Osteoarthritis and body size in Ancient Nubia

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Cover picture: Individuals with different body size, in which the joint areas of the lower limbs that can develop osteoarthritis are shown with red marks. Created by C. Chatzinikolaou after https://www.bioenciclopedia.com/aparato-locomotor/

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An examination of osteoarthritic changes of lower limbs in relation to body size in the prehistoric site of Tombos, Sudan

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Preface

The year of 2020 was unexpected and challenging for every one of us and the uncertainty surrounding everything had its impact as much in everyday life as in work and studies. As many fellow students of mine, I have also faced many difficulties conducting a research analysis in the laboratory of the faculty during the pandemic, due to the restrictions. Adapting to the new reality, I had to set aside my original research study and adopt a new one that could be conducted even if I was not able to travel back to Leiden. Thanks to Dr. Sarah Schrader, I was able to use data from her own personal osteological record and thus proceed with the new research study.

Personally, writing the MSc Thesis during the pandemic was quite a difficult task. However, being able to write my thesis and, by doing so, pursue my aim of obtaining a master of my liking and specialisation brought me a deep sense of fulfilment which balanced out all the stress and anxiety. Even though the topic was not the one I had first chosen, I was particularly pleased with carrying out the research: it was even challenging sometimes to engage with statistical analysis, perhaps not my favourite archaeological research tool.

Having said all that, I would like to thank my supervisor, Dr. Sarah Schrader, for sharing with me osteological material that was part of her personal work and, in this way, making possible for me to carry through with my research thesis. She also provided useful directions during the writing of the study.

Furthermore, I would like to thank my family for their financial help and emotional support and encouragement, without which I would not have been able to accomplish my dreams nor to complete this thesis. To all my close friends, I want to express my gratitude for their supportive words and their understanding even when, sometimes, I unintentionally lost connection with them. A special thanks to Oriol for tolerating all my stress-induced mood changes and for all the time he spent trying to understand my thesis topic and kindly providing his thoughts and help.

Chapter 1: Introduction

Skeletal remains are a fascinating area for many people related to archaeology, anthropology or other fields of interest. However, as well as interesting, the study of human skeletal materials has contributed so far to the science of archaeology as well the medical sciences to a great extent. While examining skeletal materials there is a plethora of information to be obtained; information that can be related to the social, economic and health status of both an individual and a past or present population. Additionally, human remains are among the key contributors to the forensic studies which aim at the identification of lost individuals. Nevertheless, in the area of osteoarchaeology that focuses mainly on the past, through the abundance of information that can result from the study of human remains, the quest for the health of an individual and the interpretation of the many pathological lesions, disorders or diseases that could affect the human body, seems to be first in the list of interests.

1.1. Osteoarthritis and body size

This thesis will focus on one specific pathological disease which is named osteoarthritis and which is considered to be one of the most ubiquitous pathological diseases (Austin 2016, 537; Weiss and Jurmain 2007, 473) with a controversial and multifactorial etiology (Palmer et al. 2016, 78). The importance of osteoarthritis in the osteoarchaeological field is undoubted as it is the most common disorder to be found in the majority of human joints. The disease has a substantial history of research and a great number of studies have been dedicated to its investigation. Quite recently, studies have actually shown that osteoarthritis has increased and doubled in prevalence since the mid-20th century (Wallace et al. 2017, 1). The high occurrence and development in the present and the irreversible nature of the disease has moved even more investigators and researches as well as the medical community to focus with full attention on study related to the etiology of osteoarthritis and possible ways of treatment.

Although age is regarded as the most important risk factor, both the medical and anthropological community are still trying to fully understand the additional related factors that lead to the prevalence of osteoarthritis, either major or minor ones. Mechanical loads deriving either from activity or natural movements of the body are accepted playing a key role in the incidence of osteoarthritis and considered to be one of the major factors contributing to the prevalence of the disease. Although body size (which is the combination of stature, weight and robusticity), has been characterized as of a minor factor to the disease, it is in fact an important one because of its contribution to the prevalence of osteoarthritis by involving in the mechanical movements and loading of the body (Calce et al. 2018, 46). Plenty of studies have been put forward concerning the relation of body size and osteoarthritis. Most of them support the theory that the bigger and heavier an individual is the more prone to the disease they get. Nevertheless, the study of body size in relation to osteoarthritis disease is still in its early ages and needs deeper investigation. The features of body size (stature, mass weight, robusticity etc.) have been studied separately quite extensively during the last decades. Despite this fact, investigations of the features of body size as a whole have not been conducted so thoroughly, especially those focusing on the lower limbs as recipients of the loads of the body. Thus, the aim of this thesis is to examine the relation between body size and osteoarthritis bone changes and to interpret this relation. The study will focus on the lower limbs but research regarding the upper limbs and the spine is highly encouraged.

1.2. Research question

As mentioned in the previous section the etiology that affects osteoarthritis keeps studies about the disease topical and highly important. The relation between activity and osteoarthritic changes in bones has been examined over and over again, by paying attention mainly to behavioral factors instead of physiological or genetic ones. In this thesis the main idea to be examined is whether, from a physiological perspective, the size of an individual in terms of body size ,as taken from three measurements from the femur bone (maximum length, femoral head diameter, epicondylar breadth), can affect osteoarthritis in the lower limbs and if it does so, to what extent. The focus on lower limbs has been selected, due to the presumption that the joints of those bones are the ones bearing the load of the whole body, as humans that are categorized among the bipedal animals which carry their body weight in their legs which they use for the locomotive motion (Gatesy and Biewener, 1991).

Given the above, the main research question of this thesis is whether body size affects the prevalence of osteoarthritis in the lower limbs. From the data that one osteoarchaeologist can have in their hands it is rather difficult to define the exact way that body size predisposes to osteoarthritis or/and in which stage of the disease the involvement is more determining. So the question can be better approached by examining the relation between those two, when there is already the presence of the disease in the bones. How then is osteoarthritis related to body size? To observe this relationship, it is important to first examine the incidence and frequency of osteoarthritis in that sample, so that osteoarthritis data can then be correlated with body size measurements from the same sample. Are the numbers or percentages of osteoarthritis in the sample related to body size? Does the prevalence of osteoarthritis follow any pattern towards small or large-sized individuals? The primary hypothesis is that a larger individual will add more pressure to their joints, thus leading to more significant changes of osteoarthritis; however the idea that a smaller individual that has smaller joints and joint surfaces in which the distribution of either external loads or body weight take place can develop osteoarthritis more easily, can also hold true. Moreover, considering the fact that the body is a living entity that interacts with many internal and external factors, it is important to have in mind that there is a plethora of strong confounding factors that can influence the examined relation among the variables on which the thesis is mainly focusing, thus biasing the sample. Confounding factors as well as their influence in the results will be examined, considered and discussed.

In the thesis a Nubian population site named Tombos, located in the north of today´s Sudan, will be studied to show the relation between body size and osteoarthritis. The population sample was selected due to the fact that the individuals buried in this cemetery are thought to have been exposed to limited levels of manual work, as they belonged to the upper/middle class of the society (Schrader 2012, 69) and for that reason they are considered to be a good sample for examining the results of body size in relation to the osteoarthritic changes of their joints. The sample consists of discrete burials, as well as of separate bones from a commingled context that came from extensive and repeated looting of a part of the tomb chamber where the deceased individuals were once placed. The study is based on an important hypothesis, that is that the individuals buried must have had quite “normal” weight, as we expect no obese people to live in prehistoric Nubia, considering that obesity is a modern pathology of mostly western populations (Calce et al. 2018, 50), and that is why weight has not been examined separately in relation to the disease and has only been considered as part of body size. With such a hypothesis the confounding factor of loadings due to overweight can easily be excluded. The sample is considered to be per se homogenous when controlling for this factor.

In order to examine body size, aggregate (z-scores) of all femoral measurements will be calculated and then correlated with the scoring osteoarthritic changes. Although osteoarthritic changes of this sample have been collected and previously studied from Schrader (2012), it was considered, in this thesis, important that they be analytically presented and examined in a way to be functional for the statistical analyses. Osteoarthritis will be examined in separate joint surfaces but also, such as Schrader (2012) used them, in group joints and a different scoring method will be applied. Osteoarthritis will not be examined as a whole in this study. Each osteoarthritic change will be examined separately and will be tested for its correlation with body size. The relationship among the three osteoarthritic lesions will be examined as well, so as to observe if the three of them are unrelated and can be present without the occurrence of one of the others (Myszka et al 2020, 4-6), or if they follow a linear pattern of occurrence and all three can imply the existence of osteoarthritis, as many studies suggest.

As has already been discussed, age is an important factor that affects osteoarthritis, in terms of trigging degenerative functions in the area of joints among the bones. The clinical community almost unanimously agrees that age is highly related to osteoarthritis, as it affects the majority of the population above the age of 50 (Felson and Nevitt, 2004: 783), with women being the group most affected by the disease, especially those who belong to the older age groups (Felson and Nevitt, 2004: 783; Sowers, 2001: 447). For that reason age has been selected to be used as controlling variable to the sample. Additionally, sex, in terms of sexual dimorphism among people, is considered to be an intriguingly confounding factor and one that can highly influence the results of body size. Consequently, sex will also be one of the two controlling variables for the sample. Of course, due to the nature of the sample in which there is a lack of sexing and aging determinants, sex and age will be correlated with the other variables only when their estimation is possible.

Overall, we expect that our study will add some extra information to the complicated area of the etiology of osteoarthritis and the examination of a sample of the continent of Africa might be the stimulus for more studies globally, taking into account that body size varies greatly from human to human among different populations as well as within the same population (Stinson 2012, 588).

Chapter 2: Background

This chapter will focus on the pathological disorder of osteoarthritis and body size measurement. Osteoarthritis will be examined from the perspective of the clinical research that has already been dedicated to it. The development, symptoms and etiology of the disease will be discussed thoroughly. The role of osteoarthritis in the archaeological survey will also be mentioned. Finally, the chapter will focus on body size and its importance in the present study.

2.1.1. Osteoarthritis

Osteoarthritis (OA) is the most common joint disorder (Anderson and Loeser 2010, 16; Fahlman et al. 2013, 201; Felson 2004, 1; Felson and Nevitt 2004, 783; Lee et al. 2016, 2; Waldron 2008, 26) and the most frequent form of arthritis that can be developed on the bones of the human body (Felson et al. 2006, 635). It is characterized broadly as a degenerative joint disease since it is related to age in humans (Anderson and Loeser 2010, 15; Felson 2004, 1) but it is also regarded as a process of active repair of the bone as a reaction to the disease's formation and a response of the joint to abnormal mechanical stress that an injury has caused (Dieppe 2011, 245). Quite recently in medical studies it was observed that osteoarthritis affects all joint tissues, namely, not only the cartilage but all articular structures that contribute to the function of the joint(Felson 2004, 1; Dieppe 2011, 245). Furthermore, the progression of the disease is not always continuous, as once active can either worsen or stabilize and it is irreversible (Dieppe 2011, 246).

Osteoarthritis is a chronic disease (Fahlman et al. 2013, 201; Jeon et al. 2019, 1557) with a series of multiple factors being attributed to it, such as systemic risk and biomechanical factors (Jeon et al. 2019, 1557). For that reason the actual etiology of the disease is still unknown and it is not yet certain if it is a single disease or many disorders co-acting on a focal area (Felson et al. 2000, 635). It has been suggested, that as a disorder, osteoarthritis is a "mechanically driven but chemically mediated process"; that is to say, a disorder in which the intervention of genes, diet, hormones and bone compartments is of high importance for its progression (Sowers 2001, 448). The disease shows a universal appearance and it can affect individuals from different age ranges, although it is most commonly found in the knee, hip and hand joints of elderly people

(Felson and Nevitt 2004, 783). The occurrence, as well as the prevalence in women, especially over the age of 50, is markedly higher than men, when it comes to osteoarthritis of the knee and hand (Felson and Nevitt 2004, 783; Sowers 2001, 447), something that has occasionally its parallels in archaeological studies but is mostly observed in modern populations. Current medical studies over the incidence of the disease show that worldwide the prevalence is located around 0.1%, 4.5%, 5.6% in men and 0.2%, 19%, 16% in women in the hip, knee and spine respectively (Jeon et al. 2019, 1557). In particular, symptomatic knee osteoarthritis occurs in 13% of people over the age of 60 (Felson and Nevitt 2004, 783) and together with hip osteoarthritis are the principal causes for musculoskeletal disabilities in elders (Stevens-Lapsley and Kohrt 2010, 601; Welling et al. 2017, 1095).

2.1.2 Synovial Joints

The human skeleton has several types of joints. One of them is called synovial and is almost exclusively the one affected by the disease of osteoarthritis (Waldron 2008, 24). Among the synovial joints some are more prone than others to develop the disease (Waldron 2008, 33). The distal interphalangeal, proximal interphalangeal, carpometacarpal, hip, knee and metatarsophalangeal joints (Felson 2004, 3) are those more commonly affected. Cervical and lumbosacral spine joints are also highly affected but do not belong to the category of synovial joints (Felson 2004, 3).

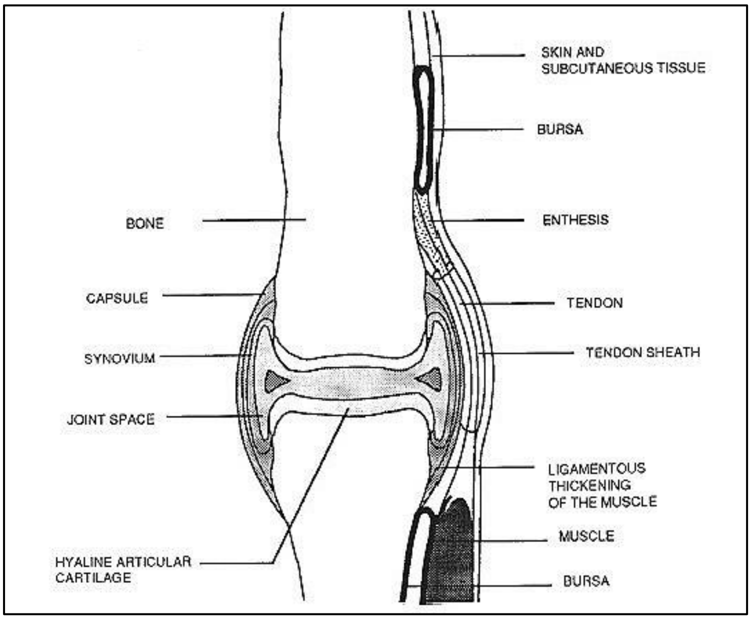


Figure 1. A normal synovial joint (Waldron 2012, 26)

Every synovial joint is an example of a well-structured system (fig. 1). In the outer layer the synovial joint consists of a capsule that encloses tendons and ligaments while in the inner layer it contains the synovial membrane (Waldron 2008, 24). The function of the synovium, which gives its name to the joints, is to “nurture” the cells of the cartilage with synovial fluid, to lubricate the joint surfaces and clean unwanted micro-organisms and debris from them (Waldron 2008, 25-6). The articulating ends of the bone that form part of the synovial joint are called subchondral bone plates and are covered with cartilage (Waldron 2008, 24). Between the cartilages there is a joint space that facilitates movement and constitutes the limit between the synovium and the articular surfaces (Waldron 2008, 24).

As mentioned above, in osteoarthritis, the whole joint is affected (Dieppe 2011, 245) and there might be development of inflammation of the synovium, cartilage overgrowth, degeneration of the menisci (particularly in the knee joint), alteration in the subchondral bone and erosion of the articular cartilage (Stevens-Lapsley and Kohrt 2010, 601). The fact that some joints are more susceptible to the disease has been attributed to several factors and reasons. One of them is thought to be that some joints are more resistant to stress than others, as for example the ankle joint which barely displays osteoarthritic lesions. One other idea suggests that susceptibility of one joint is connected with the evolution of humans to bipeds and the transition of the weight bearing form both the upper and lower limbs only to lower extremities (Felson 2004, 3). In general, articular cartilage is a complex tissue consisted of collagen matrix and a high quantity of water that contributes to its unique load-support mechanism that once altered, leads to the deformation and degeneration of the cartilage and as a result to the beginning of osteoarthritis (Felson 2004, 1, Felson et al. 2000, 640).

2. 1.3. Joint and bone alteration

With the beginning and activation of osteoarthritis disease, a series of pathologic changes, which have common features in every individual, emerge in the joint areas (fig. 2) (Loeser 2010, 372). The cartilage matrix is the first one affected when degeneration of its chondrocytes cells and breakdown of their function begin (Loeser 2010, 373; Stevens-Lapsley and Kohrt 2010, 601; Waldron 2008, 27). When the chondrocyte cells are unable to maintain the health of the cartilage, the fibrillation of the cartilage begins, resulting in erosion and destruction (Loeser 2010, 372; Waldron 2008, 27). Following these changes the synovial membrane is then affected, causing inflammation (Felson et al., 2000, 636; Loeser 2010, 372; Waldron 2008, 27). The immediate reaction of the

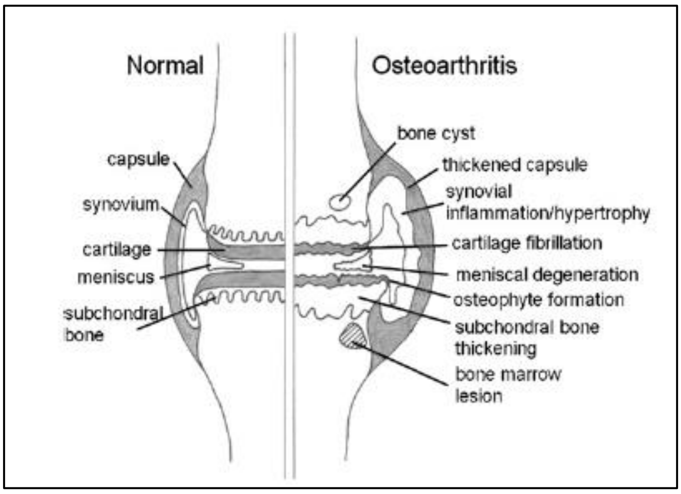


Figure 2. Pathology of osteoarthritis in the joint (Loeser 2010, 272)

bones the one leads the subchondral bone to thicken and reactive new bone, called osteophyte, to start forming in the margins of the joint (Felson et al. 2000, 636; Loeser 2010, 372; Stevens-Lapsley and Kohrt 2010, 601). This bone's growth is actually calcifying the cartilage, resulting in its loss which is actually the signature event in osteoarthritis disease (Felson 2004, 1). The soft-tissues around the joint are also affected (Felson et al. 2000, 636). The ligaments become loose and can even be led to rupture (Felson et al. 2000, 636; Loeser 2010, 372) and the muscles weaken and atrophy (Felson et al. 2000, 636). At the last stage, when the cartilage has been lost, eburnation is developed in the subchondral bone areas of the joint due to the rubbing among the bare bones (Waldron 2008, 28).

In the first stages the pathologic changes are dynamic and attempt to function as protective reactions against the injuries that are developed in the joint. (Felson 2004, 1) The formation of the osteophytes aims to stabilize the joint and thus prevent new injuries (Felson 2004, 1) The process needs a period of time before it passes from the stage of active osteoarthritis to the stabilization stage and most of the times it can be reactivated (Dieppe 2010, 245-6). When reaching the last stages the joints have undergone significant damage and irreversible pathologic changes (Felson 2004, 1). The transition from the dynamic stages to the irreversible point of degradation varies from joint to joint and it is different for each individual (Felson 2004, 1). Finally, not only does the process of osteoarthritis affect the joint itself but also the movement of the joint since the cartilage is the tissue that facilitates the normal gliding motion of the joint (Loeser 2010, 373).

2. 1.4. Expressions and symptoms

As mentioned above the changes occurring during the progression of osteoarthritis affect the whole joint. However, the changes that can be found in the last stages of progression are those that take place in the articular bones (Waldron 2008, 27); thus

Figure 3. Lipping of the proximal ulnae (Klaus 2009, 211)

they are the ones that can be found as well in the dry bone. The osteophytes, new bone formations in the marginal space of the joint, are one of the most common changes and symptoms (Waldron 2008, 27). Osteophytes are bony outgrowths, which when formed marginally, in the periphery of joints are named lipping (Myszka et al. 2020, 1). Lipping is the result of endochondral ossification that comes after the vascularization of the subchondral bone marrow (Myszka et al. 2020, 1) (fig. 3). Marginal lipping is not the only bony growth that can be found in a joint. Central osteophytes occur in the interior of the joint, periosteal and synovial and capsular osteophytes can also appear but are less common (Myszka et al. 2020, 1). Osteophytes appear in any shape and size and the bigger they are the more severe they can be characterized (Schrader 2019, 57). Their growth has been connected with responding acts over repair of a damaged joint and attempts of its stabilization (Schrader 2019, 57).

Formation of new bone can also be seen in the calcified subchondral cartilages of the joint surfaces and it appears as pitting, i.e. formation of small-size holes (Waldron 2008, 27) (Fig. 4). This pitted or porous area is characterized as erosion of the bone surface and is named porosity (Myszka et al. 2020, 1; Schrader 2019, 57). With the progression of porosity the lesion can become more severe and

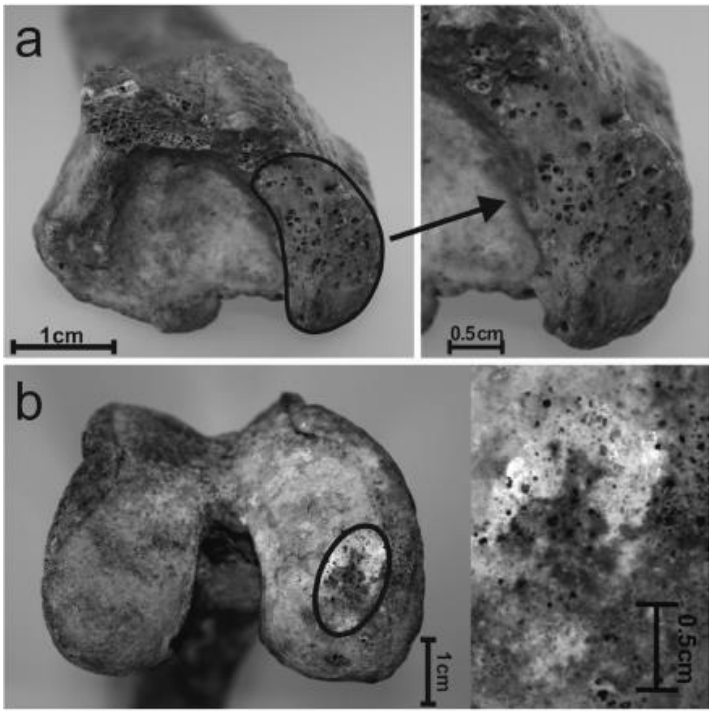


Figure 4. (a) Porosity on the distal end of radius and (b) porosity on the medial condyle of femur (Myszka et al. 2020, 2)

widespread and the porous area can cover the whole joint cartilage surface (Schrader 2019, 57). It can be manifested both as micro and macro-porosity, namely with small-sized or large-sized pitting (Myszka et al. 2020, 1). It is still not proven if porosity is a response in order to maintain the cartilage tissue (Schrader 2019, 57) but it has been suggested that it is probably connected with nutritional defects (Myszka et al. 2020,1).

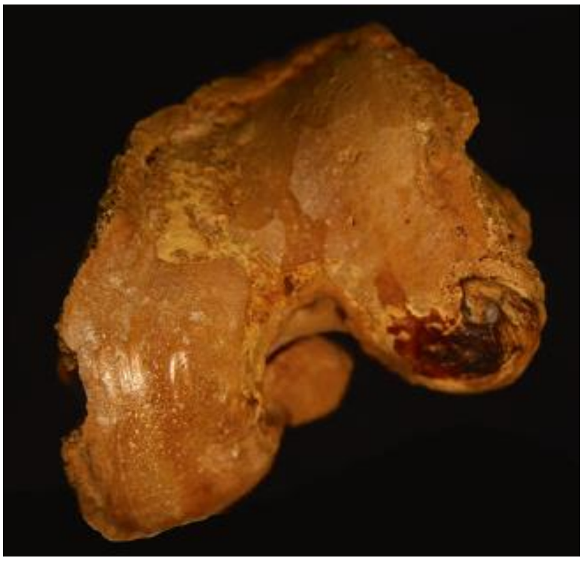


Figure 5. Eburnation on distal femur (Schrader 2019, 58)

Changes can be observed as well at the contour of the joint as it flattens and widens (Waldron 2008, 27). The most prominent change in the bones affected by the disease is eburnation, a highly polished area on the joint surface, which is caused by excessive rubbing due to continuous bone-to-bone contact during the motion of the joint (Myszka et al. 2020, 1; Waldron 2008, 27-8) (fig. 5). Extensive eburnation can lead to formation of grooves in the articular surface due to continued abrasion which are formed parallel to the direction of the movement of the joint (Myszka et al. 2020, 3). Eburnation is considered to be the most characteristic and diagnostic expression of osteoarthritis in the bones (Schrader 2019, 58-9).

In modern clinical radiographic analyses osteoarthritis is diagnosed by the presence of osteophyte formation, narrowing of the joint space and subchondral sclerosis (Ding et al. 2005, 198; Felson 2004, 2; Sowers 2001, 447; Stevens-Lapsley and Kohrt 2010, 601). In general, symptomatic osteoarthritis is diagnosed with discomfort, joint stiffness and disability as well as enlargement of the joint causing limitation of the motion (Anderson and Loeser 2010, 16; Dieppe 2010, 246; Felson 2004, 2; Felson et al. 2000, 635; Stevens-Lapsley and Kohrt 2010, 601). The knee is the most common joint developing disability, as the symptoms of osteoarthritis in this specific bone are mainly mechanical; That is, occurring with physical activity they lead to loss of function (Anderson and Loeser 2010, 17; Hunter et al. 2005, 1418; Waldron 2008, 37) Disability and pain are two of the symptoms associated with the disease, especially regarding elderly people, but they do not occur exclusively because of osteoarthritis (Anderson and Loeser 2010, 16; Dieppe 2010, 246; Felson et al. 2000, 635). Pain varies on its expression from individual to individual (Hunter et al. 2005, 1418) and does not always accompany the incidence of the disease (Stevens-Lapsley and Kohrt 2010, 601), but it is ranked among the symptoms of the patients.

2. 1.5. Etiology

Osteoarthritis, as mentioned before, is a multifactorial disorder (Hunter et al. 2005, 1419). It is believed now that both systemic and local risk factors account for the development of the disease, while some are responsible for predisposition to it. As a disease that is more observed in the elderly people, osteoarthritis is highly associated with age (Anderson and Loeser 2010, 19-22; Jeon et al. 2018, 1559; Loeser 2010, 378). Apart from age, in the most common risk factors are considered obesity, genetic factors, anatomy of the body with its biomechanical properties and previous injuries (Stevens-Lapsley and Kohrt 2010, 601; Waldron 2008, 28). Gender, race, metabolic factors, diet, bone forming and hormones are also included in the etiology of the disease but are considered as minor risk factors (Sowers 2001, 448-9; Stevens-Lapsley and Kohrt 2010, 601; Waldron 2008, 28).

Age is the only factor that seems to participate independently in the development of osteoarthritis in every person and interact with other risk factors, increasing therefore the susceptibility of one's joint to the disease (Loeser 2010, 375). In what way, though, does age predispose to osteoarthritis? It is proven that with age the chondrocytes lose the ability to recreate themselves and maintain the health of the cartilage matrix resulting in the thinness of the cartilage, particularly at the femoral side of the knee joint and the patella, as shown from MRI studies (Anderson and Loeser 2010, 21-2; Loeser 2010, 378). This way, aged joints can neither counterbalance the stress loaded to them nor function properly or address an acute joint injury (Anderson and Loeser 2010, 19-20). Age affects the whole musculoskeletal system that plays a role in the function of the joints, however, alone does not cause the disease (Anderson and Loeser 2010, 16). By ageing, muscles lose their strength and weaken, being unable to support the loads of the joints and so do joint ligaments (Loeser 2010, 375). Furthermore, joint tissues are calcified (Loeser 2010, 375) and bone marrow lesions are developed around the joints (Anderson and Loeser 2010, 19). Finally, in addition, there is a significant loss of proprioception (Loeser 2010, 375).

Biomechanical factors are also categorized among the key factors for the disease, as they are regarded by some to be the initiative step in the development of osteoarthritis in people that are predisposed to it (Felson et al. 2000, 636). However their impact in the occurrence of the disease is highly related also with age considering that the defects occur after repetition of movements in one's joint (Schrader 2019, 61). As mentioned above, cartilage thinness and degeneration may lead to a general deformation of the joint and an imbalance of its biochemical properties (Felson et al. 2000, 640). Those alterations are responsible for the imbalanced load distribution, which, in turn, again cause harm to the cartilage (Felson et al. 2000, 640) and intensify new bone and calcification formation (Anderson and Loeser 2010, 19). In general, the condition of limb alignment seems to account for the prevalence of osteoarthritis, in terms again of poor distribution of body weight and mechanical loads on the joints (Stevens-Lapsley and Kohrt 2010, 606).

Relating to height, clinical surveys have proven that taller individuals were more susceptible to the disease and were associated with osteoarthritis when compared with their controls (Welling et al. 2017, 1095, 1098). Leg and knee length are also considered to be related to osteoarthritis (Hunter et al. 2005, 1420-1; Welling et al. 2017, 1101). According to Welling et al. (2017, 1101) "long legs result in greater torque at the knee" and "length is associated with higher total and especially higher upper body size", thus length is directly related to the loads of the body. Additionally, knee height has been proven to affect patellofemoral and tibiofemoral osteoarthritis (Hunter et al. 2005, 1420-1; Tecichtaht et al. 2012, 3-4). Finally, in relation to muscle mass, although total skeletal muscle mass seems to lack a relation to the development of osteoarthritis on joints, lower limb skeletal muscle mass is thought to be connected with the disease. Individuals with lower rates of lower limb lean mass and with higher rates of fat mass present higher prevalence of knee and hip osteoarthritis (Jeon et al. 2015, 1557-8; Lee et al. 2016, 6).

Regarding to body mass, weight seems to plays a significant role as a risk factor for the osteoarthritis disorder since it increases the amount of mechanical load across the joints (Felson 2004, 6). It is thought that "every pound of weight is multiplied threefold to six fold in terms of its effects on knee loading" (Felson 2004, 6). Even more, surplus fat body weight seems to be related to the presence of osteoarthritis both at the lower and at the upper limb joints (e.g. hand osteoarthritis) (Yusuf et al. 2010, 764). Surplus fat body weight, namely obesity, is another important risk factor for the incidence of osteoarthritis (Felson et al. 2000, 639). Obese individuals are particularly susceptible to develop the disease in the knee joints, due to the excess loading that their joints undergo (Felson et al. 2000, 639; Felson and Nevitt 2004, 783). Specifically, individuals with sacropenic obesity are more associated with the disease than people with other types of obesity (Jeon et al. 2018, 1560). However, obesity is not only categorized among the biomechanical risk factors but it is also related to systemic and hormonal factors that are highly connected with the life and function of the cartilage (e.g. leptin) (Stevens-Lapsley and Kohrt 2010, 604; Yusuf et al. 2010, 764).

The risk factor of sex is still under examination. When associated with obesity it can be seen that overweight women have higher probability of forming osteoarthritis than overweight men (Felson et al. 2000, 639). In general, women have higher fat mass and lower lean mass, as well as different pelvic dimensions, knee morphology, quadriceps angle and neuromuscular strength than men which probably accounts for the higher incidence of the disease among women (Hunter et al. 2005, 1419). Modern studies have shown that women have higher prevalence of the disease on the knee joint and lumbar spine, while men have higher prevalence on the hip joint (Jeon et al. 2015, 1559). Women also manifest more severe symptoms and have a greater variety of affected joints compared to men (Stevens-Lapsley and Kohrt 2010, 602). In addition, osteoarthritis in women seems to intensify over the age of 50 and it has been connected with the withdrawal of ovarian hormones after the menopause (Stevens-Lapsley and Kohrt 2010, 604).

Joint injury is ranked among the local risk factors but it is also considered to belong both to these and to the systemic ones as they act in interaction with each other (Felson 2004, 6). An already deformed joint, with a significant thin or calcified cartilage is susceptible to a variety of injuries (Felson 2004, 4). In that way the systemic vulnerabilities act upon and combine with the local ones, such as joint deformities or previous injuries, and can lead to degenerative disorders such as osteoarthritis (Felson 2004, 4). Injuries can activate systemic factors as well. Fractures on articular surfaces, traumas in ligaments or in muscles and joint dysplasia are also responsible for the beginning of cartilage’s breakdown and the activation of osteoarthritis (Felson et al. 2000, 641).

Genetic factors are a category of factors that has been examined quite recently. Genetics seems to account for only some of the joints that are affected by osteoarthritis and the percentages of heritability on those joints vary (Felson 2004, 5; Felson et al. 2000, 638). Hand and hip osteoarthritis have been shown to be inherited and the genetic factors linked to them account for 50% of cases (Felson 2004, 5; Felson and Nevitt 2004, 783; Felson et al. 2000, 638). For the knee joints the percentage is far smaller (Felson et al. 2000, 638). Race as a factor related to the incidence of osteoarthritis is even less examined so far. Only some ethnic differences have been found and these are not so much in the prevalence of the disease as in its symptoms (Felson et al. 2000, 637). Higher rates of knee osteoarthritis have been observed in African-American women but not in men (Felson et al. 2000, 637). Additionally higher rates of disability related to the disease and more severe symptoms have been seen (Felson and Nevitt 2004, 784), but apart from that no specific study has pointed out any other ethnic differences.

Finally, vitamins, through diet, have also been proposed as factors affecting the prevalence of osteoarthritis on joints (Felson and Nevitt 2004, 789; Sowers 2001, 448-9). Vitamin D and C deficiency increase the risk of the disease when already active, as well as the risk of the loss of the joint space (Lee et al. 2016, 6; Felson and Nevitt 2004, 783), while there is strong evidence over the reduced risk for knee osteoarthritis with the intake of Vitamin C (Felson et al. 2004, 636). All in all, osteoarthritis is broadly considered as a multifactorial disorder the factors of which probably interact with each other. In addition, as Felson and Nevitt (2004, 789) mention, “osteoarthritis may be heterogeneous in its structural pathology. Risk factors for bone proliferation may be differing from those for cartilage loss”. In any case, what is proven so far is that age and biomechanical factors are those related more closely to the prevalence of osteoarthritis in joints (Felson 2004, 4).

2.2. Osteoarthritis in osteoarchaeology

Osteoarthritis has been a topic that drew the attention and the enthusiasm of many anthropologists and archaeologists over previous decades. Up until 1970 the research community had focused on the prevalence and symptoms of the disease, while later, the focus area started to be organized around more behavioral interpretations and the etiological factors of the disease (Jurmain et al. 2012, 533). Osteoarthritic lesions in skeletal human remains were broadly used to interpret functional stress and to reconstruct the different activities and occupations of past populations (Jurmain 1991, 249; Jurmain et al. 2012, 531; Palmer et al. 2016, 78; Weiss 2007, 690). The mechanical loading of repetitive movements due to everyday labor was the first and most important factor hypothesized to be connected with osteoarthritis, especially when presented with "markers" on the bones (Weiss and Jurmain 2007, 438; Weiss 2007, 690). Those "markers", named markers of activity, were exclusively associated with mechanical stress and included osteoarthritic lesions and musculoskeletal stress markers (Jurmain et al. 2012, 531). However, the more popular the interpretation of osteoarthritis as an occupational pathology became, the more controversial it started to become in the bioarchaeological and medical community (Myszka et al. 2019, 1; Palmer et al. 2016, 78). Modern clinical studies shed a light over this topic by proving that many of those occupational "markers" related to osteoarthritis were in fact as much as pathological as mechanical (Jurmain et al. 2012, 531-2). In addition osteoarthritis did not always show positive correlations with the musculoskeletal markers (entheseal changes); leading to the idea that there is probably no mutual etiology between osteoarthritis and entheseal changes (Palmer et al. 2016, 82). The long-term research has proven so far that markers take time to develop on the bone and as a result, activity, as generator factor, needs further investigation and studies of duration (Jurmain et al. 2012, 532).

Relating to the material itself, in osteoarchaeology, the object of examination of those studies is "fingerprints" that the disease leaves on the skeletal remains, considering that no other tissues can survive in the samples of past populations' human remains. In the beginning, those fingerprints or in our case the degenerative changes on the bones were thought to be found in all the human joints but quite soon they were restricted to the synovial joints and the vertebra ones, as vertebral osteophytosis (VOP). The latter has not been given so much of attention because it is regarded as poor marker of activity (Jurmain et al. 2012, 534,553; Weiss 2007, 438).

The osteoarthritic changes on bones have been divided into two broad categories according to the area of development: 1) Marginal hypertrophic changes and 2) articular surface changes (Jurmain et al. 2012, 539). The changes have also been classified into three subcategories according to their morphology: 1) osteophytes or bony spicules, 2) pitting or porosity or erosion and 3) eburnation or polishing (Jurmain et al. 2012, 539;

Myszka et al. 2020, 1, 3; Weiss 2007, 690). The changes are thought to follow a linear pattern of occurrence from lipping to porosity and then eburnation, but recently they have been observed to occur and develop independently (Myszka et al. 2020, 3, 6, 7). Osteophytes and porosity are seen in skeletal samples without being dependent on each other and osteophytes seem also to occur in “healthy” joints perhaps due to mechanical stimulus or ageing (Myszka et al. 2020, 3, 6). Eburnation is still considered to be a second stage of degeneration following porosity (Myszka et al. 2020, 3). The changes are evaluated and recorded by one of the broadly accepted ordinal scoring systems that record the existence and severity of each of the changes (Jurmain et al. 2012, 539). The levels follow clinical systems of recording (slight, moderate and severe) and need the occurrence of two of them in order to make a diagnosis of osteoarthritis, unless there is presence of eburnation that is regarded as a determining criterion (Jurmain et al. 2012, 539; Palmer et al. 2016, 80).

The many years of research have proven prolific but have also shown that the area of research has many limitations. Of course many of these limitations derive from the research questions themselves. The idea of associating every osteoarthritic change with repetitive activities and mechanical loading, without taking into account the multiple confounding factors has led to deadlock many times. Over recent years, age has been determined as the leading factor of the disease but the complexity of the disease and its etiology are still not taken into serious account by every researcher and are overshadowed by the most common behavioral interpretations (Calce et al. 2018, 45; Weiss 2007, 690). For example, many times sex differences in osteoarthritis are associated with activity pattern differences due to division labor rather than with differences in the physiology of the two sexes (Weiss 2007, 691).

In any case, the research on the matter of osteoarthritis is still incomplete and more paleoepidimiological and epidemiological data need to be examined in order to investigate the disease’s changes in relation to occupational stress and injury (Jurmain 1991, 247; Weiss and Jurmain 2007, 438). A longitudinal study instead of a cross-sectional one can test the hypothesis of activity markers on individuals which are engaged in physical labor for a longer duration (Austin 2016, 538; Jurmain 1991, 248). In these studies different variables and confounding factors that will contribute to the closest accuracy of the results, should also be examined and it is of high importance for the samples to be large and well-controlled (Jurmain et al. 2012, 538-9). We should not of course forget that the details we have in our hands are very specific and limited. As Myszka et al. mention (2020, 7) “when examining the skeletal material we can observe only a given stage of the disease and we are unable to reconstruct tan individual’s history to determine when a degenerative process began and how the disease developed”.

2.3. Body size

In the bioarchaeological literature, body size is often mentioned as the proxy of the estimated stature and body mass of an individual’s skeletal remains; thus, as its name indicates, it constitutes an estimation of the total corporal dimensions of an individual when alive. However, the total corporal dimension of a person is supposed to include also the robusticity of the body, which is occasionally missing from the existing body size literature. Both perspectives of what is body size and how it is estimated will be discussed later in this subchapter from an historical view.

Body size, as part of the total body growth is highly influenced by different factors as genes, environmental factors and nutrition (Kurki et al. 2010, 169; Nieves et al. 2005, 530; Wells 2012, 2). In the category of environmental factors, stress, nutrition, diseases, toxicants and effects of the physical environment can be seen as the most important (Stinson 2012, 593). Stress, diseases, toxicants and nutrition are the factors most responsible for the variation in human growth when they act upon the body during the infancy, childhood or adolescence (Stinson 2012, 593; Zakrzewski 2003, 220) which are supposed to be the periods of body composition plasticity (Wells 2012, 8). Zakrzewski (2003, 219-220) supports that an infectious disease and/or malnutrition during those periods can cause abnormal growth, retardation or smaller development in the bones of an individual. Additionally, small body size has widely been considered to be an adaptive response of the body to external pressures and stressful periods in order to maintain survival (Gibbon and Buzon 2014, 331; Kurki et al. 2010, 169; Stinson 2012, 610; Zakrzewski 2003, 220). Examples of this adaptive model can be seen in whole populations with changes in stature and body mass through long periods of time and have been attributed to different environmental constraints (Gibbon and Buzon 2014, 324; Kurki et al. 2010, 169). That is why body size has been used many times to describe health status of past populations (Kurki et al. 2010, 169; Stock et al. 2011, 352).

Growth disruptions, as already seen, are considered to have an effect on stature of a person. However, stature has proved to be also affected by physical/geographical environment, i.e. the temperature and latitude/ geographic area in which a person lives (Ruff 2000, 269). Regional variation which is related to adaptation to the climatic environment and available resources can be seen across the world (Gibbon and Buzon 2014, 327). Wells has observed (2012, 2) that in cold environments people usually have shorter limbs (especially the lower ones), while warmer environments favor the existence of long extremities. That is also stated in Gibbon and Buzon (2014, 327-8) and Zakrzewski (2003, 227) where it is mentioned that Egyptians and Nubians are supposed to have a Nilotic/Negroid (tropics) body plan with long extremities and small trunk in order to regulate the temperature of the body in the hot climate of Egypt. Besides that, body mass and lean mass were also observed to be related to regional climates. In more detail, in cold temperatures the body needs greater amounts of fat and lean mass to survive; that is why cold environments are related to higher adiposity and stronger muscles (Wells 2012, 2). However, the fact that the temperature of an environment plays a role in the shaping of body size does not signify that the body shape of individuals living across regions with similar temperatures will be the same. The distribution of fat and lean mass in each body varies from region to region and is related to more than one factor (Raxter 2008, 148; Stinson 2012, 588).

Another important factor that is considered to control body size and shape among people is genes (Gibbon and Buzon 2014, 324; Kurki et al. 169; Zakrzewski 2003, 219). It has been observed that stature and body mass are hereditary as growth is highly connected with genotype in the mammalian species (Stinson 2012, 592). However, phenotypic variations can pass on through genetics and are related to micro-evolutionary adaptations, sexual selection and general, gene flow, drift and mutation (Gibbon and Buzon 2014, 324,327; Stinson 2012, 592). The sexual dimorphism that exists in body size is also thought to be genetic (Stinson 2012, 590). Sex differences in size and body composition are associated with specific hormones that can be found among sexes (Nieves et al. 2005, 530; Stinson 2012, 590). Women show higher amounts of adiposity in comparison to men, while men show higher amounts of lean mass, stronger muscles, thicker cortical of long bones and higher stature than women (Nieves et al. 2005; Wells 2012). Part of those dissimilarities is attributed to the different age of maturation. As boys enter puberty a few years later than girls, they are supposed to have time to increase their stature and muscle mass growth (Nieves et al. 2005, 529).

However, the modeling activity on the diaphyseal cortices is strongly related to genetic differences between the two sexes, with the contribution of testosterone to the increase of periosteal growth in men and the corresponding impact of estrogen and decrease of formation activity during puberty in girls (Allen and Burr 2014, 80).

Although sexual dimorphism is in its great part gene-related, body size is many times responsible for differences that can be found between men and women. Nieves et al. (2005) present in their article that muscle mass is responsible for the mechanostatical set-point and bone density of an individual. More muscular individuals have different bone geometry due to different distribution of mechanical loads in their body, are heavier and have thicker cortical bones to support their body weight (Nieves 2005, 532-3). Hence, body mass and the distribution of it have a strong impact on weight-bearing bones not only affecting the long shaft cross-sectional properties but being connected also with the amount of lean mass appearing in the same bones (Ruff 2000, 269). Moreover, additional mechanical loading stress either from body weight or external weight, can lead many times to microdamages on the bone that can trigger the remodeling reaction (Allen and Burr 2014, 88), a reaction that contributes to the strength of the bone. Additionally, bone density and geometry seem to be able to impact stature and length of bones of an individual as well (Nieves 2005, 532-3). Generally, although lean mass and stature are the most prominent differences to be found between men and women, in reality sexual dimorphism has proven to be stronger in fat mass than in lean mass and stature and finally in body mass index (BMI) (Wells 2012, 6). Finally, one can say that it is not unjustifiable to support that all properties of body size are connected to each other and sexual dimorphism is indeed sometimes connected with small and large body size.

Body size has been observed to show a small decline during the elderly years. Mainly stature, due to compression of vertebral discs and bodies is the factor responsible for this decrease (Ruff et al. 2012, 614). However, both bone mineral density around the ages of 30 and 40 (Merritt 2015, 47) and bone remodeling activity around the age of 80, show signs of decline (Allen and Burr 2014, 85-6). Apart from that, individuals of small body size, i.e. with short stature and light weight, seem to have slower pace of remodeling activity in the bone surface, irrespective of their age, and lower ages-at-transition in comparison to taller and heavier individuals (Merritt 2015, 45), meaning that light-weight people show accelerative aging in their bones compared to taller and heavier individuals of same age.

Nevertheless, apart from its relation to age that has not been pointed so strong, body size, as seen in the paragraphs above, has long been examined for its association with health status in one person or even in population numbers. Some studies (including this one) have already aimed to discover the relationship between body size and osteoarthritis (Calce et al. 2018; Weiss 2005; 2006). Weiss (2005, 94) in a previous study supported that the more robust an individual the more likely they were to show signs of osteoarthritis in their limbs. However, the fact that males are almost always more robust and larger than females points towards sexual dimorphism rather than simple influence of body size. An important finding to be mentioned is that although osteoarthritis was correlated with robusticity in the upper limbs, it was discovered to be more prevalent in the lower limbs in individuals that had smaller joint surfaces (Weiss 2005, 94; Weiss 2006, 693). It is rather difficult to separate and identify in what amount sexual dimorphism plays a role in those results but it is obvious that body size has at least a small percent of correlation with osteoarthritis. The results of this study will support this idea.

Regarding the estimation of body size, as it has been approached in several studies so far, it can be measured either by estimating separately stature and body mass of an individual (Kurki et al. 2010, 170; Ruff 2012, 601; Stock et al. 2010, 353) or it can be directly estimated from three distinctive femoral or humerus measurements, as Weiss suggests (Weiss 2005, 90); thus also taking into account part of the robusticity of the bone. Nevertheless, in skeletal samples it is extremely difficult to calculate with accuracy the stature, body or lean mass of an individual, as there are no living tissues. Therefore, anthropologists use other proxies and tested formulas in order to calculate these measurements from the bones of defleshed bodies (Weiss, 2006: 691). For the stature estimation, the “anatomical” and/or the long bone regression “mathematical” method can be used, utilizing maximum lengths of the bones (Kurki et al., 2010: 170). In the first one, each measured skeletal element is summed and used for the stature estimation, while in the second only the maximum length of the femur is used (Kurki et al. 2010, 170; Raxter et al. 2008, 148; Ruff 2000, 273; Ruff 2012, 601-2; Stock et al. 2010, 353). For the body mass estimation of an individual, the methods used are either the “biomechanical” one with the use of the femoral head measurements or the “morphometric” method which uses the bi-iliac breadth measurements and stature (Kurki et al., 2010: 170; Ruff 2012, 602; Ruff et al. 2005, 382; Stock et al. 2010, 353). Finally, the method, also applied in this study, which uses three measurements from the same long bone in order to reconstruct body size, appears to be a combination of the methods listed above (with measurement of maximum length, femoral head diameter) with the addition of the measurement of robusticity of the bone (epicondylar breadth). In general, although those methods are the most common ones for estimating body size, what most of the researchers suggest is to use sample references that match the body proportions of the sample in question (Ruff 2000, 273; Ruff et al 2012, 601-2).

In living populations the calculation of the actual body mass divided by the squared stature, the body mass index (BMI), is supposed to give an estimation of the body size (Merritt, 2015: 37). However, this calculation has some limitations, except the fact that it does not provide accurate numbers for the measurements because it measures skeletal samples; it cannot measure the muscle mass and can only provide an assumption about the distribution of lean mass and fat tissues (Merritt, 2015: 37). For this reason and because the femoral measurements when used in linear regression formulae have large margins of error, it is more efficient those measurements to be used as cumulative scores, as proposed by Merritt (2015) and Weiss (2006). Cross-sectional bone shaft measurements and bone density do not belong to the main methods of body size estimation. However, estimating the robusticity of an individual can definitely provide more accurate results concerning the “size” and the strength of the bones (Ruff, 2008). All in all, as mentioned above, body size constitutes a category of important information about an individual, either in relation to simply measurements or when providing additional information about the age, sex health and life of a person.

Chapter 3: Material and Methods

This chapter will focus on the materials and the methods used in this thesis. A small introduction to the archaeological site and the population from which the sample derived will be given in the beginning of the chapter. The data used as material for the study will be presented in detail, as also the methodology selected to examine the correlations among the body size and the osteoarthritic lesions.

3.1. The site of Tombos

The material used in this thesis derived from the site Tombos, located in northern Sudan, which belonged territorially in ancient Nubia (Buzon et al. 2007, 1392; Schrader 2012, 60) (fig. 6). During the New Kingdom period (ca 1550-1050 BC) Nubian population started to face the expansive politics of the Egyptian Kingdom (Buzon 2006a, 683). After Egypt destroyed completely Kerma, the most important center of Nubia, around 1400 BCE, most of the Nubian territory came under its direct control (Schrader 2019, 166). The political boundary of Egypt was extended from the First Cataract to the Fourth Cataract of the Nile River (Buzon 2006a, 683; Buzon 2006b, 26; Schrader 2019, 165). In this period of expansion, Egypt established towns to serve as centers of control and as strategic and economic points of distribution, where civil officials, priests, artisans and generally civilians from Egypt were living with their families among the local people (Schrader 2019, 167).

Tombos established during the start of the New Kingdom period as a strategic point in the area close to the Third Cataract of the Nile and served as a colonial town in the periphery of northern Nubia (Buzon 2006a, 685; Buzon et al. 2007, 1392; Buzon 2008, 165-6; Gibbon and Buzon 2014, 325; Gibbon and Buzon 2018, 3-4; Schrader 2012, 60; Schrader 2019, 169). The town was inhabited by both Nubians and Egyptians; an ethnically and biologically mixed group of people (Buzon 2006a, 683; Schrader 2019, 169). Craniometrics and strontium isotope analysis have supported the existence of both immigrants and local people living in the town of Tombos (Schrader 2019, 171).

Although 60% were categorized as having Egyptian cranial characteristics, the variability of the cranial morphology was not able to classify the individuals into clear-cut, separate groups originate either exclusively from Egypt or from Nubia. Consequently, Tombos consisted of a quite inhomogeneous sample (Buzon 2006a, 690; Buzon et al. 2007, 1393; Buzon 2008, 176). In support of this inhomogeneity, isotopic results could not set a specific area of origin, as the isoscapes were limited (Buzon et al. 2007, 1395). A lot of people seem to have been originated from different areas across Egypt and Sudan,

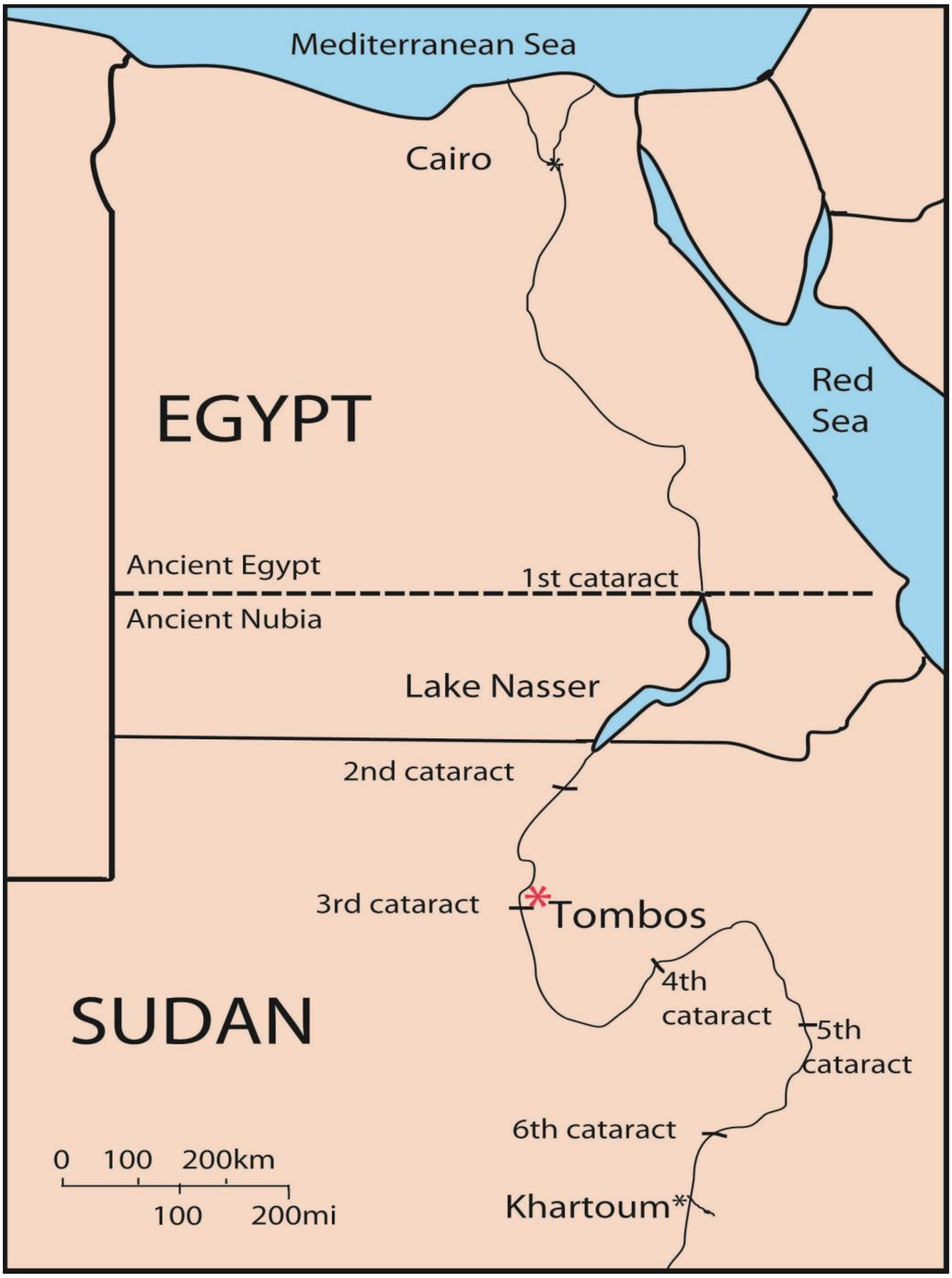


Figure 6. Map of Ancient Egypt and Nubia (https://tombos.org/)

although the food consumed would likely have been local (Buzon et al. 2007, 1395, 1399).

The burials found in Tombos cemetery, were excavated by the Purdue University and the University of California Santa Barbara team from 2000 to 2017 (Buzon et al. 2007, 1392; Gibbon and Buzon 2014, 325). The cemetery was distinguished in two different periods, the New Kingdom period (1550-1050BC) and the Third Intermediate/Napatan period (1050-332BC) (Schrader 2019), with complete burials and skeletal elements derived from commingled context found in both of the periods. This research will focus only in the material of the first period.

The vast majority of the burials were found in the Egyptian-style, in which the body was placed in extended position, and in coffins which were placed in rectilinear tomb chapels and small pyramids, sometimes mummified (Buzon 2006a, 684, 688; Buzon et al. 2007, 1393; Buzon 2008, 173; Schrader 2019, 170). Only a few burials were found as in the Nubian-style, in which the body was placed on a bed in flexed position and inside a tumulus that was constructed over it. Those Nubian-style burials have been found in the earliest layers of the tomb chambers, namely, in the first New Kingdom period (Buzon 2006a, 684; Buzon et al. 2007, 1393; Buzon 2008, 177; Schrader 2019, 170). In this period a pyramid and an area of tomb chambers were structured for the purpose of the placement of the deceased people of the town. The tomb chambers were interpreted as the area of non-elite burials (Buzon 2006a, 688). However, based on the archaeological studies conducted on the funerary remains and artifacts found in the burial context, it has been suggested that the individuals have possible belonged in the upper/middle classes of the society, thus they were members neither of the aristocracy nor of the peasants (Buzon 2006b, 30-32; Buzon 2008, 178-180; Schrader 2012, 68; Schrader 2019, 172). The structures of the cemetery were preserved in good condition. However, the area of the chambers was looted in antiquity, resulting in great disturbance and a commingled context, where only few complete individuals were able to be identified (Buzon et al. 2007, 1393; Schrader 2012, 62). It is considered that more Nubian-style flexed burials would likely have been placed in this area, although it cannot be determined with certainty (Buzon 2006a, 688).

3.2 Materials

For the purpose of this research, only osteological material from one specific site was used. The skeletal remains for this research, as mentioned in the background subchapter, derive from the chambers of the archaeological site Tombos that belong to the first period of New Kingdom. Thus, the material used in this research is supposed to be representative for the population of only the first period of Tombos' use. The sample examined is constituted exclusively of adult individuals, as the subadult bones' growth and development markers could affect the diagnosis of osteoarthritis (Schrader 2012, 62). Additionally any bone with a pathological condition or trauma (e.g. fractures) was excluded, in order for any incorrect interpretation of osteoarthritic lesions to be avoided. The bones which presented such pathological lesions and traumas could not in any case provide the accurate measurements for body size that constitute the main data used for this research.

a) Discrete burials

The discrete burials compose a sample of 32 individuals, which are in their greater part complete. The sample has successfully provided a great number of measurements of long bones and a great number of joint surfaces associated with the development of osteoarthritis. Osteoarthritis was scored for the joint surfaces of scapula, humerus, ulna, radius, os coxae, femur and tibia, while the relationship between osteoarthritis and body size was tested only in the lower limbs (os coxae, femur and tibia). Sex and age were estimated in all except 2 and 3 individuals respectively (sex estimation: n=30, age estimation: n=29). Additionally, the majority of individuals have both sides preserved, something that is useful for testing of asymmetry or handedness and footedness in the sample.

b) Commingled bones

The commingled context brought in light a number of bones that could not be identified as belonging to the same individual. However, their use is highly important, as a lot of them constitute bones that bear a plethora of additional and important information for osteoarthritis and body measurements to be added in the sample of the discrete burials. A sum of 373 separate bones was recorded and a part of them, mostly distinctive long bones with their joint surfaces (i.e. scapula, Humerus, ulna, radius, femur, tibia, os coxae) was selected for further examination. Their distribution can be seen in the table below (Tab. 1). The different bones were used for the recording of osteoarthritis in the commingled sample but only the femoral bones were utilized for the correlations between osteoarthritis and body size.

Table 1. Distribution of the commingled context

Scapula	Humerus	Ulna	Radius	Femur	Tibia	Os coxae
18	77	27	26	70	78	60

Although informative, the additional data of the commingled context have some limitations. The long bones and especially those of the lower body, that are to be used for the body size measurements, cannot provide us with information of age. Furthermore, sex estimation can also not be accomplished through the standard methods that use the pelvis bones. For that reason, sex was computed through long bone size regression equations, which were calculated from the discrete burial long bone measurements and then applied to the comingled remains (Appendix: A.1). Most of them presented high probability, allowing us to be more confident about using them for the analyses. When the separate bones were added to the discrete inhumations' sample, only one of the sides was selected, to avoid repetition in the analysis; as there is no accurate way to define whether two of the bones belong at the same individual.

3.3 Methodology

a) Sex estimation

Sex was estimated based on non-metric methods of estimation according to Buikstra and Ubelaker (1994) (after Schrader 2019, 173). The main method used was estimation based on os coxae features, that is to say, pelvis morphology, and additionally cranial morphology (Schrader 2012, 64). For the commingled sample, sex estimation was instead performed with the use of metrics. As mentioned above, long bone size regression equations, which were calculated from the long bones of the individuals from the discrete inhumations, were applied to the separate bones. Thus measurements from the femur bones, as comparisons with the complete burials, were used as indicative data to infer sex to the single femoral bones of the commingled context with sometimes such high probability as 0.98 (Appendix: A.1). The sex estimation with regression analysis was conducted only for the purpose of the sex estimation of the commingled context.

b) Age estimation

Age was estimated based on cranial and pelvic morphology and degeneration according to Buikstra and Ubelaker (1994) (after Schrader 2019, 173). For the estimation the pubic symphysis and auricular surface degeneration were used, and, when these were not available tooth wear and cranial suture methods were applied instead (Schrader 2012, 64). Three categories were selected for the representation of the age ranges among the population sample. The first one comprised of young adults (19-29 years), the second one of middle adults (30-45 years) and the last one of old adults (46+ years) (Schrader 2012, 64). From the commingled bones, only those that had preserved part of the pelvis were able to be aged, but they have not been used in the second part of the research, the one with the correlations, as they could not provide body size measurements. The femoral bones used in that part could not be aged.

c) Osteoarthritis

Osteoarthritis was recorded from Schrader (2012) according to the standardized scoring method of arthritic lesions by Buikstra and Ubelaker (1994) (after Schrader 2012, 63). According to that scoring method the severity of each separate osteoarthritic lesion, namely lipping, porosity and eburnation, were measured in an ordinal scale from zero (0) to four (4). The different stages of progression for all three of them can be seen in the Appendix (A.2). The lesions were measured from all the synovial joint surfaces in the bones selected; in total 12 joint surfaces: Glenoid Fossa (fig. 8), proximal humerus, distal humerus, proximal ulna, distal ulna, proximal radius, distal radius, acetabulum, proximal femur, distal femur, proximal tibia, distal tibia, shown also in the Appendix (A.3). Osteoarthritis was also measured in grouped joints in the

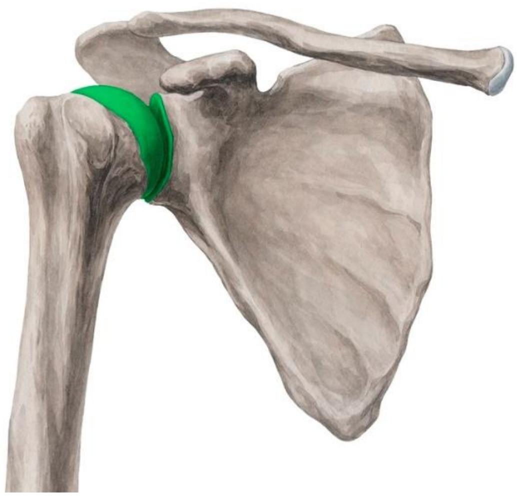


Figure 7. Proximal humerus surface and glenoid fossa (https://www.kenhub.com)

lower limbs, in order for the relationship of the osteoarthritic changes in joint surfaces that connect with each other and use the same tissues of the joint to be observed. This was only applied to the complete burial sample. The joints that were studied were the hip joint (fig. 9), which includes the acetabulum and proximal femur joint surfaces, and the knee joint (fig. 10), which includes the distal femur, patella and proximal tibia joint surfaces. The joints can be seen in the following pictures.

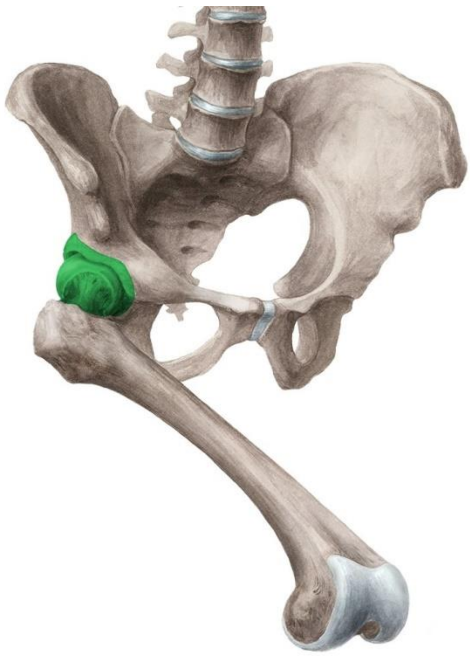


Figure 9. Hip joint (https://www.kenhub.com)

Figure 10. Knee joint (https://www.kenhub.com)

In this study, osteoarthritis scores were given to all the preserved joint surfaces from the bones derived from the discrete burials as well as from each separate bone from the commingled context. The results found were also converted into percentages so the rates of the individuals and bones affected by the disease in the sample to be observed. In order for a bone to be considered as affected by the disease, it was decided that the bone should present the minimum number of osteoarthritic presence (1) in the ordinal scoring system that was also used from Schrader (2010, 153). When used for the correlations, osteoarthritis was recorded as either absent or present instead of the analytical ordinal scale from 0 to 4, aiming to facilitate statistical analysis, as in a bivariate system. When there was not enough information to conclude that a joint surface has not developed any form of osteoarthritic lesions, the data was recorded as non observable and has not been given any value. In the analytical statistics only the joint surfaces of the lower body from the complete burial sample and the femoral bone from the commingled ones were used and were both recorded in the system of absence/presence.

As mentioned before, osteoarthritis was recorded and presented in this study in a slightly different way from the first publication (Schrader 2012), in order to facilitate later on the statistical correlations and so each osteoarthritic trait to be observed separately. In her article, Schrader (2012) uses eburnation as the determinant of osteoarthritis. However, in this work, the presence of each of the osteoarthritic lesions (lipping, porosity, eburnation) is considered determinant of the disease. Consequently, each lesion is presented and correlated separately with body size measurements. Furthermore, osteoarthritic lesions are examined as much in grouped joints, like in Schrader's publication (2012), as also in separate bones and separate joint surfaces of each bone. The presentation of the frequency of osteoarthritis refers to the whole sample and to each bone that has shown traits of the disease, in order for a clear image of the incidence of the disease in the population to be given. The different methods used in the two studies are no more than a proof that osteoarthritis can be recorded and used according to a variety of different scoring systems.

d) Body size

Measurements of three different features of humerus and femur bones were taken according to Standards for Data Collection by Buikstra and Ubelaker (1994). Maximum length, head diameter and epicondylar breadth (fig. 9) were recorded respectively for both the humerus and femur bones in order to provide sufficient measurements for the long bones' size for each individual. All measurements were taken in millimeters and a digital sliding caliper, an osteometric board and a tube measure were used. The data was stored in an Excel document.

The femoral bone was selected for both the commingled and complete sample as the indicative bone of measurements of body size for each individual. Femur measurements are considered excellent proxies for human stature and indicators body size's analogy (Schrader 2012, 64), which is why they were selected from the sample. Additionally lower limbs are considered as the recipients of the mechanical loading of the whole body and therefore, also related to osteoarthritis pathology.

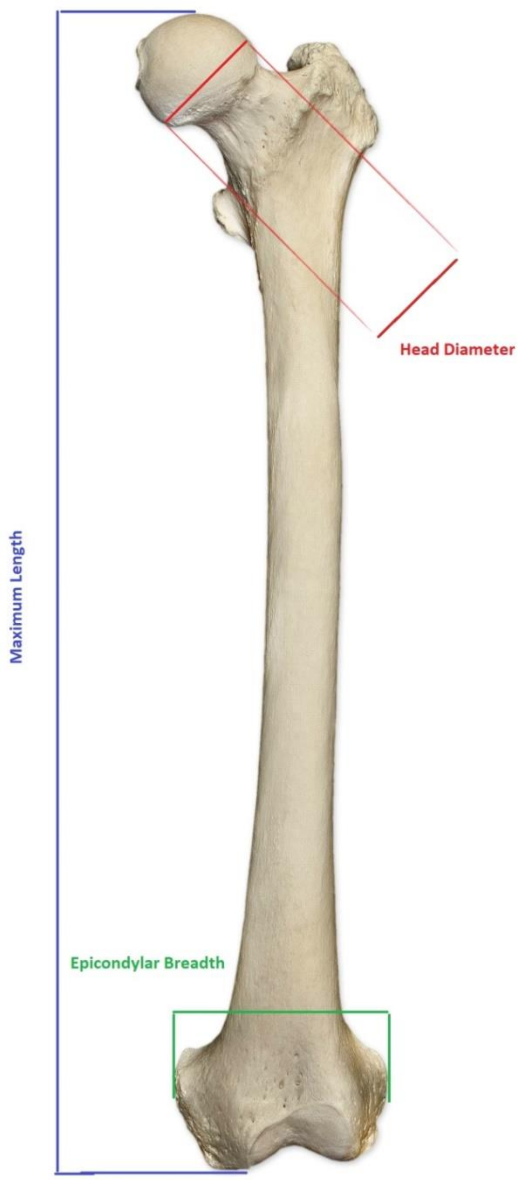


Figure 8. Body size measurements of the femoral bone (after https://www.osteoporosisinstitute.org/femur/)

The three different measurements of femur (i.e. maximum length, femoral head diameter and epicondylar breadth) were converted in separate aggregate scores (i.e.z-scores), which were later averaged in order to produce one composite aggregate score for each individual or one aggregate score for each femoral bone from the sample of the commingled context. As mentioned in Schrader (2012, 64) “in using z scores, numerically larger numbers, such as maximum length, will be weighted equally in mathematical calculations as smaller measurements, such as maximum head diameter and epicondylar breadth”, that is why z-scores were selected instead of the exact numerical measurements. Additionally z-scores are considered to facilitate the obtainment of results when one of the measurements is missing; something that is highly common not only among the commingled context but also in the discrete burials. Those composite z-scores were used in the statistical analyses as the body size variable which was correlated with osteoarthritis one.

3.4. Statistical Analyses

a) Statistical tests

Before any statistical analysis the data were distinguished into four variables; body size, age, sex and osteoarthritis from each separate synovial joint of the lower body. All of them except from body size constitute categorical variables, either ordinal or nominal. Ordinal variables are variables that have two or more categories and those categories can be ordered or ranked (Drennan 2009, 65). Nominal variables are variables that have two or more categories, but which do not have an intrinsic order. Those that are divided into two categories are called dichotomous (Drennan 2009, 65). In the sample used in this research, the ordinal variable is the variable of age (young adults, middle adults, old adults), while both sex and osteoarthritis are dichotomous nominal variables (male/female, absence/presence). Only body size is considered among the continuous variables which are quantitative; they can be measured along a continuum and they have a numerical value (https://statistics.laerd.com).

As the majority of data are categorical in their characteristics and cannot be quantified specific consideration over the exact statistical tests had to be taken. As mentioned in Schrader (2012, 64-5), the relationship between different scales like ordinal, nominal or/and continuous ones is best examined through non-parametric statistical tests that are able to detect correlations between them. The exact non-parametric test used for the correlations was the Spearman's nonparametric rank correlation coefficient (rs). To test distribution across the groups the Mann-Whitney U test was applied. Furthermore, paired t-tests were applied to the discrete burial sample to test whether there was significant difference between the left and right sides for both osteoarthritis and body size. All the analyses were conducted with the statistical program SPSS (Version 26).

b) Confounding factors

Many times the relationship between two variables is not only a two-sided relationship but it is affected by more factors and other variables. In order to test the unaffected correlation between two variables and to observe the changes in the results when introducing more than two variables in the correlation, different statistical tests have to be done. The variables that have the ability to affect the sample are named confounding variables and can be controlled by statistical methods in order to be separated from the variables to be correlated in the first place. In other words confounding variables are a type of bias that when adjusted can be controlled. In this study the two confounding variables selected for controlling are both sex and age, although for the commingled sample only the confounding variable of sex can be applied and this only with the help of regression analysis from the femoral bones of the complete burial sample, as mentioned above.

Age, as mentioned in previous chapters, has been considered over the last years to be one of the major contributors to the development of degenerative pathological conditions and, therefore, of osteoarthritis. Age might seem sometimes to be an inseparable variable to the disease as it is considered among the risk factors of osteoarthritis; however its relationship with osteoarthritis can be controlled and thus teased apart with the help of statistical tests. The same procedure can be applied in sex as confounding variable. Sex is thought to affect both osteoarthritis, as considered among the minor contributing factors, and body size. For example, men are thought to be typically larger and have more muscles than the women, thus having greater body size (Schrader 2012, 64). Consequently more muscles and/or more weight or larger body should also have an effect upon weight bearing joints and possibly an involvement on the development of the disease. For that reason controlling of sex is important if the research question is focused on the relationship between body size and osteoarthritis irrelevant of the sex of each individual.

Chapter 4: Results

In this chapter sex and age estimation results, osteoarthritis data, body size measurements and osteoarthritis correlations will be analyzed. The percentages of the presence of osteoarthritic lesions will be presented analytically and each trait of osteoarthritis will be shown as recorded for its prevalence in the sample. Later on, the mean numbers of the sample and the body size calculations will be given, as well as the results taken from the tests for normality and distribution of the sample. Finally the non-parametric correlations between body size and osteoarthritis and also correlations with controlling for sex and age confounding factors will be presented. Additionally correlations of osteoarthritic lesions between the various joints of the lower body will be shown.

4.1. Sex and age estimation

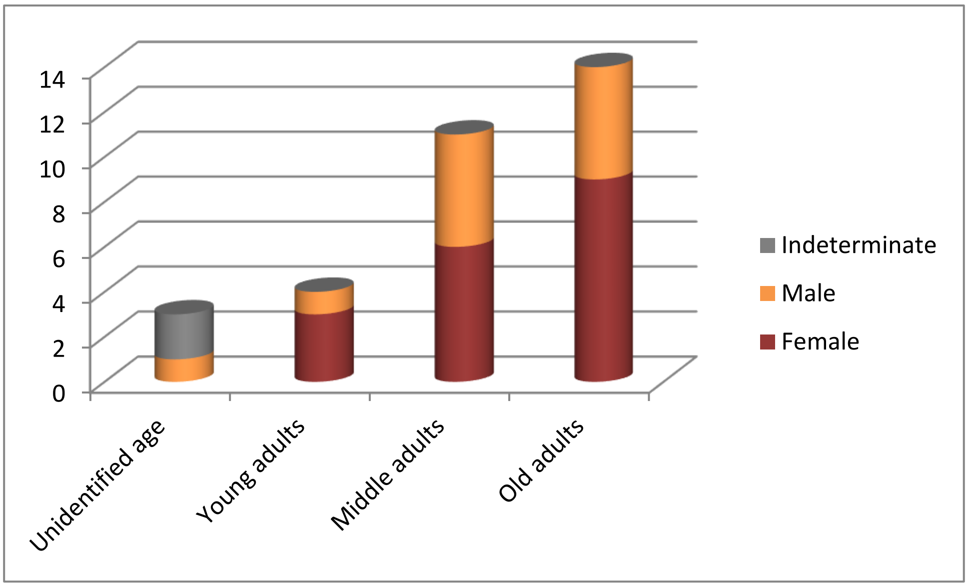
a) Sex

Sex was estimated in both the discrete and the commingled burial context. Half of the individuals (56%), i.e. 18 out of 32, from the discrete burials were identified as female, while 38% (i.e. 12 out of 32) as male and 6% (i.e. 2) as indeterminate (Tab. 2). The distribution in sex according to estimations for the commingled sample was similar. From the total number of 62 femurs, 35 were identified as belonging to a female individual, which accounts to the 56% of the sample. The remaining 27 bones, that is to say 44% of the sample, were recognized as belonging to a male individual. As can be seen, half of the sample both in the discrete and the commingled burials consists ultimately of female individuals. Thus a consideration has to be taken, over the fact that the sample is more likely to produce some bias, as the spread is more representative in the female data (Gibbon and Buzon 2014, 326). However, it should be noted that the separate bones cannot be considered as individuals but rather as bones belonging to individuals (Schrader 2012, 65).

b) Age

Age estimation was conducted only in the discrete burial sample and the aged individuals were separated according to the age ranges mentioned in the methods chapter. The majority of individuals belonged to the last age range of old adults, with middle adults and young adults following. Analytically: 4 individuals, accounting for the 13% of the population, belonged to the first category of young adults, 11 individuals, i.e. the 34% of the population sample, were categorized as middle adults, while 14 individuals, representing 44%, were categorized as old adults. 9% of the sample, i.e. 3 individuals, were not able to be aged and were recorded as having unidentified age. Males and females were distributed quite equally among the age ranges, even after taking into consideration the overrepresentation of females in the sample.

Table 2. Sex and age estimation for the discrete burial sample

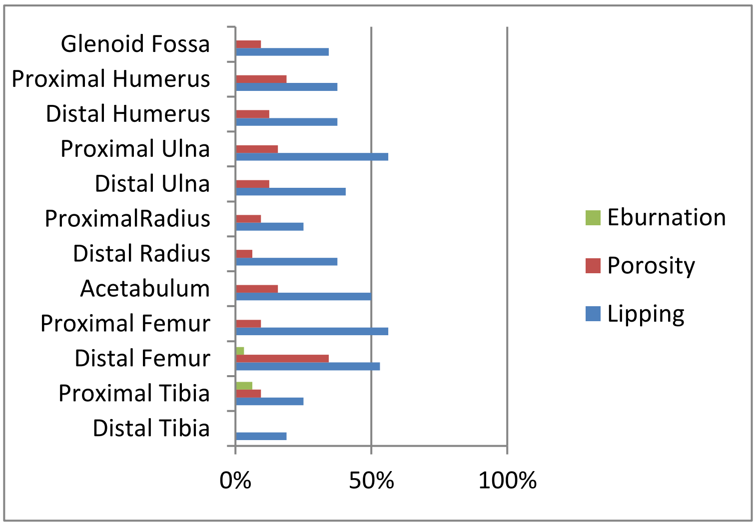


4.2. Osteoarthritis

The results showed that the percentages of the different traits of development of osteoarthritis varied among the joint surfaces. Out of the three traits of osteoarthritis (lipping, porosity, eburnation), lipping was observed to be the most common indicator of joint degeneration in the sample. All of the joint surfaces displayed presence of lipping in at least one of the individuals of the complete inhumations and at least one of each different bone element of the context of the commingled remains. The analytical recording of the osteoarthritic changes can be found in the Appendix (A.4, A.5).

All in all, the skeletal region which showed more indicators of the disease was part of the upper limb's region, more specifically the ulna bone. The ulna was the element that displayed the highest scores of lipping both in the complete burials with occurrence of 72% in the sample (23/32 individuals) and also in the commingled context with a total of 70% occurrence (19/27 elements). In particular, the joint surface most affected by lipping was the proximal joint surface of the ulna with a percentage of 56% (18/32 individuals) as recorded of the complete sample. Likewise, the femur proximal joint surface exhibited a percentage of 56% (18/32) of lipping in the complete sample, while in total, the femur was placed second as bone element in the category of lipping occurrence both in the complete burials with a total number of 69% (22/32) and as well in the commingled context with a total number of 45% (31/69 elements).

Table 3. Prevalence of the osteoarthritic changes in the discrete burial sample



In general, the joint surfaces as recorded from most to least affected with lipping in the discrete burial's sample were as follows: proximal joint surface of ulna with 56% (18/32), proximal joint surface with 56% (18/32), distal joint surface of femur with 53% (17/32), acetabulum with 50% (16/32), distal joint surface of ulna with 41% (13/32), proximal humerus, distal humerus and distal radius with 38% (12/32), glenoid fossa with 34% (11/32), proximal radius and proximal tibia with 25% (8/32) and finally, distal tibia with only 19% (6/32) and can be seen in the Table 3. From the total amount of bones, fewer samples exhibited porosity in comparison to lipping. All but one joint surfaces (distal tibia) displayed osteoarthritic traits of porosity with the joint most affected to be the distal femur with 34% occurrence (11/32). All the other joints ranged between two to six cases out the total number of individuals. Finally, the majority of the complete burial sample showed no indicators of eburnation. The only bones affected of eburnation were the femur and tibia, which displayed the trait only in the knee joint with a percentage of 6% (2/32) in the proximal surface of tibia and 3% (1/32) in the distal joint surface of femur.

Relating to the commingled bones, as mentioned above, the ulna was the element which exhibited the highest rates of lipping (70%), while femur and acetabulum also showed preliminary indicators of lipping in their joint surfaces, as affecting almost half of the total amount of each elements (femur: 31/69, acetabulum: 27/60). In glenoid fossa and radius the presence of osteoarthritic lipping was found to be significant, though lower than the ones already mentioned. In the former, it was observed to affect 39% (7/18) of the individuals while in the latter, it was 38% (10/27). The humerus and tibia were the elements that showed the fewest indicators of lipping in the commingled sample with the first displaying a percentage of 29% (22/77) and the second a percentage of 26% (20/78). Porosity was again less present, however the trait was found in all the bones except from the radius. Ulna and acetabulum showed the highest percentages in porosity, 26% and 22% respectively. In the glenoid fossa, femur and tibia the percentages did not exceed 17% and in the humerus only 8 elements out of 77 were affected, giving the low rate of 10%. Relating to eburnation, no indicators of the trait were present in the commingled sample except from one femur. The results can also be seen more analytically in the Appendix (A.6).

As for the distribution of the degenerative disorder of osteoarthritis among the sexes the data were recorded in tables (Tab.4, Tab. 5), in order to observe whether one sex was affected more than the other. Taking into consideration that the lower body is the skeletal region of our interest in this thesis, the distribution of osteoarthritis among males and females was tested only in the femur bone. Especially for the commingled remains, the femur bone element was the only element that could be sexed and so used for the distribution results.

In the femurs deriving from the commingled sample, the percentages of the presence of lipping in the joint surfaces were almost equally distributed. The right femurs that were estimated as belonging to females presented a rate of 32% (6/19), while those belonging to males a rate of 38% (5/13). Similarly, in the left femurs, those estimated as female showed a percentage of 44% (7/16) and the ones estimated as males, a percentage of 50% (7/14). Consequently, lipping seems to have been as prominent in males as in females, although with a slightly higher occurrence in males. When looking onto porosity results, the image is somewhat more confusing. In the right femurs, porosity seems to be exhibited in a rate of 5% (1/19) in females and 23% (3/13) in males, while in left femurs the percentages are divided as 19% (3/16) in females and 7% (1/14) in males. Those kinds of differences could derive from differences that exist between the two sides of an individual, but in a sample from a commingled context could be related to the lack of bones that come from the same individual as well as from not accurate estimation of sex of the femur bones.

Table 4. Prevalence of Osteoarthritis in the right femurs of the commingled burial context

OA femoral (right) scores of the commingled context																				
		Lipping						Porosity						Eburnation						Total
		Presence		Absence		n/o		Presence		Absence		n/o		Presence		Absence		n/o		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
sex	Female	6	**32**	3	**16**	10	**53**	1	**5**	5	**26**	13	**68**	0	**0**	6	**32**	13	**68**	19
	Male	5	**38**	0	**0**	8	**62**	3	**23**	0	**0**	11	**85**	1	**8**	2	**15**	10	**77**	13
Total		11	**34**	3	**9**	18	**56**	4	**13**	5	**16**	23	**72**	1	**3**	8	**25**	23	**72**	32

Table 5. Prevalence of Osteoarthritis in the left femurs of the commingled burial context

OA femoral (left) scores of the commingled context																				
		Lipping						Porosity						Eburnation						Total
		Presence		Absence		n/o		Presence		Absence		n/o		Presence		Absence		n/o		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
sex	Female	7	**44**	4	**25**	5	**31**	3	**19**	7	**44**	6	**38**	0	**0**	8	**50**	8	**50**	16
	Male	7	**50**	0	**0**	7	**50**	1	**7**	4	**29**	9	**64**	0	**0**	5	**36**	9	**64**	14
Total		14	**47**	4	**13**	12	**40**	4	**13**	11	**37**	15	**50**	0	**0**	13	**43**	17	**57**	30

From the discrete burials' sample, the femoral bones displayed a similar picture (Tab. 6). In the female estimated individuals occurrence of osteoarthritic lipping reached the 61% (11/18) of them while in the male ones the occurrence recorded as in 75% (9/12). Two individuals that could not be identified and remained as indeterminate displayed lipping in their femurs as well. In the complete burials' sample, porosity has proven to be more prominent in the female group, as half of them displayed the trait, whereas the male group showed only 17% (2/12) of presence. As for eburnation, only one female individual displayed that trait.

Table 6. Prevalence of osteoarthritis in the femoral bones of the discrete burial sample

OA femoral scores of individuals from the discrete burial context																				
		Lipping						Porosity						Eburnation						Total
		Presence		Absence		n/o		Presence		Absence		n/o		Presence		Absence		n/o		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
sex	Female	11	**61**	6	**33**	1	**6**	9	**50**	7	**39**	2	**11**	1	**6**	11	**61**	6	**33**	18
	Male	9	**75**	2	**17**	1	**8**	2	**17**	5	**42**	5	**42**	0	**0**	6	**50**	6	**50**	12
	Indeterminate	2	**100**	0	**0**	0	**0**	1	**50**	0	**0**	1	**50**	0	**0**	0	**0**	2	**100**	2
Total		22	**69**	8	**25**	2	**6**	12	**38**	12	**38**	8	**25**	1	**3**	17	**53**	14	**44**	32

The severity observed in each of three osteoarthritic traits was not significantly high. In the complete sample, lipping was recorded to score only up to number two in the scale from one to four and the highest number of individuals affected with that score was only 7. In detail, presence of lipping scoring two was recorded only in femur and ulna of 7 individuals, while five displayed that score in the acetabulum, two in the tibia and radius and one in the humerus. The glenoid fossa only scored the first stage in all traits. Porosity was even less severe in the sample. Only two individuals recorded to have porosity in the score of two, whereas one individual displayed in its tibia and another one in its radius porosity in the third stage of severity. Each indicator of eburnation in the sample was recorded to reach only the first stage of severity, i.e. 1 out of 4.

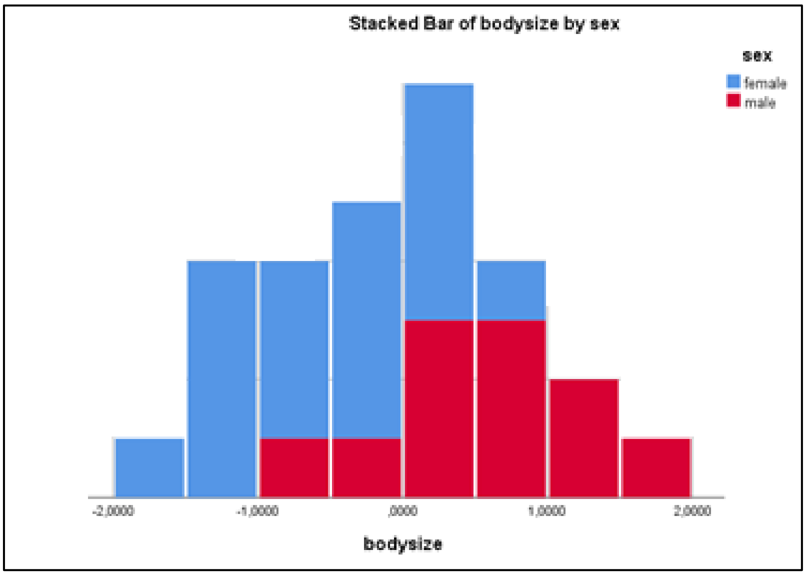
In the sample of the commingled context, the cases were as well relatively mild as reflected in their majority by a lipping score of two. More specifically, three femur, three acetabulum, one tibia, one radius, two humerus and two ulna elements had a score of two and three acetabulum, two tibia and one femur elements displayed lipping of score three. Porosity presented a score of two in only one femur and a score of three in one femur and two acetabulum elements.

Summarizing, the majority of scoring could be characterized as mild and only in few cases moderate concerning the severity of the sample. Lipping was the dominant trait in the sample but as seen relatively mild. It should be mentioned that all in all, the final record and the percentages provided are a result of a quite fragmented picture. It is important to take into consideration that a great amount of the bones found could not always have provided information about osteoarthritic lesions. A lot of bones preserved only one joint surface leading to a classification of non-observable (n/o) when recording for osteoarthritis. However when a trait was displayed the element was able to classified in the category of osteoarthritis presence. Nevertheless, the fragmentation of the sample is something that osteoarchaeologists are aware of and the difficulties of the remains, especially when associating with commingled context, should not prevent someone from displaying the data found.

4.3.1. Body size

Body size was measured out of the three measurements of the femur, after converted in aggregate scores. All individuals except two, of the complete burial sample were able to be measured for their body size. Consequently, in 30 sexed individuals body size was estimated. The majority of them were measured using two or all of the three measurements. When both sides were preserved, the aggregate scores were calculated out of the femurs of both sides. In the rare occasion that only one measurement has been preserved, its aggregate score used as the total one. Almost half of the total scores (n=16) of the discrete burials sample resulted with values higher than zero, while the other half (n=14) estimated lower than zero, thus as having negative score (Tab. 7). When comparing with the results of the sex estimation, it became clear that most of the higher numbers were associated with males whereas the lower ones were associated with females. The mean aggregate number of the discrete burial group was calculated at

Table 7. Distribution of body size according to the aggregate scores and sex



0,03 and the maximum and minimum at 1,86 and -1,84 respectively, while their SD at 0,91. The mean number of the females in the discrete burial sample was -0,49 (SD=0,69) and the one of the males 0,66 (SD=0,73).

Relating the commingled sample, the aggregate scores that were used to calculate the body size were also taken from the preserved measurements of the femur bones. As the elements of the two sides could not be counted together because it was not certain if they came from the same individual, right and left femurs were calculated separately in order to provide with mean numbers of the commingled sample. Left femurs' mean number was estimated at 0,17 with the maximum number being 1,42 and the minimum -1,32 (SD=0,83). Right femurs' mean number was calculated at -0,02 with the maximum number being 1,47 and the minimum 2,14 (SD=0,98).The difference between the two sides was within the expected range.

4.3.2 Distribution of the sample

In order to proceed with the correlations, firstly the sample had to be tested for normality; that is to say, to test if it was following a normal distribution. Tests for normality are quite important because they provide us with information of the sample and can facilitate the decision of choosing additional tests when needed. For example, when there is a need for statistical analyses and more specifically, for correlations, knowing the distribution of the sample or the kind of the variables can help choosing between parametric and non-parametric tests. As can be observed in the Appendix (A.7), body size was proved to be normally distributed in the results, as the results showed that the sig. value was greater than 0.05. The same values were observed when testing across the groups of sex and age in the same sample (Appendix: A.8, A.9).

The distribution of the categories of age and sex across the discrete burial sample was also examined. In more detail the Mann-Whitney U Test was used to compare the differences among the groups of age and sex and test whether there were differences in the median groups. From the results, age showed an equally increasing rate in both sexes and so was characterized as equally distributed. The two subgroups (males/ females) did not mark great differences and the frequency in those was highly similar (Appendix: A.10).

As mentioned above, the commingled sample was separated into the left and the right side of femurs in order to avoid any duplication as there is no certainty about which bones belong to the same individual. For reasons of extension of the discrete burial sample, one of the sides of the commingled sample was selected to be added to the former one. In that case the sample was extended and sexed elements that also have body size measurements could be used for the statistical analyses. To proceed though with one of the two sides, paired t-tests were made in order to examine the differences between the sides. Those tests were applied in the discrete group to test for asymmetry in the population. No difference was found between the right and the left side of femoral body size, thus we felt confident with continuing with the use of one side. The mean number of left side found as -0,09 while the mean number of right side -0,12. Additionally the paired sample correlation showed a significant and high correlation (Corr.=0,969 $p \leq 0.01$) between them and supported the first paired t-tests.

4.4. Correlations

As mentioned in the previous chapter, correlations following the non-parametric Spearman's correlation coefficient system were calculated after being divided into two categories, one was conducted separately for the complete burial sample (Tab. 8) and the other included both the discrete burial sample and also the commingled one. As seen in the table of the complete sample, only the lipping in the acetabulum joint correlated positively with significance with body size with a correlation number of 0,56 ($P \leq 0.01$). None of the other joints shoed any significant correlation, however porosity in acetabulum joint and lipping in the proximal joint of tibia showed a slightly higher positive correlation in comparison with the other joints, but not significant. The trait of porosity in the proximal and distal joint of femoral bone presented a slight negative correlation, but with no significant value. Eburnation has not been able to provide any correlation in any joint except for that of the distal femur. The same occurred in porosity of the distal tibia.

Relating to the correlations between sex and osteoarthritic lesions, only porosity in the acetabulum joint correlated significantly with sex with a value of 0,545 ($p \leq 0.05$). Sex, as expected, presented a high correlation also with body size, 0,647 ($p \leq 0.01$). As observed in correlations of body size and osteoarthritis, in those of sex and osteoarthritis the development of porosity in most of the joints was associated with negative correlations. Negative correlations with sex also presented in distal femur and proximal tibia eburnation development, although with insignificant value. Regarding age, it was observed to be significantly correlated with the development of lipping with almost all the joints except from the distal femoral joint. Analytically, age was correlated with the acetabulum joint with a value of 0,614 ($P \leq 0.01$), with the proximal joint of femur with a value of 0,491 ($P \leq 0.05$), with the proximal joint of tibia with a value of 0,541 ($P \leq 0.05$) and with the distal joint of tibia with a value of 0,581 ($P \leq 0.05$). None of the other joints presented any significant correlation.

Table 8. Correlations of the lower limbs from the discrete burial sample

	Body size	Acetabulum lipping	Acetabulum porosity	Acetabulum eburnation	Proximal femur lipping	Prox. femur porositvty	Prox. femur eburnation	Distal femur lipping	Distal femur porosity	Distal femur eburnation	Proximal tibia lipping	Proximal tibia porosity	Proximal tibia eburnation	Distal tibia lipping	Distal tibia porosity	Distal tibia eburnation
Body size	1,00	,561**	,411	-	,081	-,158	-	,148	-,052	,129	,309	,000	,114	,264	-	-
Sex	,647**	,314	,545*	-	,112	-,289	-	,197	-,199	-,160	,405	-,330	-,258	,433	-	-
Age	,124	,614**	-,033	-	,491*	,061	-	,104	,144	,254	,541*	,370	,190	,581*	-	-

* Correlation is significant at the 0.05 level (two-tailed).

** Correlation is significant at the 0.01 level (two-tailed).

The results of the first correlations followed controlling ones in order to isolate the confounding variables and examine the influence of them in the primary correlations. Consequently, correlations for controlling sex and age were applied to the primary correlation between body size and osteoarthritic lesions (Appendix: A.11, A.12). The outcome showed that the significant value that lipping in acetabulum had presented with body size had changed. There was no significance in the correlation, although the correlation remained relatively similar. None of the other correlations between osteoarthritic changes and body size showed any important difference when controlled for sex. Some of the correlation presented higher values, for example in proximal tibia joint. However, the significance values (p values) did not show any change. When controlling for age, similarly, there was not any important change in the values among the different joints. The only difference was observed again in the low significant correlation of acetabulum lipping and body size.

After testing for the relationship of each separate joint with body size, correlations over grouped joints were applied to test the results of them on more generalized data (Tab. 9). As the interest was focused on the lower body, two separate group joints were set; one of the hip and one of the knee. Similarly with the separate joints, body size was only significantly correlated with the lipping of the hip joint with a value of 0,657 ($P \leq 0.01$). All the other osteoarthritic lesions in hip and knee grouped joints presented just a small positive correlation of no significant value with body size. Once again, sex was significantly correlated with body size with a value of 0,647 ($P \leq 0.01$), while none of the other correlations associated with age were significant. Knee porosity and knee eburnation displayed a small negative correlation. In the age with osteoarthritis correlations, the only significant correlation was the one of the lipping in hip joint with a value of 0,474 ($P \leq 0.05$). All the other correlations showed a slight positive correlation, but insignificant. When the grouped joints were controlled for sex and age there was almost no difference observed except the fact that significant values turned out to be non-significant (Appendix: A.13, A.14).

Table 9. Correlation for the lower limbs from the complete burial sample in grouped joints

	Body size	Hip lipping	Hip porosity	Hip eburnation	Knee lipping	Knee porosity	Knee eburnation
Body size	1,000	,657**	,319	-	,328	,064	,114
Sex	,647**	,346	,403	-	,285	-,236	-,234
Age	,124	,474*	-,012	-	,300	,286	,245

* Correlation is significant at the 0.05 level (two-tailed).

** Correlation is significant at the 0.01 level (two-tailed).

In order for the sample to enlarge, data from the commingled context were selected to be added in the correlation tests. As the femur is the best proxy for body size and the only bone to be used for regression analysis in order to produce sex estimations for the commingled bones, femoral bones were selected to be used for the correlations. One side only was selected just so as to avoid duplications, thus the left side was selected for the correlations. The results showed a similar image with the correlations from the discrete burials. No significant correlations could be observed across the osteoarthritic lesions on the femoral bone (Tab. 10). Moreover, porosity presented a slight negative correlation both in proximal as in distal joint of the femur with values of -0,17 and -0,09 respectively. Sex was again highly correlated with body size with a value of 0,82 ($p \leq 0.01$). However we should be cautious about these results as the sex estimations for the commingled sample derive from indirect estimations. None of the other correlations presented any significant value and porosity was also slightly correlated with a negative value.

Table 10. Correlations of the left femurs

	Body size	Lipping	Porosity	Eburnation	Proximal femur lipping	Proximal femur porosity	Proximal femur eburnation	Distal femur lipping	Distal femur porosity	Distal femur eburnation
Body size	1,000	,243	-,205	-	,087	-,170	-	,165	-,091	-

sex	,829**	,169	-,257	-	,034	,153	-	,031	-,134	-

** Correlation is significant at the 0.01 level (two-tailed).

Due to lack of information from adult long bones relating to age, the correlations could not be controlled for that variable. Femur correlations were controlled only for sex, which was able to be estimated both in the complete and commingled burials. Controlling for sex did not create any significant difference in the first results (Appendix: A.15). No significant values for correlations were observed at all and porosity was still slightly correlated negatively.

All in all, it became clear after the statistical analysis that body size cannot be correlated significantly with the development of osteoarthritis in the joints of the lower limbs. Most of the correlations produced low positive values. The majority of them were not above the zero value, that is to say, the indicator of no correlation. Porosity showed a small difference with lipping and eburnation in most of the joints, by producing slight negative correlations of no significant value. Sex was also not particularly correlated with the disease but highly correlated with body size. Age, where it was observable and measured, presented some significant values correlated with the occurrence of lipping but remained insignificant with the other lesions. More specifically, although femur and its body size were thought to be the bone that could have the strongest relationship with the prevalence of osteoarthritis in bones, it was proved to be not particularly related, positively or negatively.

4.5. Osteoarthritic inter-correlations

Osteoarthritic changes were additionally tested in order to observe if they correlated with each other. The results showed that a few significant correlations existed between the different osteoarthritic expressions of one joint as well as between the joints of the lower limb (Tab. 11). Acetabulum lipping correlated with all the other changes in acetabulum and with distal femur eburnation. Proximal femur porosity correlated with proximal femur eburnation, distal femur eburnation, all proximal tibia osteoarthritic changes and distal tibia lipping. Proximal femur eburnation showed the same correlation matches with porosity but in the distal tibia correlated with porosity and eburnation instead of lipping. Distal femur lipping expression presented a strong relationship with distal femur porosity, while distal femur porosity correlated also with distal femur eburnation. Distal femur eburnation however, displayed significant correlations with acetabulum lipping, proximal femur porosity, proximal femur eburnation, distal femur porosity and all the osteoarthritic changes of the tibia. Proximal tibia showed a strong relationship with all proximal femur and all tibia osteoarthritic lesions. Lastly, concerning distal tibia, all osteoarthritic changes of tibia correlated with each other and all distal femur and proximal tibia changes. Generally, no specific pattern in the correlation was able to be observed. Apart from the acetabulum joint, in which all the osteoarthritic lesions seem to be related, there is a possibility that all the other correlations are aftereffects of the lack of information in the sample for the tibiae bones and the recording of porosity and eburnation. As the absence/presence system cannot include most of the times important information in generalized groups of recording we have to face the consequences of the system. In this study, in order for the correlations to be performed, osteoarthritic lesions were recorded as present, absent or non-observable when the lesion could not be examined. Additionally as the changes were recorded in both of the sides, when in one side there was no material to be detected and in the other the lesion was absent, the osteoarthritic change was recorded as non-observable, leading in this way in a plethora of recordings in the non-observable group. Consequently, the correlations may have resulted in significant values. In any case, one should be aware of the implications and limitations of the osteoarchaeological samples, especially when dealing with generalized data. For that reason, those limitations and probable errors are mentioned in this research.

Table 11. Osteoarthritic inter-correlations

	Body size	Acetabulum lipping	Acetabulum porosity	Acetabulum eburnatio	Proximal femur lipping	Proximal femur porosity	Proximal femur eburnatio	Distal femur lipping	Distal femur porosity	Distal femur eburnatio	Proximal tibia lipping	Proximal tibia porosity	Proximal tibia eburnatio	Distal tibia lipping	Distal tibia porosity	Distal tibia eburnation
Body size	1,000	**,561****	,411	-	,081	-,158	-	,148	-,052	,129	,309	,000	,114	,264	-	-
Acetabulum lipping	**,561****	1,000	**,678****	**,702****	,217	,252	,266	-,138	,228	**,364***	,195	,013	-,017	,160	,165	,165
Aceta. porosity	,411	**,678****	1,000	**,915****	,074	,182	,252	-,072	,209	,323	,347	,254	,217	,048	,263	,263
Acet. eburnation	-	**,702****	**,915****	1,000	,055	,142	,255	-,148	,246	,346	,343	,251	,237	,057	,307	,307
Proximal femur lipping	,081	,217	,074	,055	1,000	,150	,056	,339	,222	-,175	,121	-,068	-,098	,218	-,053	-,053
Prox. femur porosity	-,158	,252	,182	,142	,150	1,000	**,931****	,014	,293	**,636****	**,351***	**,429***	**,394***	**,373***	,349	,349
Prox. femur eburn.	-	,266	,252	,255	,056	**,931****	1,000	-,032	,240	**,655****	**,377***	**,427***	**,423***	,330	**,375***	**,375***

	Body size	Acet. Lip.	Acet. Por.	Acet. Ebu.	Prox. femur lip.	Prox. femur por.	Prox. femur ebu.	Distal femur lip.	Distal femur por.	Distal femur ebu.	Prox. tibia lip.	Prox. tibia por.	Prox. tibia ebu.	Distal tibia lip.	Distal tibia por.	Distal tibia ebu.
Distal femur lipping	,148	-,138	-,072	-,148	,339	,014	-,032	1,000	,477**	,006	,254	,032	,055	,239	-,045	-,045
Distal femur porosity	-,052	,228	,209	,246	,222	,293	,240	,477**	1,000	,429*	,231	,120	,129	,090	,098	,098
Distal femur ebu.	,129	,364*	,323	,346	-,175	,636**	,655**	,006	,429*	1,000	,490**	,628**	,632**	,459**	,572**	,572**
Proximal tibia lipping	,309	,195	,347	,343	,121	,351*	,377*	,254	,231	,490**	1,000	,784**	,774**	,558**	,695**	,695**
Proximal tibia porosity	,000	,013	,254	,251	-,068	,429*	,427*	,032	,120	,628**	,784**	1,000	,988**	,503**	,744**	,744**
Prox. tibia ebu.	,114	-,017	,217	,237	-,098	,394*	,423*	,055	,129	,632**	,774**	,988**	1,000	,511**	,747**	,747**
Distal tibia lipping	,264	,160	,048	,057	,218	,373*	,330	,239	,090	,459**	,558**	,503**	,511**	1,000	,713**	,713**
Distal tibia porosity	-	,165	,263	,307	-,053	,349	,375*	-,045	,098	,572**	,695**	,744**	,747**	,713**	1,000	1,000**
Distal tibia ebu.	-	,165	,263	,307	-,053	,349	,375*	-,045	,098	,572**	,695**	,744**	,747**	,713**	1,000**	1,000

Chapter 5: Discussion

5.1 Osteoarthritic changes

There is still no mutual agreement regarding the coding method of osteoarthritis. Several systems address osteoarthritic changes as a composite symptom of different expressions, that can either be absent or present; thus a symptom that can be scored dichotomously (Calce at al. 2016, 9). Rather a simplified system, however a representative one when it comes to evaluate the prevalence of osteoarthritis in a population or on specific joints (Calce et al. 2016, 9), osteoarthritis as a composite score seems to be used in a great number of bibliographic references regarding osteoarthritic changes. Between the systems of scoring and coding there are of course different combinations and methods to be used, depending on the researcher. Rogers and Waldron recognize in the recording procedure the difference of the three osteoarthritic changes (lipping, porosity, and eburnation) and suggests that in order for a joint surface to be diagnosed with osteoarthritis, it should display both lipping and porosity or a severe stage of one of them (Rogers and Waldron 1995 in Austin 2016, 540). Eburnation on the other hand is always considered as a clear indicator of the disease (Schrader 2019, 59). More complex systems of evaluation of the disorder on the dry bone have been used to measure either the severity of the disease, while using osteoarthritis as a composite expression, or to identify the different osteoarthritic indicators as separate units that can also be evaluated in a scale mode from mild to severe (Calce et al. 2016, 9). The first recording system is practical and can be applied to quite a large amount of data; nonetheless a lot of valuable information can be lost when utilizing a generalized method (Calce et al. 2016, 9). On the other hand the second recording method can be more informative and descriptive but its use in large data samples is questionable as producing extensive information of raw data (Calce et al. 2016, 9). In general the variety of such a number of scoring systems it is not always helpful as it makes the task of comparing studies and results concerning osteoarthritis disease difficult (Calce et al. 2016, 2).

In this study osteoarthritic lesions were evaluated separately and a scoring method of a scale from none, mild, moderate to severe was used. However in order for the expected data to be narrowed down and used more easily in the statistical tests, each of them later on reevaluated in a binary system of presence/absence, while sometimes when both of the sides or a whole bone with two joints was used, the category of non-observable (n/o) was added in the system. The choice of this scoring method was made after significant results of rather new studies that point to the significance of evaluating the osteoarthritic expressions separately. The main reason for this imperativeness is no other than a suggestion which supports that every osteoarthritic change is independent from the others both in development and in etiology of incidence (Myszka et al. 2020, 3). According to Myszka et al. (2020) lipping or else osteophytes occur on the subchondral bone while porosity affects a different part of the joint, the cartilage surface and that is why there is the possibility for them to be unrelated. It is supported that osteophytes can be formed without damaging the cartilage and so be present in "healthy" joints, while on the other hand full thickness cartilage deformation was observed in joints with no lipping presence (Myszka et al. 2020, 6) (Fig. 9).


Figure 9. Distal femur displaying only marginal osteophyte/lipping

In the sample of Tombos no osteoarthritic expression of porosity was recorded unrelated to this of lipping, except from one lesion in the distal femur joint of an individual from the discrete sample. Lipping though was found to be present in several joints unaccompanied by other articular changes both in the discrete and the commingled sample. Eburnation was underrepresented in this sample and when present was always related to either osteophytes or osteophytes and porosity. Those results fall in line with other studies that present that changes of degeneration in the subchondral bone come before the changes in articular cartilage (Myszka et al. 2020, 3). However they seem to come in contrast with other studies that support that porosity is the most frequent and the first change to appear in young adults (Myszka et al. 2020, 6). In the sample studied, from the four individuals estimated as young adults, one displayed porosity only in the acetabulum, one only in the proximal femurs and another one in the proximal and distal femurs but none of them showed any signs of porosity in any other joint. Additionally, porosity appeared only along with osteophytes formation. It is rather difficult to state in this study whether all three osteoarthritic changes act independently or not but it is most probable that there is a relation between them. Certainly lipping is connected with bone formation in the subchondral bone and is thought to occur in order to stabilize an affected joint whereas porosity is more commonly connected with nutritional defects (Myszka et al. 2020, 6). Therefore, although lipping and porosity could be related, their etiology can differ. Concerning eburnation which constitutes a mechanical erosion in the articular surface, Myszka et al. (2020, 7) present two theories. In the first one, it is suggested that osteophytes when formed can produce pain in the individual. In order the pain to be eliminated, the individual reduces the motion and that is why eburnation does not affect all the surfaces that display lipping (Myszka et al. 2020, 7). The second one on the other hand suggests that as the role of lipping is to repair a joint by stabilizing it is justified for them to appear in eburnated joints (Myszka et al. 2020, 7).

In respect of severity in the different osteoarthritic indicators, it has been suggested that "greater development of one condition is associated with greater development of the other" (Myszka et al. 2020, 6). In the study conducted by Myszka et al. (2020, 4) the results showed a significant correlation among the osteoarthritic expressions, except from osteophytes and eburnation and porosity and eburnation. In this study the results matched to some degree the results of the study from Myszka et al. Although the osteoarthritic lesions were hardly higher than the scale of two in the scoring method with only a few examples reaching severity of number three, i.e. moderate, when they appeared higher scores were either related to each other with same scores or the high score appeared only in the change of lipping. Only in one radius, two femurs and one tibia porosity exceeded the score of lipping, with three over two in the first two bones, with three over zero to the third and two over one to the last one. In general, most of the scores came in accordance with each other in terms of severity.

5.2. Joints

The joints of the human body are recognized as one distinct and broad category the elements of which bear many similarities. However, joints based on their function, structure as well as the repeated loading which carry daily, they present dissimilar wearing patterns and different stages of progression of osteoarthritis besides the dissimilarities in occurrence of the disease (Calce et al. 2016, 2). Plomp et al. (2013, 2) mention that "it is hypothesized that the morphology of the joint itself, may influence the development or progression of osteoarthritis by contributing to the overall stability and functionality of the joint compartment". In this way, each joint seems to be a unique entity acting upon its own terms. Even between the same joints of an individual the difference in occurrence of the disease is highly observed, if one considers the general diagnosis of the disease as unilateral (Waldron 1997, 186), occurring that is to say in one of the two sides of the body.

It is believed that differences in the presence of the disease are owed to non-pathological variances relating to the anatomy of each individual, which may put more torque on one joint than an other, in particular those that bear the weight loading of the body (Weiss and Jurmain 2007, 440). Among the joints, the femoral joint has been observed to be the one more affected either as part of the hip joint (i.e. proximal femur) or as part of the knee joint (i.e. distal joint), while the ankle joint is the one less affected in modern clinical studies with occurrence rates nine times lower than in hip and knee joint (Austin 2017, 543). Hip along with hand and spine are the joints associated with the highest percentages in the occurrence of the disease and have the highest heritability rates (Felson 2004, 5; Weiss and Jurmain 2007, 439). Regarding the relation between osteoarthritis and shape of the bone and joint, the distal femur has observed to be the most indicative (Plomp et al. 2013, 7). Distal humerus and proximal ulna, as it has been proposed in Plomp et al. (2013, 2,7), are thought to also be participants in this relation as they undergo different stress and strain in comparison to other joints due to their distinct shape. However the study of Plomp et al. (2013) has not showed remarkable results of differences in those joints.

Most certainly, some joints have been found to be more strongly associated with the disease than others but it should be mentioned that the association of those joints with osteoarthritis vary among time periods. For example osteoarthritis of the hip was more likely to be found in the prehistoric or historic times before the middle ages, while knee osteoarthritis became more common during the post-medieval era (Waldron 1997, 188). Knee osteoarthritis, which existed since the prehistoric times in rather low percentages, as it develops now by affecting the greatest amount of the population, it is considered a phenomenon that appeared quite recently, over the last one hundred years, and has doubled in prevalence since the mid-20th century (Waldron 1997, 188; Wallace et al. 2017, 4). That is the reason why in the most archaeological samples from medieval ages and before, hip osteoarthritis is the degenerative lesion that most commonly prevails among the other joints.

When focusing on the results of the present research, this study concurs with the studies mentioned above. Hip is indeed the joint most affected by osteoarthritis disease in the population of Tombos, a result that is visible both in the commingled and discrete burial sample. In both cases more than half of individuals or individual bones are affected in the area of the hip, namely the proximal femur and acetabulum. The knee joint does not show high percentages of prevalence, as is to be expected due to the prehistoric origin of the sample. Although distal femur joint presents a 53% of prevalence in the discrete burial sample, proximal tibia joint shows only 25%. In general the sample is observed to indeed be more affected in the lower limbs in comparison to the upper ones for the osteoarthritic expressions of both lipping and porosity. In correspondence with the theory of Plomp et al. which suggest that the distal femur, distal humerus and proximal ulna are recipients of different amounts of stress, thus they should present higher rates of osteoarthritis, in this study it was found that at least two of them (distal femur, proximal ulna) showed high percentages of occurrence. Distal femur as mentioned above had 53% of prevalence and proximal ulna 56%. Distal humerus presented only 38% of prevalence of the disease, a number not as high as would have been expected. Most certainly the rates are quite far from similar but one should have in mind that as was introduced in the beginning of this part of the chapter, each joint follows its own patterns of progression of the disease. Nevertheless, the high rates of the proximal ulna bone most definitely raise the attention in this sample. Studies conducted on populations with close relation to Tombos sample such as the Nubian city Kerma showed that proximal ulna along with distal femur are indeed the joints more affected by the disease after the hip joint (Schrader 2019, 103-104), being in line with the results of the present study.

It is yet not proven exactly why some joints are more prone to the disease while others are not. It has been suggested that the presence of osteoarthritis in some of the joints is a result of incorrect use of the joints with the evolution of the bipedalism (Felson 2004, 3). What that means is that while the limbs in brachiating apes were made for walking and the weight of the body was supported in all four extremities, with the evolution to bipedalism the weight bearing was limited to the lower limbs, leading those joints to face excessive amounts of stress although they were not designed to bear them (Felson

2004, 3). The upper limbs were limited to pincer grips movements that most probably led to hand osteoarthritis (Felson 2004, 3). An additional theory supports that some joints can endure more effectively heavy loads and stresses and that is why they present less osteoarthritic lesions than others (Felson 2004, 3). A great example of these joints could be the ankle joint that although is placed among the weight-bearing joints it is unlikely to develop osteoarthritis (Felson 2004, 3).

5.3. Sex

Osteoarthritis is among other factors a sex-related disease. In modern clinical studies osteoarthritis is observed to affect a greater proportion of the female population in comparison to the male one especially after the age of 50 (60% of males/ 70% of females), while in younger ages the disease is manifested more in males (Myszka et al. 2019; Sowers 2001, 447). The sex differences have been attributed to the function of the different hormones acting in the body of the two genders (Myszka et al. 2019), as well as to heritability which is higher in females (Weiss and Jurmain 2007, 440). Additionally, as Myszka et al. (2019, 2) mention that "sex is thought to be a joint specific risk factor", that is why differences in osteoarthritis between the two sexes are categorized according to prevalence in one joint instead of another.

The disease in the majority affects women in particular in the knee and ankle joints (Austin 2017, 547) with knee osteoarthritis being 2 to 3 times more frequent in women and with high degrees of probability of bilateral development of the disorder in the knee (McKean et al 2007, 400) while hip joint osteoarthritis on the other hand is the joint that is more prevalent in men (Austin 2017, 547). It has also proven that in archaeological studies men express higher rates of overall osteoarthritis in contrast to modern clinical ones (Austin 2017, 547). In a study conducted by Austin (2017, 541) the results showed that although males displayed higher ratio of osteoarthritis in their joint surfaces and generalized osteoarthritis, females' femoral bones presented the most extreme expressions of the disease. In general it is observed in bioarchaeological studies that females express more osteoarthritis in the lower limbs rather than in the upper limbs (Weiss 2005, 95; Weiss and Jurmain 2007, 440). It is believed that differences in the biomechanical environment of the lower limbs between males and females may be a result of differences in strength, quadriceps angle, joint laxity and muscle activation patterns that can be found in men and women respectively (McKean et al. 2007, 400). Especially relating to knee osteoarthritis, females often do not have the same knee-stabilizing quadriceps strength that men have (Weiss and Jurmain 2007, 440). Even after expressing osteoarthritis the affected joints show different patterns in men and women. Females with osteoarthritis produce less torque in the knee and ankle joint and their motion at the knee is limited in relation to who that keep the normal mechanisms (McKean et al. 2007, 405). Similarly, females with osteoarthritis present differences in the form of the abduction moment of the knee (McKean et al. 2007). On the other hand narrowing of the intercondylar notches of the femur when affected by the disease has been proven to be expressed in a similar way in both sexes (Plomp et al. 2013, 7).

Table 12. OA occurrence out of the individuals that recorded changes

	Male	**Female**
Glenoid Fossa	5/5	6/12
Humerus	9/9	11/17
Ulna	10/10	12/18
Radius	8/10	6/15
Acetabulum	8/10	8/16
Femur	9/11	13/20
Tibia	4/8	5/20

Relating to the present study, it revealed more or less alike patterns in the relation between sex and osteoarthritis to the majority of bioarchaeological studies. In the discrete burial sample which was able to be sexed through the sex estimation methods, males exhibited more overall osteoarthritis with numbers reaching the 84% of prevalence. Females exhibited percentages of only 51% of the disease in the sample. The percentages were estimated according to the presence of any of the osteoarthritic expressions in at least one of the sides of the body for each joint and are presented in the table 12. As it can be seen, all males displayed signs of the disease in all the joints of the upper limbs except from the radius, in which 8 out of 10 males presented osteoarthritis. The rates in the lower limbs were likewise high except for the tibia bone. Females on the other hand, have not showed that high an occurrence of the disease in the upper limbs, with exception the ulna bone, in which 12 out of 18 individuals showed signs of osteoarthritis. The prevalence of the disease was observed to be slightly higher in the lower limbs apart from the tibia which hardly showed any evidence of presence. Particularly in the femoral bone of the discrete burial sample, as already been analyzed, males displayed 75% of osteoarthritic lipping, while females displayed 60%. However regarding osteoarthritic porosity, females showed higher prevalence with a percentage of 50%, whereas males exhibited only 17%. As for the commingled singular femoral bones that were sexed, the rates in females showed a prevalence of 32 to 44% and in males a prevalence of 38 to 50% in right and left bone respectively.

Regarding the severity of the disease distributed between the two sexes, females showed more severe expressions in comparison to males. Males only developed osteoarthritis that reached the level 2 of severity in the ordinal scale of scoring and in all osteoarthritic changes and just in the ulna bone a number of five individuals showed the more extreme osteoarthritic lesions. In all the other bones, no more than three individuals in each showed severe osteoarthritis. In contrast, females showed signs of severity in level 3 of the rating scale. However, as with males only a few individuals among females presented signs of more severe osteoarthritic lesions, with females showing no extreme osteoarthritic expressions in glenoid fossa and the humerus bone. In general, the majority of the population manifested mild osteoarthritic lesions.

There is a great amount of research happening both in the bioarchaeology and medical science with the principal aim of understanding the sex-related etiology of osteoarthritis disease. There is no certainty over the biomechanical differences' influence on the prevalence of the disease, especially in the knee joint of females (McKean et al. 2007, 407). It is suggested that there is a possibility that women change their biomechanics in the beginning stages of the disease in contrast with males that maintain the same, or that this alteration is a mechanism to alleviate pain (McKean et al. 2007, 407). In any case the mechanisms responsible for the movement in joints involve not only the cartilage bones but also subchondral bone, periarticular muscles and other tissues like tendons (Calce et al. 2016, 1) that also exhibit gender-specific differences that could affect the biomechanics of the joint and thus the prevalence of osteoarthritis (Magnusson et al. 2007, 238). Nevertheless, one should have in mind that so far in bioarchaeological studies there are no homogenous results relating sex differences and their expression in osteoarthritic lesions (Myszka et al. 2019, 2). There are studies that have found remarkable results, but also others that came up with insignificant or very small sex differences in osteoarthritis (Myszka et al. 2019,2), and that is why more research over this topic should be conducted.

5.4. Age

Osteoarthritis has long been considered an age-related disease (Myszka et al. 2019, 2) and in many osteoarchaeological studies age has been observed to correlate with osteoarthritis (Austin 2016, 540; Calce et al. 2018, 45; Myszka et al. 2019, 11; Weiss 2005, 94; Weiss 2006, 692). That means that in older individuals the disease it is more likely to be manifested in comparison to younger individuals (Weiss 2005, 94). Additionally older individuals are more likely to present higher osteoarthritic scores compared with their younger counterparts (Weiss 2005, 94). The prevalence of the disease as seen in previous chapters is located between 30% in the ages of 45 to 64 and 50% above the age of 65 (Loeser 2010, 371; Myszka et al. 2019, 2). The occurrence of the disease has been demonstrated to increase with age (Calce et al. 2018, 50), such that in the elderly years almost the 80% of the population is likely to present the disease in at least one of the joints (Loeser 2010, 371). Most of the joints have the same age-related rise, but the femoral bone has been observed to have a later rise than the knee one (Sowers 2001, 447). Scientists support that age has to be the main causal factor for the occurrence and progression of osteoarthritis (Weiss 2005, 94; Weiss 2006, 690). The theory explains that due to ageing the cells and tissues, like the cartilage and the bone structure of the joint undergo a series of changes that lead to gradual destruction of the joint and more susceptibility to damages as well as decreased ability to maintain homeostasis (Loeser 2010, 380; Myszka et al. 2019, 2; Weiss 2005, 94). Apart from that it is believed that older individuals express osteoarthritis because they have suffered from more stress during their lives, as they have lived longer than their younger counterparts (Weiss 2006, 693). However osteoarthritis prevalence in relation to age has also been attributed to other factors such as hormones, nutrition and joint stability that can change during the years of a person's life (Austin 2016, 547; Weiss 2006, 693) and for that reason not all scientists agree whether ageing itself is the main risk factor for osteoarthritis (Calce et al. 2018, 50).

In this research the individuals from the complete burial sample were categorized into three groups, those of young, middle and old adults and the number of individuals belonging in these groups followed a progressive distribution, meaning that the sample had more middle adults than young ones and more old adults than those grouped in the category of middle adults. From the four young adults that were analyzed in the sample, two of them show osteoarthritic expressions of lipping and porosity in the distal femur joint and one of them showed the same expressions in the proximal femur joint as well. The former did not display any other osteoarthritic changes while in the latter almost no other bone was preserved to help in the recording of the disease. The third individual displayed no osteoarthritic changes while the last one showed a mild overall osteoarthritic expression manifested in almost all the joints. In the group of middle adults, the least affected bone was tibia with only one individual displaying lipping. The second least affected bone was the radius, as only three individuals displayed lipping in their joints. In glenoid fossa, four individuals scored mild lipping expressions and two of them porosity ones. Five individuals expressed lipping in both proximal and distal joints of the femur with two of them also expressing porosity, while the acetabulum scored the exact same numbers. Ulna and humerus bones were the most affected bones with seven individuals showing changes of lipping, while two of them showed porosity in ulna and three of them in the humerus bone. The group of old adults presented higher rates of osteoarthritis. Seven individuals present lipping in the glenoid fossa, of which one presented porosity. Radius lipping was evident in nine individuals while radius porosity was evident in three but one of them presented severe porosity. Ten individuals showed lipping in the acetabulum and humerus, while two and four of them showed porosity respectively. In ulna eleven individuals presented osteoarthritic lipping with five of them reaching a severity level of three. Eleven individuals exhibited lipping in the femoral bone with half of them having also formed porosity. In tibia only seven individuals showed lipping expressions and two of them porosity. Only one individual of the whole sample and the old adults group had formed eburnation in one of the distal femur joints and the corresponding proximal tibia joint.

As can be seen from the results, the oldest individuals have indeed exhibited more osteoarthritis across the joints of the body, likewise the middle adults showed more osteoarthritic changes in comparison to the group with young adults. Correspondingly, the older the individuals, the more severe the expressions which were displayed in the sample. The last group, the one of old adults, proved to have been the one that had the most moderate changes, while also severe ones and it was the only one where eburnation had developed. However, even the young adults group showed developed overall osteoarthritic changes, something that was not expected in individuals of a young age. Even more, almost all of them developed lipping in the femur, a bone that according to some studies has late rise in osteoarthritis (Sowers 2001, 447). As has been mentioned by Myszka et al. (2019, 2), the results regarding age differences in osteoarthritis among the osteoarchaeological studies do not follow a pattern but are rather distinct. A lot of studies have recorded differences that have not found a similar correspondence whereas others have not recorded any significant difference (Myszka et al. 2019, 2). In the present sample the osteoarthritic changes seem to have followed a scale of progression and severity from the youngest to the oldest ages. In addition, regarding the correlations between age and the various osteoarthritic changes, age showed a significant correlation only with the expression of lipping and a moderate one with the rest of the changes. From our sample it is still unknown if the differences found follow a universal pattern of occurrence but the results can support a relation between age and osteoarthritis. It should be mentioned that the information used for this research is limited since the commingled assemblage could not be included for the reason that age could not be estimated for it.

5.5. Muscles and tendons

Muscles and tendons are connective tissues that contribute to the normal function of the joint. Each of the participants in the mechanism of movement in the human body has a specific role: its purpose is very specific and most of the time it can leave its print on the bone. Muscles, which are responsible for maintaining strength and distributing the stress across the body act upon the bones by initiating the remodeling function which in reality is a response to the forces transmitted from the muscles to the bone (Weiss 2007, 931). These markers are very important to osteoarchaeologists because they are the only references to be preserved from the soft tissues of one's joints and can provide us with information concerning the mechanical loading and movement of the body (Calce et al. 2018, 51). In relation to osteoarthritis, Plomp et al. (2013, 8) supported the idea that ligaments might be one of the first joint compartments that are affected by the occurrence of osteoarthritis, resulting into lipping development. In like manner, muscles, due to the joint loads they create, are connected with the prevalence of the disease (Myszka et al. 2019, 3). However, sometimes strong muscles have been shown to have a protective role against osteoarthritis (Myszka et al. 2019, 3). Many researches have tried to study the relationship between osteoarthritis and muscles by looking at the markers that those tissues leave on the bones (). Most of them consider both markers of muscles (entheseal changes) and those of osteoarthritis to have a similar etiology and be connected with activity, thus examining them together (Austin 2016; Schrader 2019). In those studies males almost always appear to have higher muscle marker scores than females and when similar patterns are found in osteoarthritic changes the results are attributed to labor division (Austin 2016; Schrader 2012; Weiss 2007) However, when body size is used to control samples with great differences between sexes those differences disappear (Weiss 2007, 931-2). In a similar way osteoarthritic lesions could erroneously be strongly connected with muscle markers. Palmer et al. (2014) found that there was no significant relationship between osteoarthritis and entheseal changes. Myszka et al. (2019, 10) however, observed that although more muscular individuals were predicted to more likely have developed osteoarthritis, when the joints were examined separately the correlations were not significant. In this study osteoarthritis will not be examined along with entheseal changes. Nevertheless it is of high importance to always consider the possibilities of a strong relationship or similar etiology between them. Schrader (2012) that studied entheseal and osteoarthritic changes in Tombos found that both of the changes showed low frequency and severity in the sample, something that concurs with the results of the present study and might show a relation of the two changes.

5.6. Stature and body mass

Stature and body mass were not examined as such, separately in the study. However, they were examined as parts of body size estimations. Nevertheless it was decided that it was important to make a small reference to them as they constitute the main parts of body size. The estimation of body mass is the evaluation of body weight of an individual (Weiss 2006). In clinical studies, measuring the body weight of an individual is quite an easy task but in osteoarchaeological studies this task becomes more complicated as records of anatomical measurements are scarce (Calce et al. 2018, 50). Anthropologists have tried to create proxies for the estimation of body weight out of the preserved skeletal materials (Weiss 2006, 691). However these proxies have proven not to be precise and of course not be able to follow how body mass index of an individual fluctuated in life (Calce et al. 2018, 50; Myszka et al. 2019, 11; Weiss 2006, 691). Proxies based on femoral head demonstrated an inaccuracy in estimations by measuring heavy individuals as having small femoral heads and the opposite (Ruff 1991, 407). Proximal femoral diaphyseal size has proven to be correlated with current body weight but not showing patterns of previous fluctuations (Ruff 1991, 411).

The relationship of body mass and osteoarthritis has been studied quite extensively. In clinical studies conducted in living populations, this relationship is examined by comparing the presence of joint space narrowing in individuals affected of the disease with healthy ones (Calce et al. 2018, 50). In general, body mass is associated with osteoarthritis due to the concept that increased mechanical loadings on joints that seems to be related to the increase of body weight can lead to cartilage breakdown and failure of the joint's compartments and consequently to the development of osteoarthritis (Calce et al. 2018, 46; Felson et al 2000, 639; Jiang et al. 2011, 154; Myszka et al. 2019, 2; Sowers 2001, 448). Alternatively this relationship is attributed to the metabolic theory, which supports the act of hormones such as leptins, which are connected with obesity, lead to the development of the disease (Jiang et al. 2011, 154; Myszka et al. 2019, 2; Sowers 2001, 448). Hip and knee osteoarthritis have been observed in many studies to increase linearly with body weight (Calce et al. 2018, 46). The heavier the individual the more possibilities they have to develop the disorder in the peripheral joint sites (Jiang et al. 2011, 150). Modern clinical studies have showed that knee osteoarthritis is more significantly associated with higher body mass than hip osteoarthritis (Jiang et al. 2011, 153; Felson et al. 200, 693). However in past populations body mass has been mostly related to hip osteoarthritis but the correlation was observed to be negative (Calce et al. 2018, 50; Myszka et al. 2019, 2; Weiss 2006, 693). Some studies have proved that sex has a strong influence on the results of body mass and osteoarthritis correlations (Calce et al. 2018, 50; Myszka et al. 2019; Weiss 2006, 693) while others demonstrated no significant difference between the two sexes (Jiang et al 2011, 153). In addition there were some studies which resulted in no significant effects on osteoarthritic changes from body mass (Myszka et al. 2019,2) especially when each joint was examined separately (Myszka et al. 2019, 11).

Stature has taken less attention in comparison to body mass (Myszka et al. 2019, 3). Research has found a genetic link between height and osteoarthritis indicating that short stature is more likely to predispose an individual to the occurrence of osteoarthritis (Calce et al. 2018, 46; Myszka et al. 2019, 3). Body height has been connected with the prevalence of knee osteoarthritis (Welling et al. 2017, 1100). As taller individuals are more likely to be heavier and larger due to higher upper body mass, the knee is the recipient of excessive mechanical stress that leads to predisposition to osteoarthritic changes (Welling et al. 2017, 1101). Additionally long legs result, in any case, in greater torque at the knee (Welling et al. 2017, 1101). Generally, most of the studies result in no significant correlation between stature and osteoarthritis (Calce et al. 2018, 50). Myszka et al. (2019, 11) in particular demonstrated that stature had a negative dependence with one of the osteoarthritic changes, i.e. porosity. Studies relating to these two factors have proven that there is no homogeneity among populations and different samples. However they are important estimations that need to be made before the reconstruction of past lifestyles (Weiss 2006, 691). In this study it was decided that the examination of those factors would not take place due to the small sample that we have in our hands, due to the large marginal errors that these calculations produce (Merritt 2014, 38), and due to the speculation that obesity is a modern phenomenon and there is a possibility that the relationship between osteoarthritis and body mass would not have been detected (Calce et al. 2018, 50; Myszka et al. 2019, 11). In that case, even though the dependence of osteoarthritis of body mass and stature are indirectly related with the findings of this research, they were considered important to be mentioned in the discussion, as both of them constitute parts of what is considered to be a person´s body size.

5.7. Body size

Body size as used in this study and as proposed in Weiss (2005, 90), namely a composite aggregate score measured out of the z-scores of three femoral size variables (maximum length, epicondylar breadth, and maximum head diameter), was observed to be correlated with osteoarthritis in a number of studies. Large body size is most of the time associated with the prevalence of the disease, especially in the lower extremities, as it is connected with bone hypertrophy and accumulated mechanical loading which is distributed to the lower limbs (Calce et al. 2018, 46). Consequently, because larger people add more stress in their joints, the degeneration of the cartilage and all the tissues connected with the function of the joint is more likely to happen in them rather than in their smaller and lighter counterparts (Weiss and Jurmain 2007, 441). This theory seems rather logical, however a series of recent studies proved that body size is more likely to be related to osteoarthritis in the opposite way. Calce et al. found in their study that body size variables have not shown any statistical correlations with osteoarthritic changes either in the lumbar or the knee joints or in the severity of the osteoarthritic changes (Calce et al. 2018, 49-50). Only the hip joint resulted in significant correlations (Calce et al. 2018, 50). In addition to that Weiss observed in her study that smaller individuals correlated more significantly with osteoarthritis (Weiss 2005, 95). The correlations remained even after the sample was controlled for age, although it appeared only in the lower limbs (Weiss 2005, 94-5). Individuals with smaller lower limbs displayed greater osteoarthritis scores than individuals with larger lower limbs (Weiss 2005, 95). That was attributed to incapacity of the smaller joint surfaces that a smaller individual probably have to endure excessive loads and distribute them across their surface, than a larger individual with broader joints would have done (Weiss 2005, 95). What really draws attention in this study, were the insignificant correlations of body size and osteoarthritis when the sample was controlled for sex (Weiss 2005, 95). As an explanation of this, Weiss states that "the size correlation, in which smaller individuals have greater osteoarthritis scores, may actually be a sex difference", especially if we consider that sex and size were highly correlated and with a strong value of significance (Weiss 2005, 94-5). Aside, however from, the relationship of sex and osteoarthritis prevalence, the severity of osteoarthritis between the two sexes has been found not to present any difference (Calce et al. 2018, 50).

According to Weiss, who noted that upper limbs correlate with upper limb size and lower limbs correlate with lower limb size (Weiss 2005, 87), the present research was limited to the examination of lower limbs, as the aim was to test whether the weight bearing joints correlated with osteoarthritic changes. In any case, the lower limbs have proven to be more related to the body size of an individual (Weiss 2005, 87). Therefore, body size was calculated for the complete burial out of the preserved femurs of each individual, while for the commingled sample the femoral bones were selected as well to be used for the estimation of body size with the difference that they used in correlations only with themselves. Body size in the complete sample was correlated with all the joints of the lower limbs (i.e. acetabulum, proximal femur, distal femur, proximal tibia, distal tibia). All femoral measurements were converted into aggregate scores. Body size varied from 1,86 to -2,13 from femoral bones both from the discrete sample and the commingled one. Most of the individuals that were estimated as women produced scores that were under the value of zero with the exception of seven individuals. One of them scored a quite high value of 1,36. Males also included two individuals with values below zero; however the majority scored the highest values. Since the sex estimation of the commingled bones was made with regression based on the measurements from the complete sample, all the male femoral bones produced values above zero but female ones scored values from -2,13 to 0,24. From the results we can indeed observe that males in the Tombos population were in the majority, bigger than their female counterparts in height, weight and robusticity, although the exact measurements have not been estimated in this study and cannot be estimated with accuracy.

Examining more thoroughly the body size scores in relation to osteoarthritic changes in the sample, no clear pattern is observed. The largest male individual from the discrete burial sample (z-score: 1,86) displayed both lipping and porosity changes in all the bones except for the radius and femur bone where no osteoarthritis was observed. The second largest male individual (z-score: 1,48) had not developed any osteoarthritic change in the radius, femur and tibia, while in all others showed only mild lipping. The third largest male individual (z-score:1,44) showed only femoral lipping. However all the upper limbs were absent, so no accurate observation can be done. On the other hand the biggest female individual (z-score:1,36) displayed lipping only in the left ulna, femur and tibia while the other bones have not been preserved, and the second biggest female (z-score:0,79) presented mild lipping in humerus and ulna and severe lipping and porosity in distal femur and proximal tibia. Relating to the smaller individuals, the smallest male one (z-score: -0,50) has preserved only the femur and tibia and did not show any osteoarthritis. The second smallest male individual (z-score: -0,24) displayed mild expression of lipping in all the joints. In the female group, the smallest (z-score: -1,84) presented only lipping and porosity only in the distal femur, while the following two (z-scores: -1,48; -1,42) have not showed any osteoarthritic change.

In reality, the largest individuals, especially those that were sexed as males, displayed, as was expected, overall osteoarthritic changes, but not in the femoral bone. The osteoarthritis in larger female individuals was more focused on the lower limbs and ulna bone. That comes in line with the clinical studies that support that women develop more knee osteoarthritis in comparison to men. Similarly in the smaller individuals men showed more generalized patterns of the disease, while women showed only in the knee joint, if none. The smallest individuals failed to match with what Weiss (2005) states about more pronounced osteoarthritis in the small-sized individuals. No large-size individual presented any relationship with osteoarthritis in the lower limbs and furthermore, the hip joint was not affected in either the large males or the large females. Regarding the commingled context neither the two largest nor the two smallest femoral bones that were sexed as belonging to males presented osteoarthritis. In those sexed as belonging to females, one of the two largest presented lipping and one of the two smallest lipping and porosity in the distal joint, following only the results of the clinical studies as mentioned already.

Focusing in the statistical analyses, the correlations followed a quite similar picture. Apart from the osteoarthritic expression of lipping in the acetabulum, there was no significant correlation between body size and the other joints. The results were alike as well in the left femurs selected from the commingled context. No significant correlation was observed for body size and femur osteoarthritis. Likewise, when the complete burial sample was tested as divided in grouped joints, only lipping in the hip joint was significant correlated with body size. However, there were some results that draw attention and have not been observed in any of the studies conducted by Weiss or other researchers that investigate body size and osteoarthritis, probably due to the generalized scoring of osteoarthritis.

In the present study, osteoarthritis was examined through the absence or presence of each of the osteoarthritic changes which are considered to be able to develop independently and have different etiology. Consequently in the statistical analyses each expression was tested for their relationship with body size and other variables. As already mentioned, lipping showed no significant correlation with body size in any joint except for the acetabulum. Porosity did not show either any significant correlation, however presented negative correlations with body size in all of the joints both in the bones from the complete and the commingled context. The grouped joint correlations were the only ones that presented insignificant positive correlations, showing that probably the more generalized data can produce errors in their results. The negative correlations with porosity and body size indicate that smaller individuals are more likely to develop osteoarthritis expressed by porosity instead of the other lesions. This outcome has been observed recently in a research led by Myszka et al. (2019, 10), where they noticed that “smaller individuals were predicted to mare likely developed porosity”. In more detail, porosity was also showed a negative correlation with stature, something that neither lipping nor eburnation showed (Myszka et al. 2019, 11). It can thus be supported, that there is a possibility the correlation that some studies have discovered existing between small body size and osteoarthritis, is in reality dependence between porosity and body size. Lipping and eburnation are still supposed to correlate positively with body size, meaning that the larger the individual the higher the correlation with osteoarthritic expressions of lipping and eburnation in the joints. Nevertheless, the present study has not found any significant correlation.

Regarding the influence of sex in the relationship between osteoarthritis and body size, it was discussed previously that it can affect the results in a way of presenting sexual biological differences as differences existing in body size. That is why it is imperatively necessary to control for sex in the sample in order to tease apart sex from body size (Schrader 2012, 64). In this work, when controlled for sex, the correlations slightly changed. No significant values were recorded anymore in the correlations and the negative values of porosity no longer existed. Instead of them, insignificant positive ones were presented for body size and porosity. Those results prove that indeed sex can have an influence on body size and osteoarthritis something that can be seen from the significant correlation that body size with sex have. Nonetheless, when controlled for sex, correlations in the left femurs from the commingled context and grouped joints do not change; a fact that raises some questions. In contrast, when the samples were controlled for age no remarkable changes were observed, probably due to the fact that body size did not correlate with age.

Figure 10. Proximal humerus with eburnation, lipping and porosity (https://scotthaddow.wordpress.com)

In the present research, inter-relations between the three types of osteoarthritis were also tested but have not produced many significant correlations. Myszka et al. (2020, 6) mention in their article that osteophytes, namely lipping, were positively correlated with porosity, but there is no clear evidence for the precedence of any of them relating to the other. In our sample, no correlation between lipping and porosity was observed in the lower limbs, except for the acetabulum joint. Those results seem to concur with other studies that support that lipping and porosity are unrelated and in fact can be developed in one joint without the presence of any other osteoarthritic change (Myszka et al. 2020, 6). Eburnation is suggested to not correlate with any other lesion. Nonetheless, in this research eburnation showed strong relationship with porosity especially in the distal femur and tibia joints. As already mentioned, those correlations have probably resulted due to errors based on the recording system; however there are researchers that support that eburnation almost always exists accompanied by porosity and sometimes lipping (Myszka et al. 2020, 6) (fig. 10). In any case, the relationship of porosity and eburnation should be studied more thoroughly considering the fact that the modern research has showed many times that the two osteoarthritic changes may have independent etiology and as they occasionally do not occur in the same joint they may not be related (Myszka et al. 2020, 6).

5.8. Overall assessment

This study did not find significant association between body size and osteoarthritis, an outcome that needs further interpretation and research. The results did not fit in the primary hypothesis that large-size individuals show high prevalence of osteoarthritis. The population of Nubia is thought to have, like Egyptians, a Nilotic/Negroid (tropics) body plan with long extremities and short trunk (Gibbon and Buzon 2016, 328), thus belonging closely to the tallest populations to be found across the world. Although Tombos is supposed to have had a diverse population during its existence, as it was an Egyptian colonial community built in the territory of Nubia (Gibbon and Buzon 2016, 325), Upper and Lower Egyptians and Nubians were not as genetically distinct populations as they were earlier thought to be (Stock et al. 2011, 363). From research made on the Tombos sample, it was proved that little statistical difference was found in the sample (Gibbon and Buzon 2016, 330). Consequently, regarding body size the Tombos sample should have a quite homogenous picture and differences in body size should probably not derive from differences in population origins.

Although Egyptian and Nubian individuals are categorized among the tallest individuals, studies conducted over stature in the broad area of Egypt showed that a decline in stature was observed during the Middle Kingdom era (Zakrzewski 2003, 225) that could possibly be followed as well in the New Kingdom period. In Tombos in particular, some individuals were found to have been smaller than other individuals in contemporaneous Nubian sites and in their majority they were found to be smaller than the individuals who inhabited Tombos in the following period (Gibbon and Buzon 2016, 327). Is that decline in stature, however, so strong and influential that individuals of the Tombos site can be considered as being closer to small-size individuals who are supposed to be more affected from osteoarthritis? That question is difficult to answer, however the negative correlations of body size with porosity produced out of the statistical analyses imply that there is a relationship with small size. Nevertheless, it should be mentioned that porosity has not shown high prevalence in the sample, so is rather dubious whether small size as such and not as comparative in the population can be used in this case.

The variable of body size is also influenced strongly by sexual dimorphism, especially in lean and body mass and less in stature (Wells 2012, 6) although some studies have proven the opposite (Nieves et al. 2005, 532). Zakrzewski (2003, 226) noted that sexual dimorphism was found in all long bone lengths in Egyptian populations, and males were larger and taller than females. Similarly, Stock et al. (2011, 354) mention that diversity in stature across Nubian populations is accounted to sexual dimorphism. However Gibbon and Buzon (2016, 334) suggest that less variability in the size of females from Tombos is not attributed only to sexual dimorphism but also to the fact that most women came from Egypt while the male population included both Egyptian and Nubian individuals. In this study though, it was found that body size correlated with sex, so a relation between them exists at least in this sample. This relation is also responsible for important changes in the statistical analyses. The negative correlations found between porosity and body size, disappeared after they were controlled for sex. Similarly, also disappeared the significance in the correlations of body size and acetabulum lipping. Does, however, that mean that porosity is not related with smaller size in people?

The relationship of osteoarthritis with body mass is well established in the research history so far (Calce et al. 2018; Weiss 2005), yet, in this sample excessive body mass, namely obesity, is not expected, as much due to the influence of the hot environment that favored decreased body mass index (Wells 2012, 2) as to the modern origin of obesity (Calce et al. 2018, 50). A strong relationship of osteoarthritis with lean mass is also doubted. Generally, recent studies proved that entheseal changes do not show significant correlations with osteoarthritic lesions when each joint is examined separately (Myszka et al. 2019, 10). Schrader (2012, 67) found that Tombos sample displayed low occurrence and severity of entheseal changes as well as osteoarthritis. That was translated to low levels of physical activity (Schrader 2012, 67). Inhabitants of Tombos were thought to be members of the upper or middle class working as bureaucrats, professionals or tradespeople (Schrader 2012, 68). That excludes the sample from developing osteoarthritis from activity, although even the smallest movements and loadings of the body itself after years of repetition can cause damage to the joint (Schrader 2019, 61). Nevertheless, osteoarthritis can also be developed from other type of stresses. Nutrition is one of the osteoarthritis risk factors (Sowers 2001, 448-9). Small size and changes to stature and body mass within a population can also be attributed to nutrition deficiency (Kurki et al. 2010, 169, Zakrzewski 2003, 220), so size of the Tombos population as well as osteoarthritic changes can be related also to nutrition or changes in nutrition. Lastly, the only significant correlation with body size and osteoarthritic lipping in hip joint may be in fact related to mechanical loads which the body carries in this joint. Why this joint has higher prevalence in males in comparison to females it may not have to do only with composition of the body but also with the way the different sexes walk. McKean et al. (2007, 403) mention that "female subjects walked with significantly less hip internal rotation, a smaller flexion moment and a larger abduction moment than male subjects". That can probably lead to knee laxity (i.e. displacement or rotation of the tibia with respect to the femur), that is greater in women and predispose the joint to osteoarthritis (Felson et al. 2004, 640). Since in the present study a higher occurrence of knee osteoarthritis has been observed in females it can be supported that mechanical movements may play a role in the prevalence of the disease in this joint. Finally, which osteoarthritic change is associated with which factor is difficult to analyze in our sample. The results, though, indicate independence in occurrence.

Chapter 6: Future research

This chapter will present ideas for future research which could help to better understand the relationship between body size and osteoarthritis. The main focus will be given on the density, shape and geometry of the bone. Additionally, some ideas over the content and size of a sample will be presented.

6.1. Bone density, shape and geometry

In the current study, body size was only measured by means of femoral maximum length, epicondylar breadth and head diameter measurements. However bone density, shape and geometry are also considered compartments of the body size of a bone and have been observed to be related with osteoarthritic changes.

High bone density and wider geometrical bone measurements have been associated with susceptibility to osteoarthritis and in particular with the osteoarthritic change of lipping (Felson 2004, 5; Myszka et al. 2019, 3). Dense and inflexible bone is thought to be unable to bear the mechanical loadings and stress, leading to cartilage failure and occurrence of osteoarthritic lesions (Myszka et al. 2019, 3). More specifically, high bone density or mass is more associated with knee and hip osteoarthritis (Sowers 2001, 448). As Felson (2004, 5) mentions, osteoarthritis is not related to every joint, but has a stronger relation with weight-bearing joints.

Cortical bone shape, on the other hand, that in reality reflects the modelling and remodeling of the bones of an individual during their life, seems to be associated with osteoarthritis by the excessive mechanical stress that stimulate the bone formation which applies to any bone that can form the disease (Calce et al. 2018, 46). In bioarchaeological studies, this function was named "Wolff's law" and was connected with individuals who undertook physical stressful activities during their lives, thus having more massive bones (Myszka et al. 2019, 11; Ruff et al. 2006, 484). The long bone cross-sectional geometry, meaning the cortical bone shape, is thought to reflect the deposition of the bone layers from the mechanical loadings that the individuals have suffered since their adolescence and early adulthood (Ruff et al. 2006, 493). However, cross-sectional morphology which is being established in such early years like these of adolescence, is something that it is making it impossible to coincide with osteoarthritis, even though the factors leading to this establishment are similar to those of the disease and most probably they are accompanied by genetic ones (Calce et al. 2018, 46; Ruff et al. 2006, 491). Those genetic factors are probably individual functions that predispose an individual to form new bone and thus "be either predicted or not predicted to have osteoarthritic changes" (Myszka et al. 2019, 10).

Subchondral bone also endures the mechanical loadings of the body and it is likely to suffer changes in its size, though due to its reduced plasticity it is affected less than the long bone diaphyseal geometry (Plomp et al. 2013, 2; Ruff 1991, 402). In general, robusticity of the bones was observed to be correlated with osteoarthritic lesions (Calce et al. 2018, 51; Myszka et al. 2019, 3; Weiss 2005, 94). Some studies have showed that more robust individuals demonstrated significant correlations with osteoarthritis, especially in upper body (Myszka et al. 2019, 3; Weiss 2005, 94) and these findings were more pronounced in males (Weiss 2005, 94). However, Calce et al. (2018, 51) found that higher robusticity in the femoral bone was correlated with significant value with lower rates of pelvic osteoarthritis. Those results supported a probable protective role of bone robusticity to the progression of osteoarthritis instead of predisposing to it (Calce et al. 2018, 51).

As the role of bone density and shape is not yet clear in relation to the osteoarthritis disease further research on the topic is needed. Studies in recent years have shown that osteoarthritis depends not only on external factors, but also on the body and the bone composition itself. For that reason and as studies on the relation of osteoarthritis and robusticity or/and bone shape and geometry are rare (Myszka et al. 2019, 3), more attention should be given to them as they produce significant results.

Furthermore, it is of high importance for studies with greater samples to be conducted. The sample of this thesis is only of a small size, i.e. 32 complete burials and 62 separate femur bones. Samples as such can perhaps be representative of a cemetery but not always of an entire population, neither can be statistically significant. In order for statistical tests to show high value of significance, samples that consist of larger numbers of complete individuals need to be used. With this thesis we urge the scientific community to engage in research into the relationship between osteoarthritis and body size and to include larger samples. We think that the research should be dedicated to population all across the globe but the focus should be given in those that have been left on the sidelines. Additionally we believe that research that includes both the upper and the lower limbs is really important for the dependence of osteoarthritis to body size to be cleared.

Chapter 7: Conclusion

Osteoarthritis is a pathological disorder that concerns the medical and osteoarchaeological community in a great extent. Studies conducted over the last decades have been dedicated in the examination of the development, symptoms and etiology of the disease. Osteoarthritis development is identical in every person. The disease affects the joints of an individual, in particular the synovial joints, and lead to a degeneration and alteration of the cartilage and subsequently of the subchondral bone surface. The disease is expressed on the bone by three different types of change, which constitute the indicators for the examination of the disease in the osteoarchaeological studies. The three types present distinct manifestation and have named as lipping, porosity and eburnation. It is still unknown whether they follow a line of development, nevertheless recent studies support an unrelated etiology and independence of the osteoarthritic changes.

Osteoarthritis is generally supposed to occur due to a plethora of risk factors. Age though, has been recognized as the most important. Diseases, nutrition, activity and genes also hold a substantial place in the etiology of the disease. Additionally, among all the other factors sex and body size currently draw attention as they are considered to be of high importance for the prevalence of osteoarthritis. As body size we consider the combination of stature, body mass and robusticity of an individual. In this study though, body size is the aggregate score of the combination of three measurements taken from the femoral bone of a deceased individual.

Due to the recent focus of interest, body size has not been investigated exhaustively, especially in relation to osteoarthritis. The aim of this study was thus, to examine whether there is a relation between them. The study used a sample of complete burials and bones from a commingled context. Osteoarthritis was scored, when found, in all the synovial joints but the correlations were performed only in the lower limbs. The exclusion was made under the speculation that lower body should be the recipient of mechanical stress and body loads, thus representing the best proxy for body size. In the same way, as joints of the lower body endure all the mechanical stress, it was considered that would have formed higher rates and more severe osteoarthritis.

After conducting the tests, it was very clear that the speculations have proven to be wrong. Body size did not show any significant correlations with any of the osteoarthritic changes. The only outlier was lipping expression in acetabulum joint which, when controlled for sex, resulted in insignificant correlations. Sex is an important confounding factor in this relationship and it is thought that it might be too connected with body size to be teased apart in order for researchers to examine the actual influence of body size on osteoarthritis. Overall, larger individuals were seen to present a slight positive correlation in the joints of lower body with lipping osteoarthritis. The lesion known as porosity showed an insignificant opposite result. Smaller individuals were in fact correlated with porosity in all the joints. That result also matched the outcome of femurs from the commingled sample. However none of them presented any significant value.

If small body-size individuals were proven to have a greater influence in osteoarthritis prevalence than large ones, then the low rates of osteoarthritis in the sample from a Nubian population that is supposed to be categorized among the taller populations would be logical. Nonetheless, the low significant correlations which resulted from the statistical analyses indicate that body size is not strongly related to osteoarthritis. Additionally, the differences in the results between the three distinct osteoarthritic changes point out independence in development and possibly in their etiology. The question still remains. If body size does not affect and correlate with the disease then which other factors are responsible for the prevalence of osteoarthritis in an individual? Osteoarthritis as result of activity has not been examined in this study, however for this sample it was suggested that there was no strong interaction with heavy workloads in the population of Tombos. Entheseal changes were as low as the rates of osteoarthritis. It is therefore rather doubtful whether osteoarthritis could have been related to activity. Only continuing research will give an answer to these questions that so far remain unsolved.

Abstract

Osteoarthritis is a multifactorial and one of the most common diseases to be found in human bones and has a long history of research in medical as well as in archaeological studies. A number of variables have been suggested as risk factors, some of which are nutrition, hormones, diseases, age, sex, bone density, and body size. In particular body size either tested as an entity or as stature, body mass and bone robusticity separately has been suggested to be associated with the prevalence of the disease in the joints. Since body size is considered a risk factor for osteoarthritis, it was decided to test its relation to the disease in a sample from a Nubian site called Tombos. The sample consisted of 32 complete burials and a number of 373 individually bones coming from a commingled context. Osteoarthritis was recorded out of 12 joint surfaces and was separated into three categories which represented the three different types of osteoarthritic changes (lipping, porosity, eburnation). The rates of osteoarthritis were particularly low and almost no severe manifestation of development was recorded. The most prominent osteoarthritic change to be found was the lipping. Correlations for testing the relationship between osteoarthritis and body size were conducted with the help of statistical tests from the SPSS program. For the tests only the joints of the lower limbs were selected as the aim was to test the weight bearing joints. Stress in these joints is related with body size and as hypothesized, with osteoarthritis, considering that mechanical stress towards a joint can lead to development of the disease. In contrast with our speculation, body size did not correlate with any osteoarthritic change and in any of the joints except for the acetabulum one. Significant correlation presented in the acetabulum only with lipping. Porosity displayed negative and insignificant correlations with body size in all of the joints. The same was recorded as well in the femurs from the commingled context. This outcome implies an association of small-size individuals with prevalence of porosity in the joints. However with such low significant values no certain statement can be given. The same holds true for the positive correlation showed with lipping. What is important to mention is that in this research it was observed that the different types of osteoarthritis correlate differently with each variable and thus indicate independence in their occurrence. All in all, this study seems to have contributed to our understanding of the different types of osteoarthritis and hopefully have shed some light on the relationship between body size and osteoarthritis. Further research though, and in bigger samples should be done on this topic to support or reject the results which show the lack of an association between them.

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Appendix

A. 1 Sex estimation results from regression analysis, for femurs from the commingled context

Individual	FMaxL	FHeadD	FEpiB	Sex	Prob		
3907	391	36.13	68.18	Female	0.972756537456215	1	1
3905	432	44.16	75.99	Male	0.644062702265342	1	5
3911	425	39.13	74.77	Female	0.844886298119992	2	1
3906	469	47.45	75.17	Male	0.87995438750724	2	5
3920	NA	44.48	NA	Male	0.706198019172357	1	5
3921	NA	NA	76.17	Male	0.552702210682446	2	5
3922	NA	NA	78.81	Male	0.718813893820232	1	5
3923	NA	NA	76.36	Male	0.565598713146797	2	5
3913	NA	40.73	NA	Female	0.716378334374739	2	1
3914	NA	NA	74.76	Female	0.544056564532455	1	1
3915	NA	42.09	NA	Female	0.567700968952731	2	1
3916	NA	40.43	NA	Female	0.744758869682059	1	1
3917	NA	45.85	NA	Male	0.822866331105497	1	5
3918	NA	40.69	NA	Female	0.720270784072489	2	1
3908	NA	42.54	NA	Female	0.514008941863791	2	1
3909	NA	39.54	NA	Female	0.817409755972009	1	1
3910	NA	44.42	NA	Male	0.700175300089043	1	5
4425	420	42.89	NA	Female	0.548081088298722	1	1
4426	396	37.79	67.14	Female	0.949600817054215	1	1
4431	420	41.43	73.16	Female	0.697698636989622	1	1
4432	413	41.74	NA	Female	0.69752989067428	1	1
4493	397	35.55	67.14	Female	0.980271066945919	1	1
4494	420	42.99	75.71	Male	0.51243101392144	1	5
4495	390	38.59	NA	Female	0.932837609205469	1	1
4438	437	40.89	74.46	Female	0.7200348339634	1	1
4497	440	44.1	78.69	Male	0.689590849496531	1	5
4394	400	39.56	NA	Female	0.886079339051783	2	1
4395	414	47.26	NA	Male	0.875291235703062	2	5
4430	410	41.03	75.07	Female	0.703369771844332	2	1
4433	415	42.35	74.27	Female	0.587036062466204	2	1
4484	384	38.5	68.51	Female	0.926130822748311	2	1
4485	431	44.16	78.92	Male	0.697044060563775	2	5
4496	NA	40.77	NA	Female	0.712453344230893	1	1
4498	NA	46.69	NA	Male	0.874339605714802	1	5
4499	NA	46.16	NA	Male	0.843563257989529	1	5
4486	NA	46.84	NA	Male	0.88205418423576	2	5
4487	NA	35.84	NA	Female	0.963680515213114	2	1

4488	NA	43.78	NA	Male	0.631888184232894	2	5
4489	NA	40.03	NA	Female	0.779581838960216	2	1
4490	NA	NA	66.53	Female	0.920049785103688	2	1
4440	NA	41.74	NA	Female	0.608451840795412	2	1
4441	NA	45.84	NA	Male	0.822164224495157	2	5
4427	NA	NA	74.42	Female	0.567169519803032	1	1
4428	NA	NA	75.75	Male	0.523965906181718	1	5
4429	NA	38.11	NA	Female	0.899044466457537	2	1
4434	NA	NA	79.63	Male	0.762130124817853	1	5
4435	NA	NA	66.66	Female	0.917376578595283	1	1
4436	NA	NA	78.82	Male	0.719370148286273	2	5
4437	NA	43.77	NA	Male	0.630768763606249	1	5
4401	NA	37.8	NA	Female	0.91179458518817	2	1
4393	NA	NA	63.4	Female	0.964598184609721	2	1
4396	NA	NA	75.04	Female	0.524874289709189	1	1
4397	NA	45.44	NA	Male	0.792276115551351	2	5
4398	NA	43.23	NA	Male	0.568517228445749	2	5
4399	NA	NA	62.43	Female	0.972670073206181	2	1
4385	NA	44.73	NA	Male	0.730512985229899	1	5
4386	NA	45.78	NA	Male	0.817905755411972	1	5
4387	NA	42.45	NA	Female	0.524813549922333	2	1
4388	NA	NA	75.79	Male	0.526712580270175	2	5
4389	NA	NA	81.07	Male	0.826487341093425	2	5
4390	NA	NA	70.43	Female	0.797228201414655	1	1
4391	NA	NA	69.66	Female	0.82936007668915	2	1

A. 2 Scoring methods of each osteoarthritic change (after Schrader 2010, 153)

Osteoarthritis					
Lipping		Porosity		Eburnation	
Score	Description	Score	Description	Score	Description
1	Barely discernable	1	Pinpoint	1	Barely discernable
2	Sharp ridge	2	Coalesced	2	Polish only
3	Extensive spicule formation	3	Pinpoint and coalesced	3	Polish with groove(s)
4	Ankylosis	-	-	-	-

*According to Buikstra and Ubelaker, 1994 after Schrader, 2010

A. 3 All the bones and bone surfaces used for the recording of osteoarthritis

Bone	Joint surface
Scapula	Glenoid fossa
Humerus	Proximal humerus
	Distal humerus
Ulna	Proximal ulna
	Distal ulna
Radius	Proximal radius
	Distal radius
Os coxae	Acetabulum
Femur	Proximal femur
	Distal femur
Tibia	Proximal tibia
	Distal tibia

A. 4 Osteoarthritis prevalence in the complete sample

			Glenoid Fossa	Proximal Humerus	Distal Humerus	Proximal Ulna	Distal Ulna	Proximal Radius	Distal Radius	Acetabulum	Proximal Femur	Distal Femur	Proximal Tibia	Distal Tibia
Lipping	Presence	n	11/32	12/32	12/32	18/32	13/32	8/32	12/32	16/32	18/32	17/32	8/32	6/32
		%	**34**	**38**	**38**	**56**	**41**	**25**	**38**	**50**	**56**	**53**	**25**	**19**
	Absence	n	5/32	6/32	10/32	6/32	4/32	12/32	8/32	6/32	10/32	11/32	9/32	13/32
		%	**16**	**19**	**31**	**19**	**13**	**38**	**25**	**19**	**31**	**34**	**28**	**41**
	n/o	n	16/32	14/32	10/32	8/32	15/32	12/32	12/32	10/32	4/32	4/32	15/32	13/32
		%	**50**	**44**	**31**	**25**	**47**	**38**	**38**	**31**	**13**	**13**	**47**	**41**
Porosity	Presence	n	3/32	6/32	4/32	5/32	4/32	3/32	2/32	5/32	3/32	11/32	3/32	0/32
		%	**9**	**19**	**13**	**16**	**13**	**9**	**6**	**16**	**9**	**34**	**9**	**0**
	Absence	n	10/32	10/32	16/32	17/32	12/32	17/32	14/32	15/32	18/32	12/32	12/32	17/32
		%	**31**	**31**	**50**	**53**	**38**	**53**	**44**	**47**	**56**	**38**	**38**	**53**
	n/o	n	19/32	16/32	12/32	8/32	16/32	12/32	16/32	12/32	11/32	9/32	17/32	15/32
		%	**59**	**50**	**38**	**25**	**50**	**38**	**50**	**38**	**34**	**28**	**53**	**47**
Eburnation	Presence	n	0/32	0/32	0/32	0/32	0/32	0/32	0/32	0/32	0/32	1/32	2/32	0/32
		%	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**6**	**0**
	Absence	n	13/32	14/32	19/32	20/32	14/32	17/32	16/32	20/32	21/32	19/32	13/32	17/32
		%	**41**	**44**	**59**	**63**	**44**	**53**	**50**	**63**	**66**	**59**	**41**	**53**
	n/o	n	19/32	18/32	13/32	12/32	18/32	15/32	16/32	12/32	11/32	12/32	17/32	15/32
		%	**59**	**56**	**41**	**38**	**56**	**47**	**50**	**38**	**34**	**38**	**53**	**47**

A. 5 Osteoarthritis prevalence in separate bones, in the complete sample

			Glenoid Fossa	Humerus	Ulna	Radius	Acetabulum	Femur	Tibia
Lipping	Presence	n	11/32	20/32	23/32	14/32	16/32	22/32	10/32
		%	**34**	**63**	**72**	**44**	**50**	**69**	**31**
	Absence	n	5/32	3/32	6/32	9/32	6/32	7/32	8/32
		%	**16**	**9**	**19**	**28**	**19**	**22**	**25**
	n/o	n	16/32	9/32	3/32	9/32	10/32	3/32	14/32
		%	**50**	**28**	**9**	**28**	**31**	**9**	**44**
Porosity	Presence	n	3/32	6/32	7/32	4/32	5/32	11/32	3/32
		%	**9**	**19**	**22**	**13**	**16**	**34**	**9**
	Absence	n	10/32	9/32	9/32	14/32	15/32	11/32	11/32
		%	**31**	**28**	**28**	**44**	**47**	**34**	**34**
	n/o	n	19/32	17/32	16/32	14/32	12/32	10/32	18/32
		%	**59**	**53**	**50**	**44**	**38**	**31**	**56**
Eburnation	Presence	n	0/32	0/32	0/32	0/32	0/32	1/32	2/32
		%	**0**	**0**	**0**	**0**	**0**	**3**	**6**
	Absence	n	13/32	13/32	12/32	15/32	20/32	17/32	12/32
		%	**41**	**41**	**38**	**47**	**63**	**53**	**38**
	n/o	n	19/32	19/32	20/32	17/32	12/32	15/32	18/32
		%	**59**	**59**	**63**	**53**	**38**	**47**	**56**

A. 6 Osteoarthritis prevalence in the commingled sample

			Glenoid Fossa	Humerus	Ulna	Radius	Acetabulum	Femur	Tibia
Lipping	Presence	n	7/18	22/77	19/27	10/26	27/60	31/69	20/78
		%	**39**	**29**	**70**	**38**	**45**	**45**	**26**
	Absence	n	11/18	17/77	0/27	3/26	33/60	7/69	19/78
		%	**61**	**22**	**0**	**12**	**55**	**10**	**24**
	n/o	n	0/18	38/77	8/27	13/26	0/60	31/69	39/78
		%	**0**	**49**	**30**	**50**	**0**	**45**	**50**
Porosity	Presence	n	3/18	8/77	7/27	0/26	13/60	11/69	11/78
		%	**17**	**10**	**26**	**0**	**22**	**16**	**14**
	Absence	n	15/15	25/77	1/27	6/26	47/60	15/69	20/78
		%	**83**	**32**	**4**	**23**	**78**	**22**	**26**
	n/o	n	0/18	44/77	19/27	20/26	0/60	43/69	47/78
		%	**0**	**57**	**70**	**77**	**0**	**62**	**60**
Eburnation	Presence	n	0/32	0/77	0/27	0/32	1/60	0/69	0/78
		%	**0**	**0**	**0**	**0**	**2**	**0**	**0**
	Absence	n	18/18	28/77	3/27	6/26	59/60	20/69	35/78
		%	**100**	**36**	**11**	**23**	**98**	**29**	**35**
	n/o	n	0/18	49/77	24/27	20/26	0/60	49/69	51/78

A. 7 Body size tested for normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
bodysize	,078	60	,200*	,981	60	,460

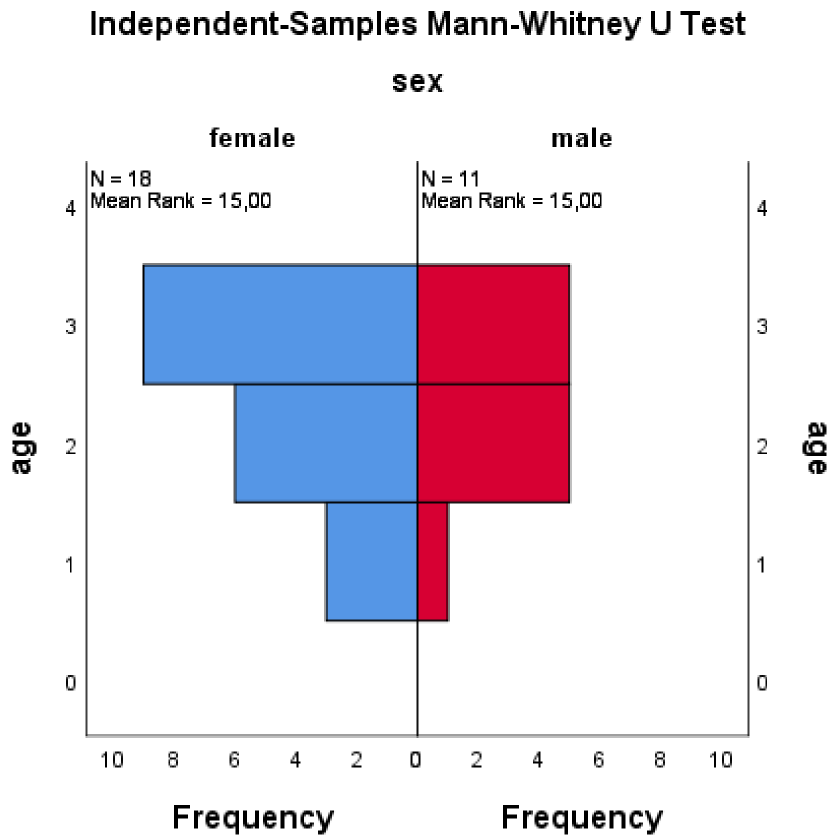
A. 8 Body size normality, tested for age

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	age	Statistic	df	Sig.	Statistic	df	Sig.
bodysize	young adult	,181	4	.	,976	4	,879
	middle adult	,168	11	,200*	,922	11	,340
	old adult	,140	12	,200*	,928	12	,357

A. 9 Body size normality, tested for age

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	sex	Statistic	df	Sig.	Statistic	df	Sig.
bodysize	female	,106	33	,200*	,950	33	,136
	male	,101	25	,200*	,974	25	,741

A. 10 Sex and age distribution for the aggregate scores



A. 11 Correlations with body size for complete burials after controlling for sex

	Body size	Acetabulum lipping	Acetabulum porosity	Acetabulum eburnation	Proximal femur lipping	Prox. femur porosity	Prox. femur eburnation	Distal femur lipping	Distal femur porosity	Distal femur eburnation	Proximal tibia lipping	Proximal tibia porosity	Proximal tibia eburnation	Distal tibia lipping	Distal tibia porosity	Distal tibia eburnation
Body size	1,000	,510	,071	-	,075	,129	-	-,040	,071	,468	,291	,460	,518	,004	-	-

A. 12 Correlations with body size for complete burials after controlling for age

	Body size	Acetabulum lipping	Acetabulum porosity	Acetabulum eburnation	Proximal femur lipping	Prox. femur porosity	Prox. femur eburnation	Distal femur lipping	Distal femur porosity	Distal femur eburnation	Proximal tibia lipping	Proximal tibia porosity	Proximal tibia eburnation	Distal tibia lipping	Distal tibia porosity	Distal tibia eburnation
Body size	1,000	,542	,433	-	-,035	-,157	-	,051	-,157	,104	,387	,001	,130	,182	-	-

A. 13 Correlations for body size in grouped joints after controlling for sex

	Body size	Hip lipping	Hip porosity	Hip eburnation	Knee lipping	Knee porosity	Knee eburnation
Body size	1,00	,675	,348	-	,231	-,077	,130

A. 14 Correlations for body size in grouped joints after controlling for age

	Body size	Hip lipping	Hip porosity	Hip eburnation	Knee lipping	Knee porosity	Knee eburnation
Body size	1,00	,654	,068	-	,167	,295	,518

A. 15 Correlations for left femur controlled for sex

	Body size	Lipping	Porosity	Eburna-tion	Prox. femur lipping	Proximal femur porosity	Prox. femur eburna-tion	Distal femur lipping	Distal femur porosity	Distal femur eburna-tion
Body size	1,00	,137	,048	-	,072	-,017	-	,128	-,030	-