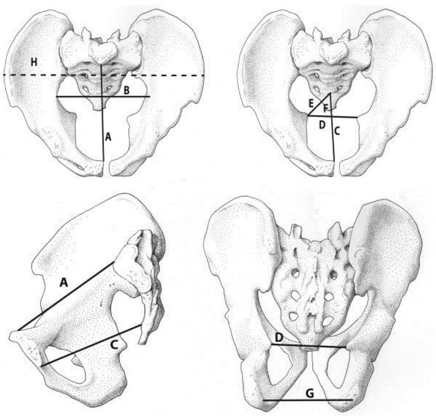


**Figure 10 Measurements that can be taken from the pelvis. H indicates the bi-iliac measurement.**

STBIB has several advantages over other potential body mass estimation methods, the most important one being that it is closely comparable in living individuals and skeletal remains (Ruff 2000, 508). The standard errors for the equations by Ruff *et al.* (1997) are relatively low, around 4 kilograms and therefore correlate relatively well with the actual body mass. STBIB have been shown to work well in both 'normal' and highly athletic modern individuals (Ruff 2000, 510). This is indicative of high muscle development that might occur due to agricultural occupation of the inhabitants of Middenbeemster. Nevertheless, even if they did not have a high muscle development the method has also been shown to work well in 'normal' modern individuals.

The STBIB has been based on a 56 sex-sample means for a worldwide sample of modern human individuals. Therefore, the sample is representative of the full range of variation in body size and shape among modern humans (Auerbach and Ruff 2004, 338). Hence, they are considered relatively unbiased in terms of reference sample composition (Auerbach and Ruff 2004, 338). The STBIB method has been used in this study for the 19th century Middenbeemster skeletal population in combination with the femoral head diameter for the estimation of body mass.

For males, the STBIB equation for estimating body mass, as adapted from Ruff *et al.* (1997), is:

$\mathbf{BM_{males}}$ = 0.373 x stature + 3.033 x (1.17x skeletal bi-iliac breadth – 3) – 82.5

For females, the STBIB equation for estimating body, as adapted from Ruff *et al.* (1997), is:

$\mathbf{BM_{females}}$ = 0.522 x stature + 1.809 x (1.17 x skeletal bi-iliac breadth – 3) – 75.5

### 2.4.2. Biomechanical methods – Femoral Head Diameter (FHD)

Biomechanical methods for estimating body mass focus on the effects of load bearing and partially on the aspects of ageing. A biomechanical method to estimate body mass is by measuring femoral head diameter, which is based on the evaluation of the load bearing capacities of the articular surface. However, Ruff *et al.* (1991) failed to find significant relationships between body mass and the femoral head. When obese individuals were included, the prediction error lowered to 12-13% for the femoral head. This discrepancy could occur because the femoral head is part of a ball and socket joint, and this joint has constrained dimensions in adulthood, and therefore fails to reflect adult weight fluctuations (Moore 2009, 3). It is hypothesized that this discrepancy would also occur when measuring the other end of the BMI scale, the underweight individuals. Nevertheless it would only occur when there has been fluctuation in adult weight and not when the weight of the individual has remained stable throughout life. Nevertheless, the femoral head diameter is a valuable measurement, because it is frequently available even in archaeological samples and is easily taken with a high reproducibility (Auerbach and Ruff 2004, 331).

The formulae to calculate the weight from the femoral head diameter have been based on the Hamann-Tod collection. The Hamann-Tod collection consists of approximately 3157 skeletons and associated records, and is housed at the Cleveland Museum of Natural History (Katzenberg and Saunders 2008, 46). This collection is primarily composed of first generation immigrants from Europe and was established in the late 19th century. The Middenbeeemster skeletal population is contemporary with the time period and to some extent with the geographical location, therefore the femoral head diameter formulae from Ruff (1991) based on the Hamann-Todd collection have been used.

The equations for femoral head body mass estimation are adapted from Ruff *et al.* (1991). For males the equation is:

$\mathbf{BM}_{\mathbf{males}}$ = (2.741 x femoral head – 54.9) x 0.90

and for females:

$\mathbf{BM}_{\mathbf{females}}$ = (2.426 x femoral head – 35.1) x 0.90

Ruff *et al.* also proposed an equation for combined sex, which is:

**BM** = (2.160 x femoral head – 24.8) x 0.90.

## 2.5 Age estimations

Post-developmental skeletal ageing is a complex matter of both genetics and environment (Meindl and Russelll 1998, 382). When an individual reaches his or hers thirties, variation in the ageing process starts to increase, both between individuals but also within a single skeleton (Meindl and Russell 1998, 382). There are multiple age estimation methods, for example, the sternal rib ageing method, ectocranial suture closure, and the pubic symphyseal and auricular surface morphology. The latter two have been used in this study, because they experience the most influence from increase or decrease in weight compared to the other methods available. Furthermore, the amount of bias and inaccuracy of age prediction vary greatly among skeletal ageing methods (Meindl and Russell 1998, 383). Nevertheless, in most circumstances inaccuracy can be minimized across the age range by including more than one method (Meindl and Russell 1998, 383).

### 2.5.1. Pubic symphyseal morphology

The pubic symphyseal face has received the most attention in estimating age at death (Russel and Meindl 1998, 385). It started in 1920, when Todd described age-related changes in humans. Todd's research provided the basis for all subsequent ageing methods, including the methods provided by Brooks and Suchey (1990), McKern and Stewart (1957), and Gilbert and McKern (1973). In this study the pubic symphyseal morphology has been scored according to a scoring system provided by (Brooks and Suchey 1990). Brooks and Suchey (1990) described six phases in both male and female for pubic symphyseal morphological changes. McKern and Stewart (1953) proposed an ageing method which was based on a sample of only men and was therefore not suitable for this study. Gilbert and McKern (1973) based their ageing method on a sample composed of only females. Thus, the Gilbert and McKern (1973) ageing method was not suitable either.

Suchey and Brooks based their method on a sample composed of modern individuals autopsied in the county of Los Angeles. There were more males than females, but both sexes were included in the sample. Analysis of the legal records showed that this sample is representative of the general population in terms of socioeconomic class in the 1980s. However, our sample was composed of 19$^{th}$ and not 20$^{th}$ century individuals. Nevertheless, the Suchey-Brooks ageing method is most sufficient for this sample and was therefore used in this study. Another potential confounding factor is that this method is based on a large multiracial sample of individuals. Indicating that, although individuals died and were autopsied in Los Angeles, they were born throughout the North American continent with a minority born in Europe, South America and Asia (Brooks and Suchey 1990, 237). On this basis it has been suggested by Brooks and Suchey (1990, 237) that their method should be an appropriate sample to use in modern as well as in prehistoric samples.

Although it has been suggested by Lovejoy *et al.* that ageing the pubic symphysis is limited to approximately the age of 40, the degenerative changes after the developmental changes of the pubic symphysis might be more indicative of life history events (*e.g.*, diet, disease, physical activity) than the developmental changes.

Although there are morphological differences between the sexes, there are key age changes that have been observed in both male and female pubic bones, which allows for a single set of descriptions (Brooks and Suchey 1990, 236-7). The first phase is indicative of a symphyseal face with a billowing surface which extends to include the pubic tubercle. Although ossific nodules may occur on the upper extremity, essential to the recognition of this phase is the lack of delimitation of either extremity.

The symphyseal face has begun delimitation of lower and/or upper extremities occurring with or without ossific nodules in the second phase. The symphyseal face may still show ridge development. Furthermore, the ventral rampart may be in beginning phases as an extension of bony activity at either or both extremities.

A symphyseal face with a lower extremity and ventral rampart in process of completion is indicative of a third phase. In this phase the symphyseal face is smooth or can continue to show distinct ridges.

Furthermore, the dorsal plateau is complete and there is an absence of lipping of the symphyseal dorsal margin.

The oval outline is usually complete at phase four; moreover, the symphyseal face is generally fine-grained and may have a distinct rim. The pubic tubercle is fully separated from the symphyseal face. Ventrally, osteophytic lipping may occur on the inferior side of the pubic bone adjacent to the symphyseal face.

The fifth phase is characterized by a completely rimmed symphyseal face with some slight depression of the face itself, relative to the rim. Moderate lipping is found on the dorsal border with more prominent osteophytic lipping on the ventral border. Furthermore, there is little to no erosion and breakdown may occur on the superior ventral border.

The last phase, phase six, is defined by an ongoing depression, shown as rim erosion, of the symphyseal face. The tubercle appears as a separate bony knob and the face may be pitted or porous. Very often the shape of the face is irregular at this stage.

Descriptive statistics related to the Suchey-Brooks age determination system (table 1) indicate that the statistics for all phases in the female sample correspond closely to the male sample. Nevertheless, the standard deviation is slightly higher in the female stages. Brooks and Suchey (1990, 7) propose that his could be due to the higher variability in the female sample.

**Table 1 After Brooks and Suchey (1990). Descriptive statistics related to the Suchey-Brooks pubic age determination system.**

| **Female** | | | | **Male** | | |
|---|---|---|---|---|---|---|
| **Phase** | Mean | Standard Deviation | 95% range | Mean | Standard Deviation | 95% range |
| **I** | 19.4 | 2.6 | 15-24 | 18.5 | 2.1 | 15-23 |
| **II** | 25.0 | 4.9 | 19-40 | 23.4 | 3.6 | 19-34 |
| **III** | 30.7 | 8.1 | 21-53 | 28.7 | 6.5 | 21-46 |
| **IV** | 38.2 | 10.9 | 26-70 | 35.2 | 9.4 | 23-57 |
| **V** | 48.1 | 14.6 | 25-83 | 45.6 | 10.4 | 27-66 |
| **VI** | 60.0 | 12.4 | 42-87 | 61.2 | 12.2 | 34-86 |

### 2.5.2. Auricular surface morphology

The auricular surface ageing method has been tested on the skeletons of the Terry Collection, to see how reliable it was on forensic cases (Lovejoy *et al.* 1985, 1). Lovejoy *et al.* (1985) stated that the method was unbiased regarding race and sex. However they also found that the younger individuals were overestimated and the older individuals underestimated in age. Moreover, they concluded that this method can only be used in combination with other methods of age estimation, for example the pubic symphysis morphology ageing method. Nevertheless, it has also been suggested by Lovejoy *et al.* (1995) that, in contrast to the pubic symphysis, the auricular surface reflects age well into the sixties.

Lovejoy *et al.* (1985) developed an eight stage model, from which age could be estimated. An advantage of the auricular surface as opposed to the pubic symphysis is that the auricular surface is more durable, with higher levels of survival and recovery. One of the disadvantages is that the age of onset for the different scoring features differs. Therefore, the age categories tend to overlap. Consequently, Buckberry and Chamberlain (2002) revised the auricular surface ageing method. The used features were transverse organization, surface texture, microporosity, macroporosity, and changes in the morphology of the apex (Buckberry and Chamberlain 2002, 234).

The revised method as proposed by Buckberry and Chamberlain (2002) was tested on a known-age skeletal population from Christ Church, Spitalfields, London, housed at the Natural History Museum, London. The Spitalfield sample is composed of both males and females, but not many subadults. Since this study does not study the subadults the Spitafield sample is very comparable to our sample. Nevertheless, the Spitalfield sample has been dated between the 11$^{th}$ until the 13$^{th}$ century, whereas our sample is a 19$^{th}$ century skeletal population. The method by Buckberry and Chamberlain (2002) allows for a more realistic interpretation of changes than the method by Lovejoy *et al.* (1985). The revised method even has a higher correlation with true age at death than the Suchey-Brooks pubic symphysis scoring system for the Spitalfield sample (Buckberry and Chamberlain 2002, 236). Therefore, despite the difference between the dating of the cemeteries and the geographical location (England and The Netherlands), the revised method of the auricular surface by Buckberry and Chamberlain (2002) is the most suitable and sufficient method and will be used in this study in combination with the pubic symphysis ageing method by Suchey and Brooks (1990).

Transverse organization, one out of the five used features, refers to the horizontally orientated billows and striae that run from the medial to lateral margins of the auricular surface (Lovejoy *et al.* 1985,5). The revised method indicates that this feature could be better scored in terms of what portion of the auricular surface is transversely organized (Buckberry and Chamberlain 2002, 236). In this study the description provided by Buckberry and Chamberlain (2002) has been used. They provided a 5-stage scoring system for the transverse organization, ranging from '90% or more of the surface is transversely organized' (scored as 1) to 'no transverse organization present' (scored as 5).

Lovejoy *et al.* (1985) described surface texture as grains, since early in life the auricular surface is finely grained and becomes more coarse and dense in older individuals. Buckberry and Chamberlain (2002, 236) scored this feature in terms of what proportion of the surface is covered by a particular type of texture. They defined the different types of texture as finely grained, coarsely grained, and dense bone. Finely granular bone is described as having grains predominantly less than 0.5 mm in diameter (Buckberry and Chamberlain 2002, 236), whereas coarsely granular bone consists of grains over 0.5 mm in diameter(Buckberry and Chamberlain 2002, 236). Dense bone refers to surface appearance, rather than the amount of bone present. It is further defined as a surface without surface granularity. The scoring system used in this study for surface texture has been a five stage scoring system. The first stage has been noted when 90% or more of the surface is finely granular , the second when replacement of the finely granular bone by coarsely granular bone occurs in some areas, the third when 50% or more of surface is coarsely granular, but no dense bone is present, the fourth when dense bone is present but occupies less than 50% of the surface and the fifth when 50% or more of surface is occupied by dense bone.

Microporosity has been defined as pores with a diameter of less than 1 mm. Furthermore, it has been scored according to presence on one or both of the two demifaces of the auricular surface (Buckberry and Chamberlain 2002, 236). The scoring system for microporosity is a 3-stage system ranging from no microporosity present to microporosity present on both demifaces (Buckberry and Chamberlain 2002, 236).

Subsequently, macroporosity has been defined as pores with a diameter greater than 1 mm. As with microporosity, macroporosity is scored according to its presence on one or both of the two demifaces as well (Buckberry and Chamberlain 2002, 236). Buckberry and Chamberlain (2002, 237) suggest that extra care should be taken when scoring macroporosity since macroporosity could be confused with cortical defects or post-mortem damage.

The last feature that Buckberry and Chamberlain (2002, 237) include in the revised ageing method is the apical change of the auricular surface. This surface can develop small osteophytic growths, or lipping, which, when more severe, can alter the contour of the surface (Buckberry and Chamberlain

2002, 237). The scoring system for the apex ranges from a 'sharp and distinct apex' to 'irregularity occurs in the contours of articular surface'. This scoring system is a 3-stage system.

**Table 2 After Buckberry and Chamberlain (2002) scoring ranges for the scored features.**

| Auricular Surface | Left | Right |
|---|---|---|
| **Transverse Organization** | 1-5 | 1-5 |
| **Surface Texture** | 1-5 | 1-5 |
| **Microporosity** | 1-3 | 1-3 |
| **Macroporosity** | 1-3 | 1-3 |
| **Apical Changes** | 1-3 | 1-3 |
| Composite Score: | | |

The age estimation has been made from the composite scores and age stages by Buckberry and Chamberlain (2002) (table 2).

**Table 3 After Buckberry and Chamberlain (2002) age estimates from composite scores and age stages.**

| **Composite score** | **Auricular surface stage** | **Mean age** | **Standard deviation** | **Median age** | **Range** |
|---|---|---|---|---|---|
| **5-6** | I | 17.33 | 1.53 | 17 | 16-19 |
| **7-8** | II | 29.33 | 6.71 | 27 | 21-38 |
| **9-10** | III | 37.86 | 13.08 | 37 | 16-65 |
| **11-12** | IV | 51.41 | 14.47 | 52 | 29-81 |
| **13-14** | V | 59.94 | 12.95 | 62 | 29-88 |
| **15-16** | VI | 66.71 | 11.88 | 66 | 39-91 |
| **17-18** | VII | 72.25 | 12.73 | 73 | 53-92 |

### 2.6 Integration of body mass and age estimations.

Combination of biomechanical and morphometric body mass estimation methods will increase the validity and confidence, as each technique is based on very different skeletal dimensions and underlying rationales (Auerbach and Ruff 2004, 332). Correlation between the FH and STBIB technique range between 0.74 – 0.81 (Auerbach and Ruff 2004, 335).

Lovejoy (1985) stated that the auricular surface could only be used in combination with other ageing methods. Therefore, the pubic symphysis and the auricular surface have both been used to obtain an accurate and precise result.

## 2.7. Pathological lesions

In the introduction, the most common types of pathological lesions associated with emaciation and obesity have been explained. Pathological lesions can be identified prior to body mass estimation in an osteological profile, which would lead to a more accurate age estimation when the body mass does influence the age estimation. Therefore, this study has included a differential diagnosis for the unidentified individuals for pathological lesions associated with body mass extremes.

### *2.7.1 Anemia*

Anemia has been diagnosed as possible, probable or definite depending on the amount of diagnostic criteria available. The general response to anemia involves skeletal changes as cribra orbitalia, porotic hyperostosis and metaphyseal widening. The degree of expression varies with the severity and duration of the anemia, which has been noted in the differential diagnosis as well.

### *2.7.2. Tuberculosis*

When thinking of tuberculosis, it is important to not only study the lesions themselves, but also their distribution within the skeleton. The bacteria which cause this disease are distributed through the blood and become arrested particularly in the marrow (Aufderheide and Rodríguez-Martin 1998, 133).

The diagnosis of tuberculosis has been based upon secondary bony lesions that result from the spread of the bacteria. The psoas major attachment at the iliac blade is an important diagnostic criteria for tuberculosis. Furthermore, spinal tuberculosis infrequently involves more than four vertebrae, and a collapse of the spine is possible (Aufderheide and Rodríguez-Martin 1998, 135). The ribs are involved frequently; the pathological lesions are most commonly found on ribs four to eight. New bone deposits, widening, and resorption are the most commonly found morphological changes on the rib surfaces.

This pathology has been scored as possible when merely one of the above mentioned criteria is present, probable when two or more are present, and definite when all of the above mentioned criteria are present.

### *2.7.3 Vitamin deficiencies*

Joint hematomas, infractions, and overt long bone fracture were common in vitamin C deficient sailors who died at Spitzbergen during an arctic expedition in the 17$^{th}$ and 19$^{th}$ century (Maat 1982). Ossification of the diaphyseal localized areas of subperiosteal hemorrhage are a hallmark of adult scurvy (Aufderheide and Rodríguez-Martin 1998, 313). Blackened tooth roots, as described by Maat

(1982), are indicative of oral hemorrhagic areas in vitamin C deficient individuals. However, it remains very difficult to diagnose vitamin C deficiency. In this study, vitamin C deficiency was merely scored as probable when the overt long bone fractures were present in combination with joint hematomas and blackened tooth roots.

Vitamin D deficiency is characterized by deformed, shortened and bowed long bones. When the spine is involved as well, kyphoscoliosis may occur. However, these are drastic changes and only occur when the individual is suffering from severe vitamin D deficiency. When scoring for these criteria, a variable expression can be expected. In this study, very slight bowing of the long bones has been scored as possible rickets, slight bowing of the long bones as probable rickets and moderate bowing or a higher degree of bowing as definite rickets.

### *2.7.4 Osteoarthritis (OA)*

OA has been scored from mild to severe, 0 indicates absent and 3 is indicative for severe osteoarthritis. Furthermore, OA has been scored for location and broken down into osteophytic lipping, extent of lipping, eburnation, and extent of eburnation. The extent of osteophytic lipping and eburnation were scored from 0 (absent) to 3 (severe) as well.

### *2.7.5 Diffuse Idiopathic Skeletal Hyperostosis (DISH)*

The condition has been scored if three or more vertebrae are fused together and the disc space is preserved. Other manifestations of the disease are ossifications of the muscle attachments of the rotator cuff and deltoid tuberosity of the humerus, ulnar olecranon, iliac crest and ischial tuberosity of the pelvis.

## 2.8 Statistical analysis

For this research, inferential statistics have been used to determine the significance of the obtained results. It has been determined whether there is a significant difference among the unidentified males' and females' BMI of the 19$^{th}$ century Middenbeemster skeletal population. This has been done by an independent samples T-test where the mean of the male and female BMI was compared.

Furthermore, it has been studied whether there is a difference between estimated and true age at death. The null hypothesis has been that there will not be a difference among the known and the estimated age at death for the emaciated or obese individuals. The alternative hypothesis has been that there will be a difference among the known and the estimated age at death for the emaciated or obese individuals. The significance level was set at $P \leq 0.05$ for all comparisons.

This study has been done on the dependent variable age and the independent variable BMI. The data that has been obtained from the measurements of the identified individuals is continuous, numerical data. Therefore, the statistical test that has been used is an independent samples T-test. The independent samples T-test has been carried out with the Statistical Package for the Social Sciences (SPSS) and provided information about the significance of the difference between the true age at death and the estimated age at death among individuals with an estimated normal BMI and the individuals with an estimated high BMI.

To study the difference in age at death this study has compared the influence of high BMI on the auricular surface as well as the influence of high BMI on the pubic symphysis. This test has been done with an independent samples T-test to compare the difference between the true age at death and the estimated age at death (estimation based on either one of the age markers) in the high BMI group.

Moreover, the correlation of the two body mass estimations has been tested and has been hypothesized to be closer to 1 than to 0. The bivariate correlation has been tested with a Pearson *r* correlation test. The body mass estimation suggested to be most accurate, the femoral head diameter, has been used solely to test the difference between true age at death and estimated age at death as well (Moore 2008, 114).

The probability level has been set to 0.05 for this comparison too, indicating that when the value is lower than or equal to 0.05, the results are significantly different. Prior to the independent samples T-test, there has been a test for whether there was or was not a difference among the true age at death and estimated age at death. This test has been done with a paired samples t-test for true age and estimated age for each BMI group independently.

Pathological lesions known to be associated with body mass extremes have been scored in the studied unidentified individuals as well. With a Pearson *r* correlation test it has been analyzed whether they were associated with body mass extremes in the Middenbeemster collection. The test interpretation is similar to that of BMI estimations correlation, indicating that 1.0 is a high association and 0 is indicative of no association.

Beforehand, both the identified and unidentified individuals of the skeletal population have been tested on normalcy with a Levene's test for equality of variances in SPSS. If the p-value is less than or equal to 0.05, the equal variance cannot be assumed.

## Chapter 3. Results

This chapter will present the results of this study. In the section on body mass estimations, the prevalence of body mass extremes in the Middenbeemster skeletal population will be assessed including the apparent difference among males and females and both the unidentified and identified research sample. The following section will assess the observed pathological lesions found in the unidentified skeletal sample of the Middenbeemster. Thereafter, the age estimations and the integration of body mass estimations and age estimations will be analyzed. The final section will consists of the confounding factors that were run into during the result collection.

### 3.1 Body mass estimations

Body mass estimations were made based on femoral head diameter in combination with bi-iliac breadth for the identified individuals. The unidentified individuals BMIs were based solely on the femoral head diameter. The femoral head diameters of the unidentified individuals have been derived from the skeletal recording forms available at the lab.

#### *3.1.1 Prevalence of body mass extremes in the Middenbeemster skeletal population*

In the Middenbeemster skeletal collection there were not any underweight individuals (figure 11, 12, 13). However, there were twelve overweight individuals in the identified individuals sample. None of the overweight individuals were affected with morbidly obesity (figure 13). Besides the two individuals affected with achondrodysplasia who had already been excluded, four of the identified individuals were not included, because they were unaccounted for. Furthermore, one of the individuals was not preserved well and therefore an accurate BMI estimation could not have been made. In total, seven individuals were excluded from the identified sample. This would leave the identified research sample at a total of 32 individuals.

The unidentified sample was composed of 91 individuals, 41 of which were female and 50 which were male. Only the definite male and females were included, the probable males and females were excluded. The probable males and females could oppose a potential bias due to the sex-specific formulae for both stature and body mass estimation.

In this study, every individual over 25 kg/m$^2$ was considered overweight. There were 41 overweight individuals, of whom three were morbidly overweight (figure 11 for females and figure 12 for males). However, one out of the three morbidly obese individuals has probably been affected with congenital hip dysplasia. This individual, outlier with a BMI of 48,92, was therefore excluded from the statistical analysis. Furthermore, the overweight individuals group consisted of 12 females and 29 males. The prevalence has also been studied in the identified sample (figure 13), which was similar to the unidentified sample. The identified sample consisted of twelve overweight, zero obese, and 20 normal weight individuals.

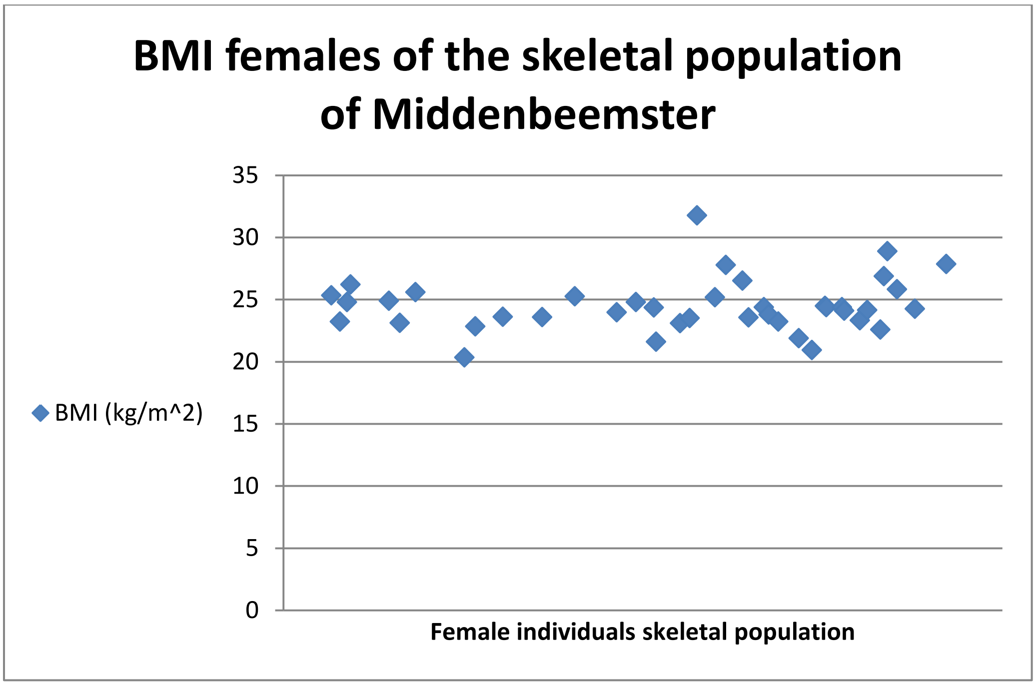


**Figure 11 Overview of the estimated BMI of the female individuals of the Middenbeemster skeletal collection. The individuals are represented on the x-axis and their BMI on the y-axis.**

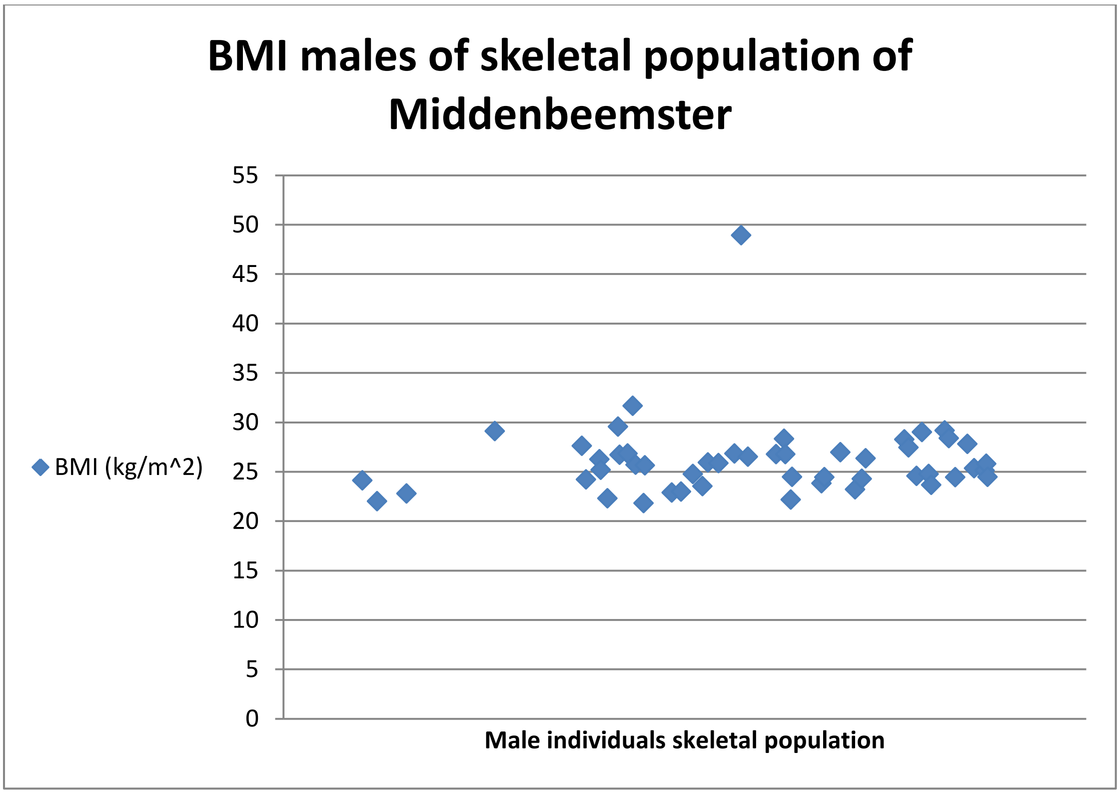


**Figure 12 Overview of the estimated BMI of the male individuals of the Middenbeemster skeletal collection. The individuals are represented on the x-axis and their BMI on the y-axis.**

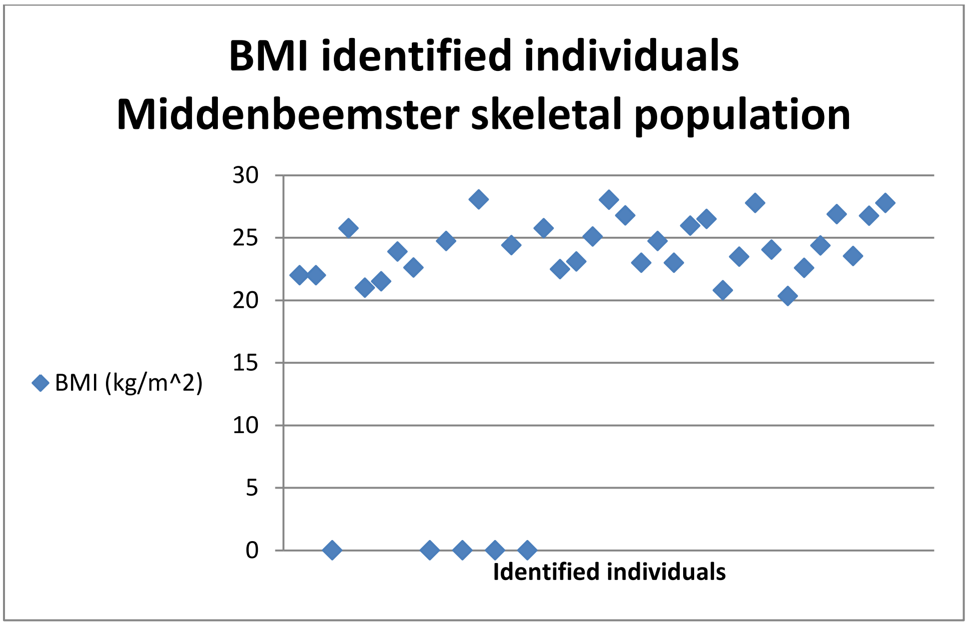


**Figure 13 Overview of the estimated BMI of the identified individuals of the Middenbeemster skeletal population. The individuals are represented on the x-axis and BMI on the y-axis.**

In the overview of the BMI of the identified individuals, it becomes apparent that there is a difference in BMI among males and females. To test whether this difference is significant, an independent samples T-test carried out by the Statistical Package for the Social Sciences (SPSS) has been performed. Equal variances may be assumed, because the Levene's test for equality has not been significant. There is a significant difference in BMI among males and female of the Middenbeemster skeletal population. The T-test for equality of means appeared to have a p value of 0.024. Therefore, the comparison has been significant for a p value lower than 0.025 which allows a direction to be given to the significant value. The mean BMI of males is therefore significantly higher than the mean BMI of females.

**Table 4 Group statistics of the independent samples T-test. F is indicative of females and M for males. N is the number of individuals, Std. deviation is the standard deviation and the std. error mean is the standard error mean. The significance of the difference among males and females in the Middenbeemster skeletal population is 0,024.**

| | Sex | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| **BMI** | F | 40 | 24,5054 | 2,12750 | 0,33639 | |
| | M | 50 | 26,0993 | 3,96123 | 0,56020 | |
| | | | | | | 0,024* |

### 3.2 Pathological lesions

The unidentified sample, consisting of 90 individuals, has been used for the correlation of body mass with diseases known to be associated with body mass. The frequency of all the scored diseases has been done prior to the correlation statistics (table 8). Due to the low frequencies of anemia, tuberculosis, and vitamin deficiencies, statistics have only been done on the presence and absence of osteoarthritis and DISH among individuals with either a high or normal BMI.

**Table 5 Pathology frequencies listed as possible, probable, definite and absent.**

| Pathology | Frequency - Possible | Frequency - Probable | Frequency - Definite | Absent |
|---|---|---|---|---|
| Anemia | 3 | 0 | 0 | 87 |
| Tuberculosis | 1 | 1 | 1 | 87 |
| Vitamin D deficiency | 0 | 3 | 0 | 87 |
| Vitamin C deficiency | 2 | 0 | 0 | 88 |
| | | | | |
| Osteoarthritis | 0 | 1 | 33 | 56 |
| DISH | 2 | 3 | 0 | 85 |

The frequencies of DISH and Osteoarthritis (OA) were sufficient to test whether the skeletal population had a positive or negative correlation of body mass with either DISH or OA. The results from the Pearson r correlation test indicate that neither one of the diseases is correlated with body mass (table 9).

**Table 6 Group statistics Pearson r correlation between body mass and observed pathological lesions. N is the number of individuals, the *r* is indicated in the table and the significance is the significance of *r*.**

Pearson r correlation

| | **Osteoarthritis (significance)** | **DISH (significance)** |
|---|---|---|
| BMI normal (N=49) | 0,063 (0.667) | 0,042 (0,776) |
| BMI >25.01 (N=41) | -0,036 (0,822) | -0,057 (0,723) |

### 3.3 Age estimations

The age estimations have been based on the auricular surface method by Lovejoy *et al.* (1985) and the pubic symphysis method by Brooks and Suchey (1990). An overview of the age estimations can be found in appendices B.

### 3.4 Integration of body and age estimation

The difference between true age at death and estimated age at death has been tested with a paired sample T-test, both corrected and not corrected for BMI. Equal variances may be assumed, because the Levene's test for equality has not been significant. The paired sample T-test was not indicative of a significant difference between true and estimated age at death. However, this test has been done to see whether the difference between true age and estimated age, would be significant with or without controlling for BMI. Therefore, when this test has been significant it would suggest that another factor than BMI might have caused the difference.

**Table 7 Group statistics of paired sample T-test true age at death compared to estimated age at death, not corrected for BMI. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean.**

| Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|
| True Age | 32 | 46,72 | 21,44 | 3,79 | |
| Estimated Age | 32 | 43,09 | 15,14 | 2,68 | |
| | | | | | 0,19 |

Thus, there is not a significant difference between the true age at death and the estimated age at death (table 7), even when tested on merely the auricular surface (table 8) in the high BMI group. The auricular surface has been proven to be less accurate than the auricular surface and should always be used in combination with the pubic bone.

Nevertheless, in some of the individuals there was a significant difference among true age at death and estimated age at death. Therefore, it was tested whether this difference occurred due to BMI. The difference between overweight or normal individuals for true age at death compared to estimated age at death from either auricular surface (table 8), pubic bone (table 9), or an age estimation from both age related features (table 10) was not significant in either case.

**Table 8 Group statistics of paired samples T-test true age at death compared to estimated age at death from auricular surface in the high BMI group. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean.**

| BMI>25,01 | Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| | True Age | 12 | 44,00 | 24,82 | 7,17 | |
| **Auricular Surface** | Estimated Age | 12 | 47,24 | 17,13 | 4,94 | |
| | | | | | | 0,51 |

**Table 9 Group statistics of paired samples T-test true age at death compared to estimated age at death from pubic symphysis surface in the high BMI group. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean.**

| BMI>25,01 | Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| | True Age | 6 | 42,17 | 29,09 | 6,14 | |
| **Pubic Symphysis** | Estimated Age | 6 | 35,72 | 15,04 | 11,88 | |
| | | | | | | 0,33 |

**Table 10 Group statistics of paired samples T-test true age at death compared to estimated age at death, among individuals with a high BMI. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean.**

| | Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| **BMI>25,01** | True Age | 12 | 44,00 | 24,82 | 7,17 | |
| **BMI>25,01** | Estimated Age | 12 | 45,19 | 16,62 | 4,80 | |
| | | | | | | 0,79 |

Levene's test for equality is indicative of the assumption of equal variances. The independent samples test results in the difference between normal and overweight individuals for the difference they have in true and estimated age at death. The difference among the true age at death and estimated age at death is not significantly different for normal BMI or overweight BMI (table 11). The attempt to estimate body mass of the identified individuals was done with two body mass estimation methods. The body mass estimation average was taken to perform the statistics upon. However, out of the 32 selected individuals, 11 did not have a result of STBIB and merely had a result of the FHD. One out of the 32 selected individuals merely had the STBIB to estimate body mass. Therefore, the correlation between the two methods has been tested as well.

**Table 11 Group statistics independent samples test among normal and high BMI. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean. TA is indicative of true age at death and EA for estimated age at death.**

| | Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| **BMI<25,01** | Difference TA and EA | 20 | 12,90 | 9,07 | 2,03 | |
| **BMI>25,01** | Difference TA and EA | 12 | 10,69 | 10,68 | 3,08 | |
| | | | | | | 0,537 |

The correlation between the FHD and the bi-iliac breadth for the individuals who had both measurements (**N=20**) was just 0,30. Nevertheless, Moore (2008) concluded that the morphometric method of STBIB appeared to fail for body mass estimations outside of the normal range (*r* =0,30). Therefore, the statistics performed also included a measurement that studied the difference of estimated age and true age at death between estimated normal BMI and estimated high BMI in which the estimated BMI resulted from the FHD measurements (table 12).

**Table 12 Group statistics independent samples test among normal and high estimated BMI from the Femoral Head Diameter. N is number of individuals, std. deviation the standard deviation and std. error mean is the standard error of mean. TA is indicative of true age at death and EA for estimated age at death.**

| | Age | N | Mean | Std. deviation | Std. error mean | Significance |
|---|---|---|---|---|---|---|
| **BMI (FHD) <25,01** | Difference TA and EA | 17 | 10,83 | 7,75 | 1,88 | |
| **BMI (FHD) >25,01** | Difference TA and EA | 15 | 13,48 | 11,46 | 2,96 | |
| | | | | | | 0,445 |

### 3.7. Confounding factors

Merely the mean of the estimations has been used for the statistical analysis. Therefore the age estimations may produce a distribution reflecting the skeletal reference population upon which the ageing method was based, rather than the age structure of the cemetery being analysed (Meindl and Russell 1998, 383). Such mimicry tends to be marked when indicators correlate poorly with actual age. Nevertheless, in this sample, true age and the estimated age did not differ significantly from each other. The body mass estimation might have reflected the skeletal reference population, though this is uncertain since the actual weight in unknown.

Lovejoy (1985) stated that the auricular surface could only be used in combination with other ageing methods. However, due to poor preservation of the pubic symphysis, this study had to use solely the auricular surface for age estimations of some individuals. Nevertheless, the results were not significant for the average age estimation compared to true age at death and neither were they significant for the auricular surface age estimation compared to the true age at death. Therefore, it can be suggested that, in this sample, the auricular surface age estimation did not deviate significantly from the true age at death and could thus be used in some of the individuals as the method for age estimation.

Femoral head diameter is an articular surface dimension which is not overly affected by differences in activity or muscular loading. Therefore, muscle development during life in the physical demanding occupation of farmer might not have been reflected well in the femoral head diameter. Furthermore, STBIB alone fails to account for body mass extremes. It might have been more preferable to estimate body mass from diaphyseal breadth or cross section dimensions.

Identification of individuals could have been incorrect, and that might have caused the apparent difference between true age at death and estimated age at death. This is plausible due to the cemetery being redesigned in 1829; human skeletal material was removed to larger pits after the grave was full or because the kin wanted the skeletal remains to be placed in the catholic cemetery which was opened in 1866.

## 3.8 Summary

The 19$^{th}$ century skeletal population of the Middenbeemster included no underweight individuals; approximately 54% of the skeletal population had a normal estimated body mass and the other 44% of the skeletal population had a higher than normal estimated body mass. The difference in male and female body mass estimations resulted in a significantly higher body mass for males. Osteoarthritis and DISH were observed pathological lesions in a sufficient amount to run statistics. However, neither showed a significant correlation with body mass. Although the influence of body mass has been tested on the average age estimation of both age markers, on the auricular surface alone and on the pubic symphysis alone there was not a significant influence of body mass on the age estimations. Furthermore, the statistics to compare the body mass estimation methods resulted in a very low predictive power. Therefore, the influence of one of the body mass estimation methods, the femoral head diameter, on both age related features has been tested as well. The influence of the femoral head diameter body mass estimation was not significant. Although this research has some confounding factors it still remains a contribution to the growing information about this skeletal population.

# 4. Discussion

This chapter will review all of the results and relate them to the contexts mentioned in the introduction. The first part will discuss the metabolic processes of bone synthesis and absorption. This will support the choice in methods. Thereafter, the prevalence of body mass extremes in the 19$^{th}$ century Middenbeemster skeletal population will be discussed, including the significant difference in male and female body mass estimation prevalence. Furthermore, the correlation of pathological lesions and body mass estimations will be discussed. Moreover, the influence of body mass estimations on age related features will be reviewed. The bio-cultural context will place the results in a historical framework and provides more information about the prevalence of high BMI. The last sections will contain the evaluation of the research design and methods and suggestions for further research.

## 4.1 Metabolic processes of bone synthesis and absorption

The general concept that mechanical loading influences bone structure is often referred to as 'Wolff's law' (Katzenberg and Saunders 2008, 183). Thus, with an increase in mechanical loading, bone cell differentiation will be in favour of differentiation in osteoblasts (Bonewald and Johnson 2008, 2). Therefore, it should be possible to estimate body mass from the skeleton, including the extremes emaciation and obesity (Moore 2008, 109). The femoral head diameter measurement would result in a higher number when the mechanical loading stimulated osteoblast formation. Therefore, with the formulae provided by Ruff *et al.* (1991) it was possible to estimate the weight of the individuals in their living form, from their skeletal remains. Furthermore, Ruff also provided a formula that was based on the breadth of the iliac blades (1991). Combined, the formulae had an a correlation of 0.74 to 0.81 with actual weight, as tested by Auerbach and Ruff (2004, 335). However, the correlation of the two methods in this study was just ($r$) 0,30. That raises the question whether the correlation with actual weight is accurate or not. Unfortunately, the actual weight at death cannot be traced, since there are no archival records of the Middenbeemster skeletal population indicative of weight.

## 4.2 Prevalence of body mass extremes

It was hypothesized that the skeletal population would primarily consist of underweight individuals, because the skeletal population probably worked in the physically demanding agricultural sector. Furthermore, the inhabitants of the Middenbeemster would have come across some difficulties in the 19$^{th}$ century, namely an unsuccessful harvest, cattle plagues, and epidemics such as typhus and cholera (Aten *et al.* 2012). However, intensive literature research also revealed that the inhabitants of the Middenbeemster were reliving the glory of the 16$^{th}$ century in the 19$^{th}$ century. Britain had allowed Dutch food products into their country, there were a string of successful harvests, and the dairy companies were booming, which would all have contributed to a healthy community with enough nutrition and possibilities to feed every individual.

The results showed that none of the individuals represented in the skeletal population were underweight. All individuals could be categorized in the 20-25 kg/m$^2$ (normal weight), in the 25-30 kg/m$^2$ (overweight) or in the over 30 kg/m$^2$ (obese) group. Out of the 90 individuals that were included in this study, 41 where overweight and three of these 41 were even afflicted with obesity. However, one out of the three obese individuals has probably been affected with congenital hipdysplasia and was therefore excluded from the statistics. Nevertheless, 44% of the analyzed individuals of the skeletal population were overweight.

Sparacello and Marchi (2008, 491) made the observation that lower limb robusticity significantly increases when terrain becomes more rugged. This would lead to higher body mass estimations. However, since the Middenbeemster terrain is without relief the robusticity and thus the body mass estimation could be lower than it might actually have been. It has also been suggested that when the mobility increases, the amount of mechanical loading also increases, leading to higher BMI. Research on the cortical area of males and females of the Middenbeemster skeletal population was indicative of a highly mobile population, comparative to early modern humans and athletic samples (Saers 2012, 57). The body mass estimations method used in this study have also been tested on highly athletic females and early modern humans and were accurate and precise and therefore, remain to be appropriate to estimate body mass (Ruff 2000; Porter 2002).

The amount of overweight individuals contributed to the hypothesis that the Middenbeemster was a healthy community with enough nutrition and possibilities to feed every individual.

### 4.3 Pathological lesions associated with body mass extremes

The ability to recognize pathological lesions with a correlation to body mass extremes could prevent osteologists from inaccuracies with the interpretation of the entire skeletal profile when a pathological lesion associated with a body mass extreme has been detected. Some traits show a greater relationship with body weight and body mass, but by identifying the distribution pattern of these traits on the skeleton, it might be possible to distinguish random trauma from the combined effects of excessive body mass (Moore 2008, 109).

In this skeletal population, it appeared that pathological lesions associated with body mass extremes did not have a correlation with body mass. Heavier individuals did not show signs of osteoarthritis, but according to Messier *et al.* (1996, cited in Moore 2008, 107) heavy to normal weight individuals may actually have a musculoskeletal system designed to handle larger loads. Therefore they do not need the stimulation in bone differentiation in favour of osteoblasts that would enable mobility despite the higher mechanical load associated with a greater weight.

In a study by Moore (2008), obese individuals did have a significant relationship with DISH and Osteoarthritis (OA). Especially OA of the left medial tibia, which seems to endure most of the force in both males and females, was significantly correlated with obesity. It might be that the BMI extremes of this skeletal population were not extreme enough to show correlation with diseases. Furthermore, Moore (2008, 110) suggested that obese individuals were more likely to develop bilateral OA. This assumption might be tested in further research.

### 4.4 Body mass extremes and influence on age related features

Age markers were tested both separately and combined for influence of body mass. Nevertheless, there was no significant influence of body mass on age related features. This might be, similar to the pathological lesion correlation, because the estimated body masses might have needed to have been more extreme in order to produce a significant result.

Furthermore, it could be that the metabolic process that stimulates the differentiation of bone in favour of osteoblasts is more stimulated when the gain in weight is due to fat than when it is due to muscle. This difference in fat and muscle is an interesting topic for further research.

### 4.5 Bio-cultural history

Although it has been 200 years since this skeletal population lived, we may say that the economic ban established in 1632 might have had an influence on not only the economic status, but also on the nutritional and health status of the inhabitants of Middenbeemster of the 19$^{th}$ century. Every individual that wanted to make a living in Middenbeemster after 1634 had to prove that they could provide for their family before they could enter the city (Aten *et al.* 2012). The less prosperous inhabitants that had been living in the Middenbeemster before 1632 were not evicted, but were supported by the community with food, clothes, and other necessary utilities (Aten *et al.* 2012). Therefore, the economic, nutritional, and health status during the 19$^{th}$ century was probably above average.

When studying body mass it is always questioned whether extreme muscle development is reflected accurately or whether the estimation merely states information about the body fat estimation of an individual. Males tend to have occupations that require heavier lifting than female occupations and should therefore always be considered separately from females when attempting to estimated body mass (Auerbach and Ruff 2004). Females and males were therefore separated in this study. The results were that males did have a significantly higher BMI than females.

Nevertheless, despite that the postcranial measurements of the lower limbs were used to estimate body mass and the agricultural sector was physically demanding, it was also suggested by Ruff *et al.* (1897, 2000, 2002, 2006) that agriculture has been more demanding of the upper limbs than of the lower limbs. Therefore, the increase in upper limb muscle strength would probably not have caused biases in the results. Research by Saers (2012, 97) suggest that males were generally more mobile than females and performed more strenuous manual activities. Furthermore, the role of females was not the same for all females (Saers 2012, 97).

The ingestion of dairy might have contributed to the high BMI that has been observed in this study (Fredriks *et al.* 2000, 322). Furthermore, it has been suggested that a higher BMI might be beneficial for older individuals to be considered healthy. This would raise the healthy BMI range from 24.9 as an upper limit to 28 for the elderly population. Although this could be, this study did not encompass enough older individuals with accurately defined age estimations to conduct research on different age groups.

It has been suggested that agriculturalists, like the individuals from the skeletal population of Middenbeemster, generally display lower amounts of sexual dimorphism than hunter-gathers (Larsen 1995, 188). The agriculturalists do display a higher amount of sexual dimorphism than industrial populations (Larsen 1995, 188). Sexual dimorphism in this context is interpreted as being the result of sexual division of labour, where males and females perform different tasks (Jaap Saers 2012, 16). Comparison with other rural skeletal populations opposes difficulties such as differences in cultural practices, differential preservation, excavation strategies, and selective curation (Larsen 1995, 186). In this study, the results indicated that there is a significant difference in BMI of females and males from the skeletal population of the Middenbeemster. Thus, this research is indicative of sexual dimorphism in the 19$^{th}$ century skeletal population of the Middenbeemster.

Although all identified individuals were buried in the 19$^{th}$ century, the unidentified individuals might have been buried before the 19$^{th}$ century. The unidentified individuals could therefore have been exposed to other environments than the identified individuals. Nevertheless, the unidentified and identified samples show a similar pattern in distribution of BMI. Therefore, it can be suggested that the unidentified sample, which predates the 19th century, would have been exposed to similar environments as the identified individuals from the 19th century.

### 4.6 Research design and methods

Body mass estimation requires a near to complete skeleton. When fragmentary remains are the only available material, body mass estimation is not always possible, and when it is possible, it can be problematic due to the assumption that one is dealing with equivalent body shapes (Ruff, 2000). Nevertheless, a skeleton sample would be an advantage, because some changes on the skeleton would not necessarily be apparent on radiographs, nor would they be symptomatic (Moore 2008, 111).

For this research design and methods it is important to know that there might be an osteological paradox. This paradox suggests that the results from the skeletal population are not the same as they would have been in the living population (Katzenberg and Saunders 2008, 566). That is because the risk of death and mortality is selective, the most vulnerable people at age are the ones most likely to die (Katzenberg and Saunders 2008, 566). Even when the entire cemetery is excavated, which has not been done for the Middenbeemster population, the sample is still biased toward the people in each age range who experienced  the highest risk of death (Katzenberg and Saunders 2008, 566). Therefore, the prevalence of body mass extremes in the Middenbeemster is merely the prevalence in the skeletal population and not in the 19th century living population. Furthermore, the prevalence of pathological lesions is not similar to the prevalence of disease in the living population. It could be that the individual affected with disease could not withstand the disease long enough to develop pathological bony lesions and is therefore not included in prevalence estimations.

Although it is known that bone tissue responds to mechanical loading, the biomedical literature is unclear on what type and level of physical activity or exercise is needed to affect bone mass and more importantly bone strength. Furthermore, substantial evidence exists that exercise can increase bone mineral density during growth and development, particularly adolescence, exercise seems to have less long-lasting impact on the adult skeleton.

Body mass estimations had a correlation coefficient ($r$) of just 0,30. Because the actual weight was unknown, the correlation of actual weight and true weight is supposedly a hiatus in the results. The correlation between the two body mass estimations should be closer to 1 to have any predictive power. However, just from these results, it cannot be concluded were the hiatus is coming from;

could it be that one method is better than the other? Or could it be that the formulae are just not appropriate for this research sample? Since the actual weight is probably not traceable, no conclusions can be made as to whether the femoral head diameter or stature-bi-iliac breadth should be preferred in further research.

Nevertheless, Moore (2008, 109) concluded that the morphometric method of STBIB appeared to fail for body mass estimations outside of the normal range (*r* =0,30) and femoral head diameter does not account for the broad range of body mass in modern human populations. This study focused on the normal to overweight individuals, with a few outliers affected with obesity; therefore, the femoral head diameter could be suggested to be most appropriate for this study. Although most appropriate, the femoral head diameter body mass estimation did not show significant influence on the age related features.

Since adults vary in weight over their lifetimes and a change in weight constitutes a direct change in mechanical loading of the lower limb, femoral cross-sectional size in adults should be more correlated with current body weight than with weight at 18 years. However, research by Ruff (2002,402) is indicative of a higher correlation of body weight at the age of 18 and femoral head diameter. Therefore, the actual adult weight is not reflected in the femoral head diameter. This raises questions as to when and for how long in life BMI extremes had to occur in order for it to change skeletal morphology. For example, does low or high BMI need to be present during the adolescent growth period? Furthermore, it can be questioned whether low or high BMI associated with the cause of death causes any change in skeletal morphology at the macroscopic level. Moreover, it should be studied how long or how often low or high BMI need to occur for the onset of morphological changes.

Other methods for the estimation of body mass might have a higher correlation with body mass than femoral head diameter and STBIB. These methods include cross sectional area and bone mineral density. Moore (2008, 110) studied the cross sectional and bone mineral density correlation with body weight and found a correlation of *r*= 0,57 for males and *r*=0,62 for females. Nevertheless, this method does not have a significant correlation with obesity either, whereas the width measurements of the distal and proximal ends of the femur and DISH were selected by Moore (2009, 110) as the most significant signal.

It has become apparent from the identified individuals sample that the age estimation has limitations. The limitation of age estimation for the pubic bone has been after the developmental changes stopped and degenerative changes started, thus after approximately 40 years of age the limitation of the age estimation for the pubic symphysis has been reached (Lovejoy *et al.* 1985). Furthermore, the auricular surface is slightly better than the pubic symphysis, but even this age related feature has age estimation limitation. This limitation is set at approximately 60 years of age (Lovejoy *et al.* 1985). Although some of the identified individuals should not have been included, because they exceeded the age estimation limitations, these individuals were needed to run appropriate statistics upon.

As more information about the individuals of the skeletal population of Middenbeemster is being contributed through osteological and historical (archival) research, the results obtained in this study will become more and more valuable by allowing it to be interpreted within an increasingly detailed framework.

# 5. Conclusion

According to Wolff's law, it should be possible to estimate body mass from the skeleton, including the extremes of emaciation and obesity (Katzenberg and Saunders 2008, 183). Wolff's law states that an increase in mechanical loading may cause an increase in bone synthesis (Katzenberg and Saunders 2008, 183). By applying body mass estimations with the femoral head diameter and STBIB formulae, the age estimation with the pubic symphysis and auricular surface, and an overall differential diagnosis of the observed pathologies, this research has studied three main research questions in the $19^{th}$ century skeletal population of the Middenbeemster.

The first aim of this research was, namely, the prevalence of body mass extremes in the Middenbeemster skeletal population during the late $19^{th}$ century. It was hypothesized that the research sample would primarily consist of underweight, or even starved individuals. The sample was composed of individuals who possibly suffered from unsuccessful harvests, cattle plagues, and epidemics (Aten *et al.* 2012). Nevertheless, this hypothesis could be rejected after the first results came in. The skeletal population of the $19^{th}$ century Middenbeemster were all estimated to be of normal weight, overweight, or even obese weight. This might be indicative of a healthy, well-fed community that took care of their less prosperous individuals (Aten *et al.* 2012). Furthermore, the temporary set-backs that affected the individuals might have been not severe or not long enough to be reflected in the skeletal remains. Moreover, this research is indicative of sexual dimorphism for BMI in the $19^{th}$ century skeletal population of the Middenbeemster.

The second aim of this study was to establish the influence of body mass on two age-related features, namely the pubic symphysis and the auricular surface of the Middenbeemster skeletal population of the late $19^{th}$ century. It was hypothesized that the body mass extremes would influence the age-related features. Although the influence of body mass has been calculated on the average age estimation from the combination of both age related features, on merely the auricular surface and on solely the pubic symphysis the results were not significant. Moreover, it has also been studied whether one out of the two body mass estimation methods could have provided a significant result. This method failed to have a significant result as well. Therefore, from this $19^{th}$ century skeletal population of the Middenbeemster, it can be suggested that the influence of body mass on age related features is not significant. However, this could have been because a more extreme body mass is needed for the result to be significant. It might also be that the metabolic process that causes the bone differentiation to be in favour of osteoblasts with heavier mechanical loading might have a more extreme influence when the differentiation is stimulated by fat instead of muscle.

The third aim of this study was to assess the correlation between diseases known to be associated with either one of the body mass extremes and the body mass of the Middenbeemster skeletal population of the late 19$^{th}$ century. Nevertheless, the pathological lesions were not as apparent as expected. Therefore, the only two pathological lesions that could be tested on significance were osteoarthritis and DISH. Neither one of the pathological lesions showed a significant result. Nevertheless, the pathological lesion might still be correlated to body mass, but the body mass might have to have been more extreme. Furthermore, the osteological paradox might be of influence here. The osteological paradox suggests that because the skeletal population is only a subsample of a subsample of a subsample (i.e., not every individual of the living population has been buried in the cemetery, not the entire cemetery is excavated, and not every individual excavated has been used in this study). Therefore, the skeletal population does not reflect the living population.

This research has been a contribution to the growing knowledge about this 19$^{th}$ century skeletal population of the rural city of Middenbeemster. Furthermore, this research suggests that the accuracy and precision of the body mass estimation methods might need revision. Nevertheless, for the identification of individuals in the forensic, and also in the archaeological research field this research suggests that more focus should be on the age estimation for older individuals. The body mass estimation does not cause a significant difference in age estimation and thus the skeletal remains will have an appropriate age estimation, but not when the individual has exceeded the age of 40 (pubic symphysis) or 60 (auricular surface).

This research studied the correlation of the two body mass estimation methods. This correlation should be closer to 1, because they should be the same. Nevertheless the correlation was just $r$=0.30. Moore (2008, 109) also suggested that the STBIB does not appear to work for body mass estimation outside of the normal range. Therefore, this research has also conducted statistics on merely the femoral head diameter. It might be that femoral head diameter does not reflect the broad range of body mass that exists in the modern human population (Moore 2008, 109). Nevertheless, the research sample was composed of normal to overweight individuals with a few outliers that were affected with obesity. Therefore the femoral head diameter has been the most appropriate method to estimate body mass.

The Middenbeemster sample consists, according to Saers (2012, 58), of highly active and mobile individuals. The body mass estimations used in this study were also tested on highly active female athletes and early modern humans (Ruff 2000; Porter 2002). Therefore, the body mass estimation methods used were most accurate and appropriate for this skeletal population.

Moreover, the age estimation did have a high correlation with true age at death. Although it was suggested that age estimation would deviate from true age at death, it appeared that they were rather similar. Therefore, there has not been a significant difference among true and estimated age at death, and body mass in this study did not influence the age related features enough to cause a significant difference.

Statistical significance is not equivalent to interpretative significance. Hence, the results were not significant. In future research, the research sample should be expanded and the BMI of the individuals should be known to potentially acquire a significant result. Furthermore, when the BMI would be more extreme (extremely low or high) the results could be significant as well. Therefore, future research should have a larger research sample with more known, extreme BMI.

## 5.1 Further research

Moore (2008) concluded that OA in obese individuals was more likely to develop bilaterally than uni-laterally. Further research could score for OA in overweight and obese individuals to test this assumption.

As there are so many factors in the literature concerning the effect of juvenile obesity, this is a very important area of research (Moore 2008, 113). It is important to understand the biomechanics of obesity in juveniles to ensure that overweight children are not permanently damaging the joint surface or mechanical properties of their bones (Moore 2008, 113). Furthermore, studying obese juveniles through life should provide insight into the duration of time needed for extreme body mass to affect the morphology of bone.

Furthermore, the importance of the pubic symphysis is limited to the ageing of adults up to approximately 40 years of age (Meindl and Russel 1998, 385). The appearance of fusion of the ventral rampart of the pubic symphysis is typically completed before age 35, marking the end of developmental activity (Meindl and Russel 1998, 385). After this fusion, all changes are degenerative, highly variable, and not particularly valuable for age estimation (Meindl and Russel 1998, 385). Could this be indicative of a higher influence of body mass on age-related features after the age of 35, since that would be post-development and merely due to degenerative changes? Although this could be an interesting project, the age estimations have showed age limitations after approximately 40 and 60 years of age; the pubic symphysis and auricular surface, respectively. In order to test the hypothesis that a higher BMI might influence the age related features after the developmental changes and thus merely due to degenerative changes, first the age estimation methods should be reconsidered. Further research should therefore, include more accurate and precise age estimations for the older individuals. Furthermore, it could be interesting to look at the more extreme body masses to see whether that would influence the age related features and at what level body mass causes the onset of change in morphology.

Another element that should be studied is what would happen with bone turnover when one loses a significant amount of weight. This could provide information about the assumption that the skeleton is accustomed to certain loads and attempts to overcompensate (Moore 2008, 114). Perhaps the mechanism is more biochemical and reflects overcompensation to the decrease in adipose hormones.

Other body mass estimation methods should also be considered, for example Moore (2008, 110) suggested that cross-sectional area and bone mineral density would be most significant. She suggested that the proximal femur cross-sectional area would have the highest correlation with weight. Therefore, further research should include the correlation between the cross-sectional area with the morphological and biomechanical body mass estimation to test what method should be preferred. Nevertheless, the morphological and biomechanical body mass estimation used in this study are not invasive, easy to conduct and inexpensive and will therefore probably remain the preferred methods for the estimation of body mass from skeletal material. Unfortunately, the integration of femoral cross-sectional area with morphological and biomechanical body mass estimations exceeds the scope of the current study and has yet to be done.

Beforehand, it was hypothesized that the research sample could be composed of many starved or underweight individuals. However, it turned out that this sample was composed of normal, overweight and even obese individuals. Therefore, subsequent research towards the other end of the BMI scale, the lower end, has yet to be performed.

## Glossary of terms

**Achondroplasia** A hereditary form of dwarfism with limb shortening, almost normal trunk and vault development, and a small face; caused by a congenital disturbance of cartilage formation at the epiphyses (White and Folkens 2005, 419).

**Ankylosis** An abnormal, complete immobility or fixation of a joint resulting from pathological changes in the joint (White and Folkens 2005, 419)

**Cranium** The bones of the skull except for the mandible (White and Folkens 2005, 421).

**Cribra orbitalia** Lesions of the roof of the orbit, usually in the form of bilateral pitting of the orbital part of the frontal (White and Folkens 2005, 420).

**Diaphysis** The shaft of a long bone (White and Folkens 2005, 420).

**Eburnation** Worn, polished, ivory-like appearance of bone resulting from exposure and wear of adjacent subchondral bone at a joint (White and Folkens 2005, 420).

**Endochondral ossification** A process of bone development in which cartilage precursors are gradually replaced by bone tissue (White and Folkens 2005, 420).

**Epiphyses** The cap at the end of a long bone that develops from a secondary ossification centre (White and Folkens 2005, 420).

**Kyphosis** The collapse of one or several vertebral bodies causing a sharp angle in the spine (White and Folkens 2005, 423).

**Lesion** An injury or wound; an area of pathologically altered tissue (White and Folkens 2005, 423).

**Lipping** Bone projecting beyond the margin of the affected articular surface, usually in osteoarthritis (White and Folkens 2005, 423).

**Metaphyses** The expanded, flared ends of the shaft of a long bone (White and Folkens 2005, 423).

**Morphology** The form and structure of an object (White and Folkens 2005, 423).

**Necrose** Tissue damage resulting from cell death (Sadava et al. 2007, G-19)

**Osteoarthritis** Most common form of arthritis, characterized by a destruction of the articular cartilage in a joint, and accompanied by bony lipping and spur formation adjacent to the joint (White and Folkens 2005, 424).

**Osteoblasts** The bone-forming cells responsible for synthesizing and depositing bone material (White and Folkens 2005, 424).

**Osteoclasts** Cells responsible for the resorption of bone tissue (White and Folkens 2005, 424).

**Osteocyte** Living bone cell developed from an osteoblast (White and Folkens 2005, 424).

**Osteomalacia** A disease that causes a softening of the bones, usually linked to general malnutrition-particularly in deficiencies in protein, fat, calcium and phosphorus (White and Folkens 2005, 424).

**Osteoporosis** Increased porosity of bone due to reduction in bone mineral density (White and Folkens 2005, 424).

**Porosity** A condition in which many small openings pass through the surface (White and Folkens 2005, 425).

**Porotic hyperostosis** A condition exhibiting lesions, usually of the cranial vault, representing a thinning and often complete destruction of the outer table of the cranial vault (White and Folkens 2005, 425).

**Postcranial skeleton** All bones except the cranium and mandible (White and Folkens 2005, 425).

**Remodeling** a cyclical process of bone resporption and deposition at one site (White and Folkens 2005, 425).

**Resorption** The process of bone destruction by osteoclasts (White and Folkens 2005, 425).

**Rickets** A form of osteomalacia resulting from vitamin D deficiency (White and Folkens 2005, 425).

**Sexual dimorphism** Differences between males and females (White and Folkens 2005, 425).

**Symphysis** A type of cartilaginous joint in which fibrocartilage between the bone surfaces is covered by a thin layer of hyaline cartilage (White and Folkens 2005, 425).

## Abstract

Body mass increases when nutritional status increases and decreases when there is a lack of essential nutrients. Bone is a dynamic organ that continuously undergoes a process involving bone absorption and formation. Previous research has focused on average body mass estimations or pathological responses to body mass extremes. However, limited research has been done towards body mass estimation accuracy when body mass falls under an extreme.

In the summer of 2011, the laboratory for human osteoarchaeology and the Dutch archaeological company Hollandia excavated a cemetery in Middenbeemster, The Netherlands. This skeletal population is unique since the cemetery could be linked to detailed historical information, including age, sex, and cause of death. The aim of this study was to study the prevalence of body mass extremes in the 19th century skeletal population. Furthermore, it has been studied whether the age related features experience influence from body mass and whether pathological lesions known to be associated with body mass have a correlation with body mass in the Middenbeemster skeletal population as well.

Body mass estimations have been made with both the femoral head diameter and stature-bi-iliac breadth (STBIB). The age estimations, to assess the influence of body mass on age related features, have been made with both pubic symphyseal morphology and auricular surface morphology. The age estimations were compared to the true age at death, which were available from historical data. Special care has been taken in interpreting the results, because confounding factors may have caused bias. It appeared that the skeletal population of Middenbeemster was composed of primarily normal and overweight individuals, with a significant difference among males and females. Furthermore, there has not been a significant influence of body mass on age related features in this skeletal sample. The correlation of pathological lesions known to be associated with body mass was not significantly correlated with body mass in this skeletal sample. Together with other research, this study will be part of the enormously detailed historical framework of the population of 19th century Middenbeemster.

## Abstract

Body Mass Index (BMI) is iemands lichaamsgewicht gedeeld door het kwadraat van de lengte. Wanneer de voedingsstatus toeneemt, zal ook de BMI toenemen. Aan de andere kant, zal met een afnemende voedingsstatus ook de BMI afnemen. Bot is een dynamisch orgaan en ondergaat continue een proces waarbij zowel bot absorptie als formatie betrokken zijn. Eerder onderzoek heeft voornamelijk een gemiddelde BMI gebruikt of heeft alleen gekeken naar de pathologische reactie van BMI extremen. Er is nog weinig gedaan naar BMI schattingen voor extreme BMI.

In de zomer van 2011 hebben het laboratorium voor menselijke osteoarcheologie en het Nederlandse Archeologisch bedrijf Hollandia een begraafplaats in de Middenbeemster, Nederland, blootgelegd. Zij hebben ongeveer 500 individuen opgegraven die gekoppeld konden worden aan historische en archief informatie. Hierdoor kan de leeftijd, geslacht, maar ook mogelijk de doodsoorzaak van deze personen achterhaald worden. Het doel van dit onderzoek was om de prevalentie van een extreme BMI in de skeletten van de 19^e^ eeuw populatie te bepalen. Daarnaast ontstond de mogelijkheid om te onderzoeken of lichaamsgewicht invloed heeft op leeftijd gerelateerde kenmerken, doordat de echte leeftijd van een aantal personen bekend was. Ook is gekeken of aandoeningen die geassocieerd worden met lichaamsgewicht, ook een correlatie hebben met lichaamsgewicht in de 19^e^ eeuwse populatie van de Middenbeemster.

De BMI schattingen zijn gemaakt door te kijken naar de diameter van de kop van de femur en de breedte van de *iliac* bladen in combinatie met de geschatte lengte van de persoon in kwestie. De leeftijdsbepalingen, om de invloed van lichaamsgewicht op leeftijd gerelateerde kenmerken te bepalen, zijn gemaakt met zowel de *pubic symphysis* als de *auricular surface*. De leeftijdsbepalingen zijn vergeleken met de echte leeftijd. Verder is er gekeken naar de correlatie van verschillende aandoeningen en het lichaamsgewicht.

Het is gebleken dat de populatie van de Middenbeemster voornamelijk bestaat uit personen met met normale of overgewicht BMI, met een significant verschil tussen mannen en vrouwen. Verder is er geen significante invloed op lichaamsgewicht en leeftijd gerelateerde kenmerken. De voorgestelde correlatie met aandoeningen geassocieerd met lichaamsgewicht, bleek in dit geval niet geassocieerd te kunnen worden met lichaamsgewicht. Desalniettemin draagt dit onderzoek bij aan de informatie beschikbaar over deze 19^e^ eeuwse populatie uit de Middenbeemster.

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## List of figures

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## Appendices A – Overview of identified individuals sample.

| Name | Feature and Find Number | Date of Birth | Date of Death | Sex | True Age | Estimated Age | Average BMI |
|---|---|---|---|---|---|---|---|
| **Stijntje H.** | MB11S457V0960 | 1784 | 1841 | F | 57 | 59,94 | 25,77 |
| **Barend H.** | MB11S427V0938 | 1815 | 1842 | M | 27 | 26,37 | 21,01 |
| **Adrianus P.** | MB11S1530435 | 1791 | 1848 | M | 57 | 38,72 | 21,52 |
| **Grietje M.** | MB11S482V1048 | 1759 | 1836 | F | 77 | 59,94 | 23,90 |
| **Krelisje V.** | MB11S160V0613 | 1819 | 1847 | F | 28 | 27,17 | 22,62 |
| **Lijsbeth de G.** | MB11S466V1010 | 1788 | 1831 | F | 43 | 33,77 | 24,75 |
| **Cornelis M.** | MB11S158V0427 | 1789 | 1849 | M | 60 | 50,64 | 28,06 |
| **Grietje R.** | MB11S302V0509 | 1785 | 1858 | F | 73 | 38,03 | 24,42 |
| **Trijntje R.** | MB11S157V0470 | 1797 | 1854 | F | 57 | 55,68 | 25,76 |
| **Jacob B.** | MB11S363V0766 | 1770 | 1831 | M | 61 | 66,71 | 22,50 |
| **Neeltje E.** | MB11S331V0735 | 1771 | 1845 | F | 74 | 57,70 | 23,09 |
| **Aaltje de G.** | MB11S350V0844 | 1820 | 1843 | F | 23 | 23,33 | 25,10 |
| **Antonia S.** | MB11S349V0752 | 1751 | 1844 | F | 93 | 61,66 | 28,05 |
| **Dirk O.** | MB11S374V0861 | 1753 | 1833 | M | 80 | 66,71 | 26,78 |
| **Grietje O.** | MB11S344V | 1816 | 1836 | F | 20 | 29,33 | 23,00 |
| **Cornelis W.** | MB11S285V0452 | 1785 | 1856 | M | 71 | 58,93 | 24,75 |
| **Geertje W.** | MB11S174V0408 | 1820 | 1865 | F | 45 | 33,77 | 23,00 |
| **IJsbrand B.** | MB11S180V0432 | 1822 | 1847 | M | 25 | 34,28 | 25,97 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Trijntje V.** | MB11S345V0757 | 1818 | 1846 | F | 28 | 59,94 | 26,50 |
| **Klaas E.** | MB11S306V0561 | 1824 | 1855 | M | 31 | 37,86 | 20,79 |
| **Elisabeth M.** | MB11S388V0952 | 1827 | 1861 | F | 34 | 18,37 | 23,47 |
| **Muus O.** | MB11S251V0624 | 1829 | 1864 | M | 35 | 47,57 | 27,77 |
| **Aafje S.** | MB11S485V1034 | 1774 | 1853 | F | 79 | 59,94 | 24,06 |
| **Unknown** | MB11S151V0666 | Unknown | Unknown | F | 24 | 44,67 | 20,34 |
| **Unknown** | MB11S498V1071 | Unknown | Unknown | F | 48 | 63,33 | 22,59 |
| **Unknown** | MB11S466V1010 | Unknown | Unknown | F | 43 | 33,77 | 24,37 |
| **Unknown** | MB11S501V1097 | Unknown | Unknown | F | 20 | 18,37 | 26,88 |
| **Unknown** | MB11S313V0926 | Unknown | Unknown | M | 46 | 47,57 | 23,53 |
| **Unknown** | MB11S368V0794 | Unknown | Unknown | M | 20 | 26,37 | 26,76 |
| **Unknown** | MB11S369V0886 | Unknown | Unknown | F | 30 | 37,86 | 27,78 |

**Appendices B – Age estimations auricular surface and pubic symphysis unidentified female sample.**

| ID Number | Geslacht | BMI (kg/m^2) | Estimated Age Auricular | Estimated Age Pubic | Average estimated |
|---|---|---|---|---|---|
| **MB11S400V064** | F | 25,33 | 17,33 | 25,00 | 21,17 |
| **MB11S70V045** | F | 23,21 | 17,33 | 19,40 | 18,37 |
| **MB11S530V290** | F | 24,80 | 51,41 | 38,20 | 44,81 |
| **MB11S560V061** | F | 26,21 | 63,33 | n.a. | 63,33 |
| **MB11S880V094** | F | 24,89 | 44,64 | 30,70 | 37,67 |
| **MB11S970V156** | F | 23,13 | 63,33 | 60,00 | 61,66 |
| **MB11S11V00213** | F | 25,60 | 33,60 | 38,20 | 35,90 |
| **MB11S1510V666** | F | 20,34 | 29,33 | 60,00 | 44,67 |
| **MB11S160V0613** | F | 22,83 | 29,33 | 25,00 | 27,17 |
| **MB11S183V0311** | F | 23,60 | 17,33 | 25,00 | 21,17 |
| **MB11S309V0616** | F | 24,36 | 69,48 | 30,70 | 50,09 |
| **MB11S311V0956** | F | 21,61 | 17,33 | n.a. | 17,33 |
| **MB11S331V0735** | F | 23,09 | 72,25 | 43,15 | 57,70 |
| **MB11S339V0728** | F | 23,52 | 69,48 | 48,10 | 58,79 |
| **MB11S345V0757** | F | 31,77 | 59,94 | n.a. | 59,94 |
| **MB11S360V0762** | F | 25,19 | 66,71 | 48,10 | 57,41 |
| **MB11S369V0886** | F | 27,78 | 37,86 | n.a. | 37,86 |
| **MB11S383V0880** | F | 26,51 | 44,64 | 48,10 | 46,37 |
| **MB11S388V0952** | F | 23,55 | 17,33 | 19,40 | 18,37 |
| **MB11S401V0876** | F | 24,37 | 29,33 | n.a. | 29,33 |
| **MB11S405V0882** | F | 23,80 | 44,64 | 34,45 | 39,54 |
| **MB11S413V0896** | F | 23,24 | 51,41 | 30,70 | 41,06 |
| **MB11S430V0965** | F | 21,87 | 33,87 | n.a. | 33,87 |
| **MB11S441V0932** | F | 20,93 | 17,33 | n.a. | 17,33 |
| **MB11S452V0985** | F | 24,48 | 37,86 | n.a. | 37,86 |
| **MB11S453V0973** | F | 24,38 | 29,33 | 25,00 | 27,17 |
| **MB11S466V1010** | F | 24,37 | 29,33 | 38,20 | 33,77 |
| **MB11S468V1009** | F | 24,09 | 66,71 | n.a. | 66,71 |
| **MB11S481V1046** | F | 23,33 | 29,33 | 38,20 | 33,77 |
| **MB11S487V1096** | F | 24,16 | 29,33 | n.a. | 29,33 |
| **MB11S498V1071** | F | 22,59 | 63,33 | n.a. | 63,33 |
| **MB11S216V0233** | F | 23,59 | 48,90 | 43,15 | 46,03 |
| **MB11S243V0381** | F | 25,26 | 51,41 | 43,15 | 47,28 |
| **MB11S278V0584** | F | 23,97 | 51,41 | n.a. | 51,41 |
| **MB11S294V0487** | F | 24,80 | 63,33 | 48,10 | |
| **MB11S501V1097** | F | 26,88 | 17,33 | 19,40 | |
| **MB11S504V1109** | F | 28,88 | 72,25 | n.a. | |
| **MB11S512V1105** | F | 25,82 | 51,41 | 43,15 | |
| **MB11S527V1153** | F | 24,25 | 37,86 | n.a. | |
| **MB11S553V1183** | F | 27,84 | 51,41 | n.a. | |

## Appendices B – Age estimations auricular surface and pubic symphysis unidentified male sample.

| ID Number | Geslacht | BMI (kg/m^2) | Estimated Age Auricular | Estimated Age Pubic | Average estimated |
|---|---|---|---|---|---|
| MB11S590V133 | M | 24,10 | 37,86 | 35,20 | 36,53 |
| MB11S700V067 | M | 22,00 | 72,25 | 45,60 | 58,93 |
| MB11S920V124 | M | 22,78 | 29,33 | 28,70 | 29,02 |
| MB11S1580V427 | M | 29,09 | 55,68 | 45,60 | 50,64 |
| MB11S3060V561 | M | 24,74 | 37,86 | n.a. | 37,86 |
| MB11S3130V926 | M | 23,53 | 59,94 | 35,20 | 47,57 |
| MB11S3170V649 | M | 25,93 | 55,68 | n.a. | 55,68 |
| MB11S3250V676 | M | 25,86 | 51,41 | 23,40 | 37,41 |
| MB11S3370V714 | M | 26,83 | | 61,20 | 61,20 |
| MB11S3420V737 | M | 48,92 | 72,25 | n.a. | 72,25 |
| MB11S3470V741 | M | 26,49 | 66,71 | n.a. | 66,71 |
| MB11S3680V794 | M | 26,76 | 29,33 | 23,40 | 26,37 |
| MB11S3740V801 | M | 28,32 | 66,71 | n.a. | 66,71 |
| MB11S3750V815 | M | 26,77 | 63,33 | 53,40 | 58,36 |
| MB11S3790V851 | M | 22,15 | 37,86 | 18,50 | 28,18 |
| MB11S3800V821 | M | 24,45 | 37,86 | 35,20 | 36,53 |
| MB11S4020V901 | M | 23,83 | 63,33 | 35,20 | 49,26 |
| MB11S4041V134 | M | 24,44 | 29,33 | 23,40 | 26,37 |
| MB11S4161V507 | M | 26,94 | 55,68 | 35,20 | 45,44 |
| MB11S4270V938 | M | 23,20 | 29,33 | 23,40 | 26,37 |
| MB11S4320V981 | M | 24,26 | 37,86 | n.a. | 37,86 |
| MB11S4350V929 | M | 26,33 | 59,94 | 35,20 | 47,57 |
| MB11S4641V012 | M | 28,25 | 51,41 | n.a. | 51,41 |
| MB11S4671V022 | M | 27,45 | 37,86 | 28,70 | 33,28 |
| MB11S4731V003 | M | 24,57 | 33,60 | n.a. | 33,60 |
| MB11S4771V030 | M | 28,98 | 72,25 | 45,60 | 58,93 |
| MB11S4821V048 | M | 24,75 | 59,94 | n.a. | 59,94 |
| MB11S4841V024 | M | 23,66 | 59,94 | n.a. | 59,94 |
| MB11S4941V057 | M | 29,15 | 59,06 | n.a. | 59,06 |
| MB11S4971V059 | M | 28,38 | 37,86 | n.a. | 37,86 |
| MB11S2260V282 | M | 24,20 | 29,33 | 35,20 | 32,27 |
| MB11S2230V304 | M | 27,61 | 55,68 | n.a. | 55,68 |
| MB11S2360V335 | M | 26,23 | 34,10 | 23,40 | 28,75 |
| MB11S2370V348 | M | 25,16 | 66,71 | 60,00 | 63,36 |
| MB11S2420V338 | M | 22,31 | 66,71 | 61,20 | 63,96 |
| MB11S2500V402 | M | 29,56 | 66,71 | 45,60 | 56,16 |
| MB11S2510V624 | M | 26,70 | 59,94 | 35,20 | 47,57 |
| MB11S257V1006 | M | 26,81 | 29,33 | 37,15 | 33,24 |
| MB11S261V0422 | M | 31,64 | 66,71 | n.a. | 66,71 |
| MB11S263V0445 | M | 25,68 | 37,86 | 35,20 | 36,53 |
| MB11S269V1032 | M | 21,80 | 37,86 | n.a. | 37,86 |

| | | | | | |
|---|---|---|---|---|---|
| **MB11S270V1067** | M | 25,61 | 23,33 | n.a. | 23,33 |
| **MB11S290V0472** | M | 22,87 | 29,33 | n.a. | 29,33 |
| **MB11S297V0498** | M | 22,97 | 55,68 | n.a. | 55,68 |
| **MB11S502V1062** | M | 24,42 | 29,33 | 23,40 | 26,37 |
| **MB11S511V1126** | M | 27,80 | 66,71 | n.a. | |
| **MB11S516V0112** | M | 25,35 | 66,71 | n.a. | |
| **MB11S524V1120** | M | 25,10 | 59,06 | 35,20 | |
| **MB11S525V1119** | M | 25,78 | 17,33 | n.a. | |
| **MB11S526V1160** | M | 24,46 | 66,71 | n.a. | |