BUSY BONES

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Osteoarthritis and musculoskeletal markers
as evidence of physical activity
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in post-medieval the Netherlands

Universiteit Leiden

Picture source: Poster for the Dorset Candalemas Fair, Dorchester Saturday 13th February 1886 (retrieved from: http://countrystandard.blogspot.com/2008/07/ skeleton-at-plough-dorset-1886.html)

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Preface

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1. Introduction

Human remains have always been a special category of archaeological find, fascinating scientists and the general public alike. Over the past few decades in particular, methods have been developed to glean all possible knowledge from the human skeleton. How old was the person? Was it a male or a female? From what diseases did the individual suffer? Although we can now answer quite a few of these questions with relative certainty, one lasting evasive query is which activities a skeletal specimen engaged in during his or her lifetime. With the exception of a few extraordinary cases such as the Tudor warship the Mary Rose (see Stirland 1991, Stirland and Waldron 1997) it has proven near impossible to determine one exact occupation from the skeletal remains. The many different activities a person undertook in his lifetime create a palimpsest of different signs on the bones, making it difficult for the osteoarchaeologist to determine the exact type of work in which the person might have been engaged. Only in cases where the activities in which the population engaged are already known (such as the crew of the Mary Rose) can exact activities be assigned to a skeleton with a reasonable degree of certainty. This study will therefore limit hypotheses to activity levels rather than single activities.

In an effort to overcome the limitations mentioned above, researchers continue to develop methods and test hypotheses to delineate skeletal markers of activity. In the substantial body of literature thus created, several large categories of markers can be distinguished. A first category is that of the pressure facets such as squatting facets (see for example Baykara and Yilmaz 2007). Another activity marker is presented by traumata, more specifically stress fractures and fracture patterns. A third type of activity marker is cortical thickness. Degenerative joint diseases have also been used extensively to try and ascertain activities of past populations. Within this area of research, osteoarthritis is most frequently used. A last skeletal marker is based on the morphology of muscle and ligament attachment sites on bone. These activity markers are most often defined as musculoskeletal stress markers.

In an ideal situation, all possible skeletal markers would be used together in order to get the clearest possible results. However, due to the time and resource restraints inherent in a master's thesis, this study will only focus on the last two activity marker categories mentioned above, namely osteoarthritis (OA) and musculoskeletal stress markers (MSMs). The decision to combine these two was based partly on their applicability to the same sample. Both can be applied to the upper limb and both primarily need an age-restricted sample. Also, OA and MSM's are actively being researched, with promising results being presented in current literature, making them a fascinating area of study. They have also been used together in literature (e.g. Molnar et al. 2011, Wilczak et al. 2004).

1.1 <u>Osteoarthritis</u>

Osteoarthritis is a joint disease occurring in synovial joints. The paleopathology is well discussed by Tony Waldron (Waldron 2009, 27-40). His description will be summarized here. Osteoarthritis is a disease which causes the erosion of the joint cartilage. In skeletal remains, it is quite easily recognized as it changes the basic morphology of the joint. Bone can react to osteoarthritis in four ways: it can form new bone, on the joint surface as well as at the edges of the joint (marginal osteophytes); the surface of the bone can become porous, the whole joint contour can change; and, areas on the joint surface can attain a polished appearance. This last, very characteristic, osteoarthritic change is called eburnation (figure 1).

Figure 1: Distal tibia showing clear, advanced eburnation on the condyle related to osteoarthritis of the knee (source: https://osteoware.si.edu).

Osteoarthritis has a multifactorial etiology, in which age, sex, genetic factors, body mass index, activity and trauma all play a role. Age might well be the most important element, showing the highest correlation with osteoarthritis (Weiss 2005, 94). However, recent studies have shown that genetics could be responsible for osteoarthritis in fifty percent of all cases, although this is likely to be an overestimation (Weiss and Jurmain 2007, 439), whereas the exact influence of the other factors is still unclear. This problematic etiology naturally has dire consequences for the study of activities based upon osteoarthritis. As Tony Waldron puts it “attempts that are sometimes made to attribute an occupation to a skeleton on the basis of the presence and distribution of OA are –of course- futile and doomed to failure” (Waldron 2009: 29). In cases of extreme mechanical loading, such as in farm workers, osteoarthritis might however still be useful (Weiss and Jurmain 2007, 440).

Contrary to what Waldron’s pessimistic vision suggests, there have been quite a few studies which have attained information on occupations through osteoarthritis. Research on osteoarthritis started as early as the nineteenth century, although the first widely acknowledged activity studies which used OA were those by Angel in the 1960’s. Angel (1966) studied archaic skeletons from the site of Tranquility, coining terms such as ‘atlatl elbow’ to indicate osteoarthritis as a result of using a spear thrower (Pearson and Buikstra 2006). After a period of increasing pessimism that culminated in the nineties, researchers have started studying OA again. The most recent studies tentatively state that it might be possible, at least on a population level, to gain data on activities (Molnar et al. 2011). For example, Watkins (2012) conducted a study in which osteoarthritis prevalence could be related to difference in social context between two African American sample groups.

1.2Musculoskeletal stress markers

The term musculoskeletal stress marker refers to the observation of the morphology of muscle and ligament attachment sites to deduct information about past activities. The basic premise is that these attachment sites are subject to bone remodeling as a result of the mechanical loading to which they are subjected. This concept harks back to the fundamental principle of Wolff’s law; that is that bone, being a living part of the human body, will adapt itself to its circumstances, i.e. the strain it is under. When a bone is under mechanical stress, new bone will grow in that area (Wolff 1892). Logical as this assumption is, it must be stated that there is insufficient clinical research on MSM’s because they do not pose symptoms, so theorizing on MSM etiology is as yet unproven (Pearson and Buikstra 2006: 224).

An early study on these musculoskeletal stress markers was conducted by Dutour (1986). He used the term enthesopathies to describe bony lesions at the insertion sites of ligaments and muscles. He then compared his observations of archaeological specimens with modern examples of known etiology to try and establish their cause. His term 'enthesopathies' is still used as a synonym for musculoskeletal stress markers by some current researchers, although recent studies, particularly by Mariotti et al. (2004) have changed the meaning of this word, substituting musculoskeletal stress markers as the general term. The two must therefore not be used interchangeably.

MSM research has become increasingly popular since the early eighties (see Merbs 1983 for another early example), although it was only with the introduction by Hawkey and Merbs of an adequate scoring standard in 1995 that publications really started multiplying. In 1998 Kenneth Kennedy published a summary of the first symposium on activity patterns and musculoskeletal stress markers, thereby further defining and structuring the field. In the same volume of the International Journal of Osteoarchaeology, two more papers on MSM's were published, one establishing a link between craniofacial markers and chewing of leather in Alaskan Eskimo women (Steen and Lane 1998), another showing a link between environment and muscle markers as well as sexual division of labor in prehistoric Khoisan Foragers (Churchill and Morris 1998).

As in all new lines of research, after a period of great enthusiasm and optimism, more critical studies begin to appear. For musculoskeletal markers, several good critical articles were written by Elizabeth Weiss. She proved that apart from any activity-related etiology, muscle markers were also correlated with age, sex, and body size. Size and sex are of course partially interdependent variables, yet the highest correlation was found to be with age (Weiss 2003, 2007) especially in the lower limb (Weiss 2004). Because males normally show larger MSM's due to hormonal sex differences, larger MSM's in women than males in a population is often taken to suggest an activity-related etiology. Current research is however showing that this is not necessarily so, at least not for all MSM's (Weiss et al. 2012), thereby complicating studies into the sexual division of labor.

While these confounding variables make the deduction of past activities from musculoskeletal stress markers more complicated, this should not lead to their rejection as evidence of activity. With caution and the necessary caveats, these markers can still offer valuable data. MSM's have thus been used to study the transition from hunting and gathering to farming in the Levant (Eshed et al. 2004), adaptation and cultural change in middle Holocene foragers from Siberia (Lieverse et al. 2009), or to confirm division of labor between castle dwellers and farmers in early Medieval Great Moravia (Havelkovà et al. 2011) to name but a couple of the myriad studies and questions to which MSM's have been applied. Also statistical corrections for age and size are being developed (Niinimäki 2011).
The above serves to illustrate that although a lot of research is being done on MSM's, no true consensus has as yet been reached in the scientific community. The field is still in a stage of 'trial and error', with plenty of room for discussion.

1.3 Research question

In this thesis the relationship of osteoarthritis and musculoskeletal stress markers to levels of activity will be studied. The aim is to establish whether it is possible to discern division of labor and the social differentiation inherent therein from these skeletal markers of activity. Note that it is not the specific occupation of an individual that will be researched, nor whether he or she led a physically strenuous life. Rather, a scoring system for upper limb OA and MSM's will be applied to the whole sample. These scores will then be submitted to statistical analyses to see if any groups with different scores appear. The demonstration of heterogeneity or homogeneity in MSMs and OA will then be considered in the context of differences in activity within a rural farming community for post-medieval The Netherlands. An accessory research question is whether a sexual division of labor can be distinguished, as this would provide information about the gender roles within the society. The last, smaller, research question is whether MSM and OA scores can help determine handedness in the population, ergo whether the left or right hand was usually the dominant limb.
The sample is from the cemetery site of Middenbeemster which was excavated in the summer of 2011 by the University of Leiden. Middenbeemster is located in the Beemsterpolder, a UNESCO world heritage site. The cemetery contains

inhabitants from the whole Beemsterpolder. In addition to the archaeological information that was gathered during the excavation campaign, pertinent historical data from the cemetery are also known. There are archives of names and dates of death for some of the population, as well as marriage contracts and declarations of birth. There is also a map on which the name of every person in a plot is indicated for those buried from 1829 onwards. These archival data pertain mainly to the later interments from the eighteenth and nineteenth century. Although linking the archive information to specific skeletons has not proven easy, it is possible in a certain amount of cases. These historical data will not be used during the earlier stages of this study, as this kind of foreknowledge could bias the interpretation of the results. It will however be consulted once the results have been generated.

The Beemsterpolder is a collection of rural villages, founded in the early seventeenth century by immigrants from Amsterdam. Its economy was mainly based on agriculture. As this was a simple farming community, its basic social structure can be taken to consist of a large group of farmers and craftsmen, with a smaller group of more elite families. These elite families could for instance have been gentleman farmers. In any case, the higher class likely would not have engaged in actual agricultural labor, nor would they have practiced any other physically taxing profession. The goal is therefore to evaluate whether, if osteoarthritis and musculoskeletal stress markers are examined for a sample of the population, this social differentiation will become apparent. The societal stratification and resulting variation in the activity patterns of the inhabitants of the Beemster should have a biological reflection on the skeleton. The interment of autochtone immigrants in the cemetery might partly confound this differentiation, yet cannot be corrected for and must therefore simply be borne in mind. Differences between men and women will also be studied, to test the findings of recent studies that differences in OA and MSM's are inconclusive.

As the cemetery of Middenbeemster contains individuals of similar geographic origin, the genetic variability within this population can be assumed to be very limited. This minimal variation in DNA effectively eliminates genetics as a confounding factor, making the Middenbeemster population even more appealing as a research sample. So, given that Middenbeemster presents us with a well-defined small gene pool population, can we determine differences in activity level within this community? And if so, can this tell us anything about social differentiation? On a more methodological level, it will be interesting to see whether OA and/or MSM scores turn out to be useful activity markers for this sample, and whether they concur or contradict each other. The literature is still rampant with discussion on the sense and nonsense of using osteoarthritis as an activity marker, whereas the use of musculoskeletal markers is just emerging from its infancy, and at a stage where every new study changes the field. Both OA and MSM’s therefore need testing on as many samples as possible to reach a generally accepted scientific method for their use. On yet another level, this research question will provide new data on an as yet untested, newly excavated population. Given the good preservation of the human remains recovered from Middenbeemster, this could well become a skeletal reference collection and thus must be examined in as many ways as possible. Lastly, because the Beemsterpolder is a UNESCO world heritage site, any historical information which can be gathered is of great value.

2. Middenbeemster: the historical context

Before proceeding to the actual osteological study presented in this thesis, it is necessary to create an archaeological and historical framework for the sample that will be used. As mentioned above, the skeletal specimens used originate from the recently excavated cemetery site of Middenbeemster.

The sample from Middenbeemster that will be used in this study mainly dates to the eighteen-hundreds. In this period, after the global Industrial revolution, the Netherlands were lagging behind in industrialization relative to their neighbors. Modernization came to the Netherlands only in the second half of the nineteenth century, and then it came first to Noord-Brabant and Twente, not to the central region of Amsterdam in which Middenbeemster is situated (Drukker and Tassenaar 1997, 332-333). Even so, the Dutch economy grew steadily, relying almost exclusively on its own domestic agriculture for food (Winde 2006, 70,79). Middenbeemster fits perfectly in this picture. Two historically recorded events show that the technological modernization of Middenbeemster happened quite late. Steam-powered water pumps were only taken into use between 1877-1885 (Jong et al. 1998, 32), and the steam-tram between Alkmaar and Purmerend (two cities in the proximity of Middenbeemster) only stopped in Middenbeemster from 1895 onwards (Stichting Platform Werelderfgoed Nederland, 3). As for population density, historical sources record that in the year 1840, the Beemster counted 2971 inhabitants (Falger et al. 2012, 127). In this period, the province of Zuid-Holland had an increasing fertility rate, with the population growing faster in this area than in the rest of the Netherlands (Wintle 2000, 24). The population growth was possibly somewhat retarded in the eighteen thirties, due to the cross-European cholera epidemic that struck the region of the Beemster in 1832 (Falger et al., 125). Another possible growth deterrent is the famous potato blight of the eighteen forties, which devastated the Irish population but also greatly affected the Netherlands, with many families stepping down on the social ladder and a large part of the population coming close to the verge of famine (Bergman 1967). The exact effect of this blight on Middenbeemster is hard to evaluate, especially as their economy was mainly based on dairy, and this livestock is often associated with the farming of cereal crops which can serve for human food as well as providing straw for the animals. Still, it must be born in mind, especially as all food prices went up during this crisis (Bergman 1967, 398).

The population interred in Middenbeemster was thus from a non-industrialized agricultural village community. Its agriculture relied mainly on dairy-farming on pastures with rich polder-clay soil. Other agricultural activities which are mentioned in historical sources are the cultivation of linseed and rapeseed (Jong et al. 1998, 27).

2.1The site

There is as yet no definitive report of the excavation of Middenbeemster because the field work was done only last summer. Therefore, all information here is from reports of preliminary investigations, namely the report by Griffioen (2011) and that by Klooster (2008), except when another reference is explicitly given.

Middenbeemster is a village in the Dutch province of Northern-Holland (figure 2).

Figure 2: A map of the Netherlands with Middenbeemster indicated by the red dot. (Source: http://d-maps.com/carte.php?num_car=18126&lang=en)

The village did not develop organically, but was founded by Dutch settlers from the nearby city of Amsterdam in the early seventeenth century. To be able to colonize this area of land, the settlers first had to reclaim the marshy lake land. The Beemsterlake, which was actually a result of peat mining in the Middle Ages, was drained and raised with silty sand between 1609 and 1613. The thus elevated area was divided into a strict geometric checkerboard pattern (figure 3). The Beemster was the first area of reclaimed land in which this combination of ingenious water engineering and idealistic structuring of the landscape had ever been undertaken (ICOMOS 1999, 87). Therefore the Beemsterpolder has a unique historical significance, especially as its human-made landscape has remained relatively unchanged up until today.

Originally, the settlers planned to build five churches. They dug ditches around five lots and used the clay to heighten the area within the created enclosure. In the end, only one of the five churches was built, the church in Middenbeemster. The church is located next to a crossroads of two of the main roads through the Beemster, namely the Rijperweg and the Middenweg. The lot of land containing the church and cemetery has the address 'Middenweg 148', which literally means 'Middle road', a name that places extra emphasis on the central location within the community. The crossroads marks the exact geographical centre of the Beemsterpolder (Dr. Menno Hoogland, personal communication), and is still in use today. Because of its very central location, and its slight elevation above the landscape, the church would have been a dominant presence within the landscape. The construction of the church started in 1618 and it was consecrated in the year 1623. Archival information suggests that there might have been a cemetery at Middenbeemster prior to the planning of the new church in 1615, but this remains to be proven by excavation, as it would have been located beneath the present church.

The cemetery was located to the right of the church, within the encircling ditch. The majority of the inhabitants of Beemster were interred in this cemetery, as well as many people who were born in Beemster but went to live elsewhere. The majority of the roughly five hundred excavated burials date to the eighteen- and nineteen hundreds. Although the graveyard was in use since 1613, most of the skeletons in our sample date to the last period of use, namely 1829 to 1866 (Falger et al. 2012, 135). This hypothesis is put forward because the cemetery was cleared and raised in 1829, with most of the older skeletons moved to ossuaries (Dr. Menno Hoogland, personal communication). Some older skeletons, especially those buried in the clay (which was the first elevation layer) remained *in situ*, yet the top layer was removed and new sand was deposited. All the deceased from the last three decade period would be interred in the sandy top layer.

In theory the cemetery should be a neatly organized checkerboard pattern of graves. In the archival data, twelve orderly rows of graves are depicted. In reality, the excavators found several levels of graves which did not always follow the same pattern, with the number of rows varying between eleven and thirteen (van Spelde 2011: 14). Graves were often 'stacked' atop one another, and would also overlap, thus causing the regrettable commingling of individuals. To add to the confusion, subadult graves were often simply dug into, atop, or partially through older adult graves (van Spelde 2011: 15).

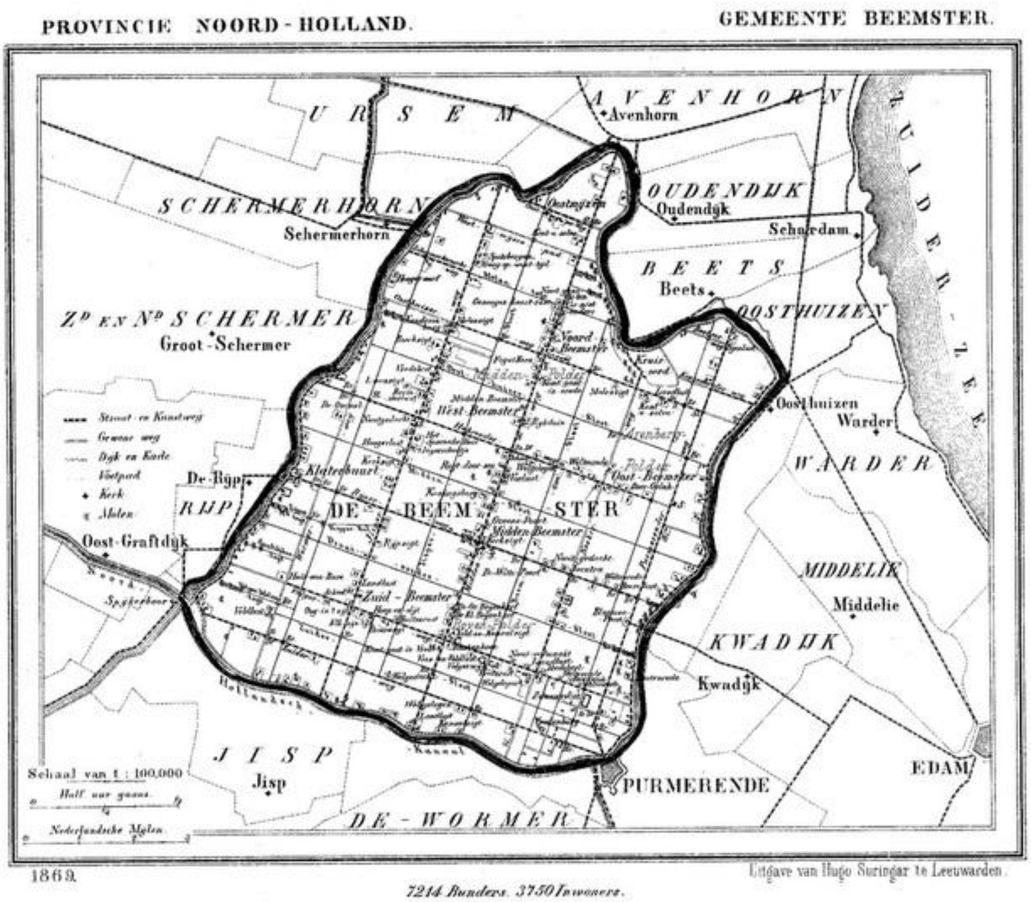

Figure 3: Map of the Beemster polder, clearly showing the geometrical division into blocks (Source: http://www.humanosteoarchaeology.com/middenbeemster-2011.html)

3. Methodology

3.1 Sample

As mentioned in the introductory chapter, the skeletal sample used for this study originates from the post-medieval cemetery of Middenbeemster. From this collection of skeletons, a selection of individuals was made. The selection was mainly based on age and sex. Skeletons which showed signs of severe pathology were excluded, as well as all significantly commingled finds.

a) Age

As age has been shown to be the most important factor in both OA and MSM's, this was the primary selective criterion. The age category of the sample was limited to late young adults (26-35) and middle adults (36-49). All younger individuals (<25) were excluded because the activity markers were not yet sufficiently developed in these age categories, and developmental differences between individuals could provide an extra confounding factor as not all people mature at exactly the same rate and age. Although signs of osteoarthritis and pronounced muscle attachments were noticeable on some younger skeletons, these manifestations were never quite as apparent and unambiguous as in older individuals. Furthermore, the absence of clear activity markers on most younger skeletons analyzed as a preliminary test also caused these age categories to be excluded, as older specimens could give a clearer, more straightforward pattern.
Once this lower boundary was established, all specimens above the middle adult age range (50 + years) were also excluded from the study. There are several good arguments for the exclusion of old adults from studies of OA and MSM activity markers. First, older individuals provide too many confounding factors in the form of (other) pathological changes to the skeleton. For instance, in the Midden-Beemster population, diffuse idiopathic skeletal hypertrophy (DISH) seems to be quite prevalent in older individuals. As DISH is associated with generalized new bone formation and also specifically with osteophyte formation, this disease renders research on MSM's within an afflicted skeleton virtually impossible. On top of the higher prevalence rates of pathology in older individuals, there are also significant physiological differences in the way bone reacts to activity between

young and old individuals. Cortical (outer) bone as well as trabecular (inner, spongy) bone both tend to lose substance with increasing age. The bone will become less dense and less thick (Waldron 2009, 19). Although this does not necessarily mean that muscle attachment sites become less pronounced with increasing age (indeed, the opposite has been observed), it does mean that different physiological reactions are happening, making it necessary to treat older individuals separately. A last important argument for the exclusion of old adults is that MSM and OA scores will always be relatively high in this age category. This is a logical result of the long accumulation period during which bony changes can happen in older specimens. These generalized high scores would skew any statistics which also used younger individuals, and could potentially even obscure differences in activity levels within the age category.

This list of confounding factors when other age categories are incorporated made the decision to use only late young adults (26-35 years of age) and middle adults (36-49 years of age) clear. This age range has also already been used successfully in studies of musculoskeletal stress markers (see for example Wilczak 1998).

Still, it must be noted that this thesis will not analyze the entire population of Middenbeemster, which means excluding a significant amount of data on the population level. It also means that no conclusions can be made regarding the occurrence and pattern of OA and MSM's in young and old individuals. However, the disadvantages of selecting a broader sample stated above clearly show that incorporating younger (< 26) and older (50+) individuals would confound the study insofar as to make it impossible to reach solid conclusions. Therefore the advantages of limiting the age range greatly outweigh the disadvantages.

b) Sex

One of the research questions of this study is whether sexual division of labor is apparent when OA and MSM scores of males and females are compared. To optimally study this aspect, skeletons were chosen to create a sample that contained an acceptable proportion of males and females. As there was a sufficient number of skeletons which were complete enough for sex estimation, and sexual dimorphism was generally well-pronounced, achieving a sexed sample with roughly even sex distribution was straightforward. A sample of twenty-seven females and twenty-one males was selected for analysis (table 1). The slightly higher number of females is due to the larger number of women who die in the late young adult age bracket, most likely as a result of the dangers inherent in childbirth.

Table 1: The division of age and sex in the studied sample.

		Age		Total
		Late young adults	Middle adults	
Sex	Female	15	12	27
	Male	9	12	21
Total		24	24	48

c) Excluded specimens

Within the subsample of late young adult and middle adult males and females, there were still some specimens which proved unsuited for this line of research.
All specimens with pathological lesions which could obscure musculoskeletal markers and signs of osteoarthritis were discarded from the sample. Examples are individuals who suffered from severe residual rickets and osteomalacia (figure 4), fractures, and the abovementioned DISH.

Figure 4: Medial bowing of both humeri due to osteomalacia in a late young adult female. This pathology caused the individual to be excluded from the sample.

All individuals in which MSM's and OA could be a secondary symptom of another (primary) pathology were also excluded. This includes examples in which the OA or MSM's were 'simple' secondary pathologies, as well as examples in which MSM's and OA developed as a compensatory response of the body to a primary pathology or trauma. An example of the first category is secondary OA in a joint that has been dislocated. An example of compensatory strong muscle developments and arthritis would be when one arm develops OA and strong

MSM’s because the other arm was no longer useful due to a badly-healed fracture. The person would naturally stress the remaining functional arm more severely, placing all the strain that was usually divided over two limbs on this one arm, thus such cases are not useful indicators of ‘regular’ activity levels in a population. Furthermore, in this case all conclusions about normal handedness are of course impossible. This does not mean that these individuals would not pose interesting research topics, but only that they fall outside the scope of the current study. It is necessary to know what the ‘norm’ is for our Middenbeemster collection before analyzing the abnormal cases.

Apart from exclusions on pathological grounds, several other factors caused specimens not to be included in the sample. For instance, although many find numbers represented only one individual with little commingled remains, some of the boxes of skeletons brought in from the excavation held several individuals. Whenever the degree of commingling was too severe to reestablish distinct undisputable individuals the specimen was not used. Another factor was completeness; to be useful, both upper limbs needed to be present in the specimen. At a very minimum, the scapula, clavicle, humerus, radius and ulna needed to be present and in acceptable condition from both the left and right side of the body, as well as the os coxae for sexing. In practice, generally complete skeletons were opted for, although admissions were made when only one or two of the elements were scored as absent. More complete skeletons also gave more insight into pathology and a more solid sex and age estimation.

A last factor for elimination from the sample was the preservation state of the bone, and specifically of the outer, cortical bone (figure 5). Although the skeletal material from the Middenbeemster cemetery is in generally good condition, even verging on excellent, some individuals were afflicted by a taphonomic process of weathering which caused the cortical bone to flake off. These individuals were thus excluded from the study as the changes on the cortical bone surface are crucial for the study of both OA and MSM’s.

Figure 5: Example of a humerus whose preservation state was too poor to be included in the sample. The cortical bone has flaked off and both epiphyses are missing.

3.2 Methods

All specimens used in this study underwent a general osteobiographical analysis prior to being studied for signs of osteoarthritis and musculoskeletal markers.

a) General osteobiographical analysis

Every skeleton got a complete basic osteological examination, registered on skeletal data recording forms provided by Dr. Andrea Waters-Rist of Leiden University. Completeness, basic dental data, basic non-metrics, metrics, age, stature and sex were all recorded, as well as pathology and a listing of commingled remains. Eight individuals were entirely analyzed by the author herself, the others by fellow Master's students from the human osteology MSc program at Leiden University.

To estimate sex, a combination of methods was used. Traits were scored using the Workshop of European Anthropologists (WEA) method for the cranium, mandible and pelvis. The pelvic traits described by Phenice were also taken into account (Phenice 1969), as well as various extra indicators and a list of measurements on relevant bones.

To achieve an age estimation, a host of different methods were combined. The aging method based on dental attrition published by George Maat was used (Maat 2001), as well as the pubic symphysis aging method by Suchey and Brooks (1990), the auricular surface aging method by Buckberry and Chamberlain (2002), the sternal rib end method by Işcan et al. (1984) and finally the cranial suture closure method by Meindl and Lovejoy (1985). For the pubic symphysis and sternal rib end estimation, sex-specific casts were used to determine the correct phase.

Using this wide variety of techniques to estimate age and sex ensured that a reliable estimation could be achieved in all analyzed specimens, even though these archaeological skeletons were naturally rarely entirely complete.

The techniques used gave a sex estimation of male, probable male, indeterminate, probable female or female. However, as the sexual dimorphism in our sample was very clear, no examples of 'indeterminate' were encountered. For statistical purposes, probable males were seen as males in this study, and probable females as females. Combining the data in this fashion was necessary to increase the sample size to an acceptable number. The validity of these groupings will have to be tested in the future.

b) Activity marker registration

The activity marker registration was based upon a macroscopic analysis of the skeletal elements under study.

For this thesis, the OA and MSM activity markers on the upper limbs were selected. The scoring of musculoskeletal markers is best undertaken on the limbs, thus excluding the bones from the axial skeleton. Also, osteoarthritis of the spine is extremely prevalent in the Middenbeemster collection, making it unsuitable for social differentiation research. The lower limb was also discarded from the study, because any scores on these bones will be confounded by the weight bearing function of this part of the skeleton. Also, some lower limb MSM's can even be higher in the elite. In intensive horseback riding for instance, the linea aspera on the femur can become very pronounced (Capasso et al. 1999, 104).

The biomechanical complexes of the shoulder and elbow were selected to create a logical, cohesive field of study. Three musculoskeletal markers which reflect muscles active in elbow movement were selected, as well as three musculoskeletal markers for muscles active in the shoulder. All these MSM's are present on the humerus, radius and ulna. Together with these MSM's, any signs of osteoarthritis of the elbow will therefore also be registered, as well as in the shoulder joint. The acromioclavicular joint was also included because it functions in closely related movements.

3.3 OA

The sites which were examined for signs of osteoarthritis were the following. For the shoulder the glenoid cavity, humeral head, acromion and acromial end of clavicle. Then for the elbow the capitulum, trochlea, radial head and proximal ulna.

A simple scoring system was created for these sites, which divided all bone elements into specimens with no sign of osteoarthritis (score of 0), specimens with mild osteoarthritis (a score of 1), moderate osteoarthritis (score of 2), and severe osteoarthritis (score of 3).

The joints surfaces were scored based on the three main signs of osteoarthritis; namely osteophytes and lipping, joint contour deformation, and eburnation. Porosity and pitting on the joint surface was also taken into account. It must be stated that many recent authors see eburnation as the foremost or even only reliable indicator of osteoarthritis. This is in following of Tony Waldron and Juliet Rogers, who found eburnation to be the most reliable trait with the least interobserver error (Waldron & Rogers 1991). Although eburnation is indeed a sure and diagnostic sign of osteoarthritis, this narrow interpretation overshoots its purpose by eliminating other good signs of the pathology. In Waldron's textbook on paleopathology he even notes that other markers of osteoarthritis can be used (Waldron 2009, 27-28).

It must also be observed that osteoarthritis causes different reactions in different joints. On a basic biomechanical level this makes perfect sense, as a hinge joint such as the elbow moves differently from a ball and socket joint such as the shoulder, and a rotation joint such as the radioulnar joint has yet another motion pattern. For instance, in the radioulnar joint eburnation will occur quite quickly, at the end of the mild and in the moderate stage of the disease. In the shoulder however, in both the humeroglenoid and acromioclavicular joints, porosity, pitting, osteophytic lipping, and general joint contour deformation will most often occur first. Eburnation in these joints indicates a severe stage of osteoarthritic pathology. Only joint contour deformation seems a solid general indicator; when substantial deformation is observable, this always indicates an advanced stage of osteoarthritis. Because of these nuances, the scoring system could not be reduced to a simple generalized "checkbox" method. Therefore, the method was split into separate categories: These categories provide an indication of how osteoarthritis affects bone in the different stages. However, it must be seen as an indication rather than an absolute rule, as idiosyncratic variation will occur within each stage of this joint disease.

1. Radioulnar joint
   0 = absence of any signs of OA
   1 = small patches of eburnation that cover less than half of an articular facet. Very slight osteophytic lipping can occur
   2 = over 50 % eburnated coverage of an articular facet, osteophytic lipping present, slight porosity/pitting possible
   3 = most of the articular facet (over 75%) shows eburnation, there is pronounced osteophytic lipping, porosity/pitting is usually present, joint contour is significantly deformed

2. Elbow joint (radiohumeral and ulnahumeral)
   0 = absence of any signs of OA
   1 = mild to moderate lipping and possibly small osteophytes on the joint surface, the surface is slightly porous
   2 = pronounced lipping, osteophyte formation at joint edges as well as on joint surfaces in many cases, porosity (possibly slight) is present
   3 = Very pronounced lipping and osteophytes, eburnation is present

3. Shoulder and acromioclavicular joint
   0 = absence of any signs of OA
   1 = slight osteophytic lipping, possible porosity and pitting on the joint surface
   2 = osteophytic lipping distinct, moderate deformation of the joint surface, porosity/pitting present
   3 = osteophytic lipping, pronounced joint contour deformation, porosity/pitting present, eburnation present

Although standardized scoring systems are available, none seem to have actually gained generalized use in the academic literature, and most are either too detailed or not useful for the limited study undertaken here. A noteworthy example is the scoring system by Buikstra and Ubelaker (Buikstra & Ubelaker 1994). Their method presents nine traits which are subdivided into three to five categories, yet does not distinguish between different joint types. Since this technique seemed both overly time-consuming for the research questions and not entirely reliable given the two different joint types involved, the decision was made not to follow their scoring system. To maintain a certain degree of simplicity in scoring osteoarthritis, the relatively uncomplicated scoring method outlined above was created. This quite straightforward technique will best benefit the research questions posed at the beginning of this study.

3.4 <u>MSM</u>

a) The muscles

For musculoskeletal marker analysis, six sites on the same functional complexes as those chosen for osteoarthritis were selected.

For the shoulder complex, these sites include the M. pectoralis major attachment site, the M. latissimus dorsii/teres major attachment site, and the M. deltoideus attachment site. All these MSM's are located on the humerus. For the elbow complex, the brachioradialis attachment site on the humerus was examined, as well as the triceps brachii attachment site on the ulna and the biceps brachii attachment site on the radius.

Originally the sites were chosen in following Weiss' upper limb study (Weiss 2007). However, some adjustments to the list of MSM's she studied were made. The latissimus dorsii and teres major attachment sites were scored together as they soon proved hard to distinguish from each other on the bone. This combination is also made by Mariotti et al. (2007) (see table 2), thus providing a viable precedent. Also, the brachioradialis attachment site on the humerus was added to the study to obtain equal parts of the shoulder and elbow functional complex. These MSM's should create as broad as possible an upper limb functional overview within the constraints of the study. Lastly, they are also on areas of the skeleton which are generally well-preserved in the Middenbeemster collection.

Table 2: List of shoulder and elbow entheses used by Mariotti et al. Note the division into functional complexes and the combination of the latissimus dorsii and teres major on the humerus. (Mariotti et al. 2007, 292)

Enthesis	Functional Complex
Costoclavicular lig. (clavicle)	Shoulder
Conoid lig. (clavicle)	
Trapezoid lig. (clavicle)	
M. pectoralis major (clavicle)	
M. deltoideus (clavicle)	
M. pectoralis major (humerus)	
M. lat. dorsii/teres major (humerus)	
M. deltoideus (humerus)	
M. triceps brachii (scapula)	Elbow (flexion/ extension)
M. brachioradialis (humerus)	
M. biceps brachii (radius)	
M. triceps brachii (ulna)	
M. brachialis (ulna)	

The muscles used in this study are well described in many books on human anatomy. Here, the Sobotta atlas (Ferner and Staubesand 1975) was consulted to provide a brief description of all studied muscles. For more information on the movements of the upper limb see appendix A.

The first muscle that was analyzed is the pectoralis major. The pectoralis major muscle is a strong predominantly fleshy muscle which originates from the clavicle, sternum, costal cartilage and for a small part from the obliquus externus abdominis muscle (figure 6). It is inserted by means of a flat tendon into the humerus at the tuberculis majoris humeri, and it is this insertion site which will be scored in this study. The pectoralis major is used when lowering the arm or rotating it medially.

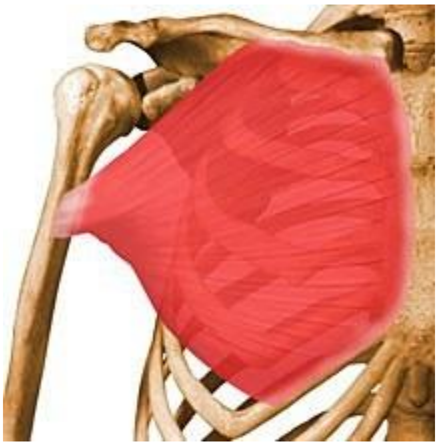

Figure 6: The Pectoralis Major muscle. Note its insertion site on the humerus. [1]

The next muscle under scrutiny is the latissimus dorsii (figure 7). The latissimus dorsii muscle is a large triangular muscle running from the spine across the back towards the humerus. It originates from the six lowest thoracic vertebrae and all lumbar vertebrae spines, the sacrum and the iliac crest. It is also attached to three of four lower ribs and the lowest point of the scapula. It runs along the back to the humerus, where it inserts by means of a tendon to the floor of the intertubercular sulcus of the humerus. Its main functions are pulling the arm backwards and downwards.

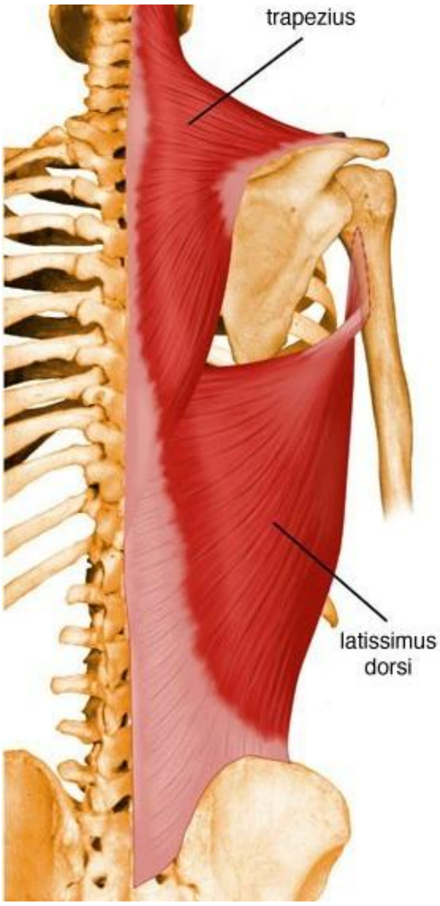

Figure 7: The latissimus dorsii muscle. Note its insertion site on the humerus. [1]

Another muscle to be observed is the teres major. The teres major muscle is a smaller muscle which originates from the lower lateral border of the scapula. It is inserted onto the humerus by a tendon which attaches to a crest on the tuberculus minor (figure 8). Its attachment site is located very close to that of the latissimus dorsii, yet slightly more dorsal. In practice, the teres major and latissimus dorsii attachment sites on the humerus are most often indistinguishable, therefore they will be scored together.

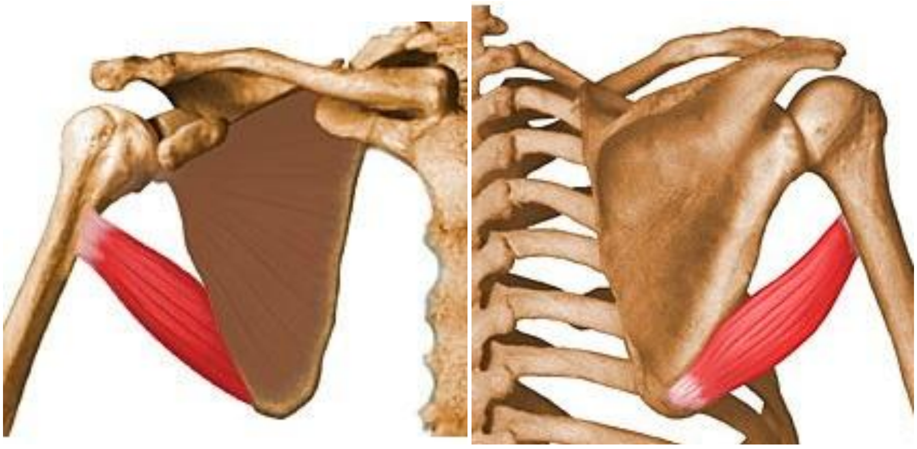

Figure 8: The teres major muscle. Left: anterior view, right: posterior view. Note its insertion site on the humerus. [1]

The fourth muscle used in this study is the deltoideus or deltoid. The deltoid muscle is the hood-shaped muscle which covers the shoulder. It originates from the acromial third of the clavicle, the acromion, and the scapular spine (figure 9). The deltoid runs over the shoulder onto the humerus, where it attaches to the deltoid tuberosity. The deltoid a crucial muscle which is involved in a large number of movements. It can lift (up to a horizontal orientation), extend, flex, and laterally and medially rotate the humerus.

Figure 9: The deltoid muscle. Note its insertion site on the humerus. [1]

The last muscle to be scored on the humerus is the brachioradialis (figure 10). The brachioradialis muscle is a long thin muscle which originates on the lateral supracondylar ridge of the humerus. Its insertion site is located on the proximal end of the styloid process of the radius. This muscle will be scored on its site of origin on the humerus. It plays a role in the flexing, pronating and supinating of the lower arm.

Figure 10: The brachioradialis muscle. Note its origin site on the humerus. [1]

One muscle will be scored on the radius, namely the biceps brachii. The biceps brachii is made up of two elements (figure 11). First, there is the caput longum which originates from a long tendon which runs from the supraglenoid tubercle on the scapula over the humerus. The second element is the caput breves, which originates from the coracoid process. Both elements insert into the radial tuberosity, which is the site that will be scored for this study. This muscle is used when flexing and supinating the forearm, as well as for structural support in holding the head of the humerus in place and in aiding the flexing of the shoulder joint.

Figure 11: The biceps brachii muscle. Note its insertion site on the radial tuberosity. [1]

The last muscle used in this study is the triceps brachii, which will be scored on the ulna (figure 12). The triceps brachii is a more complex muscle made up of three parts; the caput longum, caput laterale, and caput mediale. It originates from the infraglenoid tubercle on the scapula, and the lateral and dorsal side of the humerus (figure 11). The muscle insertion site is located on the olecranon of the ulna, although the caput mediale also continues a little further onto the forearm. It will be scored on the olecranon. The triceps brachii is active in the extension of the lower arm, the adduction and extension of the arm and the bracing of the elbow joint, for instance when pushing an object.

Figure 12: The triceps brachii muscle. Note its insertion site on the olecranon of the ulna. [1]

The muscle attachment sites which will be scored in this study are all indicated in the figures 13 and 14 below:

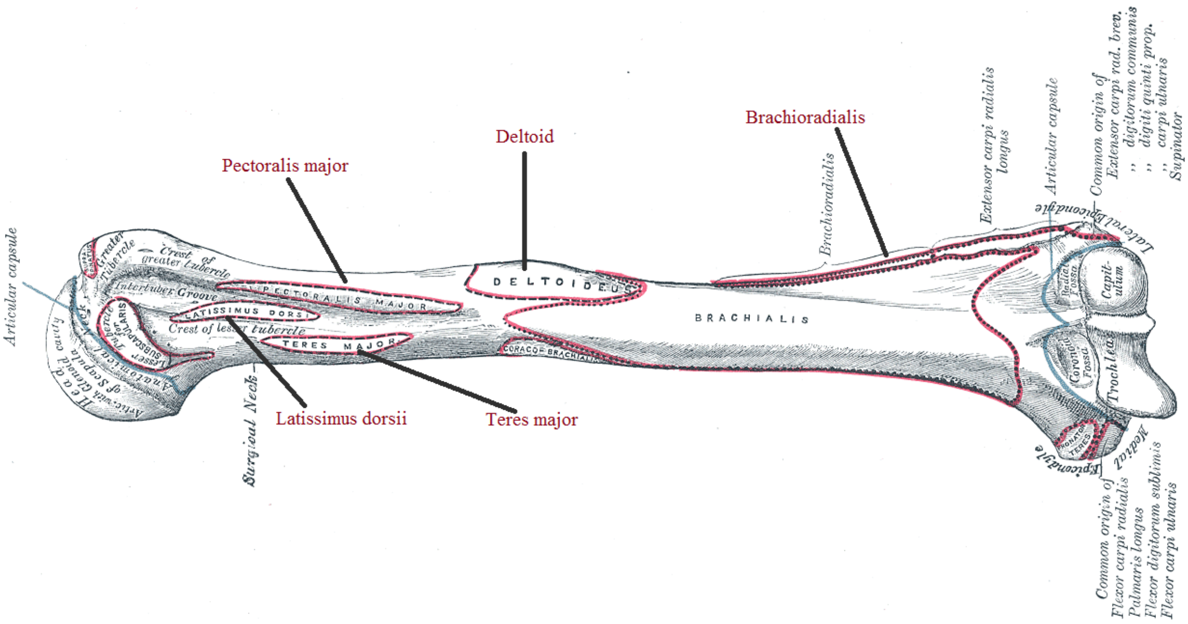

Figure 13: Regions of muscle attachment on the humerus (after Gray 1977, 145)

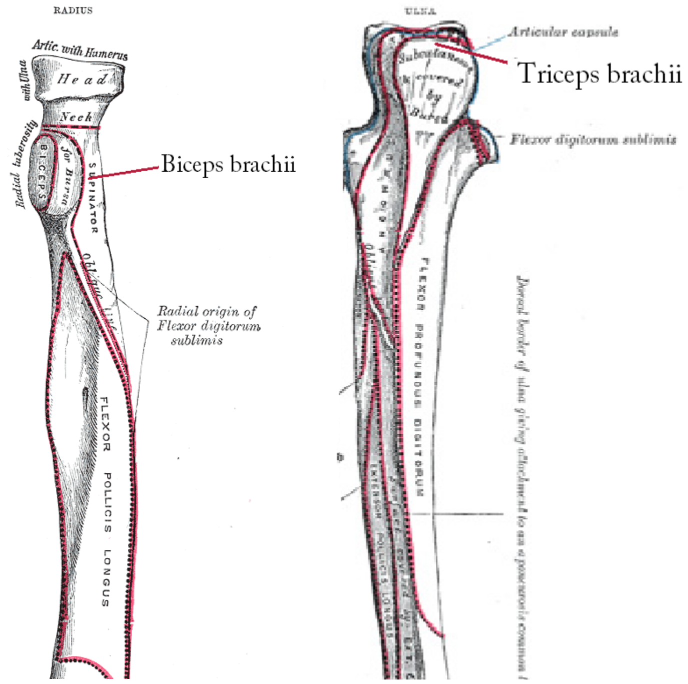

Figure 14: regions of muscle attachment on the radius (left) and ulna (right) (after Gray 1977, 151-153)

b) Scoring method

When it comes to scoring musculoskeletal markers of activity, several standards are available. The most commonly used method was created by Hawkey and Merbs (1995). Their scoring system has proven its use through wide application. However, they do not provide enough sufficiently clear photographs, nor do they account for the complicated etiology of true enthesopathies (hook-like new bone growth at muscle attachment sites which have a different formation history) within their methods.

Another method was created by Robb (1998). His method is, however, seldom used making it impractical for future comparison of this study to other research. He provides five stages of MSM's which require seriation based on how pronounced the MSM's are, something that is simply not feasible within our lab infrastructure. Yet another scoring technique is that of Wilczak (1998). Her method involves digitized chalk outlines of musculoskeletal markers and was deemed too impractical for application. Quite recently, a method was developed by Villotte (2006) who took the difference between fibro-cartilaginous and fibrous entheses into account, something none of the other methods had done. However, although the author has successfully applied his method (Havelková et al. 2011), it has not seen any wide use and focuses largely on the difference between pathological activity-related enthesopathies and 'normal' muscle attachment sites.

The method also does not incorporate other MSM signs. A recent study has shown that not accounting for the difference between fibrous and fibro-cartilaginous entheses does not greatly bias the results (Niinimäki et al. *in press*, 3). Therefore, the Villotte method was not applied, as the advantages of this method did not outweigh the disadvantages.

A last relevant scoring system is that of Mariotti et al. (2004, 2007). They created a scoring method mainly based on that defined by Hawkey and Merbs (1995), but with better photographs and a separate scoring category for enthesopathies. In their 2007 article, they updated their method, creating a standardized form in which osteophyte formation, osteolytic lesions and general robusticity could be scored. It is this form which was adapted to include only the muscle attachment sites discussed here and used for analysis. They created an individual robusticity scoring guide for each attachment site visible in Table 1, with descriptions and illustrations for each robusticity score. All six MSM's treated in this study were described in their scoring method. The system proved very user-friendly and efficient. For each muscle attachment site the robusticity score must be established. Their system allows for fine grading with low robusticity (i.e. slight development) subdivided into categories 1a – 1b – 1c, high development as score 2 and very high development as score 3. However, they warn against subdividing category 1 when not absolutely necessary as this increases the inter-and intraobserver error without adding much to the general picture. Thus, a robusticity score of 1, 2 or 3 was allotted to each MSM in this study. Next, the level of osteophytic formation must be scored. This was done in comparison to the pictures provided by Mariotti et al. (2004). A score of zero to three was given, wherein zero equals no osteophytes and three equals very pronounced osteophytic formation. Lastly, the level of osteolytic lesion formation must be observed in their scoring system. This ranges from zero which means no osteolytic lesions, to three which means very severe osteolytic lesions. These scores were also based on the pictures available (Mariotti et al. 2004).

A blank example of the created data recording form is provided in appendix B.

4. Confounding factors

As mentioned in the methods chapter, some confounding factors could be avoided in the sample. For instance, genetic variability is not an issue as our population was small and local. Also, as the time-span during which the cemetery was used was quite short, and nearly all skeletons in our sample can be assumed to have been buried between 1829 and 1866, there is a good delimitation of the period during which these people lived. The shifts in activity patterns, professions and way of life over time on the population level is thus largely excluded as a confounding factor.

Another factor was the general morphology of specimens from Middenbeemster. Very early in this study, it became clear that the population had a high general level of robusticity. Initially, it was thought that this would become a confounding factor, as generally robust individuals would score high on the MSM robusticity tests. After analyzing a few specimens however, it became clear that a general robust build does not necessarily mean that muscle attachment sites are also well developed, so this population-wide sturdiness did not create a confounding factor.

Another element which was considered a potential problem at the start of this study was the possible influence of sexual dimorphism on the musculoskeletal stress marker score. As males have a generally larger body size compared to females, the corresponding size of the muscle attachment sites could hypothetically cause them to receive higher MSM scores. This is of course because larger muscle attachment sites are related to larger bodies whereas the actual morphology of the MSM is related to strain. This concern was however proven unfounded, as the scoring method by Mariotti et al. (2004, 2007) does not incorporate the absolute size of muscle attachments but rather the surface changes and the relative size, ergo the size of the MSM relative to the bone upon which it is present. Therefore, using the same scoring system for males and females did not confound the results.

An issue which did become an important confounding factor was the state of preservation of the bones. As the Middenbeemster population is an archaeological collection, even well-preserved specimens are not in perfect condition. In general the collection holds many complete and well-preserved specimens. However, the scoring of OA in the acromioclavicular joint requires the presence of the acromion on the scapula. This skeletal element breaks off easily during post-depositional processes, and is therefore often not recovered during excavation. Also, the acromion is sometimes made up of two pieces as a form of variation in the skeleton called a non-metric trait. The top piece of the acromion or 'os acromiale' is then a separate small bone which is easily overlooked during excavation. Other than that, the articular facets which were scored for osteoarthritis were usually present and well-preserved. Only the radial head seemed quite prone to degradation.

For musculoskeletal markers, preservation was more of an issue. To score these elements correctly the cortical bone needs to be perfectly preserved, as properties such as osteolytic lesions, surface rugosity and even small osteophytes will become invisible as soon as the cortical bone is even slightly degraded. Preservation of the olecranon process of the ulna was often less than ideal, and many humeri showed flaking and weathered cortical bone which rendered them relatively useless. Despite these difficulties, it was possible to obtain an acceptable sample size.

A more methodological problem was presented by the musculoskeletal scoring method. Although it was generally quite easy to use, some elements balanced on the verge between two scores (for instance 1 or 2, or 2 or 3). To solve this issue, pictures were taken of all stages of the first group of skeletons which were studied, and all following specimens were compared to these pictures. Thereby the scoring system was at the very least consistent within the study, and the ambiguity for 'borderline' elements was minimized.

5. Results

In this chapter, the data on osteoarthritis and musculoskeletal markers of stress will be analyzed. Osteoarthritis and MSM's will be analyzed separately first, before combining these data. This way, any pertinent results from the separate datasets will become apparent, which can be significant in themselves and can help understand the aggregated data. After these initial analyses, it will be interesting to see what the combined data tell us and whether they concur, given that they both should pertain to the activity pattern of one single organism, namely the human body.

5.1 Osteoarthritis

An overview of the results of the analysis of joint facets for osteoarthritis is presented in table 3.

Osteoarthritis was most prevalent in the acromioclavicular joint. Eleven individuals were affected by OA in the left clavicle (37.93%), eighteen in the right clavicle (54.55%). The corresponding facets of the acromion on the scapula also showed quite a high (if slightly lower) frequency of osteoarthritis; eight specimens had OA on the left (26.67%), and nine showed signs on the right (28.13%).

Another joint surface which was prone to osteoarthritis was the glenoid cavity of the scapula. Remarkably, this articular facet showed signs of osteoarthritis when the humeral head was still unmarred. Osteoarthritis was almost always in its earliest stages (score 1) in the glenoid, with the main symptom being lipping. Twenty-nine point fifty-five percent of individuals were affected in the left glenoid. Of those affected with OA in the left glenoid, 92.3% had a score of 1 (mild). Twenty-six percent had osteoarthritis in the right glenoid, of which 91.6% with score 1. The pure technical aspect of the humeroglenoid joint might explain why the glenoid is affected before the humeral head, since the latter is a relatively smooth ball and therefore via the laws of physics structurally more resilient than a flatter surface such as the glenoid.

Table 3: Osteoarthritis data. Each column represents the amount of times a specific score was given to a specific facet. The last two columns show the amount of times a specific facet was affected by OA in absolute number well as in percentage, regardless of the severity of the score. Scores 4 and 5 are not taken into consideration as they mark (respectively) when a trait is not recordable or a skeletal element is absent.

	Absent (0)	Mild (1)	Moderate (2)	Severe (3)	Not recordable(4)	Element absent (5)	Sum OA	% OA
Left Clavicle	18	9	2	0	10	9	11	37,93
Right Clavicle	15	14	4	0	9	6	18	54,55
Left Acromion	22	6	1	1	6	12	8	26,67
Right Acromion	23	6	2	1	4	12	9	28,13
Left Glenoid	31	12	1	0	2	2	13	29,55
Right Glenoid	34	11	1	0	0	2	12	26,09
Left Humeral Head	39	3	0	0	3	3	3	7,14
Right Humeral Head	37	4	1	0	2	4	5	11,9
Left Capitulum	45	0	1	0	1	1	1	2,17
Right Capitulum	42	0	1	0	2	3	1	2,33
Left Trochlea	44	3	0	0	1	0	3	6,38
Right Trochlea	40	2	0	0	2	4	2	4,76
Left Radial Head	38	3	1	0	5	1	4	9,52
Right Radial Head	36	2	1	0	3	6	3	7,69
Left Ulnar Head	41	3	0	0	4	0	3	6,82
Right Ulnar Head	37	4	0	0	4	3	4	9,76

a) Assymetry and handedness

To determine whether there was statistically significant asymmetry between left and right sides, a Spearman rho test was done. This test evaluates the level of correlation between two variables. The test was run for each individual couple of left and right joint facets. The closer the correlation coefficient (r) is to zero, the lower the true correlation, whereas a correlation coefficient that approaches +1/-1 indicates a significant positive/negative correlation. The associated p-value must be lower than 0.05 for the results to be considered statistically significant. The statistical program used to calculate the tests is SPSS 17.0.

The correlation coefficient (r) between left and right clavicles was 0.800, with a two tailed value of $p < 0.000$. This means that the positive correlation between these two variables is relatively high (closer to +1 than 0). The same holds for the acromion; although the correlation coefficient was lower here ($r = 0.604$), the result was still significant ($p = 0.002$). The correlation between the left and right glenoids and humeral heads was also high (glenoid $r = 0.787$ and $p < 0.000$, humeral head $r = 0.766$, $p < 0.000$). These results indicate that there is a high correlation between left and right sides in this sample. Therefore, the difference between left and right cannot be very large.

The elbow presents a very similar story. The correlation between left and right capitulum is 100%, although given that only one individual had osteoarthritis on the capitulum, and he showed moderate osteoarthritis on both these humeral surfaces, this result was not unexpected. The trochlea have a correlation coefficient of 0.806 ($p < 0.000$). The radial heads show the same high similarity with a correlation factor of 0.706 ($p < 0.000$). Lastly, the ulnae also support this high correlation between left and right, with a correlation factor of 0.805 ($p < 0.000$).

So, when testing the correlation between the individual left and right joints, a significant correlation is revealed. However, as all of the r-values are less than one, there is room for difference between both sides. Could it then be possible to observe asymmetry when comparing all OA information from the left upper limb to all OA information of the right upper limb? To answer this question, a separate OA score was calculated for the left and right upper limb of each individual. This OA score was simply the highest level of OA the individual showed in any joint. A more accurate way of measuring how affected a limb is by osteoarthritis would be to add up all individual joint facet OA scores of that limb. However, as many specimens could not be scored in every single joint facet included in this study (due to missing skeletal elements or postmortem degradation of the bone) it was impossible to use the total sum as a reliable measure of OA affectedness. Therefore, the highest score an arm received was used as an indicator. Having established these OA scores, the frequency of each osteoarthritis 'score' per limb was calculated (tables 4 and 5).

Table 4: The frequency with which each OA score occurred for the left and right upper limbs in the sample. One individual was too incomplete to incorporate in the analysis.

OA Score	Left frequency	Left percent	Right frequency	Right percent
0	27	57.4	20	42.6
1	16	34.0	21	44.7
2	3	6.4	5	10.6
3	1	2.1	1	2.1
Total	47	100	47	100

These frequency tables show slightly higher OA scores for the right upper limb. To establish how high the correlation between left and right upper limb score actually was, a Spearman's rho test was done. This test showed a strong, significant correlation between osteoarthritis scores in the left and right arm. The correlation coefficient was 0.691 ($p = <0.000$). This means that there is a statistically significant correlation between the left and right arm when all OA data per upper limb are combined.

Knowing that there are significant correlations between the left and right limb, is it then possible to find any significant differences as well? To test this, a Friedman's test was run. This nonparametric test assesses the level of difference between two variables. For this test, the prevalence data from table 3 were used. The test will thereby give a result for the dominance of left or right side for the entire sample rather than per individual. This way, incomplete individuals will not confound the results. There are no significant differences between the left and right sides of any of the joints: for the clavicles $\chi^2 = 0.333$, $p = 0.564$, for the acromion $\chi^2 = 2.000$, $p = 0.157$, for the glenoid $\chi^2 = 0.000$, $p = 0.1000$, the humeral heads $\chi^2 = 0.333$, $p = 0.564$), the capitula $\chi^2 = 1.000$, $p = 0.317$, trochlea $\chi^2 = 2.000$, $p = 0.157$, the radial heads $\chi^2 = 2.000$, $p = 0.157$, and lastly for the ulnar heads $\chi^2 = 0.000$, $p = 1.000$.

As a last test for handedness, the individual OA scores per upper limb were compared using a Friedman's test. The results ($\chi^2 = 3.769$ $p = 0.052$) give a p-value which is only 0.002 point too high to be considered statistically significant. Thus, this result is on the verge of significance, and must be noted. As the right limb scores slightly higher, this limb is probably slightly more developed than the left, indicating right hand dominance.

a) Sex

Another question was asked of the osteoarthritis data, and that is whether osteoarthritis prevalence differed significantly between males and females.

Table 5: The OA scores by sex

		OA score individual								
		0		1		2		3		Total
		n	%	n	%	n	%	n	%	
Sex	female	12/27	44.4	11/27	40.7	2/27	7.4	2/27	7.4	27
	Male	10/21	47.6	9/21	42.9	2/21	9.5	0/21	0	21
Total		22/48	45.8	20/48	41.7	4/48	8.3	2/48	4.2	48

When observed in a simple table (table 5), osteoarthritis seems to be equally distributed between males and females. A Spearman's rho test also found no statistically significant correlation between sex and osteoarthritis prevalence (r = -0.060, p = 0.686). For females, 55.6% of individuals are affected, for males 52.4 %.

Further Spearman's rho tests found no significant correlation between sex and osteoarthritis prevalence or level of severity in any of the joint facets.

b) Age

A last analysis was undertaken to examine whether osteoarthritis was correlated with age in our sample. The first step in this analysis was to take the highest OA score an individual achieved on any left our right joint surface used in this study and list that as their OA score, as was done for each separate limb in the handedness analysis (see above). A simple crosstabulation was executed to count the number of individuals with OA per age category (table 7). It must of course be noted that not all individuals could be scored at all sites, therefore this OA score is not absolute. It is however the best achievable indication of the individual OA score for an archaeological sample.

Table 6: The OA scores by age. Late young adult = 26-35, middle adult = 36-49.

		OA score individual								
		0		1		2		3		Total
		n	%	n	%	n	%	n	%	
Age	Late young adult	11/24	45.8	13/24	54.2	0/24	0	0/24	0	24
	Middle adult	11/24	45.8	7/24	29.2	4/24	16.7	2/24	8.3	24
Total		22/48	45.8	20/48	41.7	4/48	8.3	2/48	4.2	48

This table (table 6) shows that the same number of individuals is affected with OA in each age category (namely 13 LYA's and 13 MA's), with eleven late young adults and eleven middle adults showing no signs of osteoarthritis. What is interesting though, is that while OA prevalence is the same for both age categories, the severity of osteoarthritis is higher in middle adults, with four individuals showing moderate OA and two showing severe OA. To test the correlation between osteoarthritis and age, a Spearman's rho test was executed. This test shows that the correlation is not statistically significant ($r = 0.129$, $p = 0.383$).

5.2Musculoskeletal markers

Before the statistical analysis of the MSM data, a few general observations could be made. A surprising observation was the relatively low mean robusticity of the deltoid on the humerus (figure 15 and 16). Only one individual received a score of three (the maximum score), and the majority of specimens received a score of 1 (table 7). This was unexpected, as the deltoid is involved in a lot of upper body movements (see methods chapter). Another interesting observation is the generally low mean robusticity score of the latissimus dorsii/teres major. As the latissimus dorsii is a large important back muscle which is attached to a small surface on the humerus, the robusticity was expected to be higher. Another observation is the high robusticity scores of the brachioradialis muscle. Although the mean score for this small muscle insertion site on the distal humerus is not extremely high, it did receive a total of fifteen maximum robusticity scores. A last observation is the high development of the biceps brachii and pectoralis major (figure 16). The biceps is in fact only highly pronounced in males (figure 17), thereby skewing the ranking. The pectoralis major is well developed in both sexes, although this is not unexpected as it is a large important chest muscle.

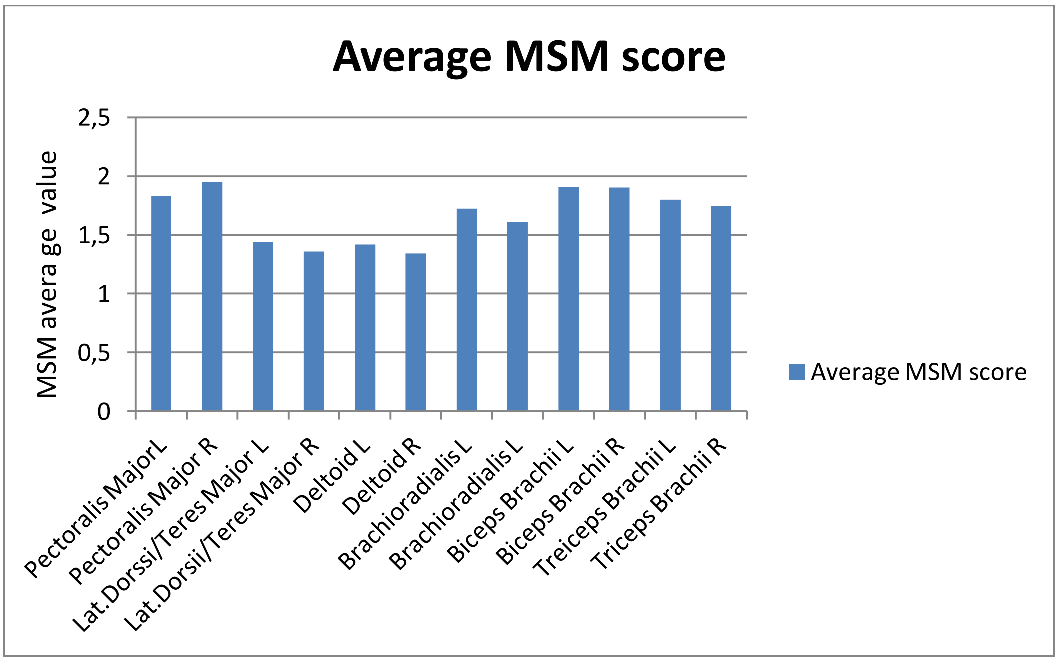

Figure 15: A bar chart representing all mean MSM scores per muscle attachment site. Note the low scores for the deltoids and the Latissimus dorsii/teres major.

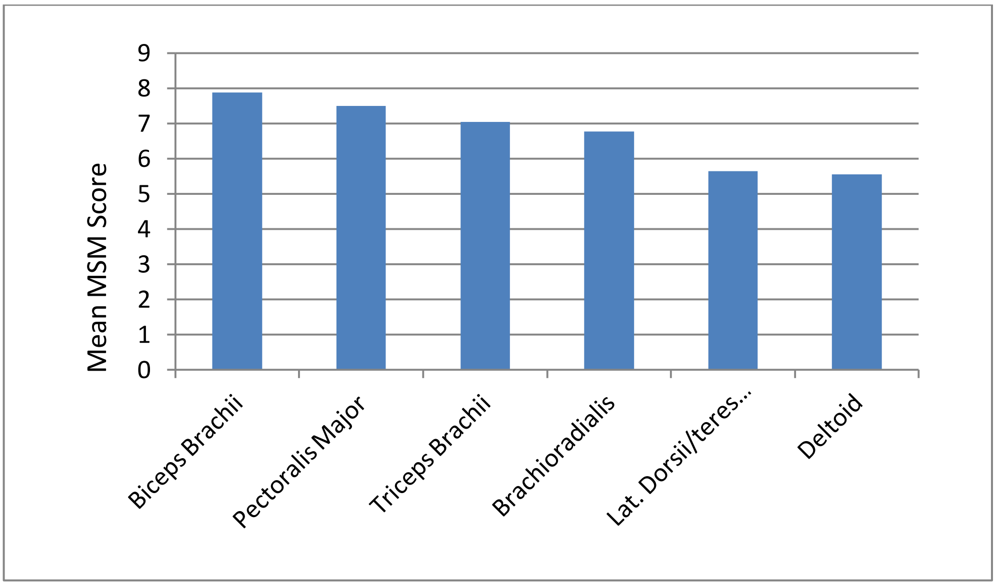

Figure 16: bar chart showing the ranked mean MSM scores per muscle. Left and right are combined.

Another observation was that osteophytic formations and osteolytic lesions were the exception rather than the rule (tables 8 and 9). On the pectoralis major, only four examples of osteophytic formation were recorded (4.9%), and two of osteolytic lesions (2.5%). The latissimus dorsii/teres major had no examples of osteophytic formation but did show eight instances of osteolytic lesions (10.4%). The deltoids showed no incidence of either osteophytes or osteolytic lesions. The brachioradialis showed only one instance of osteophyte formation (1.2%), and even then only a score one, on a left humerus. It showed no instances of osteolytic lesions. The biceps brachii on the radial tuberosity showed some more varied responses of bone to mechanical strain. Here, thirteen instances of osteophyte formation were recorded (14.9%), with one radius receiving a score two and one even obtaining a maximum score of three. It also showed five instances of osteolytic lesions (5.8%). Lastly, the triceps brachii attachment site on the ulnar olecranon showed osteophytic formations eleven times (14.3%) and had an osteolytic lesion only once (1.3%). Finding the highest incidence of osteophyte formation on the ulnar head is not surprising, as the morphology of this bone and the strain placed upon it make the olecranon prone to bony spurring. For figures displaying the proportion of each robusticity, osteophytic formation and osteolytic lesion score per muscle attachment site, see appendix D.

Table 7: Frequencies of Musuloskeletal stress marker robusticity scores per muscle attachment site. L indicates left, R indicates right. The total is always 48.

	Score 1		Score 2		Score 3		Score 4 (Not recordable)		Score 5 (element absent)	
	n	%	n	%	n	%	n	%	n	%
Pectoralis Major L	14	29.2	25	52.1	3	6.3	5	10.4	1	2.1
Pectoralis Major R	11	22.9	24	50	5	10.4	5	10.4	3	6.3
Lat.Dorsii/Teres Major L	27	56.3	13	27.1	0	0	7	15.6	1	2.1
Lat. Dorsii/Teres Major R	28	58.3	11	22.9	0	0	6	12.5	3	6.3
Deltoid L	26	54.2	16	33.3	1	2.1	4	8.3	1	2.1
Deltoid R	27	56.3	14	29.2	0	0	4	8.3	3	6.3
Brachioradialis L	22	45.8	12	25	9	18.8	4	8.3	1	2.1
Brachioradialis R	22	45.8	13	27.1	6	12.5	4	8.3	3	6.3
Biceps Brachii L	20	41.7	22	45.8	3	6.3	2	4.2	1	2.1
Biceps Brachii R	17	25.4	23	47.9	2	4.2	2	4.2	4	8.3
Triceps Brachii L	21	43.8	17	25.4	2	4.2	8	16.7	0	0
Triceps Brachii R	19	39.6	15	31.3	3	6.3	8	16.7	3	6.3

Table 8: Frequencies of Musuloskeletal stress marker osteophyte formation scores per muscle attachment site. L indicates left, R indicates right. The total is always 48.

	Score 0		Score 1		Score 2		Score 3		Score 4 (Not recordable)		Score 5 (element absent)	
	n	%	n	%	n	%	n	%	n	%	n	%
Pectoralis Major L	40	83.3	2	4.2	0	0	0	0	5	10.4	1	2.1
Pectoralis Major R	38	79.2	2	4.2	0	0	0	0	5	10.4	3	6.3
Lat.Dorsii/Teres Major L	40	83.3	0	0	0	0	0	0	7	14.6	1	2.1
Lat. Dorsii/Teres Major R	39	81.3	0	0	0	0	0	0	6	12.5	3	6.3
Deltoid L	42	87.5	0	0	0	0	0	0	5	10.4	1	2.1
Deltoid R	41	85.4	0	0	0	0	0	0	4	8.3	3	6.3
Brachioradialis L	42	87.5	1	2.1	0	0	0	0	4	8.3	1	2.1
Brachioradialis R	41	85.4	0	0	0	0	0	0	4	8.3	3	6.3
Biceps Brachii L	38	79.2	5	10.4	1	2.1	1	2.1	2	4.2	1	2.1
Biceps Brachii R	36	75	6	12.5	0	0	0	0	2	4.2	4	8.3
Triceps Brachii L	33	68.8	5	10.4	1	2.1	1	2.1	8	16.7	0	0
Triceps Brachii R	31	64.6	4	8.3	0	0	2	4.2	8	16.7	3	6.3

Table 9: Frequencies of Musuloskeletal stress marker osteolytic lesion scores per muscle attachment site. L indicates left, R indicates right. The total is always 48.

	Score 0		Score 1		Score 2		Score 3		Score 4 (Not recordable)		Score 5 (element absent)	
	n	%	n	%	n	%	n	%	n	%	n	%
Pectoralis Major L	41	85.4	0	0	1	2.1	0	0	5	10.4	1	2.1
Pectoralis Major R	37	77.1	0	0	1	2.1	0	0	7	14.6	3	6.3
Lat.Dorsii/Teres Major L	35	72.9	5	10.4	0	0	0	0	7	14.6	1	2.1
Lat. Dorsii/Teres Major R	34	70.8	3	6.3	0	0	0	0	8	16.7	3	6.3
Deltoid L	42	87.5	0	0	0	0	0	0	5	10.4	1	2.1
Deltoid R	40	83.3	0	0	0	0	0	0	5	10.4	3	6.3
Brachioradialis L	43	89.6	0	0	0	0	0	0	4	8.3	1	2.1
Brachioradialis R	41	85.4	0	0	0	0	0	0	4	8.3	3	6.3
Biceps Brachii L	43	89.6	1	2.1	1	2.1	0	0	2	4.2	1	2.1
Biceps Brachii R	39	81.3	2	4.2	0	0	1	2.1	2	4.2	4	8.3
Triceps Brachii L	39	81.3	1	2.1	0	0	0	0	8	16.7	0	0
Triceps Brachii R	37	77.1	0	0	0	0	0	0	8	16.7	3	6.3

a) Assymetry and handedness

The first question to address is whether the musculoskeletal marker data can be used to assess handedness. To answer this question, a Spearman's rho test was executed between left and right MSM sites. To facilitate analyses, robusticity scores, scores for osteolytic lesions, and scores for osteophytic lesions were added together per musculoskeletal marker, creating a single score per muscle attachment per side for each individual. The test showed a significant correlation between left and right pectoralis major scores (correlation coefficient 0.642, p <0.000). The latissimus dorsii/teres major muscle however showed no significant correlation (r = 0.247, p = 0.135), indicating that there might be a difference between them. The deltoids on the other hand showed near perfect symmetry, with a correlation coefficient of 0.947 (p <0.000). The brachioradialis muscles were also highly correlated (correlation coefficient 0.842, p <0.000). The same was true of the biceps brachii, with a correlation coefficient of 0.708 (p <0.000) and of the triceps brachii, with a correlation coefficient of 0.718 (p <0.000). Thus, except for the latissimus dorsii/teres major muscle attachment site, all musculoskeletal markers point towards a high degree of symmetry between both upper limbs.

A simple descriptive test was run to check which side of the body would generally develop a more pronounced latissimus dorsii/teres major muscle.

Table 10: Mean MSM score for left and right latissimus dorsii/teres major muscle attachment sites.

	N	Mean	Standard Deviation
Lat.Dorsii/Teres Major Left	39	1.45	0.597
Lat.Dorsii/Teres Major Right	38	1.36	0.486

As table 10 shows, the left latissimus dorsii/teres major muscle attachment site was generally slightly more pronounced.

So, when measuring asymmetry between left and right upper limbs per specific muscle attachment site, only the latissimus dorsii shows significant asymmetry. As a next test of handedness, Friedman's tests were executed between left and right musculoskeletal stress marker scores per muscle attachment site. These Friedman's tests found no statistically significant differences between any of the muscle attachments sites. For the pectoralis major, the results were χ^2 = 2.571 p = 0.109, for the latissimus dorsii/teres major χ^2 = 0.250 p = 0.617. This lack of significant difference between latissimus dorsii/teres major muscle attachment sites was unexpected based on the above noted results and needs further analysis (see discussion chapter). The other MSM's were also not significantly different.

The deltoids had a χ^2 value of 1.000 ($p = 0.317$), and the brachioradialis muscles had a value of $\chi^2 = 1.000$ ($p = 0.317$). The biceps brachii result was $\chi^2 = 0.286$, $p = 0.593$ and the triceps brachii result was $\chi^2 = 0.500$, $p = 0.480$. The Friedman's tests thereby effectively showed no evidence of handedness.

Can we then find differences between the left and right arm when comparing all MSM's from the left upper limb to all those from the right? As a first step towards answering this question, a general MSM score was given to each limb per skeleton. To achieve this score, the maximum robusticity a person had achieved was added up with the maximum osteophyte formation score and his or her maximum osteolytic lesion score. As with osteoarthritis, maximum scores per individual were summed up to give a general idea of a person's MSM scores. As noted above, this is not an ideal method of estimating general MSM score, but an absolute sum (which would be a better reflection of the real MSM score) of all robusticity, osteophyte formation and osteolytic lesions scores could not be achieved as too many of the specimens were incomplete. The created general MSM scores for the left and right limb showed a very similar distribution pattern, from which no signs of handedness could be observed. Both sides had general MSM scores ranging from one to seven. Since the calculations of frequencies showed a very similar pattern, a Spearman's rho test was done to see whether this apparent correlation was also statistically significant. The results of this test; a correlation coefficient of 0.585 ($p < 0.000$), showed that the left and right upper limb were indeed correlated. To test for any differences between the left and right upper limb, a Friedman's test was run. The result of this test was the following: $\chi^2 = 0.800$ $p = 0.371$. This indicates that there is no statistically significant difference between overall left and right musculoskeletal stress marker scores. The only difference in MSM's between the left and right upper limb thereby remains the latissimus dorsii/teres major muscle attachment site.

b) Sex

The next question was whether there was a significant correlation between sex and musculoskeletal marker scores. Males were expected to display higher MSM scores, as they are generally larger, more robustly built and more muscular. A Spearman's rho statistical test was executed to determine the correlation between sex and MSM's. For the MSM's, the combined sum of the maximum scores for robusticity, osteophyte formation, and osteolytic lesions per individual was used to simplify the analysis (see above) as the focus is on the general picture per individual rather than on specific muscle attachment sites.

The test showed no correlation between sex and MSM score, the correlation coefficient of 0.209 ($p=0.154$) was too low to point to a correlation and the p-value was too high for the result to be considered statistically significant. This result is not as surprising as it may seem. Musculoskeletal marker scores measure the response of the bone to strain, which is not necessarily the same as the size and robusticity of the muscles (see discussion).

The distinct muscle attachment site were also examined for correlation with sex. To test this, the mean score for each muscle attachment site for males and females was calculated. The results were shown in a bar chart (figure 17).

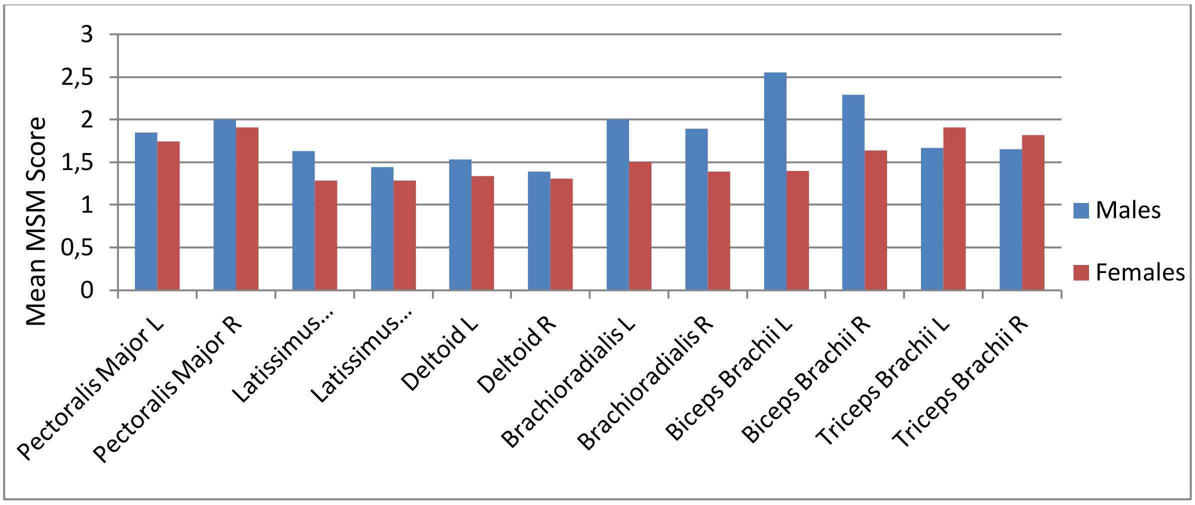

Figure 17: Bar chart representing the mean MSM scores by sex. The males are represented in blue, females in red.

This chart illustrates that there are differences between males and females. There seems to be a difference between both sexes, with males having generally more pronounced muscle attachments. The biceps brachii and brachioradialis in particular show sexual dimorphism, with males scoring higher. The only muscle which is more pronounced in females is the triceps brachii. When mean MSM scores for males and females are calculated, there also seems to be a difference. Females had a mean MSM score of 2.81 +/- 1.52, males had a mean MSM score of 3.43 +/- 1.36. These results indicate that although there was no statistically significant correlation between sex and musculoskeletal stress markers, this could simply be because MSM score higher for males in some attachment, yet higher for females in others (i.e. the triceps).

c) Age

What correlation does age have with musculoskeletal stress marker scores? According to the literature on musculoskeletal markers, there should be a correlation (see chapter 2). A Spearman's rho statistical test showed that there was a significant correlation between age and MSM ($r = 0.393$, $p = 0.006$). This correlation is solid, but not extremely high, suggesting that age will influence the overall MSM score of an individual.

As expected, the mean MSM score was higher in middle adults than in late young adults. In late young adults the mean MSM score was 2.54 +/- 1.22, whereas in middle adults the mean MSM score was 3.62 +/- 1.53. This difference fits in the general theoretical framework surrounding musculoskeletal markers which states that MSM scores increase with age.

d) Functional complexes

The last statistical test which was done on the musculoskeletal marker data aimed to see whether certain muscle attachment sites showed high correlation in their score. If this was the case, functional complexes of muscles which were used together for a certain activity could be identified. A Spearman's rho test was therefore executed between all MSM's. The results show no obvious pattern of muscle use, but did show some interesting correlations. The whole table containing all correlation tests can be consulted in appendix E.

The first muscle observed for correlations was the latissimus dorsii/teres major, which was of interest because of its asymmetry. The tests gave a high correlation between the left and right deltoids and the left latissimus dorsii/teres major ($r = 0.464$, $p = 0.03$ for the left and $r = 0.523$, $p = 0.01$ for the right deltoid). There was however no correlation with the right latissimus dorsii/teres major (left $r = 0.053$, $p = 0.753$ and right $r = 0.109$, $p = 0.511$). This same correlation was present between the left latissimus dorsii/teres major and both pectoralis major muscles, with a correlation coefficient of 0.406 ($p = 0.009$) for the left and a correlation coefficient of 0.456 ($p = 0.004$) for the right. Once again there was no significant relation between the right latissimus dorsii/teres major and these muscles. Other

muscles which showed a high correlation with the left latissimus dorsii/teres major muscle attachment site were the left brachioradialis (correlation coefficient 0.338, $p = 0.038$) and the left biceps brachii (correlation coefficient 0.383, $p = 0.019$). The right brachioradialis and biceps brachii did not show significant correlations with this left latissimus dorsii/teres major. The left triceps brachii did however show a significant correlation with the right latissimus dorsii (correlation coefficient 0.492, $p = 0.004$). This is the only muscle attachment site with which the right latissimus dorsii showed a correlation.
Having thus analyzed the latissimus dorsii/teres major data, the next step was to see how the pectoralis major attachment site related to the other muscle attachment sites. These left and right pectoralis major scores showed significant correlation with the left latissimus dorsii/teres major, as mentioned above. They also correlated with both deltoids and with the left brachioradialis There was a significant correlation between the right pectoralis major and the left triceps brachii (correlation coefficient 0.392, $p = 0.020$) as well.
The brachioradialis was analyzed next. There was a significant correlation between the left brachioradialis and the right biceps brachii (correlation coefficient 0.360, $p = 0.024$). Other correlations for this muscle attachment site have been mentioned above.
For the biceps brachii and triceps brachii, all significant correlations have already been mentioned. The meaning of this complex correlation pattern will be discussed in chapter 6.

e) Intra-observer error

A re-analysis of five skeletons by the author gave the exact same results, save for one muscle robusticity score for the brachioradialis which was given a score two the second time yet a score one the first time. Therefore, the intra-observer error of the Mariotti et al. (2004, 2007) method was low.

5.3 Osteoarthritis and musculoskeletal markers combined

When combining the data from osteoarthritis and musculoskeletal markers, the most obvious question is whether these two skeletal markers of activity are correlated. If they are both good activity markers, they should show a positive correlation. A Spearman's rho test was executed to assess the correlation between OA and MSM's. The result was a correlation coefficient of 0.212 ($p = 0.149$), which is not statistically significant. Thus, the data show no correlation, negative or positive, between osteoarthritis and musculoskeletal markers when tested with a Spearman's rho test. This means that individuals with higher OA scores are not necessarily more likely to show higher MSM scores, and vice versa. To consolidate this conclusion, a Friedman's test was run to test for significant differences between OA and MSM scores. This test found a statistically significant difference between OA and MSM scores ($\chi^2 = 46.000$ $p < 0.000$). As MSM's and OA are both used to measure the same thing (i.e. activity level), the lack of correlation and the significant difference are remarkable.

Separate bar charts showing the frequency of individual OA scores and individual MSM scores help clarify the results (figure 18 and 19).

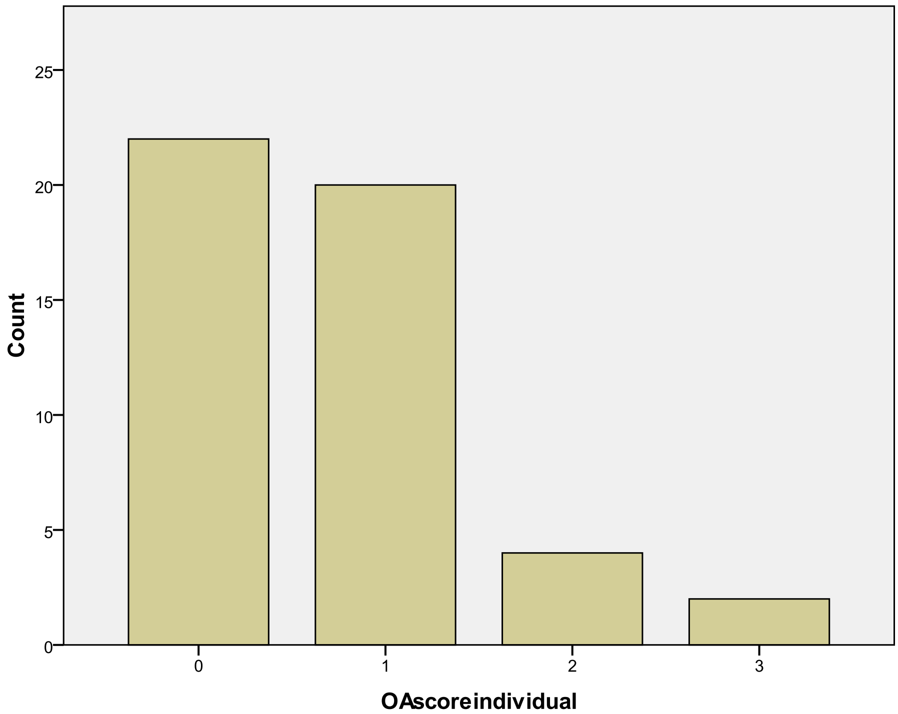

Figure 18: Bar chart for OA score distribution, showing the distribution pattern of individual OA scores within the population.

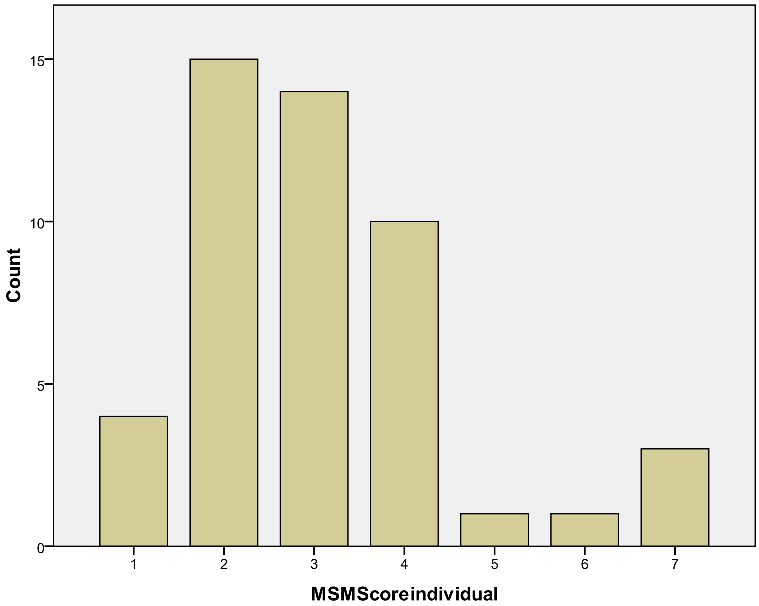

Figure 19: Bar chart for MSM score distribution, showing the distribution pattern of individual MSM scores within the population.

It is clear from these two charts that there is no direct association between the activity markers. As a further illustration, a scatter plot combining both datasets was constructed (figure 20):

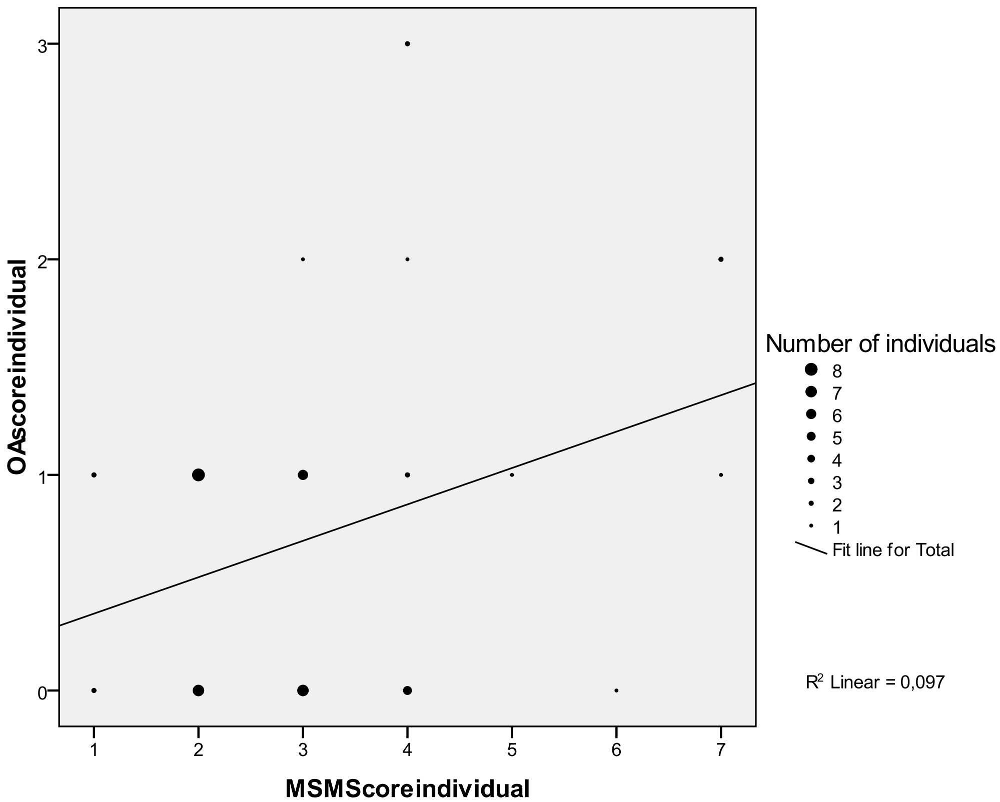

Figure 20: Scatter plot showing all individual MSM scores on the x-axis and all individual OA scores on the y-axis. The size of the dot corresponds with the number of individuals it represents

When the distribution of the dots is analyzed, no pattern becomes evident. There is no sign of any grouping of values which could help establish individuals or groups of individuals with higher and lower activity levels, although the highest MSM scores do correspond with OA scores of at least one. However, when the slope of the fit line is analyzed, it appears to indicate at least a low correlation between OA and MSM scores. If there were no correlation whatsoever, this line would be horizontal. This fit line represents the R^2 value. This is a statistical value which varies between zero and one. If the R^2 value is one, knowing one factor means you can exactly predict the other (i.e. if we knew the OA score we would know the MSM score and vice versa), there is an absolute correlation. If the R^2 value is zero, one score cannot help you predict the other, therefore there is no correlation. In this case, the R^2 value is very low (0.097), therefore there is a slight correlation, even if this correlation was not high enough to be statistically significant in the Spearman's rho correlation test. This low correlation suggested by the R^2 value does not conflict with the significant difference provided by the Friedman test.

As there is a relationship (however slight) between osteoarthritis and musculoskeletal markers of stress, further comparisons were made between the combined OA/MSM data and the data on handedness, age and sex.

First, the question of handedness was asked of the combined dataset. A Spearman's rho test was done, comparing individual OA and MSM score of the left to individual OA and MSM scores of the right upper limb. This test showed that there was no asymmetry between upper limbs when combining osteoarthritis data with musculoskeletal marker data. The correlation coefficient was 0.671 ($p = < 0.000$). The left and right upper limb thus have a statistically significant positive correlation.

If the results of combined osteoarthritis and musculoskeletal marker data support the data generated on handedness, would they also support the generated results on correlation with age and sex of these activity markers?

When the osteoarthritis and musculoskeletal marker scores of the skeletons are compared to their sex, the results of the Spearman's rho test shows that there is no statistically significant correlation between sex and the combined activity score. The correlation coefficient was 0.218 ($p = 0.137$). The mean scores did however differ for males and females, with males scoring slightly higher. The mean combined OA/MSM score for females was 3.59 with a standard deviation of 2.04, whereas the mean combined OA/MSM score for males was 4.05 with a standard deviation of 1.66.

When the combined OA and MSM data are tested for correlation with age, the Spearman's rho test finds a statistically significant correlation (r = 0.34 (p = 0.017). When these data are further analyzed, it becomes clear that the middle adults have generally higher scores than the late young adults. For the late young adults the mean score is 3.08 with a standard deviation of 1.25, whereas for the middle adults the mean score is 4.50 with a standard deviation of 2.15.

6. Discussion

In this chapter, the results generated in the prior chapter will be analyzed. Some data on osteoarthritis and musculoskeletal markers will be discussed separately, but for the large questions of correlation with age, sex and activity, both activity markers will be treated together. This way, the data can be maximally combined, and all significant and/or unexpected differences in the intra-population distribution patterns between both skeletal markers of activity can be analyzed and explained, insofar as possible.

6.1 Osteoarthritis

The first result mentioned for the osteoarthritis data was the high prevalence of osteoarthritis in the acromioclavicular joint (figure 21). In modern populations, OA of this joint is not uncommon, a degenerative result of increasing age. Interestingly, the majority of individuals in older age categories at Middenbeemster (aged 50+) showed at least moderate osteoarthritis at the acromioclavicular joint. These old individuals were not included in this study (as explained earlier), but do support the hypothesis that acromioclavicular OA had a very high prevalence in this post-medieval population.

Figure 21: Depiction of the right shoulder, showing acromioclavicular osteoarthritis (source: http://www.shoulderdoctor.co.uk/img/sd_info_09.jpg)

Peterson (1983) conducted a study on one hundred and sixty-eight dissected modern cadavers, on which he studied the prevalence, severity, and stages of osteoarthritis in the acromioclavicular joint. He mainly looked at the cartilage and intra-articular disc, yet also incorporated osteophytes as a symptom. Peterson found that the gradual degeneration of the acromioclavicular joint is a normal part of the aging process (Peterson 1983, 438). Although his article did not focus on the bony changes of osteoarthritis, he does mention that marginal lipping and osteophytes occur when the cartilage starts to become affected, which is after the first stages in which only the disc is affected. Therefore, it is evident that bony changes are associated with the later stages of osteoarthritis. If we compare the data from our population to Peterson's results, it is clear that, even though acromioclavicular osteoarthritis is a common and normal degenerative change, the severity of changes that we are seeing in late young adults (26-35 years of age) and middle adults (36-49 years of age) is too high to be attributed to age-related changes. Therefore, it is highly likely that the population of Middenbeemster was involved in a much more strenuous and physically taxing lifestyle than modern-day populations.

So, aside from the high activity rates suggested by the acromioclavicular joint, what do the combined arthritis data mean for OA as a skeletal marker of physical activity? Figure 18 in chapter 5.3 showed the distribution of OA scores across the sample. It is unlikely that all individuals without signs of osteoarthritis could plausibly belong to the elite. It is possible that the people who show signs of arthritis in both age categories were engaged in more strenuous physical activity, although this will require analysis with archival data for occupation. However, as said, this percentage of people with OA is too low to plausibly include all who engaged in manual labor for our agricultural population, as only twenty-six of forty-eight analyzed individuals were affected by osteoarthritis. It is more likely that only some of the persons involved in strenuous physical activity were affected by osteoarthritis, and that these were already predisposed to OA by other factors such as genetics. The other people engaging in strenuous labor were not as predisposed to OA, thus did not suffer from osteoarthritis as a result of their work, at least in our 26 - 49 year old age bracket.

a) Comparisons to other research

To make any further sense of the osteoarthritis results, they should be compared to data on other populations. In this manner, the relative overall physical activity level of the population might be established. The acromioclavicular OA has suggested that the degree of physical activity in the Middenbeemster population was likely quite high. Several comparisons to other studies are made for osteoarthritis, to see if such an analyses is useful and to assess the confounding factors involved in such comparisons. The first comparison presented is between Middenbeemster and Alkmaar - Sint Laurenskerk. This comparison was chosen because of its geographical and temporal proximity to the Middenbeemster collection.

In the Middenbeemster sample 60.4% of individuals had osteoarthritis in at least one of the joint of the shoulder. For the elbow joint, osteoarthritis prevalence is 12.5%. The shoulder prevalence seems very high, yet does not distinguish between different severities of the joint disease, as a mild score is by far the most common. Even so, both percentages are markedly higher than those recorded in other populations. In Alkmaar burials were excavated from inside the church called the Sint Laurenskerk (Baetsen 2001). These burials date from the eighteenth century up until the year 1830, and are thereby slightly earlier than our site. In this Alkmaar sample, shoulder osteoarthritis was found in two percent of individuals, and elbow osteoarthritis in five percent of the population (Baetsen 2001, 62-64). Therefore this population shows lower osteoarthritis prevalence rates that the Middenbeemster sample. However, several factors could explain this large difference. First off, the Alkmaar sample is of an urban population, which would naturally show different patterns of osteoarthritis than our rural Middenbeemster population. Also, it is unclear from the publication of Alkmaar which joint facets were included in the shoulder and elbow scores. If the acromioclavicular joint was not included in the shoulder score of Alkmaar, this could explain part of the difference. Although even when only osteoarthritis of the humeral head and glenoid surface are scored, the osteoarthritis prevalence of 37.5% is still markedly higher than the two percent in Alkmaar. Another factor to consider is that it is quite possible that osteoarthritis in its early stages was not recognized in the Alkmaar collection. The signs of mild osteoarthritis are quite subtle, and easily overlooked if the study does not focus upon this specific joint affliction. It is also not mentioned in the Alkmaar study which diagnostic criteria were used for osteoarthritis. If, for instance, only eburnation is used as a diagnostic criterion, the results will be radically different from Middenbeemster, where a whole list of subtle changes in the joint were used (see chapter 3).

These remarks clearly illustrate the difficulties involved in comparing osteoarthritis prevalence rates between populations. The best solution to these issues would be to re-examine different populations using the same scoring methods. However, even obtaining the exact methods used by other authors would facilitate comparison.

Another comparison was made between osteoarthritis in the Middenbeemster sample and the adult sample from the African Burial Ground Project (ABGP). This collection is from a cemetery of enslaved Africans from an urban environment in New York (Wilczak et al. 2004). It must be noted that this African burial ground collection is likely to be very genetically diverse. Slaves were imported from all over Africa, and this continent has the highest internal genetic variability in the world (as a logical result of the path of human evolution). This ABGP collection is thereby different from our Middenbeemster sample both in genetics and activities, and if our methods are valid, this difference could show up in the results. Even so, similar results could also stem from genetic differences, therefore caution must be taken with the interpretation. The ABGP study used a scoring method very similar to the one used for the shoulder and acromioclavicular joint in this study. The ABGP study gave OA results for the 25-49 age range, making it comparable to our sample. They had a prevalence of moderate to severe OA in the shoulder of 13%. For the elbow, moderate to severe OA was present in 32.6% of males and 19.4% of females. This elbow score is markedly higher than in the Middenbeemster population, and also shows a sex difference which is absent in the Middenbeemster sample. The shoulder, on the other hand, shows a lower OA rate than the current study (13% compared to 37.5%). The main problem with this comparison is that the ABGP does not include mild OA in their percentages, so the shoulder scores cannot be taken into account. Its prevalence rate might be significantly higher if mild scores were added, especially as the Middenbeemster sample showed that mild shoulder OA can be quite common. The high prevalence of pronounced OA in the elbow in the ABGP population is however noteworthy, as this prevalence is much higher than in Middenbeemster even though mild scores were not included in the percentage. This large difference may point to different activities as well as different genetic backgrounds.

Another comparison can be made with the canons (male religious order) buried in a chapel of the church of Sint-Servaas in Maastricht (Jansen and Maat 2002). Although the 22 individuals in this sample are all over 40 years of age, a comparison was still made because Maastricht is also located in the Netherlands. The burials in the chapel in Maastricht date from 1070 – 1521 A.D. All these canons were wealthy men with little physical activity and quite possibly high body mass. Still, the prevalence of shoulder osteoarthritis was 19% and elbow arthritis 46%. It must be noted that a 100% prevalence of DISH was reported for this population, confounding OA observation, as both hypertrophic bone formation and high body mass (Weiss 2006) influence OA. Even so, it is remarkable that this high percentage of elbow osteoarthritis was reached, much higher than in the active lower class population of Middenbeemster.

Yet another Dutch sample available for comparison originates from Dordrecht. It was published by Maat et al. (1998). In a cemetery next to a Franciscan monastery, citizens of Dordrecht were buried. The authors state that the deceased were quite likely of a relatively high socioeconomic status. The burials are from an earlier time period than Middenbeemster, from between 1275 and 1572 A.D. All age categories are included, but most individuals analyzed were adults. The prevalence of shoulder OA was 8% (11 out of 147 specimens) and elbow OA 4% (7 out of 165 specimens). These prevalence rates are radically different from those of the canons mentioned above, as well as of the Middenbeemster sample. As this was an urban population, their activity levels could have been significantly lower, yet many crafts and trades still required a good deal of physical effort prior to the industrialization. This indicates that Maat et al. (1998) were likely correct in suggesting that the skeletons were of persons of relatively high social status. It can also be taken to indicate that our Middenbeemster sample had a much more strenuous lifestyle than these citizens of Dordrecht. Even with the younger individuals included in Dordrecht, this assumption remains plausible, given the large difference.

These results show that, although comparison is not simple when one has to take into account different definitions of OA and different scoring methods, the Middenbeemster population does show a very high prevalence of osteoarthritis, supporting the hypothesis that this population led a physically taxing life. The only gap in this conclusion in the high prevalence of OA in the canons of

Maastricht, yet given their pathological condition and probable high body mass they are better excluded from the general picture.

The discussion of osteoarthritis results concerning sex, age and handedness, will be combined in with the MSM data in the following subchapters.

6.2Musculoskeletal markers

Several results of the musculoskeletal data need closer consideration. First off, the generally low robusticity of the deltoid needs to be examined. The most important function of the deltoid is the abduction of the arm beyond the initial fifteen degrees for which another muscle, the supraspinatus, is responsible (Drake et al. 2010, 676). Basically, any upper limb movement in which the arm is lifted more than fifteen degrees will use the deltoid muscles. So, to interpret the deltoid robusticity, other MSM sites must be considered. A relevant analyzed muscle is the brachioradialis.

The brachioradialis shows a high incidence of maximum robusticity. This small muscle is active in the elbow joint and forearm. It helps flex the elbow when the lower arm is midpronated (this means the palms are in a vertical plane facing each other). Of course the muscle will also move when other upper limb motions occur, yet it is put to the most use and under the most strain in this movement. Flexing of the elbow with the hand in this position suggests the lifting of relatively small objects. The individuals who have maximum robusticity scores for the brachioradialis could possibly all have held the same occupation, or a similar one, which required intensive use of this muscle. It is however impossible to derive the exact profession from such limited evidence. When combined with the low scores for the deltoid, this could mean lifting objects no larger than the range between both medially facing palms when the arm is fifteen degrees or less removed from the body. These arm movements and positions could also be sustained when using a hoe, or driving a cart. Perhaps even the use of a shovel could explain this pattern. Interesting as these options are, it is impossible to reach solid conclusions based on the data available.

Furthermore, the high development of the pectoralis major could also point to the use of a shovel, although any action which requires the arm to be lowered or rotated medially could be responsible. The setting down of possible heavy loads could also explain its pronounced appearance.

A last musculoskeletal marker result which should be discussed is the correlation between different muscle attachment sites described in section 5.2 d. In an effort to make sense of these correlations, two diagrams were created (figures 22 and 23).

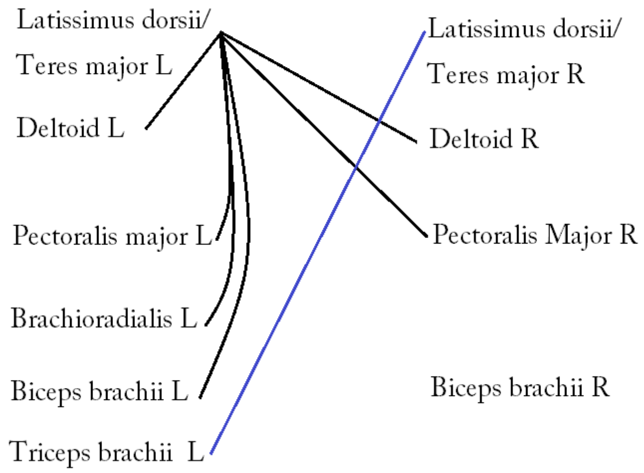

Figure 22: Correlations between the latissimus dorsii/teres major muscle attachment site and other muscle attachment sites. Correlations with the left in black, right in blue.

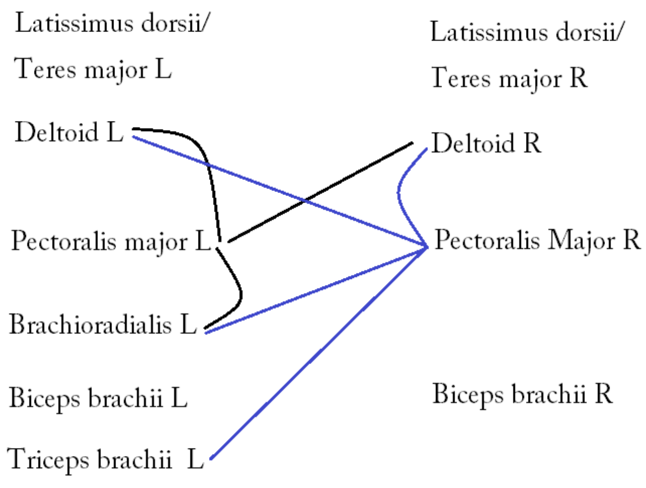

Figure 23: Correlations between the pectoralis major muscle attachment site and other muscle attachment sites. Correlations of the left indicated in black, the right in blue.

As visible in the diagrams above, many muscles correlate with the left latissimus dorsii/teres major muscle attachment site, whereas only the left triceps brachii correlates with the right latissimus dorsii/teres major muscle attachment site. A last additional correlation not shown on the diagrams is that between the left brachioradialis and the right biceps brachii. The fact that the left latissimus dorsii/teres major insertion site correlates with many muscles, whereas the right insertion site of this muscle does not could mean that this right latissimus dorsii/teres major is underdeveloped relative to the rest of the musculoskeletal markers. It could however also mean that they were used in a different manner. The pattern of correlation presented by these musculoskeletal markers is too unclear to derive any further conclusions on possible functional complexes other than the standard anatomical ones. Further analysis with more MSM sites is necessary to establish the true meaning of the correlations.

a) Comparisons to other research

A next step in the analysis of the musculoskeletal stress marker results is the comparison to other studies. It was difficult to find any comparable studies in this young field of research. Of the available research, many used the 'old' Hawkey and Merbs (1995) scoring method instead of the Mariotti et al. (2004, 2007) system used in this study. Some also used the Villotte scoring method (e.g. Havelková et al. 2011). Even when the same scoring method was used, comparison is not possible when different muscle attachment sites were used. Therefore comparison can only be made on a general level. None of the examples stem from the close geographical area of Middenbeemster (i.e. the Netherlands) however. Comparable studies in this limited area were unavailable because the field of MSM studies is still too new.

A first comparison was made with the study of the African Burial Ground Poject. This comparison is interesting because these researchers also studied osteoarthritis as an activity marker (see above). It does present a lot of issues in comparability, yet one must work with the information available. The ABGP study used a scoring method based on the Hawkey and Merbs (1995) system, yet only took moderate to severe hypertrophy or muscle attachment sites into account, disregarding minimal development. They also rated hypertrophy and lesions on the same continuous scale. Ergo, their scoring system ran from minimum robusticity to maximum osteolytic lesions. Hereby osteolytic lesions are seen as the highest activity-related change possible to an MSM, a debatable concept. A last confounding factor is that they included all individuals 15 and older, which includes twenty-five individuals younger than 25 and twenty-eight 50+ individuals in a sample of 160 specimens. Adding older and younger individuals than in the Middenbeemster sample could “even out” in the end result, yet makes comparisons a lot less viable. The researchers created ‘frequencies’ for well-pronounced MSM’s. For males, the frequencies of relevant muscles are: deltoid 62.2%, pectoralis major, latissimus dorsii and teres major 59.3 %, biceps brachii 33.8%, triceps brachii 15.7% and brachioradialis 1.3%. For females, they are deltoid 48.4%, pectoralis major, latissimus dorsii and teres major 42.2%, triceps brachii 14.8%, biceps brachii 8.2% and brachioradialis 3.6%. These results are hard to grasp, but the data must be interpreted as a sort of high development frequency.

They are comparable to the data of this study, simply by observing the order of the scores (by sex as well as in general). What is immediately obvious is that the deltoids get the highest scores in the ABGP population, closely followed by the pectoralis major/latissimus dorsi/teres major. The authors combined the pectoralis major with the latissimus dorsii/teres major sites for scoring, which makes comparison more difficult. Their decision to combine the pectoralis major with the two other MSM’s is hard to understand, given the distinct nature of this muscle attachment site. Nevertheless, although the differences in MSM development can be partially due to differences in the scoring system and the genetic background, they still indicate a much higher relative development of these muscles in the ABGP sample than in the Middenbeemster sample. The brachioradialis muscles in the ABGP sample are ranked much lower compared to the other MSM’s than in the Middenbeemster site. This could be a result of a specific activity in the Beemster population, but a genetic etiology is also possible.

The ABGP sample also shows larger sexual differences. Interestingly, the largest sex difference is in the biceps brachii, as it is in the Middenbeemster sample. This could point to a general human physiological difference between the sexes or to an activity frequently undertaken by males in both groups. In their sample, triceps brachii scores are nearly equal. This whole comparison demonstrates two things. One, that comparing data when different methods and different systems of aggregation are used is very difficult. Two, that although a significantly different pattern is visible in the ABGP population, it is not clear how much of this is due to activity versus genetic differences between African slaves and Dutch rural villagers.

Another study used for comparison is Eshed et al. (2004)'s research on MSM's in Natufian hunter-gatherers and Neolithic farmers in the Levant. Their study used musculoskeletal stress markers from the upper limb. The muscles available for comparison are the teres major, the pectoralis major, the deltoid, the latissimus dorsii, the triceps brachii and the biceps brachii. The brachioradialis muscle was scored together with another muscle (the extensor carpi radialis longus) so is not comparable. The latissimus dorsii and teres major were scored separately. They used the scoring system of Hawkey and Merbs, but (like in the ABGP study) placed robusticity and stress lesions on one continuous scale. The rank order of development of these muscles in their Neolithic (i.e. agricultural) sample is pectoralis major > deltoid > teres major > latissimus dorsii > triceps brachii >biceps brachii. This ranking is notably different from the Middenbeemster sample. In the Dutch sample, the biceps scored highest of all muscles rated, and the deltoid the lowest. This difference could be partially due to different scoring method, and genetic differences. The different ranking order, especially given the complete opposite ranking of the biceps brachii is however likely to be at least partially activity-related. The same can be said when the Middenbeemster sample is compared to the hunter-gatherer sample, where the ranks are pectoralis major > deltoid > latissimus dorsii > biceps brachii > triceps brachii > teres major.

Interestingly, Eshed et al. also did not find any statistically significant side dominance in the upper limbs. They did however find right side dominance when the male teres major and triceps brachii were observed individually (Eshed et al. 2004, 307-309). As for sexual dimorphism, all MSM's were more pronounced in males in the Neolithic group, although the deltoid was more pronounced in females in the hunter-gatherer group. The triceps brachii was even the highest sexually dimorphic muscle in the Neolithic sample, being much more developed in males. This could mean that its high pronunciation in females in the Middenbeemster sample could indeed be activity-related rather than being a physiological sex difference.

6.3 Handedness

If the osteoarthritis data or musculoskeletal stress marker data showed a significantly higher or lower score for one limb than the other, this could point to asymmetrical physical activity levels during the individual's life. This asymmetry could then be inferred to be a result of the individual being left-handed or right-handed.

When summarizing the osteoarthritis result, it is clear that no such obvious pattern is visible. An analysis of the individual joint facets showed no evidence of left-or right-handedness. When the entire arms were compared, the scores were slightly higher for the right arm, yet this slight difference was not statistically significant. Still, as the p-value of 0.052 is only slightly too high to be statistically significant, a predisposition towards the right arm can still be supposed. When osteoarthritis and musculoskeletal marker data are combined, there is also no evidence of handedness.

Yet, when the musculoskeletal marker data were regarded separately, one significant asymmetry did show up. The left latissimus dorsii/teres major muscle insertion site was more pronounced than the right side, and this difference was statistically significant. On first sight, this result is disconcerting, as the right upper limb would be expected to score higher, being the dominant limb in the majority of people. However, consider what the left and right arm do during strenuous physical activity. The dominant hand is mainly used for precision and aim. So, when you engage in a physical activity which requires the use of both hands, the left limb is more likely to be used for brute force while the right limb guides the movement. This hypothesis could be connected to activities such as using a shovel, a rake, or a scythe. As the latissimus dorsii is a large strong back muscle, this concept could explain why the left side is more strongly developed. The teres major also fits this hypothesis, as although it is not a big strong muscle, it does assist in the same movements as the latissimus dorsii, namely medially rotating, and extending the humerus. The only movement that the latissimus dorsii executes without the teres major is adducting the humerus.

The general high symmetry between upper limbs could further be seen as an indication of strenuous physical activity. The use of the dominant hand is most important when the task requires fine motorism (Wilczak 1998, 321), yet when heavy lifting, pushing or pulling is required, both arms will be used equally.

6.4 Sex

Osteoarthritis showed no significant correlation with sex. For musculoskeletal stress markers, the general correlation was also too low to be significant, even if the individual muscles do show a certain pattern. The mean combined OA/MSM scores were slightly higher for males, yet this difference was not statistically significant. The interpretation of this result is rather difficult. On the one hand, it could point to the problems of osteoarthritis and musculoskeletal markers as evidence of activity, yet on the other hand it could be due to gendered division of labor.

For both osteoarthritis and musculoskeletal stress markers, the scores could be expected to be higher for males, as they generally engage in more strenuous physical activity. The fact that this is not the case could be taken to mean that osteoarthritis and musculoskeletal stress markers are not good markers of physical activity. However a recent article also found no strong correlation between sex and osteoarthritis, and states that there has never been a consistent correlation between these two variables (Weiss 2005, 95). Also, females have been found to be more susceptible to osteoarthritis in many studies, because of the oestrogen in their bodies and the associated estrogen receptor genes (Spector and MacGregor 2004). This higher susceptibility could effectively cancel out any activity-related differences between males and females. These facts suggested that osteoarthritis should be excluded as a marker of sexual division of labor in this study.

As for musculoskeletal stress markers, these are usually found to be more pronounced in males (for an example see Eshed et al. 2004, 309). Although the general correlation between sex and overall MSM was too small to be significant, there was an interesting pattern of differences between the individual muscle attachment sites. Males have more pronounced muscle attachments, especially in the biceps brachii. This muscle is used when flexing the forearm and when moving it so that the palm faces downwards, as well as exercising some supportive tasks. It’s high development could point to the habitual carrying of heavy loads on the forearms by men (Capasso et al. 1999, 58). Only the triceps brachii insertion site on the ulna is an exception to the pattern of stronger muscles (or at least more prominent muscle attachment sites) in males. In this last MSM females had generally higher scores. The triceps brachii muscle is active in the extension of the lower arm, the adduction and extension of the arm and the bracing of the elbow joint, for instance when pushing an object. It is also exercised when, starting from a flexed position of the elbow, one pulls or pushes something down. This last movement could correspond to the milking of dairy cattle.

For musculoskeletal stress markers, given the results mentioned above, tentative conclusions can be made on the sexual division of labor, even though they must be handled with care. The lack of statistically significant correlation between MSM score and sex suggests that both males and females engaged in physical activities that were similarly strenuous. The differences in which muscle attachment sites were more pronounced can then be taken to mean that men and women engaged in some different physical activities. Which physical activities those were cannot be derived from the limited amount of muscle attachment sites evaluated in this study. Even so, it is an interesting conclusion that the differences between both sexes in musculoskeletal stress markers are not simply a reflection of physiological sex but rather a reflection of gender and the role of males and females in society.

6.5 Age

When it comes to the relationship between osteoarthritis, musculoskeletal stress markers, and age, the results are more clear-cut and promising than they were for sex. Testing the correlation of these skeletal activity markers with age has two main goals. The first goal is to establish separate subsets of data per age category to improve the comparability of the data to other studies of activity markers. The second goal is to evaluate the methodological implications of the relationship between age and activity markers. If a correlation is present, this is an important etiological factor to bear in mind in any study of osteoarthritis or musculoskeletal stress markers.

The osteoarthritis prevalence was not correlated with age, yet the severity of OA did increase with age. The prevalence and severity must therefore be treated separately. First, prevalence must be discussed. In the sample, the same number of late young adults as middle adults was affected with osteoarthritis. This suggests that other etiological factors apart from age dictated the prevalence of OA.

Possible factors include genetic influences, influences of anatomical variation and body mass index (Weiss and Jurmain 2007). These factors are not connected to age but can in part dictate whether an individual suffers from osteoarthritis. Therefore these factors can cause osteoarthritis prevalence to be equal in different age groups.

As for severity, it was noted that although the number of affected individuals is equal for both age categories, there was a notable increase in the severity of the pathology in the higher age category. This increasing severity of osteoarthritis in older individuals is quite logical, as once osteoarthritis affects a joint, the disease will always proceed to worsen. Once the disc between both joint facets and the associated cartilage starts to wear down, it will invariably continue to do so. Therefore, if prevalence rates are the same for both age categories, osteoarthritis severity can be expected to be higher in middle adults, as they probably already had the disease when they were late young adults and thus the affliction has had more time to progress.

When the correlation between age and musculoskeletal markers of stress is regarded, a less disputable pattern becomes visible. MSM's show a statistically significant correlation with age. This correlation is a positive one, ergo when age increases the prominence of muscle attachment sites also increases. This result concurs with existing MSM data from other studies (for examples see introduction). The correlation coefficient was 0.393, which is not extremely high. This simply indicates that MSM's are significantly correlated with age, but that other factors also influence the appearance of MSM. Of course, according to the current theories on musculoskeletal stress markers, one of these factors is physical activity. Therefore, the correlation signifies the accumulative nature of musculoskeletal markers, with bone continuing to adapt itself to strain in the same manner over time, while illustrating the presence of other factors in MSM etiology.

6.6 Activity and social differentiation

All these individual results bring us back to the central question of this thesis: can osteoarthritis and musculoskeletal stress markers be effectively used as evidence of physical activity, and can we combine them to distinguish a hard-working group of ‘commoners’ from a smaller elite group who were not as physically active? As the scatter plot in chapter 5 illustrates, it was in fact not possible to distinguish two distinct groups based on the combination of these skeletal activity markers.

For osteoarthritis, it is quite likely that the individuals who were affected by this disease engaged in strenuous labor, yet these individuals represent only a part of the group which was physically highly active (see separate discussion above).

For musculoskeletal markers, it could be hypothesized that the small group of four individuals who received a score of zero were in fact the members of the elite. The pattern is however not unambiguous enough to present any certain conclusions.

At this point in the research, the archival data from Middenbeemster can be consulted, as this information can no longer bias the observations. Because of the recent nature of the excavation the archival data are still undergoing analysis. Therefore, exact data from the archival sources have not yet been assigned to specific excavated individuals used in this study. Thus, direct links between specimen and past activities could not be made. Consulting the data from the town councils registers of death did however give information on the different professions which were practiced in post-medieval Middenbeemster. In these ‘death registers’, the name, age at death, date of death, and profession of an individual are recorded, as well as the name, profession, and relation to the deceased of whoever came to declare the death. These records are not directly linked to the cemetery of Middenbeemster, but they do pertain to inhabitants of the Beemster and are therefore a good indication of the professions practiced by the Middenbeemster skeletal collection. The registers for 1830 to 1835 were consulted. Common professions included farmers of course, but also a host of other careers such as:

Workers	Cargo drivers	Servant girls
Tailors	Garden aids	Mill bosses
Handmaidens	Saddle makers	Innkeepers
Housewives	Village policemen	Gardeners
Sailors	Cobblers	Bakers
Watermillers	Merchants	Carpenters

Preachers	Tailor's servants	*"Bode"*
Artists	Housekeepers	*"Kastelein"*

Two of the professions encountered in the archives were hard to translate into English. A "bode" is a sort of administrative aid of the town council who delivers documents and letters. A "kastelein" is either a bailiff, a steward, or a tavern keeper, the last option being the most likely in the context of Middenbeemster.

This varied assortment of professions helps explain why no distinct groups were observable from the data. If the people of Middenbeemster practiced such diverse professions, their activity markers are bound to show a corresponding amount of diversity in their expression. Therefore, our MSM and osteoarthritis results do concur with the expected patterns of physical activity in the Middenbeemster collection. The individuals with an osteoarthritis score of zero and an MSM score of one or two could quite possibly represent the elite group. These individuals include S453V0973 and S481V1046, two late young adult females, who had an OA score of zero and an MSM score of one. Individuals with an OA score of zero and an MSM score of two were S487V1096, S487V1096, S216V0233 and S495V1041, four late young adult females, S092V0124 and S313V092 who are middle adult males, and, S514V1106, a late young adult male. If all these specimens belonged to the elite, this would mean that nine out of forty-eight individuals in the sample were of elite status. This number seems rather too high to be plausible. Therefore, only S453V0973 and S481V1046 who achieved the lowest possible scores for both activity markers are suggested to have possibly belonged to the highest step on the social ladder. Further research tying the archival data to specific individuals will be able to test this suggestion.

6.7 Evaluation of OA and MSM's as evidence of physical activity

At this point in the study, the usefulness of osteoarthritis and musculoskeletal stress markers can be evaluated. Forty-eight skeletons were analyzed for both types of activity marker in the upper limb. Did this analysis provide the information about social division which was hoped for? Can OA and MSM's be used as activity markers?

Osteoarthritis in itself proved that the population interred in the cemetery of Middenbeemster had a physically strenuous lifestyle. This information concurs with what was expected from a Dutch rural village in the eighteen hundreds. Furthermore, high osteoarthritis scores and prevalence rates in one joint did not mean that other joints would also score so high. This points to use-related differences between joints and thus to activity, although some joints will of course be more vulnerable to OA than others on a biomechanical and physiological level. OA was also useful on an inter-population level, although differences in diagnostic criteria do confound comparisons. The last two issues illustrate the need for methodological improvements (see next chapter).

The musculoskeletal stress markers proved the existence of sexual division of labor, although the exact activity patterns of males and females could not be extrapolated. Corrections for body size and body mass are necessary for these sex differences to be entirely reliable, a suggested further refinement of the data (Weiss et al. 2012). The high level of symmetry between upper limbs concurred with the OA data, further pointing towards strenuous physical activity. The complex pattern of correlations between different muscle attachment sites could not be structured into functional muscle groups, but is nonetheless noteworthy. Lastly, the recent nature of the scoring method used made it difficult to compare the MSM scores of the Middenbeemster population to other populations, thus only very general comparisons could be made. This made it impossible to establish the relative level of physical activity based on the MSM's alone. Luckily the OA data answered that question.

When both datasets were combined, two individuals could be distinguished as possible members of the elite. Once the archival data are assigned to the specific burial plots, it will become apparent whether these to specimens did indeed belong to the upper class of Middenbeemster. Both datasets also showed a high amount of individual variation, which concurs with the diverse professions practiced by the population.

These conclusions prove that both skeletal activity markers can indeed be used for analysis of physical activity levels and social differentiation. However, some of the merits of this study lie on a more methodological plane. Osteoarthritis severity increased with age, yet the prevalence rates were the same for both age categories. This points towards the influence of other etiological factors in this joint disease.

The outlined OA scoring method was effective. For musculoskeletal markers, the Mariotti et al. 2004 and 2007 scoring method proved easy to use and reproducible. Still, many researchers keep using the older system of Hawkey and Merbs (1995). Perhaps the fact that Mariotti et al.'s (2004, 2007) articles were published in the Collegium Anthropologicum made them less accessible than articles from (for instance) the International Journal of Osteoarchaeology or the American Journal of Physical Anthropology.

Although the obtained results paint an optimistic picture for the use of OA and MSM's as markers of physical activity, a lot of questions remain. In particular, how should the results of OA and MSM be interpreted, as they both have a complex multifactorial etiology, yet the exact nature and composition of this etiology is unclear. Also, although osteoarthritis and musculoskeletal stress marker data are both activity markers, they were only slightly correlated according to the R^2 value, while not sharing a statistically significant correlation according to the Spearman's rho test and showing a statistically significant difference. As OA and MSM's stem from a rather different physiological background, with OA being a 'negative' pathological result of strain, whereas MSM's are a 'positive' reaction of muscle attachment sites to strain by adapting their morphology, this very low correlation is not entirely surprising, yet still unexpected. Could this mean that, although they are both affected by activity to a certain extent, different types of activity are responsible for OA than MSM's? Could, for instance, one activity marker be more susceptible to repetitive movements, whereas the other is more susceptible to frequent intense strain? Is there in fact a difference in the way bone reacts to repetitive movements as opposed to frequent intense strain?

So, for this study of the Middenbeemster population as well as for further studies that wish to use OA and MSM activity markers, better knowledge of their etiology is needed. This knowledge is necessary to be able to reach more specific, high resolution information about the activities of a population, rather than being constrained to generalized conclusions such as those about general physical activity levels and the absence or presence of sexual division of labor.

7. Future research

The evaluation of osteoarthritis and musculoskeletal markers of stress clearly illustrates the need for further research on these activity markers. Further research is necessary for the Middenbeemster collection as well as on a more general, methodological level.

7.1 The Middenbeemster collection

On the level of the specific Middenbeemster collection, several further studies would provide useful information. This further research is necessary to gain as complete a picture as possible on the physical activity, and related issues of social differentiation, of the Beemster population. Given that this is a new, well-preserved skeletal collection, all possible data should of course be gathered.

Firstly, it would be useful to study the signs of osteoarthritis and musculoskeletal stress markers in the early young adults and old adults. These age categories fell outside the sample used in this study (see chapter three), however they still need analysis to answer the following questions. Are early young adults indeed too young to show sufficiently developed MSM's? What is their osteoarthritis prevalence? Do all old adults have MSM's which are too pronounced to be useful for differentiation, due to the long accumulation period of bony reaction? Or is there still a discernible difference between individuals? What is their osteoarthritis prevalence? And, if these age categories are also examined, can a good correction factor for age in these activity markers be established for the Middenbeemster collection? Would adding these age categories change the results on sexual division and handedness?

Secondly, further study should compare the results of the present study to other studies of activity markers for the Middenbeemster population. What is the correlation of OA and MSM's with non-metric traits associated with activity such as os acromiales and squatting facets? How do OA and MSM's correlate with studies of cortical bone thickness? According to recent research, cortical thickness and MSM's should correlate (Niinimäki 2012), which could mean they respond to the same type of physical stress and thereby to the same or similar activities. Thirdly, the present study should also be compared to a broader spectrum of other studies, especially other agricultural populations. Hopefully, future studies will also start using the Mariotti et al. 2007 scoring system to facilitate MSM comparison.

Lastly, the results of this study should be analyzed with the archival data once it is available. Thereby, the results of this activity study can be compared to the actual social status and occupation of the individuals involved. This will be an excellent test of the accuracy of MSM's and OA to reconstruct activity.

7.2 General future research

On a broader, non-site specific level there is also need for further research on the reliability of osteoarthritis and musculoskeletal stress markers as skeletal indicators of physical activity.

For osteoarthritis, two main issues remain to be addressed. The first is the absence of a widely used reliable scoring method. The absence of a uniform scoring method makes comparing different studies extremely difficult. From the experience gained in this study, it seems that it would be most useful to create a separate scoring system per joint, or at least per group of joints with similar processes of osteoarthritic reaction. Also, it would be of great use if the same universal scoring method could be applied as a detailed meticulous score for in-depth research, as well as as a quicker less detailed scoring method when osteoarthritis is not the sole focus of the research. Given that OA is a very common pathology, not every study needs a high-resolution description of its expression. If a uniform scoring method is only applicable as a very time-consuming system, it will never be universally adopted. Therefore an abbreviated version must also be created.

The second issue with osteoarthritis is the etiology. Although most influencing factors of OA formation are known, more research is necessary to establish the importance of each etiological factor. Also, as genetics can play a large role, it would be of great use to know the genes involved in OA, and how different population are more or less predisposed to OA.

When it comes to musculoskeletal stress markers, nearly every aspect needs further research. It is still not conclusively established that the macroscopic properties of a muscle attachment site can in fact be used as an indicator of physical activity. Even so, many osteoarchaeological studies (including the present one) have used MSM's as activity markers. This how the basic assumptions about MSM's urgently need to be examined. As with osteoarthritis, etiology is an important issue. Many questions remain to be answered, such as, is the biological chain of reactions that causes bone to grow and change truly triggered by muscle use? Does repetitive movement produce the same MSM morphology as frequent intense strain? How does trauma influence MSM's, for instance when a muscle has been ruptured? What is the exact relationship with age, sex, body size and body mass? To answer such questions, clinical studies could be of great value. However, as musculoskeletal stress markers are not pathological nor symptomatic, such research is unlikely to happen. Which other studies can be done to improve (or even prove) the reliability of MSM's as an activity marker? Recent studies on sheep (Zumwalt 2006) and mice (Wallace et al. 2012) provide rather unpromising results, but then these studies are done on animals without non-weight bearing limbs. For good results, studies should be done on animals with non-weight bearing limbs. As this would limit available study species to unpractical options (such as kangaroos), studies on humans might be preferable. Ideally, dissection of human cadavers of known age, sex, medical history, and occupation should be done, preferably on individuals who engaged in a limited number of different activities in a repetitive fashion during their lifetime. Using fresh cadavers would add information on muscle size and characteristics to the skeletal data. It should be noted that muscle size is not the only indicator, and that muscle can react to strain in different ways (e.g. sinewy, wiry fibrous muscle formation). Additionally, studies on known age-at death and known occupation skeletal collections should be undertaken. A recent study by Cardoso and Henderson (2010) did just this. Their results challenge the usefulness of MSM's, yet all their samples had mean ages between 47 and 60, ages by which MSM's are generally thought to lose their informative value. Their study proves that, especially as studies actually evaluating MSM usefulness are still few, all results should be treated with great care. Until solid evidence linking MSM's to activity is available, discussion on their usefulness will remain rampant.

On top of research into etiology, the scoring method for MSM's should be standardized. As of now, comparing different datasets verges on the impossible. The scoring method devised by Mariotti et al. (2004 for osteophyte formation and osteolytic lesions, 2007 for robusticity) is already a good step in the right direction, but does not yet include a scoring system for each musculoskeletal stress marker site. Their method gives general scoring methods for osteophytes and osteolytic lesions (2004 article), and site-specific robusticity scoring methods for twenty-three postcranial entheses (2007 article). Because their system has a separate set of evaluative criteria for robusticity per muscle attachment site, no extra distinction between different entheses types (i.e. fibrocartilaginous and fibrous) is necessary. On top of standardizing the data collection, uniform methods of data processing should be created. This is necessary to create useful and comparable aggregated datasets, whereas now every study combines and adds up data in their own manner.

a) The bone former conundrum

A major confounding factor which must also be addressed for OA and MSM's to become reliable is the bone former conundrum. It has been stated (Rogers et al. 1997) that some individuals are inherently more prone to new bone formation as a physiological reaction to a stimulus than others. The new bone formation takes three forms. There is the formation of new bone at a joint, in the form of osteophytes, as well as new bone formation as enthesophytes at attachment sites of muscles, tendons and ligaments, and finally new bone formation in the form of ossification of other soft tissue, most notably cartilage (Waldron and Rogers 1990, 125). Such an individual disposition could seriously skew any interpretation of osteoarthritis severity (Ortner 2003, 547) or musculoskeletal stress marker development level. However, there is as yet no true knowledge about this whole phenomenon, although Waldron states that "It is not certain what proportion of the population are bone formers but it may be up to a fifth" (Waldron 2009, 72). Although it can be assumed that anyone who has ever analyzed human skeletons has noticed that some individuals form more bone than others, this general "knowledge" cannot be taken as fact. It is quite remarkable that a concept which is so fundamental to any osteological research has not yet been investigated further. A discussion on this topic is slowly emerging, with Felson and Neogi (2004) criticizing Rogers et al. (2004)'s ideas on bone formers and the relation between bone formers and osteoarthritis. Hopefully, future researchers will study whether 'bone former' is a valid concept, and if so what the genetic or physiological explanation is. Only through in-depth research of large samples can a true understanding of new bone formation in pathology, old age, or idiosyncrasy be reached.

8. Conclusion

Establishing the physical activity and associated social differentiation of a past population based on the skeleton is a fascinating yet precarious area of research. Looking at osteoarthritis and musculoskeletal stress markers on the skeleton provides tantalizing glimpses into past life, yet does not allow the osteoarchaeologist to draw many detailed conclusions. For the Middenbeemster collection, it can be concluded that the inhabitants of the Beemster led a physically strenuous life, as both the prevalence rates of osteoarthritis and the lack of pronounced handedness in both OA and musculoskeletal stress marker data support this hypothesis. These people lived in a farming village prior to the arrival of advanced technological aids. The majority of them worked hard from an early age (early occurrence of OA), performing manual labor on dairy farms, crop farms, serving the higher class, or producing products. The women performed different tasks than the men, and the evidence of this gendered division of labor is seen in the differences in their muscle attachment sites. Two specimens show markedly low scores of musculoskeletal markers and no osteoarthritis. These individuals might well have belonged to the social elite.

The picture thus painted by these skeletal markers of activity fits in well with the historical data for the non-industrialized rural Beemster population. But does this mean that both activity markers are reliable? Osteoarthritis is surely a useful pathological indicator of physical stress on a population level. It cannot however be used to establish different professions or social statuses within a population, at least not as an isolated activity marker. Given the current trend in research towards inter-population rather than intra-population research, osteoarthritis is certainly a valuable indicator of activity. Even so, the limitations and confounding factors must be kept in mind, and more research into etiology is necessary, especially as genetics will play a larger role on the inter-population level.

As for musculoskeletal stress markers, too little is known of the factors at work in their formation, necessitating the use of great caution in and with any study which uses them (including this study). If knowledge of MSM's is to be gained through osteoarchaeological studies, it will take decades to reach any degree of consensus on their viability as an activity marker. It would be much better to first gain knowledge through research on modern skeletons and cadavers. Also, for both activity markers, more uniformity in registration of the skeletal traits is necessary to increase comparability between studies. Even so, every new study does add valuable data to the field of activity marker research. This particular study confirmed once again that musculoskeletal stress markers are positively correlated with age, and that for osteoarthritis, although the prevalence was surprisingly uncorrelated with age, the severity did go up with age.

Lastly, the slightly enigmatic concept of 'bone formers' must be addressed by further research. If this is indeed a genetic predisposition that will influence every bony reaction, it is of the highest importance that more become known about the how, when, what and who of generalized non-pathological hypertrophic bone formation.

The final conclusion of this thesis is therefore that although osteoarthritis and musculoskeletal stress markers can lift a tip of the veil around physical activity and social differentiation in the past, they provide insufficient reliable data to achieve a detailed picture, especially as the correlation between these activity markers is rather slight. However, adding information about all other activity markers to the data collected in this study will bring the activity patterns and social differentiation in Middenbeemster into better focus. Only through continuing research can the complete, true picture of the past be revealed.

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Extra literature

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9. Appendixes

Appendix A: Muscle movement

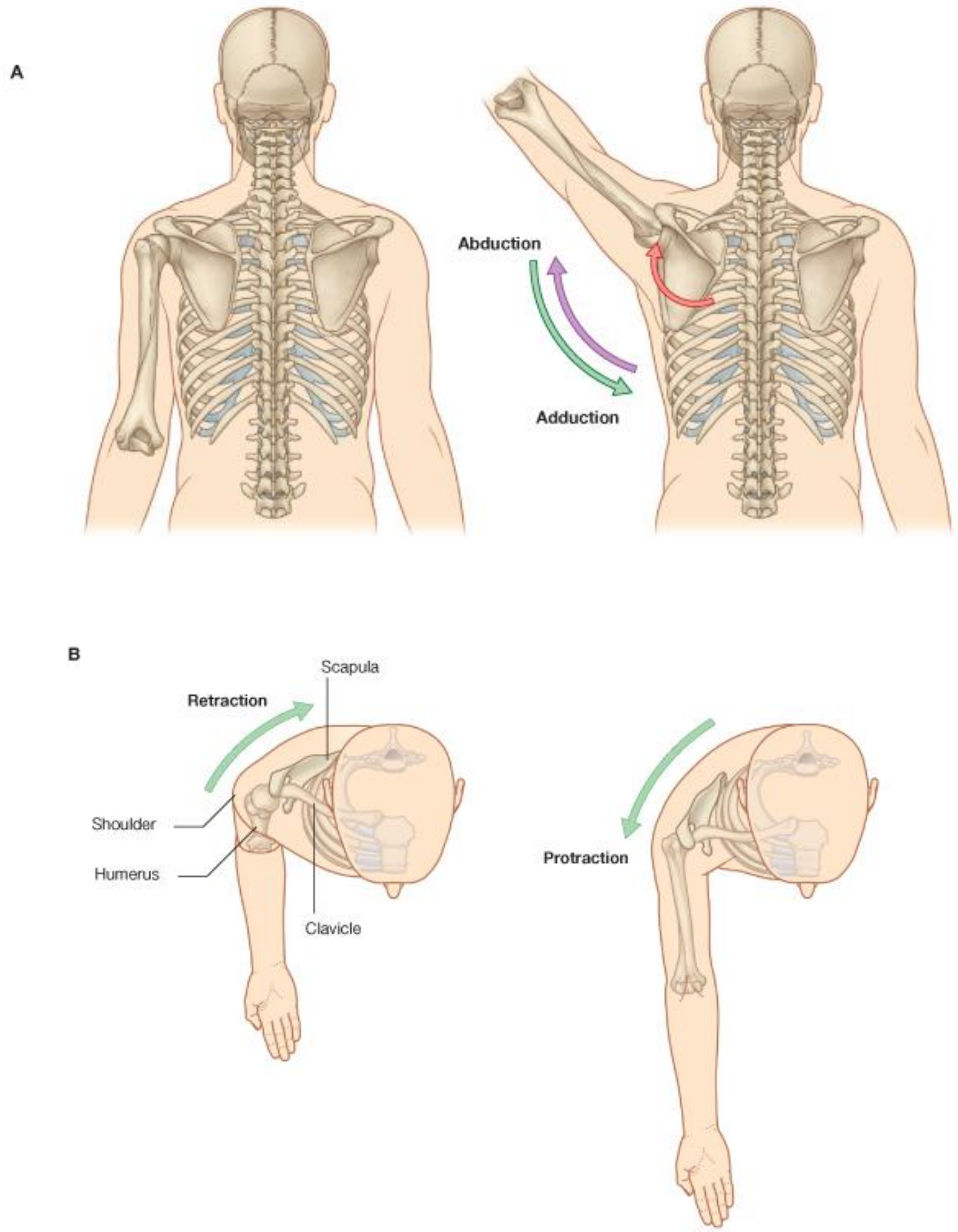

Figure A.1: Movements of the scapula. A: rotation. B: retraction and protraction (Drake et al. 2010, 610)

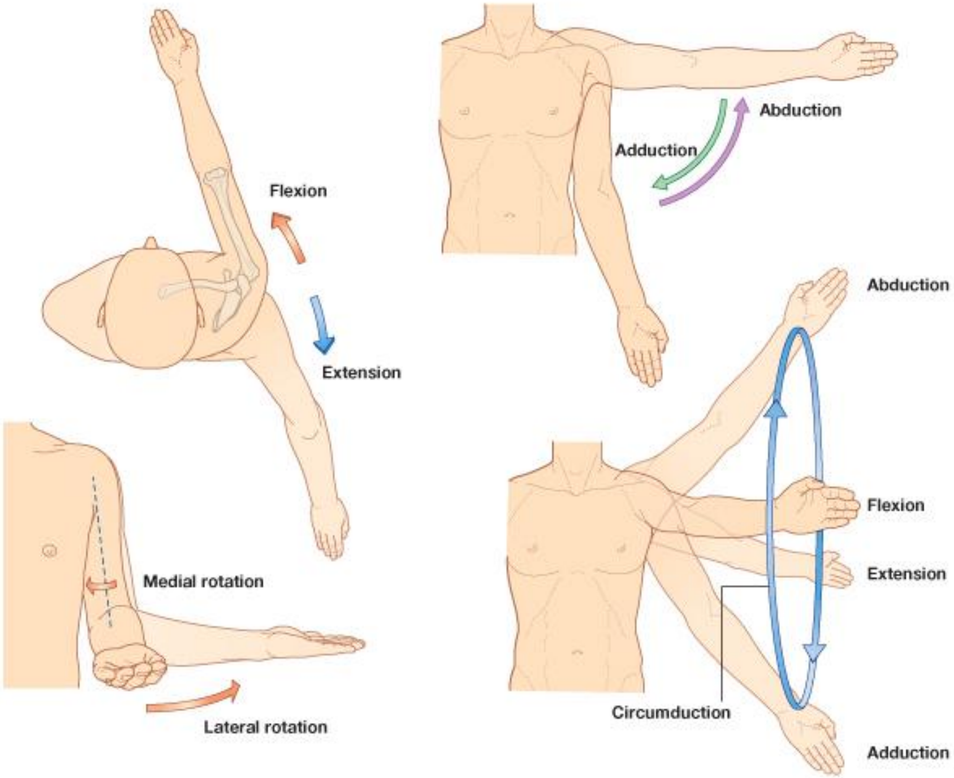

Figure A.2: Movements of the arm at the glenohumeral joint (Drake et al. 2010, 611)

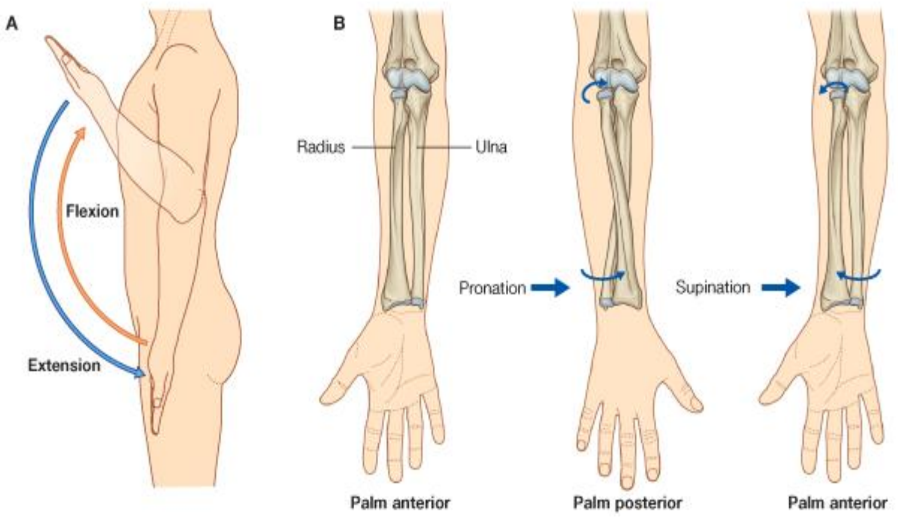

Figure A.3: Movements of the lower arm. A: flexion and extension at the elbow. B: pronation and supination (Drake et al. 2010, 611)

Appendix B: Data Recording Form

Specimen number: Date recorded:
Sex: Age:

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1. **Osteoarthritis:**

Score : 0 = Absent; 1 = Mild; 2 = Moderate; 3 = Severe
(mark "/" if skeletal element not present, "NR" if not recordable)

	Left	Right
ACROMIOCLAVICULAR		
Clavicle: Acromial end		
Scapula: Acromion		
SHOULDER		
Glenoid		
Humeral Head		
ELBOW		
Humerus: Capitulum		
Humerus: Trochlea		
Radial head		
Proximal ulna		

Comments:

2. **MSM**

Score: Osteolytic formation (OL): 0 – 1 – 2 – 3a – 3b
Osteophytic formation (OF): 0 – 1 – 2 – 3
Robusticity (Rob): 1 – 2 – 3
(mark "/" if skeletal element not present, "NR" if not recordable)

	Left			Right		
	Rob	OF	OL	Rob	OF	OL
HUMERUS						
M. Pectoralis major						
M. lat. Dorsii/Teres major						
M. Deltoideus						
M. Brachioradialis						
RADIUS						
M. Biceps Brachii						
ULNA						
M. Triceps Brachii						

Comments:

Appendix C: Frequencies of OA scores

The following two bar charts illustrate the frequency of each osteoarthritis score per joint surface. Scores range from absent to severe (0-3), with score 4 and 5 being respectively not recordable and skeletal element absent.

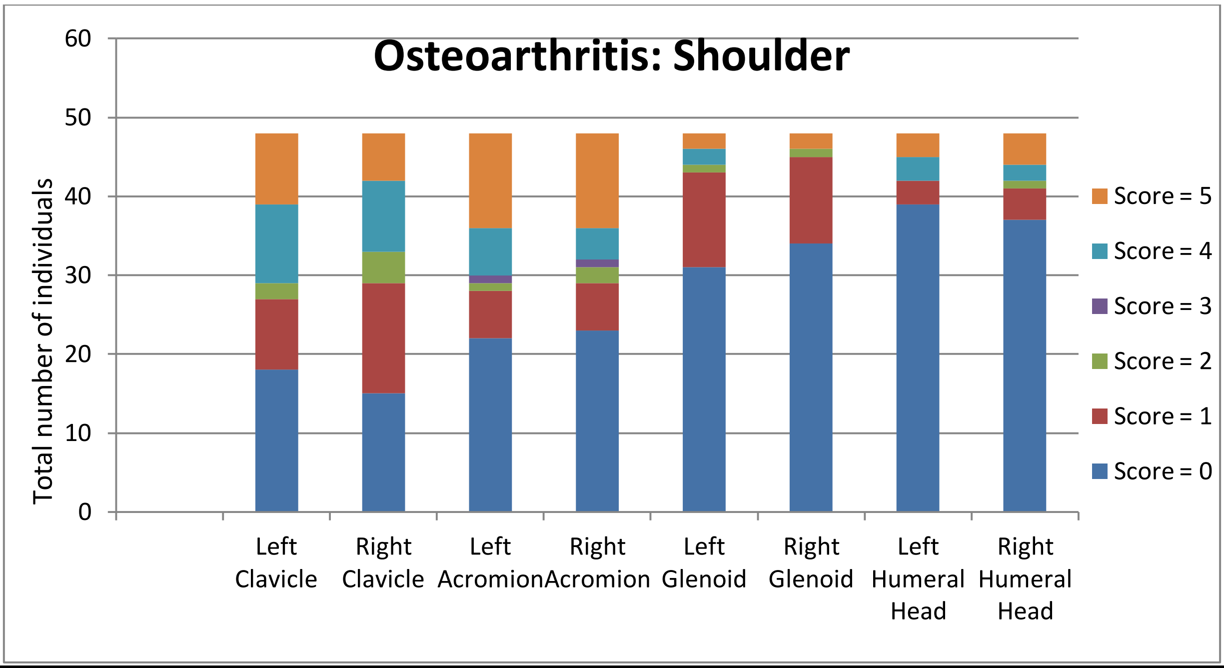


Figure C.1: Bar chart showing the frequencies of each osteoarthritis score per element of the shoulder complex. 0 = absent, 1 = mild, 2 = moderate, 3 = severe, 4 = not recordable, 5 = absent.

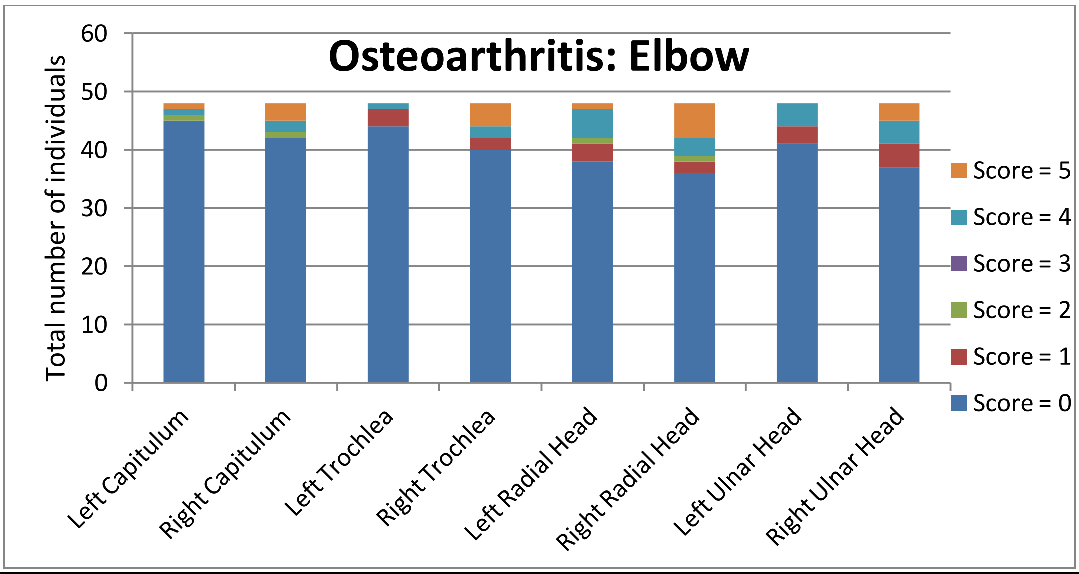


Figure C.2: Bar chart showing the frequencies of each osteoarthritis score per element of the shoulder complex. 0 = absent, 1 = mild, 2 = moderate, 3 = severe, 4 = not recordable, 5 = absent.

Appendix D: Frequencies of MSM score per muscle attachment site

The following tables show the frequency of different score per muscle attachment site. The left and right sides are presented in one table as separate bars. As robusticity scores range from 1-3, scores of zero are absent for this trait. A score of four signifies that the skeletal element was present, yet the muscle attachment site was too damaged or degraded to score, thus the trait was not recordable. A score of five signifies that the skeletal element was not present.

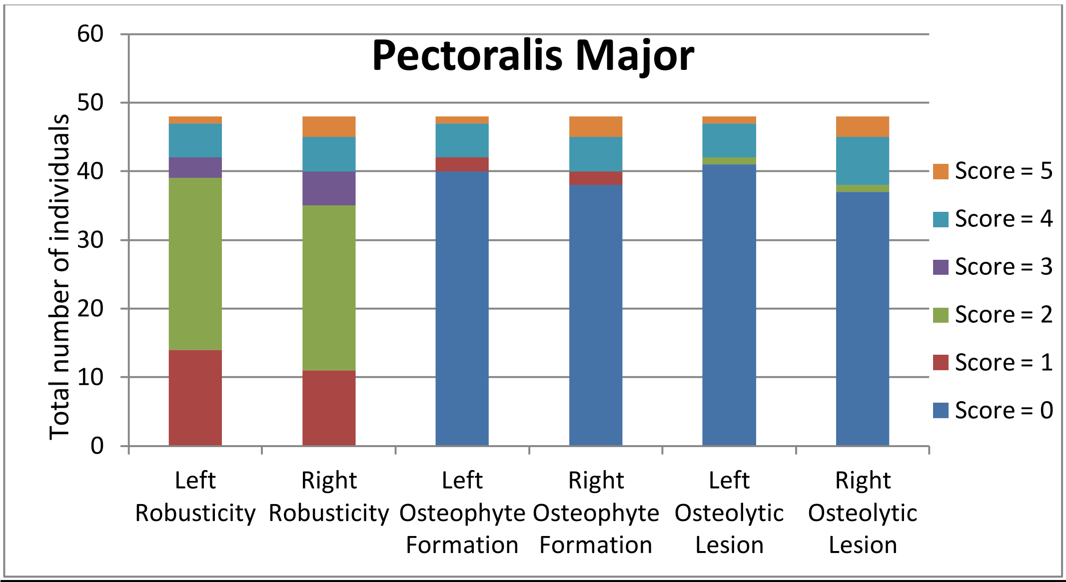


Figure D.1: bar chart representing the relative frequency with which an MSM score was given to the left and right pectoralis major for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

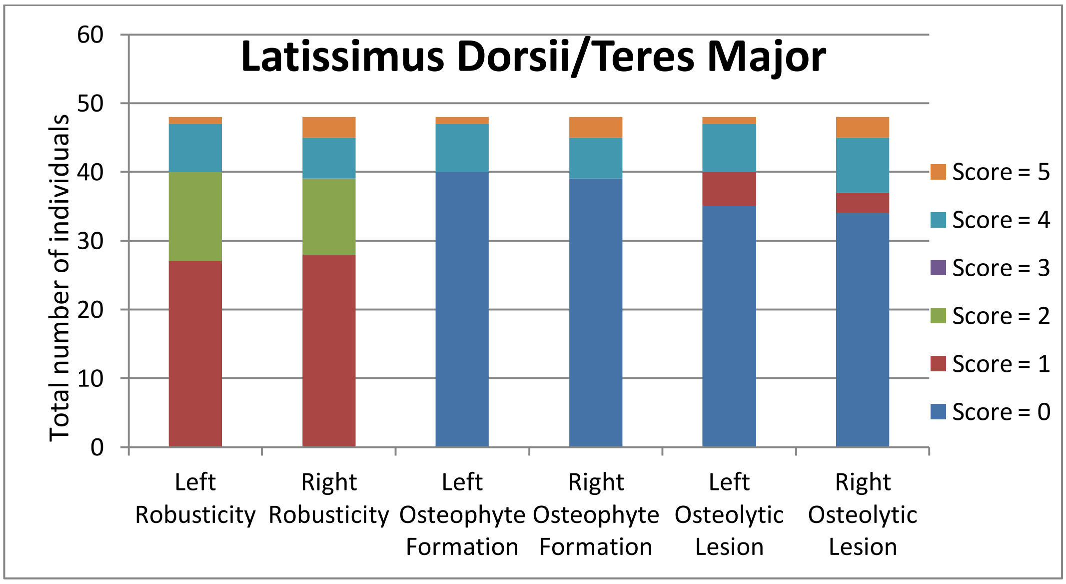


Figure D.2: bar chart representing the relative frequency with which an MSM score was given to the left and right latissimus dorsii/teres major for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

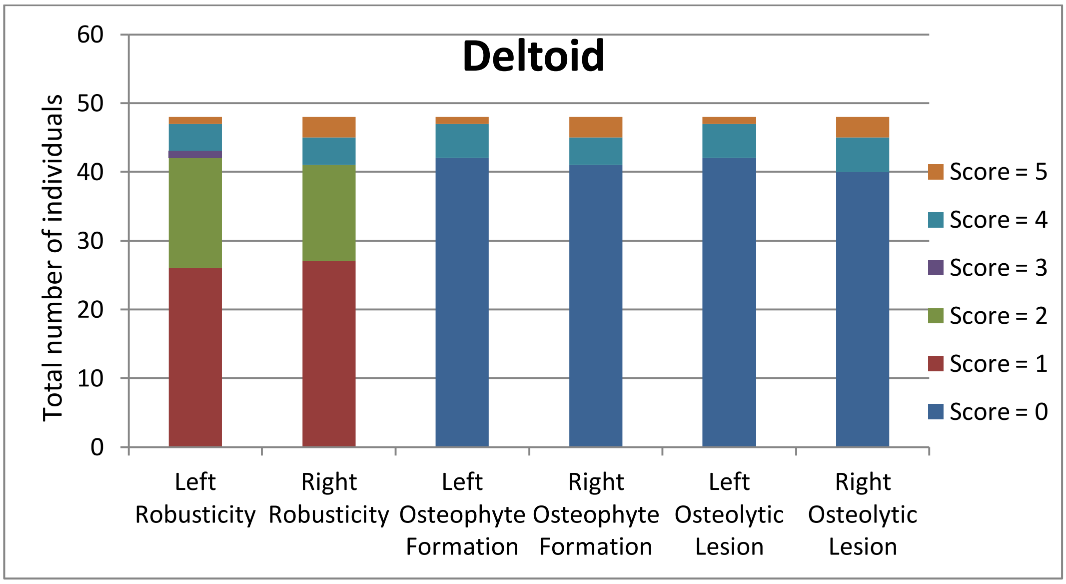


Figure D.3: bar chart representing the relative frequency with which an MSM score was given to the left and right deltoid for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

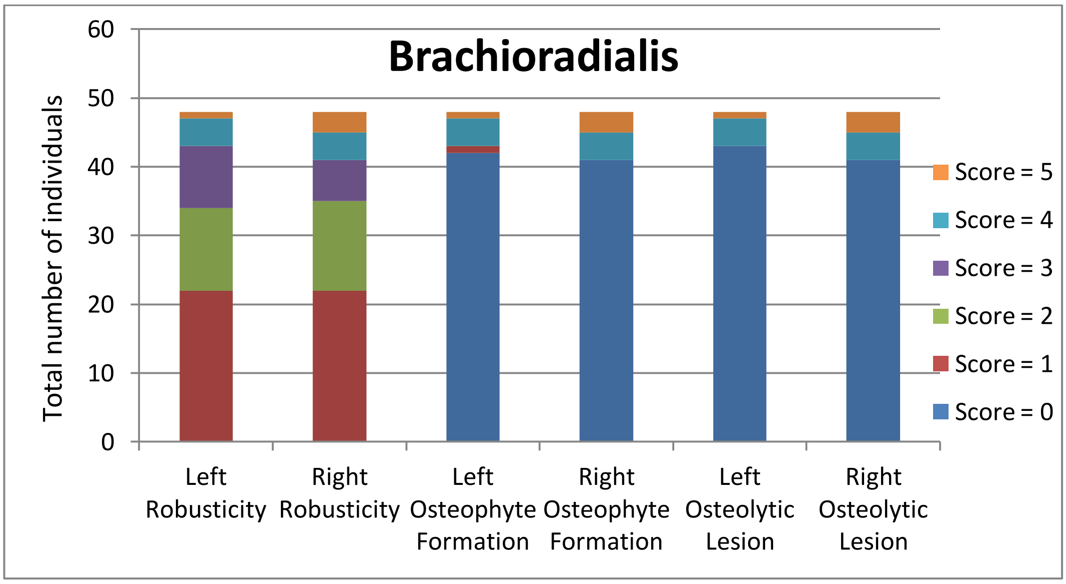


Figure D.4: bar chart representing the relative frequency with which an MSM score was given to the left and right brachioradialis for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

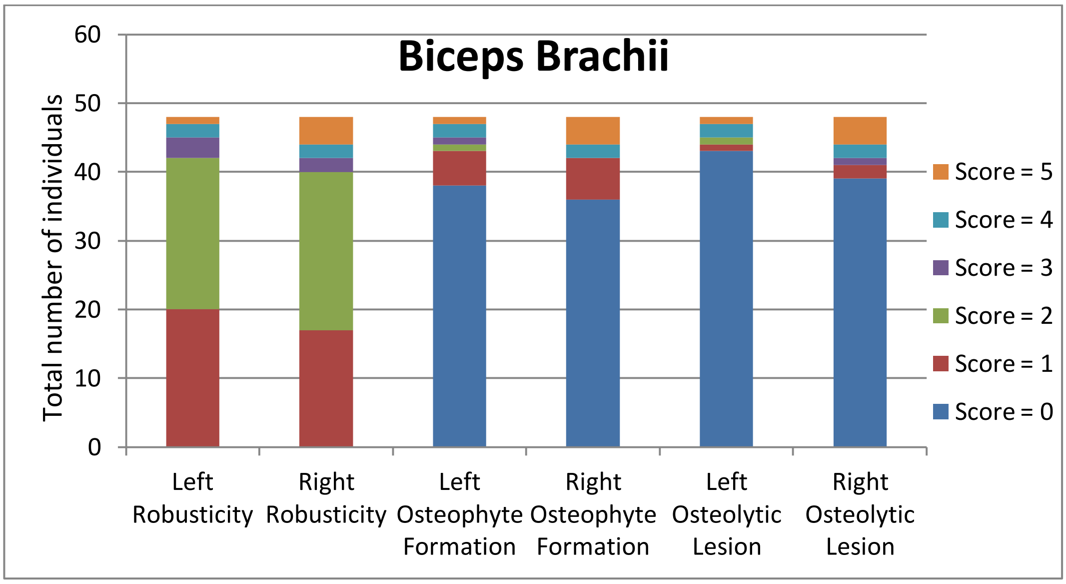


Figure D.5: bar chart representing the relative frequency with which an MSM score was given to the left and right biceps brachii for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

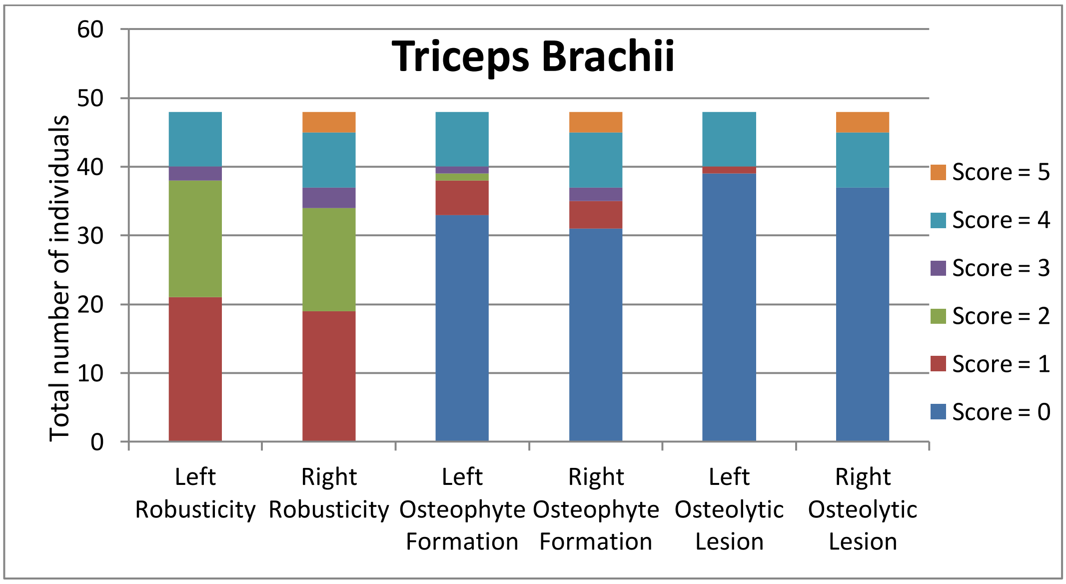


Figure D.6: bar chart representing the relative frequency with which an MSM score was given to the left and right triceps brachii for robusticity, osteophyte formation and osteolytic lesion formation.. Score 0= absent (not possible for robusticity), 1 = least development, 2 = moderate development, 3 = pronounced development.

Appendix E: MSM correlation table

The following table shows the Spearman's rho test executed to analyze handedness based on individual muscle attachment sites, as well as to analyze possible correlations between individual muscles. The table has been split into four subtables.

Correlations

			PecMajL	PecMajR	LatDorsL	LatDorsR
Spearman's rho	PecMajL	Correlation Coefficient	1,000	,642**	,406**	,144
		Sig. (2-tailed)	.	,000	,009	,388
		N	42	39	40	38
	PecMajR	Correlation Coefficient	,642**	1,000	,456**	,288
		Sig. (2-tailed)	,000	.	,004	,075
		N	39	40	38	39
	LatDorsL	Correlation Coefficient	,406**	,456**	1,000	,247
		Sig. (2-tailed)	,009	,004	.	,135
		N	40	38	40	38
	LatDorsR	Correlation Coefficient	,144	,288	,247	1,000
		Sig. (2-tailed)	,388	,075	,135	.
		N	38	39	38	39
	DeltL	Correlation Coefficient	,330*	,576**	,464**	,053
		Sig. (2-tailed)	,033	,000	,003	,753
		N	42	39	40	38
	DeltR	Correlation Coefficient	,359*	,569**	,523**	,109
		Sig. (2-tailed)	,025	,000	,001	,511
		N	39	40	38	39
	BracradL	Correlation Coefficient	,333*	,369*	,338*	,189
		Sig. (2-tailed)	,036	,025	,038	,269
		N	40	37	38	36
	BracradR	Correlation Coefficient	,130	,305	,273	,103
		Sig. (2-tailed)	,437	,059	,102	,540
		N	38	39	37	38
	BicBracL	Correlation Coefficient	,185	,301	,383*	,271
		Sig. (2-tailed)	,261	,070	,019	,110
		N	39	37	37	36
	BicBracR	Correlation Coefficient	,056	,151	,120	,210
		Sig. (2-tailed)	,740	,360	,479	,206
		N	38	39	37	38
	TricbracL	Correlation Coefficient	,207	,341	,209	,492**
		Sig. (2-tailed)	,233	,052	,244	,004
		N	35	33	33	32
	TricBracR	Correlation Coefficient	,266	,392*	,160	,195
		Sig. (2-tailed)	,116	,020	,367	,269
		N	36	35	34	34

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			Delt L	Delt R	Bracrad L	Bracrad R
Spearman's rho	PecMaj L	Correlation Coefficient	,330*	,359*	,333*	,130
		Sig. (2-tailed)	,033	,025	,036	,437
		N	42	39	40	38
	PecMaj R	Correlation Coefficient	,576**	,569**	,369*	,305
		Sig. (2-tailed)	,000	,000	,025	,059
		N	39	40	37	39
	Lat Dors L	Correlation Coefficient	,464**	,523**	,338*	,273
		Sig. (2-tailed)	,003	,001	,038	,102
		N	40	38	38	37
	Lat Dors R	Correlation Coefficient	,053	,109	,189	,103
		Sig. (2-tailed)	,753	,511	,269	,540
		N	38	39	36	38
	Delt L	Correlation Coefficient	1,000	,947**	,279	,191
		Sig. (2-tailed)	.	,000	,077	,250
		N	43	39	41	38
	Delt R	Correlation Coefficient	,947**	1,000	,222	,210
		Sig. (2-tailed)	,000	.	,179	,194
		N	39	41	38	40
	Bracrad L	Correlation Coefficient	,279	,222	1,000	,832**
		Sig. (2-tailed)	,077	,179	.	,000
		N	41	38	43	39
	Bracrad R	Correlation Coefficient	,191	,210	,832**	1,000
		Sig. (2-tailed)	,250	,194	,000	.
		N	38	40	39	41
	Bic Brac L	Correlation Coefficient	,163	,219	,200	,112
		Sig. (2-tailed)	,315	,185	,215	,505
		N	40	38	40	38
	Bic Brac R	Correlation Coefficient	,231	,167	,360*	,261
		Sig. (2-tailed)	,158	,304	,024	,103
		N	39	40	39	40
	Tricbrac L	Correlation Coefficient	-,056	,088	,144	,192
		Sig. (2-tailed)	,746	,621	,396	,277
		N	36	34	37	34
	Tric Brac R	Correlation Coefficient	,153	,214	,127	,251
		Sig. (2-tailed)	,364	,217	,460	,152
		N	37	35	36	34

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			BicBrac L	BicBrac R
Spearman's rho	PecMaj L	Correlation Coefficient	,185	,056
		Sig. (2-tailed)	,261	,740
		N	39	38
	PecMaj R	Correlation Coefficient	,301	,151
		Sig. (2-tailed)	,070	,360
		N	37	39
	LatDors L	Correlation Coefficient	,383*	,120
		Sig. (2-tailed)	,019	,479
		N	37	37
	LatDors R	Correlation Coefficient	,271	,210
		Sig. (2-tailed)	,110	,206
		N	36	38
	Delt L	Correlation Coefficient	,163	,231
		Sig. (2-tailed)	,315	,158
		N	40	39
	Delt R	Correlation Coefficient	,219	,167
		Sig. (2-tailed)	,185	,304
		N	38	40
	Bracrad L	Correlation Coefficient	,200	,360*
		Sig. (2-tailed)	,215	,024
		N	40	39
	Bracrad R	Correlation Coefficient	,112	,261
		Sig. (2-tailed)	,505	,103
		N	38	40
	BicBrac L	Correlation Coefficient	1,000	,708**
		Sig. (2-tailed)	.	,000
		N	45	39
	BicBrac R	Correlation Coefficient	,708**	1,000
		Sig. (2-tailed)	,000	.
		N	39	42
	Tricbrac L	Correlation Coefficient	,212	,187
		Sig. (2-tailed)	,201	,281
		N	38	35
	TricBrac R	Correlation Coefficient	,251	,241
		Sig. (2-tailed)	,139	,156
		N	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			TricbracL	TricBracR
Spearman's rho	PecMajL	Correlation Coefficient	,207	,266
		Sig. (2-tailed)	,233	,116
		N	35	36
	PecMajR	Correlation Coefficient	,341	,392*
		Sig. (2-tailed)	,052	,020
		N	33	35
	LatDorsL	Correlation Coefficient	,209	,160
		Sig. (2-tailed)	,244	,367
		N	33	34
	LatDorsR	Correlation Coefficient	,492**	,195
		Sig. (2-tailed)	,004	,269
		N	32	34
	DeltL	Correlation Coefficient	-,056	,153
		Sig. (2-tailed)	,746	,364
		N	36	37
	DeltR	Correlation Coefficient	,088	,214
		Sig. (2-tailed)	,621	,217
		N	34	35
	BracradL	Correlation Coefficient	,144	,127
		Sig. (2-tailed)	,396	,460
		N	37	36
	BracradR	Correlation Coefficient	,192	,251
		Sig. (2-tailed)	,277	,152
		N	34	34
	BicBracL	Correlation Coefficient	,212	,251
		Sig. (2-tailed)	,201	,139
		N	38	36
	BicBracR	Correlation Coefficient	,187	,241
		Sig. (2-tailed)	,281	,156
		N	35	36
	TricbracL	Correlation Coefficient	1,000	,718**
		Sig. (2-tailed)	.	,000
		N	40	36
	TricBracR	Correlation Coefficient	,718**	1,000
		Sig. (2-tailed)	,000	.
		N	36	39

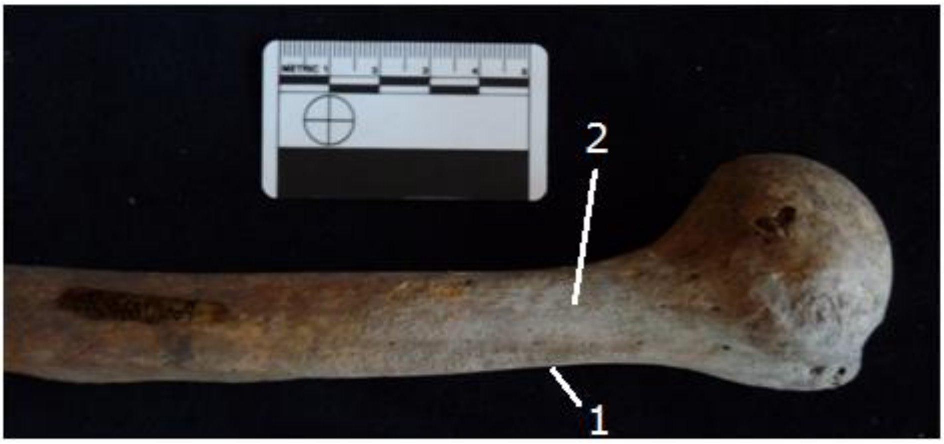
**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

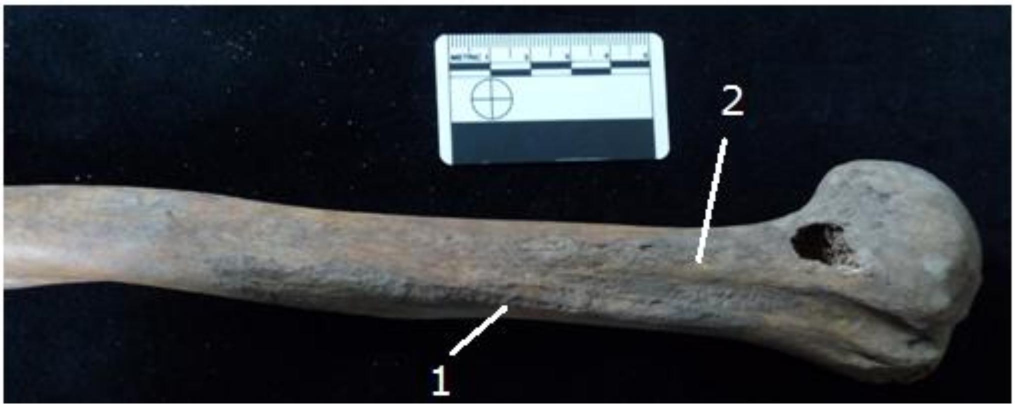
Appendix F: Example pictures of musculoskeletal markers

Making clear representative pictures of MSM's is not an easy feat, as so much depends on the tactile evaluation of rugosity and making a 2D image of a three-dimensional element inevitably means some information is lost. These images are therefore only meant to give an indication of each musculoskeletal stress marker score. They must not be taken to be absolute representations of MSM scores.

a) Pectoralis major and latissimus dorsi/teres major



Individual MB11S468V1009: Score 1 robusticity for both pectoralis major and latissimis dorsii/teres major in a middle adult female. Note the smooth surface of the proximal humeral diaphyses, absence of pronounced crests and rugosity



Individual MBS402V0907: Robusticity score 2 for both pectoralis major (1) and latissimus dorsii/teres major (2) in a middle adult male. Note the formation of two distinct crests, one on either side of the intertubercular sulcus (groove running from the humeral head) and the appearance of a longitudinal fossa on the pectoralis major attachment

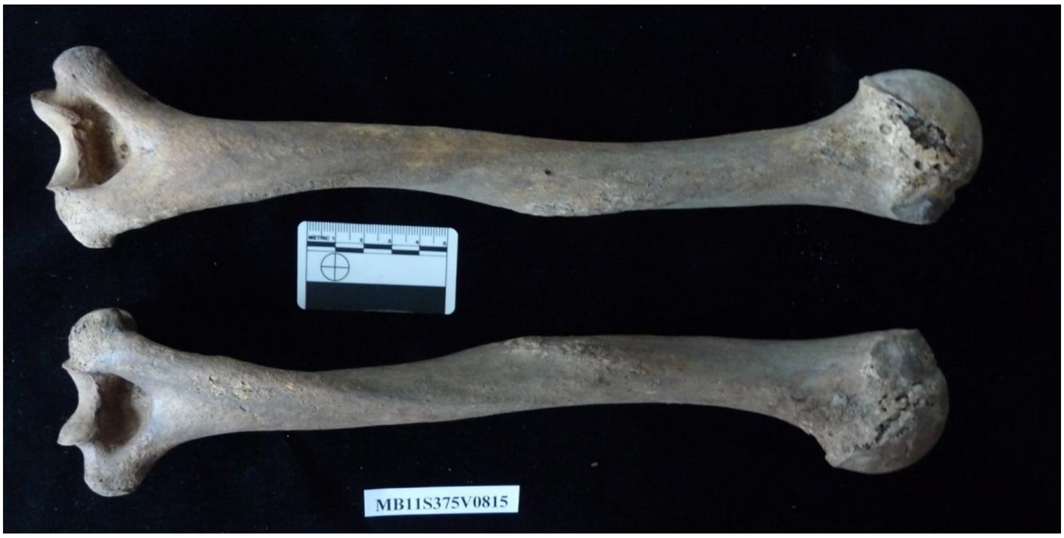
Individual MB11S358V0763: Robusticity of 3 (maximum robusticity) of the pectoralis major (upper crest on the picture) of a middle adult female.

Individual MB11S358V0763: score 1 osteophyte formation on the pectoralis major of a middle adult female. Note the tiny hooks of bone.

b) Deltoid

Individual MB11S358V0763: Deltoid robusticity of 2 on the left humerus of a middle adult female

Individual MB11S358V0763: Deltoid robusticity of 2 on the left humerus of a middle adult female, close-up of the humeral diaphyses showing the two deltoid crests which are raised and moderately rugose



Individual MB11S375V0815: Deltoid robusticity scores of 3 (maximum score) on an old adult male. Humeri photographed in posterior view to show lateral crest. Individual not used in study.

c) Brachioradialis

MB11S467V1022 Brachioradialis robusticity score 1 in a late young adult male. No crest is visible, the surface of the muscle attachment site is smooth

Brachioradialis robusticity score 3 (maximum score) in a late young adult male. Note the sail-like projecting crest.

d) Biceps brachii

Individual MB11S487V1096: Biceps brachii score 1 robusticity in a late young adult female

Individual MB11S488V1037: Biceps brachii score 2 robusticity in a middle adult female. Slight osteophyte formation (score 1) on the lower rim.

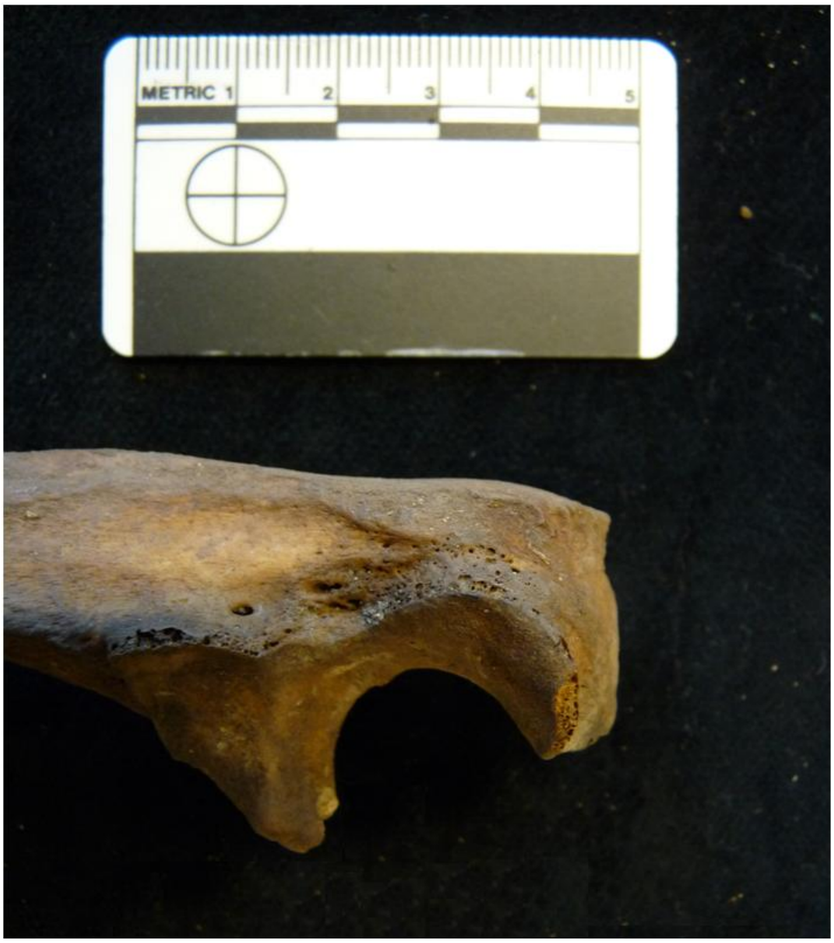
Individual MB11S432V0981: robusticity score 3 (maximum robusticity) in a late young adult male

Individual MBS402V0907: Grade two osteophyte formation on the biceps bachii of a middle adult male.

Individual MB11S427V0938: Osteolytic lesions score 3 (maximum score) on the biceps brachii attachment site of a late young adult male (robusticity score 2, no osteophytes)

e) Triceps brachii

Individual MBS402V0907: Robusticity score 1 for the triceps brachii on a middle adult male



Individual MB11S088V0094: Robusticity score 2 for the triceps brachii on a late young adult female

Individual MBS356V0864: Robusticity score 3 (maximum robusticity) and osteophyte formation score 3 (maximum osteophyte formation) for the triceps brachii of a middle adult female.

Appendix G: Example pictures of osteoarthritis

As for musculoskeletal stress markers, making good images of osteoarthritis (and especially eburnation) is not easy. The following pictures are meant as illustrations of OA, not as absolute representations of what each stage of osteoarthritis looks like. When the joint surface is shown, the angle can obscure the osteophyte formation and lipping and vice versa.

MB11S358V0763 moderate osteoarthritis on the acromial end of the left clavicle of a middle adult female

MB11S358V0763 mild osteoarthritis on the acromion of the scapula, corresponding with clavicle pictured above. Note how the joint disease is less severely manifested on the scapula

Individual MB11S053V0290: moderate osteoarthritis in the glenoid of a middle adult female. Note the porosity and lipping

Individual MB11S524V1120: osteoarthritis on the radial head of a middle adult male. Note the porosity and osteophyte formation.

Individual MB11S524V1120: osteoarthritis on the capitulum of the humerus of a middle adult male, corresponding to the radial head shown above.

Abstracts

English abstract

From the Dutch cemetery of Middenbeemster, individuals from the rural community of the Beemster were excavated, mostly dating to the nineteenth century. The Beemster had an agriculture-based economy, focused on dairy farming. It was a relative latecomer to modernization and farming machinery. This dissertation establishes levels of physical activity and associated social differentiation in the Beemster, based upon skeletal markers of activity in the upper limbs. These are osteoarthritis (OA) and musculoskeletal stress markers (MSM's). OA is a joint disease, and MSM's are the sites at which muscles attach to bone, whose morphology may be indicative of muscle use and strain. The high prevalence of OA established that this population engaged in generally strenuous physical labor, more so than contemporaneous Dutch settlements. Although OA severity increased with age, its prevalence did not, indicating that joint-related wear was already occurring in young adults. MSM's suggested a gendered division of labor. Males had more pronounced MSM's in all sites but the triceps brachi. Males were especially involved in activities exercising the biceps and brachioradialis, as these showed the highest sexual dimorphism. In general, the pectoralis major muscle was highly pronounced, whereas the multifunctional deltoid muscle was the least developed. There was a clear positive correlation of MSM's with age. The high symmetry between upper limbs in OA and MSM results also points to strenuous physical activity. Two young adult females had low scores for OA and MSM's, suggesting they led less strenuous lives and could have belonged to a more elite class. The study also evaluated the usefulness of the methods. Both need further study to become reliable, especially MSM research which is in its infancy. Osteoarthritis was concluded to be most useful on an inter-population level. There was a very low correlation between OA and MSM's, thus combining them to reconstruct activity in past populations is of limited use. Further standardization of scoring methods is also necessary for both skeletal activity markers. Overall, this research contributed to our understanding of OA and MSM's as activity markers, both separately and combined, while also providing new data on activity levels in a post-medieval Dutch population.

Dutch abstract

Op een kerkhof te Middenbeemster (Nederland) werden individuen uit de rurale gemeenschap van de Beemster opgegraven, voornamelijk daterend tot de negentiende eeuw. De Beemster had een op landbouw gebaseerde economie met een focus op melkvee. Het was een laatkomer in de modernisatie en invoer van landbouwmachinerie. Deze thesis bepaalt het niveau van fysieke activiteit en de geassocieerde sociale differentiatie in de Beemster, op basis van kenmerken op het skelet. Deze zijn osteoarthrose (OA) en morfologische verschijningsvormen van spieraanhechtingen op bot ("MSM's"). OA is een gewrichtsaandoening, en MSM's zouden indicatief zijn van het spiergebruik. OA bewees dat deze populatie zware fysieke arbeid verrichte, zwaarder dan gelijktijdige Nederlandse nederzettingen. Hoewel de graad van OA toenam met leeftijd, bleef het aantal gevallen per leeftijdscategorie gelijk, waaruit blijkt dat jongvolwassenen reeds slijtage aan hun gewrichten vertoonden. MSM data toonden een seksuele verdeling van wer. Mannen hadden sterker ontwikkelde MSM's op alle sites behalve de triceps brachii. Mannen gebruikten met name hun biceps en brachioradialis meer. Algemeen was de pectoralis major sterk ontwikkeld, waar de multifunctionele deltoideus de minst ontwikkelde MSM was. MSM's toonden een duidelijke positieve correlatie met leeftijd. De sterke symmetrie tussen beide armen in zowel OA als MSM's wijst ook op zware fysieke activiteit. Twee jongvolwassen vrouwen hadden lage scores voor zowel OA als MSM's, wat erop wijst dat zij mogelijks minder zwaar fysiek werk verrichten en tot een meer elitaire klasse behoorden. Een tweede doel van deze studie was de twee methodes te testen op bruikbaarheid. Zowel osteoartrose als MSM's moeten verder onderzocht worden om betrouwbaar te worden als bewijs van activiteit. MSM onderzoek staat echt nog in de kinderschoenen. OA wordt best gebruikt op het inter-populatie niveau. Er was heel weinig correlatie tussen OA en MSM's, dus ze combineren om de activiteit van archeologische populaties te achterhalen is van beperkt nut. Verdere standaardisatie van de registratiemethoden is ook noodzakelijk voor OA en MSM's. Algemeen heeft dit onderzoek bijgedragen aan onze kennis van OA en MSM's als activiteitskenmerken, zowel apart als gecombineerd, terwijl het ook nieuwe data aanbracht over de fysieke activiteit in een postmiddeleeuwse Nederlandse populatie.