A key to past occupations

Activity related osteoarthritis in human remains from the Medieval and Post-Medieval period of North-West Europe

Esther 't Gilde BSc

Studentnr: s0952907

Bachelor scriptie: ARCH 1043BASCRY

Supervisor: Dr. A.L. Waters-Rist

Universiteit Leiden, Faculteit der Archeologie

Utrecht, 13 June 2012

Table of contents

Chapter 1 - Introduction

The history of research on activity and osteoarthritis (OA) goes back a long time. Angel's (1966) pioneering work on prehistoric activity patterns talks about changes in the elbow because of intense and repeated throwing of a spear. Merbs (1983) researched the correlation of OA and activities such as hide scraping, cutting, and sewing or harpoon throwing and kayak peddling in the Hudson Bay Inuits. White (2011) looked at the prehistoric Stillwater Marsh population in Nevada, where women showed an increased rate of lumbar vertebral OA, interpreted as the carrying of heavy loads.

OA does not have a single cause; it is a multi-factorial process. Activity is one of the main factors linked to OA next to gender, age and disease (Kumar and Clark 2009). In the cases above, knowledge of past ways of life is needed to make strong associations between specific activities and osteoarthritis. This knowledge of historic or ethnographic activities is not always available. Certainly in older archaeological samples, information about occupation or activities is rarely at the archaeologist's disposal. If available, it may not always be as specific as needed for analysis (Jurmain 1999, 138). Therefore, it would be most helpful to know what kind of movements (e.g. kneeling, squatting) can lead to osteoarthritis, without needing to know the specific historical or ethnological activity.

Also, the apparently clear relationship between activity and osteoarthritis is not as straightforward as it may seem. Jurmain (1999, 51) explains that in the osteological research world "many researchers agree that chronic overuse is a major cause" of joints wearing out and so of OA. But, on the same page, he states that "the hypothesis is far from widely accepted by clinical researchers".

Petersson and Jacobsson (2002) mention that the prevalence of OA in Europe and America is generally higher than elsewhere in the world. A search of only one population (e.g. North Western Europeans) narrows down the risk of a different expression due to geographical differences. The Medieval and post-Medieval period is interesting as little research has yet been done in this time frame.

In this thesis I will elucidate the complicated relationship between activity and OA. I will do this by looking at recent clinical literature on the subject and I will compare this to research done in the archaeological field.

1.1 Osteoarthritis

The word osteoarthritis, ending in "–itis", suggests it is infectious disease. However, this is not correct as usually there is no infection. Osteoarthritis is a degenerative disease which affects synovial joints (Robbins 2005, 1304). OA mostly occurs in weight bearing joints, especially the spine, hip and knees (White et al. 2011, 441). It is the most common joint disease in both modern and ancient times (Rogers and Waldron 1995, 32).

The main symptoms of OA are joint pain, instability and gelling. Gelling includes stiffness and pain after immobilization (for example, getting up in the morning). Signs pointing towards OA can be joint tenderness, crepitus on movement, limitation of range of movement, bony swellings and / or wasting of muscles (Kumar and Clark 2009, 520).

As mentioned, the etiology of OA is still very much debated. Many factors are involved but it is certain that mechanical factors have a significant role (Kumar and Clark 2009; Ortner 2003; Jurmain 1977; Waldron 1997). Jurmain (1999, 50) states this can be clearly seen "by the onset of degenerative changes following severe trauma". OA is divided into two categories based upon cause: primary and secondary osteoarthritis. Primary OA is caused by factors such as (old) age, systemic factors (e.g. hormones), genetic predisposition, and mechanical stress (such as activity) (White et al. 2011, 441). An illustration of how these factors come together to cause OA can be seen in figure 1.

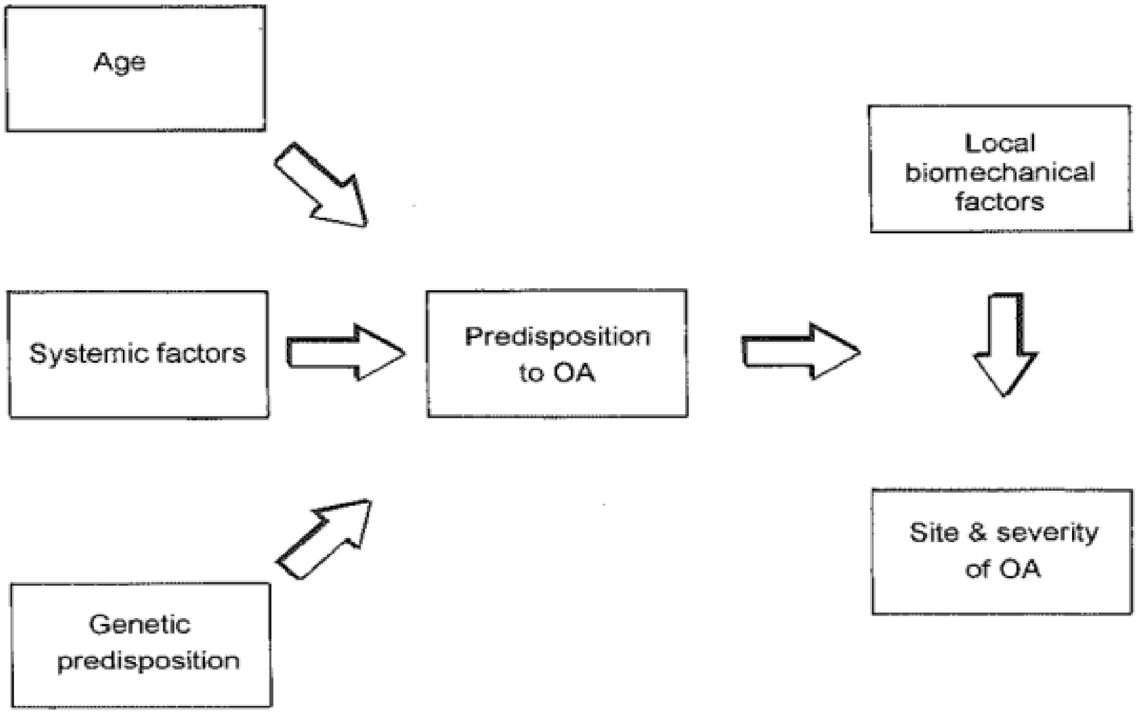

Figure 1. Causes of primary osteoarthritis (figure from Rogers and Waldron 1995, 34).

Secondary osteoarthritis is mostly seen at an earlier age and is caused by trauma or bacterial infections (White et al. 2011, 441).

For my thesis, I will focus on primary osteoarthritis (OA) because activity is seen as a factor related only to primary OA. Primary OA is an inherent part of the ageing process; everybody has some form of osteoarthritis by sixty years of age (White 2011, 441). Of course, not every person has clinical symptoms, which are said to occur in about 25% of cases (Kumar and Clark 2009, 518). The prevalence of OA increases with age and tends to be more common in females than in males in modern populations (Rogers and Waldron 1995, 32).

OA is one of the most commonly encountered skeletal pathology, next to trauma and infection, because it is easily observed on skeletal tissues once soft tissues have decomposed. Hence, there have been many studies of osteoarthritis by osteoarchaeologists such as Jurmain (1977; 1995; 2007). Recent studies have called for better research into the different factors causing osteoarthritis (such as activity) in (clinical) studies where the other factors are known (such as age and sex) (Weiss and Jurmain 2007).

Osteoarthritis is characterized by a focal loss of articular cartilage and the subsequent reaction of the bone to this. Osteoarthritis ranges from atrophic disease, in which there is only cartilage damage without any bone reaction, to hypertrophic disease in which there is massive reaction of the bone (Kumar and Clark 2009, 518-9). The three main components of OA are (Ortner 2003, 546):

1. Breakdown of articular cartilage.
2. Reactive bone formation or sclerosis of the subchondral bone and the underlying trabeculae, also possibly associated with bone cyst formation.
3. New growth of cartilage and bone at the joint margins, also called osteophytes.

Figure 2 is a simple representation of a normal joint and a joint affected by OA.

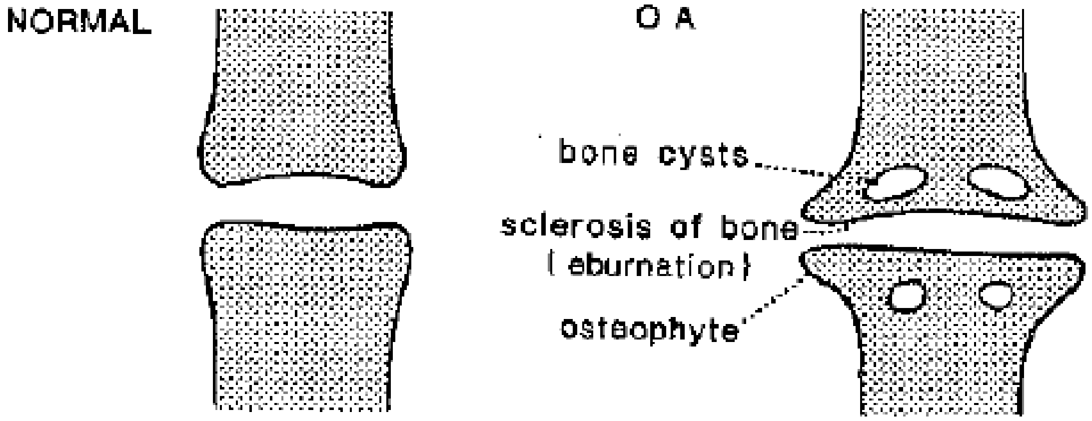

Figure 2. Normal joint vs. joint with OA (figure from Rogers and Waldron 1995, 7).

Figure 3 shows an X-ray of a knee joint with early osteoarthritis. On the medial side (on the left) the joint space is narrowed, due to thinning of the cartilage. The arrows show marginal osteophyte formation.

Figure 3. X-ray of a left knee (figure from Kumar and Clark 2009,519).

Diagnosis of OA in clinical and archaeological setting differs. Clinical diagnosis is mostly based on symptoms and radiology, especially joint space narrowing (Rogers and Waldron 1995, 43). These radiographs are taken when all tendons, cartilage, and other soft tissues are still present. As this cannot be replicated in the archaeological setting other criteria must be used. According to Rogers and Waldron (1995, 44), eburnation (a smooth shiny surface) is a good criteria for diagnosing OA. Otherwise, at least two of these signs must be present:

- Marginal osteophytes and/or new bone on the articular surface;
- Pitting on the joint surface; or
- Alterations of the bony contour of the joint.

In figure 4 we see a knee joint from prehistoric California in posterolateral view. The distal femur and proximal tibia exhibit signs of OA as used in archaeology. We can see marginal osteophytes on the edges of both the femur and tibia, porosity of the articular surfaces of both bones, and two patches of eburnation indicated by the arrows.

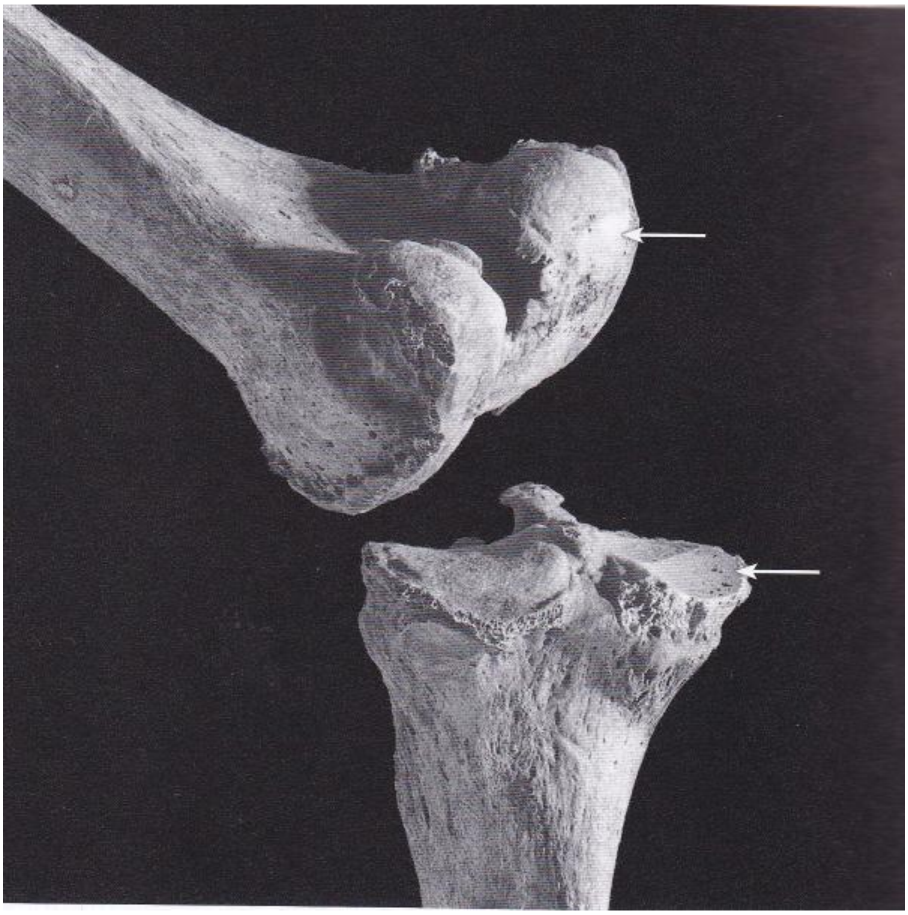

Figure 4. Knee with OA (figure from White 2011, 442).

Eburnation indicates where the cartilage has broken down to the point where the bones are articulating directly with each other, causing them to polish each other. This is mostly seen in severe cases of OA (Ortner 2003, 547) and tends to occur at the point of maximal mechanical loading of the joint. Sometimes the eburnation patch is grooved or scored; this generally occurs in the direction of the movement of the joint (Rogers and Waldron 1995, 35-6), particularly in joints with a hinge like action, such as the knee and elbow (Ortner 2003, 548).

Porosity and pitting sometimes takes place within the eburnation patch but it can also be present without. Pitting is sometimes associated with underlying subchondral cysts (Rogers and Waldron 1995, 37). Hough (2001, 2173) mentions that newly formed cartilage penetrates through gaps in the eburnated subchondral bone, which may be the origins of porosity.

Primary OA occurs in many joints in the human body. Figure 5 is a diagram showing which joints are the most frequently affected. Deep red represents "more commonly affected" and orange "less commonly affected". As we can see, load bearing joints such as the hip, knee and ankle are quite commonly affected, as well as the hands and the big toe.

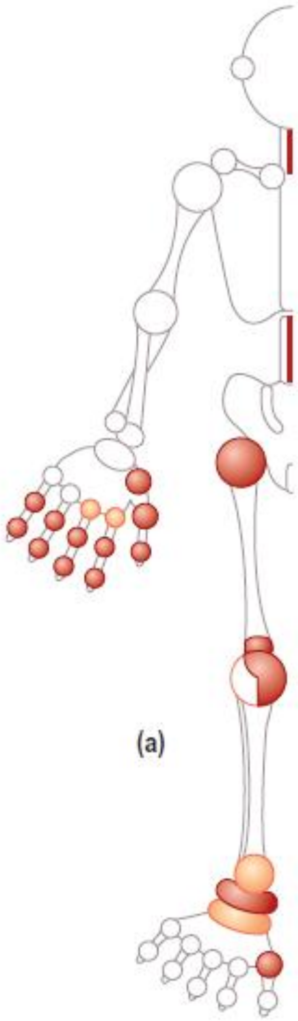

Figure 5. Joints affected by primary osteoarthritis (figure from Kumar and Clark 2009, 519).

1.2 Activity

Activity has various definitions. Activity can be described as a certain occupation such as mining or farming. It can also be defined as a certain movement of the joints such as kneeling or squatting. Activity described as an occupation is difficult to use as it does not mark out the actual movement of the joint. Two more reasons not to use this are first, as mentioned in the introduction, that the record of a profession of an individual is not always available. Second, in most cases occupations as found in the modern clinical literature are not the same jobs as they were in the Medieval or post-Medieval period. Hence, I have narrowed the search to articles speaking only of specific movements (or specific mechanical stress). In this manner, I will be able to compare this definition of activity to the archaeological literature.

1.3 Thesis objectives

For this thesis, I will improve the understanding of the relationship between activity and osteoarthritis. As stated in the introduction of this chapter, osteologists believe there to be a straightforward link between the two but this is yet to be proven by clinical researches.

I will review recent clinical literature on this topic to see what the status of the research is nowadays. I will determine which specific movements are the most likely to trigger OA. Finally, I will investigate what the recent research in archaeology states about the link between OA and activity, if it can be proven in this field and illustrate this by presenting a few case studies.

In the discussion, I will consider whether archaeological and clinical record can be compared, including a small discussion on the theory of the “osteological paradox”. The osteological paradox, as introduced by Wood et al. (1992), speaks of the three major problems in establishing a relationship between statistics calculated from archaeological skeletal material and the health status of the population they belonged to. These three problems are demographic non-stationarity, selective mortality, and unmeasured, individual- level heterogeneity in the risks of disease and death.

My main research question is as follows:

Can activity be detected in archaeological human skeletal remains in the Middle Ages of North-Western Europe?

There are two sub-questions that follow from this:

a) What types of activity cause the most frequent or severe osteoarthritis in groups from the Medieval and post-Medieval period of North Western Europe?

b) To what extent does the clinical data support the findings from the archaeological record?

Chapter 2 – Material and methods

2.1 Material

Archeological and clinical articles are the main focus of this thesis given that these contain the primary research and are the most up-to-date. Textbooks usually provide only short synopses about activity and osteoarthritis.

As mentioned in chapter 1, North Western European populations are the research focus of this thesis since the distribution and severity of OA varies amongst populations of different ancestry (Ortner 2003, 550). As an example, Stewart (1947) noted that racial variation in the structure of the vertebral column may affect patterns of movement of the vertebrae and thus affect the expression of spinal osteoarthritis. Also, Zhang et al. (2001) found that older Chinese women had a higher prevalence of radiographic knee OA compared to women from the Framingham study in the United States. Thus, narrowing the population of study to North Western Europe reduces the risk of including different expression due to biological differences in other populations.

The time period for this thesis is the Medieval and post-Medieval period. Not much research has been done yet on this time period, witnessed by the fact that I found only six articles on this specific time frame. This is perhaps surprising since it is a time when occupation specialization was common. Studying these groups could be interesting because individuals are tied to their occupations for life, meaning they are tied to the same repetitive movements for a long period of time, which could result in unique and distinct patterns of OA.

Clinical diagnostics (i.e. symptoms and joint space narrowing on radiographs) are not criteria that can be used to study OA in archaeology. Only features of OA that affect the skeleton can be found in archaeology. To synchronize these two types of data, I used only clinical articles that mention OA with bone deformation (more on this in paragraph 2.2 “Methods”).

There is a great deal of clinical literature on the subject of activity and osteoarthritis. As it was not possible to consider every joint in the human body, I decided to narrow it down to three specific joints. I chose the large joints of the lower extremities, the hip and knee, and the spine. All three are major weight bearing joints. As mentioned, OA occurs mostly in these types of joints and evaluation of these joints has been undertaken “more commonly and systematically than any other joints in the body” (Jurmain and Kilgore 1995, 444).

In order to answer my research questions I have been searching clinical peer-reviewed journal articles with the words “occupational/ occupation/ work related”, “osteoarthritis” and “knee”, “hip”, and “spine” in different combinations. I have also searched with “activity” and “osteoarthritis”. I have searched the archaeological articles with the words “osteoarthritis”, “activity/occupation” and “medieval/ Middle Ages/post-Medieval”. All articles on osteoarthritis and activity in general, without mention of time or place, were included. These articles were mostly reviews and thus should be applicable to all times and places.

2.2 Methods

2.2.1 Clinical articles

I have included 23 clinical articles and 1 article based on cadaveric material (Videman et al., 1989). Articles include populations from England and Wales, Germany, Sweden, Denmark and Finland. There are fourteen articles about knee OA, eight articles about hip OA, two about spinal OA and four general articles discussing the relationship between activity or occupation and osteoarthritis. These do not add up to 24 since several articles are about more than one joint. Of these articles, one was a prospective cohort study, eleven were case-control studies, two were cross-sectional studies and ten were (systematic) literature reviews. According to Lievense (2001), a prospective cohort study is the best design for a clinical study on this subject, followed by a case-control study.

A prospective cohort design is a study where a cohort of similar individuals, who differ in certain aspects (in this case occupation) are followed over a certain amount of time, to determine the rates of a certain outcome (in this case OA). This kind of study starts before the outcome is reached. Only the study by Toivanen et al. (2010) meets this requirement.

The case-control studies are studies where cases (patients with OA) are compared to controls (healthy individuals). In these articles the cases and controls are matched in age and sex, to get as little bias from these variables as possible. A total of eleven studies were of this type. Some studies were made of men only (Seidler et al. 2001; Seidler et al. 2008; Vingård et al. 1991).

Cross-sectional studies are made of individuals, about a certain subject (such as OA and activity), at one point in time. These individuals are representative for a part of or for the whole population. The two cross-sectional studies are by Rytter et al. (2009), and Videman et al. (1990).

The studied activities that may be related to OA frequency are kneeling, squatting, walking, sitting, jolting, standing, driving, lifting/carrying, jumping, climbing stairs, and ladders or working in twisted positions. Some are further divided into light, medium, and heavy exposure or knee-moment (Maninnen et al. 2002; Sahlström and Montgomery 1997; Sandmark et al. 2000; Seidler et al. 2001).

In the studies, cases are selected based on different criteria. One criterion is hip or knee replacement in the patients used as cases (Coggon et al. 1998; Coggon et al. 2000; Manninen et al. 2002; Sandmark et al. 2000; Vingård et al. 1991), which is seen as clear proof of severe OA as this is only done in severe cases (Verhaar and Van Der Linden 2003, 281). We can assume that there will be bony changes present.

The other criterion is radiographs of the joints (Cooper et al. 1994; Croft et al. 1992; Jensen et al. 2000; Klussmann et al. 2010; Rytter et al. 2009; Sahlström et al. 1997; Seidler et al. 2001; Seidler et al. 2008; Toivanen et al. 2010). Radiographs of the knee are mostly assessed by standards of Kellgren and Lawrence (1963) (Cooper et al. 1994; Klussmann et al. 2010; Toivanen et al. 2010):

- Grade 0 = no changes,

- Grade 1 = doubtful narrowing of joint space and possible osteophytic lipping,
- Grade 2 = definite osteophytes and possible narrowing of joint space,
- Grade 3 = moderate multiple osteophytes, definite narrowing of joint space and some sclerosis and possible deformity of bone ends,
- Grade 4 = large osteophytes, marked narrowing of joint space, severe sclerosis, and definite deformity of bone ends.

Other radiographs are assessed by individually determined criteria, mentioned in the articles, by Rytter et al. (2009) and Sahlström and Montgomery (1997). Hip and spine radiographs are assessed on joint space narrowing and osteophyte growth (Seidler et al. 2001; Croft et al. 1992).

Most articles use a threshold to be included in the study, such as at least grade 3 from Kellgren and Lawrence as used in Cooper et al. (1994), including only moderate and severe cases of OA. This should provide us with a sample of OA that has bony changes.

Data analysis is statistical and most articles (such as Coggon et al. 1998; Manninen et al. 2008; Sahlström et al. 1997) use (multivariate) logistic regression modeling with odds ratio (OR) and 95% confidence intervals (95% CI). These are commonly used statistical models in clinical research, that allow the researchers to put in several variables and see what effect they have separately or together on a variable such as osteoarthritis.

2.2.2 Archaeological articles

Nine articles and one book are used in the archaeological part of my thesis. Of these articles and book, the book and three articles are literature reviews (Jurmain 1991; Jurmain 1999; Jurmain and Kilgore 1995; Weiss and Jurmain 2007). The other six articles are case studies of osteological material. One study (Jurmain 1977) analyzes the knee, hip, shoulder, and elbow. The vertebral column is analyzed in three cases (Knüsel et al. 1997; Sofaer-Derevenski 2000; Waldron and Stirland 1997), two other cases examine hand OA (Waldron and Cox 1989; Waldron 1996). I chose to keep the cases of hand OA as there is so little literature on the subject and I also look at the method with which the case is studied.

The literature reviews are based on both clinical and archaeological literature. Case studies use mostly material from the United Kingdom, except one from the United States (Jurmain 1977). I decided to use this anyway since it was the only study I could find on hip and knee OA, which is a large part of my clinical review. I also chose this study because it split the population according to ethnicity (White, African-American, Indian and Eskimo). Arguably, the White population can be used as a surrogate for the European population, as most will be immigrants from this part of the world and the prevalence of OA is about the same in the US as here (Petersson and Jacobsson 2002).

The osteological material is graded on OA, according to standards: own standards (Sofaer-Derevenski 2000) or a previously made one (Waldron 1996). For the greater part, these include the diagnostic criteria for OA from Chapter 1. Age and sex are defined, where possible, from osteological standards (Jurmain 1977; Sofaer-Derevenski 2000; Waldron 1996; Waldron and Stirland 1997) or from records (historical: Waldron and Cox 1989; recent: Jurmain 1977).

Some articles compare two or more populations. Some are from the same time era (Waldron and Stirland 1997), others are from different times (Jurmain 1977; Sofaer-Derevenski 2000; Waldron 1996). Almost all research was based on articulated skeletons but Waldron and Stirland's (1997) is partly based on commingled remains from a sunken ship. In table 1 is an overview of the archaeological articles.

Table 1. Archaeological case studies on osteoarthritis.

Article	Geographic location and population	Time period	Joint(s) examined	Age/sex determination	Number of individuals examined	Occupation/activity known?	Pathologies and standards for OA used
Jurmain 1977	United States Whites (Terry collection) Blacks (Terry collection) Indians (from Pecos Pueblo) Alaskan Eskimo's (from the Smithsonian)	 20th cent 20th cent 13th cent proto-historic(until the 18th cent)	Knee, Hip, Shoulder, Elbow	Morgue records Morgue records Standard osteological techniques Standard osteological techniques	107 males, 103 females 116 males, 118 females 111 males, 97 females 80 males, 66 females	No	Standard used: Jurmain 1975.
Knüsel et al. 1997	Monastery in Fishergate, York (UK) Gilbertine canons, working men and priests and wealthy people.	13-14th cent	Vertebral column	Previously done, no mention of it in the article	81 males	Yes, from records	Osteophytes , joint surface contour change , porosity, cyst porosity, sclerosis, eburnation, and Schmorl's nodes.
Sofaer-Derevenski 2000	Wharram Percy (UK) Ensay Island (UK)	10th-16th cent 16th -19th cent	Vertebrae from complete spines or complete segments of spine	Sex : standard osteological criteria by Brothwell (1981) and Stewart (1976). Age: dental wear (Brothwell 1981; Kieser et al. 1983; Miles 1962, 1963).	31 males, 28 females (Wharram Percy) 28 males, 28 females (Ensay)	Wharram Percy: occupation from annals Ensay: occupation from records and ethnographic data	Apophyseal facet scored for presence/absence and severity of facet remodeling, osteophytes, pitting, and sclerosis/eburnation.

Stirland and Waldron 1997	Crew of the *Mary Rose* (sunken flagship of Henry VIII) (UK) Cemetery from Norwich (UK)	1545 AD 1254-1468 AD	Commingled vertebrae Vertebral columns	Sex on the *Mary Rose* known from records: they were all men. Age on the *Mary Rose*: stages of ossification on the apophyseal rings of the vertebral bodies. Sex Norwich: previously determined Age Norwich: pubic symphysis, rib ends, ossification stage of the thyroid cartilage in males. Also same method used as on the *Mary Rose* sample.	1238 vertebrae and sacra from the *Mary Rose,* all male. 5628 vertebrae and sacra from Norwich, all male.	Yes, from record on the *Anthony Roll* for the crew of the *Mary Rose.* No record for the Norwich cemetery. Possibly some were soldiers.	Osteoarthritis of the facet joints, marginal osteophytosis, Schmorl's nodes and ossification into the ligamentum flavum.
Waldron 1996	Several archaeological sites in England, including Allington Avenue, Ashstead, Brighton Hill South, Farringdon Street, Great Chesterford, Kellington, Merton Priory, Red Cross Way, Royal Mint, Southgate Street, Spitalfieldsand Ulwell.	Medieval (500 until 1500 AD) and post- Medieval (from 1500 AD on)	Hands	Standard anthropological techniques for sex, age was not included in this article	77 males, 87 females and 4 unknown sex	No	Standard used: Rogers and Waldron 1995.
Waldron and Cox 1989	Crypt burials in a church in East-London (UK)	1729-1869 AD	All joints (especially hands and spine)	From records gathered by using the coffin plates	376 individuals, no sex or age mentioned	Yes, from records	Standard used: Rogers et al. 1987.

Chapter 3 – Results

In this chapter I will present the results of this literature search in detail. I will start by reviewing the clinical articles, then I will present the archaeological articles.

In order to understand the results given in the clinical articles, a short introduction of the statistics used is in order. Most used are the odds ratio (also sometimes called relative ratio) and the 95% confidence interval (CI). The risk of an event (in this thesis OA being caused by activity) is elevated when the odds ratio is more than one. But: the odds ratio gives a relative chance, it does not give an absolute risk. The 95% CI gives an indication of whether the effect is significant. When a 95% CI does not include the number one, it is significant (Perera et al. 2008).

3.1 Clinical results

First, I will introduce the results of the studies, then the results of the reviews. In table 2 a summary of the study articles is shown, ordered alphabetically in prospective cohort, case-control studies and last cross sectional studies.

Table 2. Results of clinical studies.

Prospective cohort study							
Article	Geographical area	Population	Joint(s) examined	Diagnosis of OA	Threshold for inclusion?(in radiographic diagnosis)	Activities studied	Relevant results
Toivanen et al. 2010	Finland	369 men and 454 women	Knee	Symptoms and radiographic changes (Kellgren and Lawrence 1963).	No	6 categories: 1. Light sedentary work 2. Other sedentary work 3. Physically light standing work 4. Medium heavy work involving movement 5. Heavy manual work 6. Very heavy manual work	- 11,4% with knee OA. - Increased risk of knee OA due to very heavy manual work.
Case-control studies							
Article	Geographical area	Population	Joint(s) examined	Diagnosis of OA	Threshold for inclusion?(in radiographic diagnosis)	Activities studied	Relevant results
Coggon et al. 1998	Portsmouth and North Staffordshire (UK)	210 men and 401 women (cases) and 611 controls	Hip	Hip replacement surgery within 18 months after the study.	Not Applicable	Lifting 10, 25 or 50 kg more than ten times a week at work Also others but only climbing of stairs and walking more than 3,2 km were significant.	- Increased risk in men lifting more than 10 kg for a prolonged time. - Risk even higher with 25 kg and longer periods of lifting. - Further increased risk with frequent climbing of stairs and walking more than 3,2 km (women).

Coggon et al. 2000	Portsmouth, Southhampton and Stoke-on-Trent (UK)	518 cases (205 men and 313 women) and 518 controls	Knee	Knee replacement surgery	Not Applicable	Different levels of lifting and whether an average working day involved any of 8 specified occupational activities, especially kneeling and squatting.	- Risk of OA higher with prolonged kneeling or squatting for more than one hour/day over one year - Also significant: occupational lifting, walking for 3,2 km/day (women), and climbing a ladder or stairs 30 times/day (men). - Risk of OA very high when lifting is combined with kneeling/ squatting.
Cooper et al. 1994	Bristol (UK)	30 men and 79 women, 218 controls	Knee	Painful , radiographically confirmed knee OA.	Grade 3 or 4 of Kellgren and Lawrence (1963) or grade 3 of Spector et al.(1992)	Squatting, kneeling, stair-climbing, heavy lifting, walking, standing, sitting, and driving.	- Higher risk of knee OA due to squatting, kneeling or climbing more than ten flights of stairs per day - Lifting over 25 kg only significant when associated with the previous three.
Croft et al. 1992	North Staffordshire and Shrewsbury (UK)	245 men (cases) and 294 men (controls)	Hip	Hip replacement for OA or radiographic OA	Joint space of 2.5mm or less Subdivision severe cases: 1,5 mm or less or hip replacement	Sitting, standing, bending, kneeling, squatting, walking more than 3,2 km/day, walking more than 3,2 km/day on rough ground, running, climbing ladders or stairs, lifting, and driving.	- All cases: higher risk of OA due to standing >2 h/d. - Only severe cases: higher risk of OA due to standing >2 h/d and heavy lifting.
Klussmann et al. 2010	Germany	739 cases (438 women and 301 men) and 571 controls (303 women and 268 men)	Knee	Radiographic OA or findings from surgery of the knee or arthroscopy	Grade 2 of Kellgren and Lawrence (1963) or grade 3 on the Outerbridge Scale (1961)	Sitting, standing, walking, kneeling/squatting, climbing stairs, jumping, lifting/carrying loads.	- Women: increased risk of knee OA with kneeling/squatting and daily lifting and carrying. - Men: only kneeling/squatting, more significant when done for a longer period of time.

Manninen et al. 2002	Kupio Province (Finland)	55 men and 226 women (cases) and 524 controls	Knee	Knee replacement surgery	Not Applicable	Standing, climbing, kneeling or squatting, walking, lifting, and driving.	- Increased risk of knee OA with medium to high workload, kneeling/squatting, climbing (only in men) or driving.
Sahlström et al. 1997	Malmö (Sweden)	266 cases and 463 controls (men and women)	Knee	Radiographic OA	At least grade 1 of the Ahlbäck scale	(a) light knee moment (b) medium knee moment (c) heavy knee moment	No elevated risk of knee OA with any knee moments.
Sandmark et al. 2000	Sweden	325 men and 300 women (cases), 264 men and 284 women (controls)	Knee	Knee replacement surgery	Not Applicable	Kneeling, standing, sitting, working with vibrations, stairs climbing, squatting. knee bending, jumping, and lifting.	Lifting at work, standing, squatting or knee bending, kneeling, and jumping strongly associated with knee OA in men. Standing, lifting at work, kneeling and climbing stairs significantly associated with knee OA in women
Seidler et al. 2001	Frankfurt am Main (Germany)	229 male cases and 197 male controls	Lumbar spine	Radiographic osteochondrosis or spondylosis	Moderate to severe osteochondrosis or spondylosis according to criteria in article	Occupational lifting/carrying of loads, whole body vibrations and twisting of the trunk	Elevated risk with high physical workload, moderate physical workload, extreme forward bending, cumulative lifting/carrying and a combination of the last two.
Seidler et al. 2008	Frankfurt am Main (Germany)	295 male cases and 327 male controls	Knee	Radiographic knee OA according to standards by Kellgren and Lawrence (1963)	At least grade 2 of Kellgren and Lawrence	Kneeling/ squatting, lifting/ carrying.	Increased risk with kneeling/squatting, lifting/carrying and combination of the two.
Vingård et al. 1991	Stockholm (Sweden)	239 male cases and 302 male controls	Hip	Hip replacement surgery	Not Applicable	Standing, sitting, walking, biking, driving, twisted positions and stair climbing	High and medium exposure more risk of OA. Static and dynamic movements both increase risk of OA.

Cross sectional studies							
Article	Geographical area	Population	Joint(s) examin ed	Diagnosis of OA	Threshold for inclusion?(in radiographic diagnosis)	Activities studied	Relevant results
Rytter et al. 2009	Denmark	231 floorlayers (men) and 258 graphic designers (men) (reference population)	Knee	Radiographic OA	Self modified Ahlbäck scale (grade 0–6). At least grade 1 (defined joint space narrowing)	Occupational kneeling	- 24% of all participants have knee OA - More chance of OA when floorlayer of 50-59 years old (compared to graphic designers)
Videman et al. 1990	Helsinki (Finland)	86 male cadavers	Spinal patholo gy	Both radiographs for osteophytes and osteological examination for facet osteoarthritis	No	Work was divided into sedentary, mixed degree of heaviness, driving, and heavy	Heavy work significant with osteophytes on radiographs.

3.1.1 Prospective cohort study

Toivanen et al. (2010) is the only prospective cohort study used in this thesis. It is a 22 year follow-up study from Finland. Healthy people were examined in 1978-80, followed and examined again in 2000-01.
Knee OA was diagnosed in 94 individuals (11,4%). This study did not include a detailed description of activity but there was enough to get an idea of common knee movement. Several risk factors such as age, sex, Body Mass Index, smoking and strenuous work were considered as co-variates. Statistical analysis showed that when adjusted for age and sex, the relative OR became significant for the relationship of very heavy manual work and knee OA (relative OR 11,5 with 95% CI 2,9- 45,8). It even became more significant when correcting for all co-variates (relative OR 18,3 with 95% CI 4,2 - 79,4). Very heavy manual work is defined as “very heavy manual work mostly consisting of continuous or fairly continuous heavy movements, often done without interruption for long periods, e.g. carrying furniture, forestry work (felling trees), heavy non-mechanized agricultural work, fishing with heavy tackle, heavy construction work and manual excavation.” (Toivanen et al. 2010, 311).

3.1.2 Case-control studies

In Coggon et al. (1998), the relationship of heavy lifting and osteoarthritis of the hip was tested. This was done as a case-control study, with 611 cases who needed hip replacement and the same amount of controls, matched for age and sex. After adjusting the statistics for other risk factors, men lifting more than 10 kg for prolonged time had more risk of hip OA. Especially the ones who had had such exposure 10 years or more before the age of 30 (OR 2,3 ; 95%CI 1,2-4,2) or if they had had 20 or more years of exposure up to 10 years before the study (OR 1,8; 95% CI 1,0-3,4). For 25 kg or more, the risk of hip OA was even higher. Also, the longer the period of lifting the higher the risk became. Further increased risk was associated with frequent climbing of stairs (when men and women were analyzed together) and walking more than 3,2 km (only women).

Coggon et al. (2000) has almost the same study set-up as Coggon et al. (1998), although it was not about the hip but about the knee. Statistical adjustment was made for Heberden's nodes (sign of generalized OA), BMI and previous knee injury. Results show a statistically significant higher risk of knee osteoarthritis with prolonged kneeling or squatting for more than one hour/day over one year (accumulated OR 1,9; 95%CI 1,3-2,8); as well as for occupational lifting, walking for 3,2 km/day (in women), and climbing a ladder or flight of stairs 30 times/day (only in men). Combined lifting and kneeling/squatting at the workplace increased the risk of knee OA even more (OR 3,0; 95%CI 1,7-5,4). Although all statistics were significant, the association between knee OA and occupational lifting was not as strong as the association with kneeling and squatting.

In Cooper et al. (1994) a case-control study for knee OA was performed with two controls matched to each case. Adjusted for BMI and Heberden's nodes, squatting and kneeling more than 30 min/day (OR 6,9; 95% CI 1,8-26,4 and OR 3,4; 95% CI 1,3-9,1) and climbing more than ten flights of stairs/day (OR 2,7; 95% CI 1,2-6,1) were significant for a higher risk of knee OA. There were no significant associations with heavy lifting or prolonged walking, standing, sitting or driving. When combined with squatting, kneeling, or climbing stairs, regularly lifting over 25 kg gave a higher risk of knee OA (OR 5,4; 95% CI 1,4-21,0).

Croft el al. (1992) is a case-control study of hip OA, performed only on men. The diagnosis was made with both radiographic joint space narrowing and hip replacement surgery. Joint space does not guarantee bony changes but as seen in Table 2, the study also used a "severe" category, which should have bony changes. The results of this category are thus the most interesting for this thesis. All cases included, only standing for more than two hours per day was significant. When looking at the severe cases only, a more distinct pattern appears. Still, standing for more than two hours per day gave a significantly higher risk of hip OA, especially for over a period of 40 years or more (OR 2,7; 95% CI 1,0-7,3). Also heavy lifting (more than 25 kg) for over 20 years was associated with a higher risk of OA (OR 2,5, 95% CI 1,1-5,7). Weaker associations were found with walking more than 3.2 km/day, particularly walking over rough ground.

Klussman et al. (2010) is a study from Germany on knee osteoarthritis. Results are divided into categories of men and women. They were not analyzed together as in previous studies. Women showed an increased risk of OA when cumulative kneeling and squatting was >8 934 hours over life (OR 2,5; 95% CI 1,4-4,7). Cumulative daily lifting and carrying ≥1 088 tons over life was also significant (OR 2,1; 95% CI 1,1-4,0). In men cumulative kneeling and squatting for 3 574 to 12 244 hours over life led to an increased risk for knee OA (OR 2,2; 95% CI 1,2-3,8). The risk became even higher if cumulative kneeling or squatting was >12 244 hours (OR 2.5; 95% CI 1,4-4,3). Lifting or carrying was not a factor for knee OA in men.

Manninen et al. (2002) is a Finnish study of severe knee OA and activity. BMI, knee injury, and leisure-time physical exercise were seen as possible confounders and were adjusted for in the statistical methods. In this article, physical workload was looked at in general (low, medium and high) based on the occurrence of sweating and rapid heartbeat. In men medium physical workload gives an increased risk of knee OA (OR 3,00; 95% CI 1,05–8,57), in women it is the same for high physical workload (OR 2,17; 95%CI 1,21–3,88). When looking at both sexes at the same time, both medium and high workload are significant (OR 1,93; 95% CI 1,18–3,16 and OR 2,19; 95%CI 1,32–3,64).
Movements increasing risk of knee OA are kneeling/squatting more than two hours per day in men and women (OR 1,69; 95% CI 1,17–2,44), and some climbing (only in men) (OR 3,06; 95% CI 1,25–7,46). Also, cumulative amount of driving was significant for elevated risk of knee OA per each 10 000 work hours (OR 1,02; 95% CI 1,00–1,12). There was no association between the risk of knee OA and lifting or walking.

In Sahlström et al. (1997) 266 people with knee osteoarthritis and 463 controls were studied. Activities were classified into:
(a) light knee moment (sitting, walking, and carrying)
(b) medium knee moment (lifting with bent knees and carrying, climbing stairs and ladders with/or without carrying objects)
(c) heavy knee moment (a and b with additional jumping with and without carrying objects) (Sahlström et al. 1997, 676).

After adjusting the knee bending for other independent variables such as overweight, haemarthrosis, sitting, and meniscus operation, the knee movements did not give a significant higher risk of knee OA (OR 1,1; 95% CI 0,7-1,8).

Sandmark et al. (2000) studied people who just had knee replacement surgery in Sweden. Several activities were looked at, separately for both men and women. The activities were rated low, medium and high exposure. For men, lifting at work (both medium and high exposure), squatting or knee bending (high exposure), kneeling (high exposure), and jumping (high exposure) were strongly associated with knee OA (OR 2,1-3,0 with strongly significant 95% CI's). Standing was also significant for high exposure but not as strongly (OR 1,7; 95% CI 1,0-2,9). Standing (high exposure), lifting at work (high exposure), kneeling (medium exposure) and climbing stairs (medium exposure) were significantly associated with knee OA in women. Most were not as strongly associated with knee OA as in men (OR 1,5-1,7 with significant 95% CI's).

In Seidler et al. (2001) an analysis was made of German men for osteochondrosis, spondylosis, and activity. Spondylosis is osteoarthritis of the spine, where the intervertebral disc becomes thinner and less compliant (Kumar and Clark 2009, 510). Osteochondrosis is a degenerative change to the bone but with different causes than OA. Here, it is judged on the same criteria as spondylosis.
A few activities were strongly significant such as working in occupations with high physical work load for a duration less than 10 years (OR 3,2 ; 95% CI 1,2-8,3) and even higher OR for 10 years or more (OR 6,2; 95% CI 3,3-11,8). Working in moderate physical work was borderline significant (OR 1,8; 95% CI 1,0 to 3,2). Other significant activities were cumulative exposure to carrying or lifting in the highest category >150 000 kg/h (OR 8,1; 95% CI 4,1 - 15,8), working in extreme forward bending for up to 1 500 hours (OR 2,0; 95% CI 1,2 - 3,5). The last one was even higher when working more than 1500 hours in extreme forward bent position (OR 4,3; 95% CI 2,3 – 8,0). Combined exposure to lifting/carrying and forward bent position, both in the highest exposure, gave a high OR of 16,1 (95% CI 6,3 – 41,5). Whole body vibration was not a significant factor for the chance of osteochondrosis/ spondylosis.

Seidler et al. (2008) is also a German article where again, only men were tested, this time on knee OA. Cumulative exposure to kneeling elevates the risk of knee OA in the highest category (>10 800h) (OR 2,4; 95% CI 1,1–5,0). Cumulative exposure to carrying/lifting was also significant in the highest category (>37 000 kg/h) (OR 2,6; 95% CI 1,1–6,1). Combining kneeling/squatting and lifting/carrying (both in high exposure) also gave an increased risk on knee OA (OR 7,9; 95% CI 2,0–31,5).

Vingård et al. (1991) is the last case-control study I will be discussing. It was performed on a Swedish population with hip replacements, consisting only of men. Several activities were studied and further divided into normal exposure (sitting, walking without burdens, standing and biking), dynamic exposure (walking with burdens and stair climbing) and static exposure (working in a twisted lock position). Men until 49 years of age with high and medium exposure to all activities had more risk of hip OA (high exposure RR 2,42; 95% CI1,45 – 4,04 and medium exposure RR 1,82; 95% CI 1,02 - 3,24). When there was only high exposure, static + dynamic activities, static activities, dynamic activities, lifted tons, and number of lifts gave a significantly higher risk of OA. When there was only medium exposure, static + dynamic activities, dynamic activities, and number of jumps were significant.

3.1.3 Cross sectional studies

Rytter et al. (2009) is the first of two cross sectional studies I will discuss. This one is from Denmark and all studied individuals were male. The researchers looked at the amount of knee OA in floorlayers (occupational kneeling) and graphic designers (no kneeling professionally) at one point in time. 24% of all participants had OA of the knee, all with osteophytes. After comparing both populations, floorlayers aged 50-59 years old were more at risk of getting knee OA than graphic designers of the same age (OR 3,6; 95% CI 1,1-12,0).

Videman et al. (1990) is the second of the two cross sectional studies. This article is not based on living people but on cadaveric material of males. The cadavers were selected based on age under 64, with known employment before death and a short disease history. Their families were interviewed for their occupations. There were no movements named, only how physically heavy the occupations were. Osteophytes on the vertebral body were assessed with radiographs and facet osteoarthritis was looked at osteologically. Heavy work progresses pathologic changes to the spine, especially moderate and severe osteophytosis of the vertebral body. For moderate and severe facet joint osteoarthritis there was no statistically significant outcome.

Overall, a positive trend is shown in most studies. Only Sahlström et al. (1997) found no relationship at all between activity and OA. Kneeling and squatting seem to be the most mentioned and researched movements for the knee OA, while lifting is a strong candidate to cause hip OA. Many movements though were only mentioned once, which will make conclusions from those difficult.

3.1.4 Reviews

There are eleven review articles I will discuss. The first is Cooper et al. (1996), speaking of occupation and activity. According to the writers, there is now clear epidemiological evidence that activity is a contributor to the risk of OA at the knee and hip. For the knee, repetitive use and heavy lifting is the primary biomechanical risk factor. In the hip, there is only a definite link between agriculture and osteoarthritis but there is no clear indication which movements cause this. Cooper et al. (1996) also quote the results of Croft et al. (1992) (see table 2) but state that these results are not as convincing as the farmers hip OA.

Felson (1994) is an extensive review about OA and occupation-related physical factors. Some joint overuse seems to be linked to OA. Felson mentions three kinds of articles he studied: geographic studies, with areas with different kinds of occupations; occupational groups studies, to see if they had high rates of OA in overused joints; and studies that look at specific physical activities, to see if those are correlated with OA. The last one is the one I also focus on. The author does not have evidence that certain movements cause OA of the knee. He does mention a few articles that have positive results on working with your hands and distal interphalangeal, proximal interphalangeal, and carpometacarpal OA. Overall, Felson (1994) concludes that occupational activities over many years can induce OA, especially knee and spine OA in miners and the hip OA in farmers.

Felson (2000) is a review of several new insights on OA, amongst those occupational factors as a risk factor. When examining specific tasks, Felson conclude that jobs with kneeling or squatting, along with heavy lifting, are associated with high rates of knee and hip OA. Turning while doing these tasks increases the risk even further. Other activities such as climbing stairs, walking on uneven ground, standing, and sitting have not yet been strongly linked with knee OA.

Genti (1989) starts with a reference to archaeological populations, in which young individuals are seen with OA in places that are not common in the clinical literature, suggesting that mechanical factors may be of influence in degeneration of cartilage. He found that the results in epidemiological studies are contradictory. He states that body position is more important than lifting of weight. He also mentions that certain movements may cause overload of the joints. The author concludes that it is not yet proven that overload causes OA. Mechanical and occupational stresses are more likely to play a role in the localization.

The review by Jensen (2008) is specifically of hip OA and heavy lifting, climbing stairs, or combined lifting and kneeling/squatting. Results are that moderate to strong evidence is found for heavy lifting and osteoarthritis. The weight must be at least 10-20 kg and the lifting must be done for at least 10 years. Farming was also moderately to strongly associated with hip OA (after 10 years). Higher exposure mostly meant there were higher risks, a “dose-response relation” (Jensen 2008, 14). Climbing stairs was not significantly increasing the risk of hip OA and there was not enough information to prove that kneeling/squatting increased the risk when combined with lifting.

Lievense et al. (2001) also examine the influence of physical workload on the hip. Results are that heavy work is moderately associated with hip OA, as is farming (more than 10 years) and frequently lifting heavy weights (more than 25 kg).

McMillian and Nichols (2005) focus on the knee and mining. Mining is further defined as prolonged kneeling or squatting. The outcome was a clearly increased risk of OA of the knee because of kneeling/squatting. A few studies used also showed that lifting with kneeling/squatting makes for a higher risk of OA of the knee.

McWilliams et al. (2011) reviewed occupational factors and knee OA. Assessed movements in the used studies are kneeling, squatting, lifting/carrying and heavy standing work. The risk from kneeling, measured as part of occupation was moderate. Other activities also gave a higher risk for knee OA, with the exception of standing work.

Vingård et al. (1996) is the third review of knee OA and physical load from occupation. In different countries physical load from occupation such as kneeling, squatting, and generally heavy loading, has been strongly associated with osteoarthritis of the knee.

Schouten et al. (2002) examined articles on both the hip and the knee. It is a review on a smaller scale since it only takes into account articles from 2000 to 2001. Evidence is present for kneeling, squatting, climbing stairs of a ladder, lifting heavy objects, and walking as risk factors for knee OA. For hip OA risk factors were climbing stairs and lifting heavy objects. Not all physical activities showed a significant result but all had positive relationships.

Again here, most reviews agree that some movements can cause some kinds of OA. Cooper et al. (1996) finds clear epidemiological evidence that activity is a contributor to the risk of OA at the knee and hip. Felson (1994) concludes “that multiple studies of individual occupations and of populations have suggested that occupation-related joint overuse is an important cause of knee, hip and other joint osteoarthritis” (Felson 1994, 74). Felson (2000) shows that several activities do cause OA but that others are not yet reliably tested. Finally, only one study (Genti

1989) says it is not proven and that activity only influences the site of OA. Overall, lifting is still linked the most to hip OA, as is agriculture. Although agriculture is not a movement and farming today is not comparable to farming in the Medieval and post- Medieval period, I did include it in this analysis. It was mentioned quite a few times in reviews, always with a positive relationship to hip OA, so I did not want to ignore this find. Kneeling and squatting are most mentioned in relation to knee OA.

3.1.5 Further analysis of clinical results

I will take a further look at the clinical articles, to see if there is a relationship between osteoarthritis and activity in the modern population of North-Western Europe. I had a few problems when I decided to make an overview of which movements cause OA in which joint. First, movements were named differently in studies. For example, sometimes kneeling was taken together with squatting, while other times it was looked at on its own or with lifting. These are difficult to compare. Second, the amounts of time spent doing activities were quite different. Some studies accumulated exposure over life, others took exposure on a daily basis or yearly basis. As well, studies did not always look at men and women together. Some studies were only of men, others of men and women separately, others of men and women together. None were made of only women. This especially is a problem with the two studies of spinal OA as both are of only men. This means I have almost no results of women and spinal OA. Only one review mentions two activities that could be related to women.

In order to get an overview I decided not to look at the time of exposure (hours/day, minutes/day, years, etc) and only analyze the movements. I decided this because when an activity is proven to be related to the development of OA, it has to be done for at least some years and on a regular basis to cause OA. The more and longer an activity is done, the more risk for OA it produces. This is what Jensen (2008, 14) calls the “dose-response relation”, higher exposure means a higher risk. For this thesis, my opinion is that it is not relevant to see exactly how long an activity has been exercised or if it has been done for either one or two hours a day since in archaeology, it is simply not possible to make such precise conclusions.

I have put the movements in three tables to see to what extent studies conclude there is a positive or negative relationship (i.e. positive = this movement causes OA; negative = this movement does not cause OA) with knee, hip and spinal OA. I have also included the reviews. In these tables the studies are divided into men and women, men, or women.

The movements that only had a negative relationship with OA were not included in the tables but they are mentioned in the text under the tables. In order to answer my research questions it is necessary to see the ratio of positive vs. negative relationships, to assess if a movement can cause OA.

Table 3. Activities and their relationship to knee OA in clinical articles.

OA of the Knee			
Activity	Positive relationship (total nr of articles)	Negative relationship (total nr of articles)	Percentage of positive outcome
Kneeling	**5** 2 men and women, 2 men, 1 women	**2** 1 men and women, 1 women	**71%**
Squatting	**2** 1 men and women,1 men	**1** 1 women	**67%**
Kneeling/squatting	**5** 3 men and women , 1 women, 1 men		**100%**
Kneeling/squatting and lifting	**5** 4 men and women, 1 men		**100%**
Turning and kneeling/squatting with heavy lifting	**1** 1 men and women		**100%**
Lifting	**5** 1 men and women, 2 women, 2 men	**4** 3 men and women, 1 men	**56%**
Lifting and climbing stairs	**1** 1 men and women		**100%**
Driving	**1** 1 men and women	**2** 2 men and women	**33%**
Standing	**2** 1 men, 1 women	**7** 7 men and women	**22%**
Climbing stairs	**4** 1 men and women, 2 men ,1 women	**5** 3 men and women, 1 women, 1 men	**44%**
Jumping	**1** 1 men	**2** 1 men and women, 1 women	**33%**
Moderate/Medium Physical Work	**2** 1 men and women, 1 men	**1** 1 men and women	**66%**
Very heavy manual work/High physical workload	**3** 2 men and women, 1 women		**100%**

Repetitive use with heavy lifting	**1** 1 men and women		**100%**

Table 4. Activities and their relationship to hip OA in clinical articles.

OA of the Hip			
Activity	Positive relationship (total nr of articles)	Negative relationship (total nr of articles)	Percentage of positive outcome
Lifting 10kg and more	**6** 4 men and women, 2 men		**100%**
Standing	**1** 1 men and women	**1** 1 men and women	**50%**
Walking more than 3,2 km	**2** 1 women, 1 men especially on rough terrain	**1** 1 men and women	**66%**
Kneeling/squatting and lifting	**1** 1 men and women		**100%**
Turning and kneeling/squatting with heavy lifting	**1** 1 men and women		**100%**
Walking with burdens and stair climbing	**1** 1 men and women		**100%**
Working in a twisted lock position	**1** 1 men and women		**100%**
Working in a twisted lock position, walking with burdens and stair climbing	**1** 1 men and women		**100%**
Agriculture	**4** 4 men and women		**100%**
Heavy work load	**1** 1 men and women		**100%**

Table 5. Activities and their relationship to spinal OA in clinical articles.

OA of the Spine			
Activity	Positive relationship (total nr of articles)	Negative relationship (total nr of articles)	Percentage of positive outcome
Carrying/Lifting	**1** 1 men		**100%**
Working in extreme forward bended position	**1** 1 men		**100%**
Lifting/ carrying and extreme forward bended position	**1** 1 men		**100%**
Mining: kneeling/ squatting	**1** 1 men and women		**100%**
Moderate physical work load	**1** 1men	**1** 1 men and women	**50%**
High physical work load	**2** 1 men, 1 men and women		**100%**

Activities with negative associations with the knee were: light sedentary work, other sedentary work, heavy manual work, sitting, walking (on uneven ground), low workload, carrying, lifting and jumping, climbing stairs and jumping, and working with vibrations. For the hip these were: sitting, kneeling, squatting, driving, bending, running, and climbing stairs. For the spine whole body vibrations, sedentary work, and driving were not associated with OA.

With these tables, we can see if any of these movements are strongly associated with OA. Several methods can be used to do this. One method is to look at every article and assess the completeness and quality of the articles as done in some more extensive reviews, such as Lievense et al. (2001). This can be weighted in the comparison between studies. Given the limitations of a bachelor thesis it was not feasible but future research should do this. Another method would have been to include the OR but this would have prevented listing the reviews in the tables. The method chosen for this thesis was to calculate the percentage of positive outcome. This can be seen in the last column of tables 3, 4, and 5.

It is quite arbitrary to make a boundary between which movement has an association or no association with OA. Here, we will look at both percentages and the number of studies. Several degrees of association are possible:

- When only one study is performed on a movement, the extent of association is not assessed, thus it is indeterminate.
- When the amount of studies with positive outcomes and negative outcomes are almost the same (between 40-60%), the movement cannot be said to be associated with OA and the results are inconclusive.
- When the amount of negative studies is more than the amount of positive studies (0-40%) or there are only negative outcomes (the movements mentioned under the table 5), the movement has no association with OA.
- When more studies have positive than negative outcome (60-100%) or there are only positive outcomes, these movements have an association with OA.

When using these degrees of association, a table of outcomes is made: table 6. The percentages are subdivided into strongly negative association (0-20%), moderately negative association (20-40%), inconclusive (40-60%), moderately associated (60-80%) and strongly associated (80-100%). All movements mentioned under table 5 are strongly negative since they only had negative results (0% positive percentage). Some of these movements were only found negative in one study and therefore are put in the indeterminate row. The negative associations were grouped in the row “No association” of table 6 but the mention of strong and moderate can be seen behind the movement. The same applies to the associated movements and the row “Association”.

Table 6. Movements and their relation to OA.

Relation to Movement \ Joint	Knee	Hip	Spine
Association	Kneeling/squatting (strong) Kneeling/squatting and lifting (strong) Very heavy manual work/High physical workload (strong) Kneeling (moderate) Squatting (moderate) Moderate/Medium Physical Work (moderate)	Lifting 10 kg and more (strong) Agriculture today (strong) Walking more than 3,2 km (moderate)	High physical workload (strong)
No association	Walking (strong) Standing (moderate) Driving (moderate) Jumping (moderate)	Climbing stairs (strong) Sitting (strong) Kneeling (strong) Squatting (strong) Driving (strong)	
Inconclusive	Lifting Climbing stairs	Standing	Moderate physical workload
Indeterminate	Turning and kneeling/squatting with heavy lifting Lifting and climbing stairs Repetitive use with heavy lifting Light sedentary work Other sedentary work Heavy manual work Low workload Lifting and jumping Climbing stairs and jumping Working with vibrations	Kneeling/squatting and lifting Turning and kneeling/squatting and heavy lifting Walking with burdens and stair climbing Working in a twisted lock position Working in a twisted lock position, walking with burdens and stair climbing Heavy work load Bending Running	Carrying/Lifting Working in extreme forward bended position Lifting/ carrying and extreme forward bended position Mining: kneeling/squatting Sedentary work Driving Whole body vibration

As can be seen in table 6, activities that have an association with OA of the knee are kneeling/squatting, kneeling/squatting and lifting, very heavy manual work/ high physical workload (all strong associations), kneeling, squatting and moderate/medium physical work (all moderate associations). For hip OA, lifting 10 kg or more (strong association) and walking more than 3,2 km (moderate association) are associated. In the spine only high physical workload is associated with OA (strong association). A few activities were quite well researched, such as lifting and climbing stairs causing knee osteoarthritis but they were found to be inconclusive due to contradictory results. Some movements are unlikely to cause OA, for example standing or walking in knee OA. Many movements were only mentioned in one study and are therefore in need of more research.

Interesting to see is that kneeling and/or squatting is moderately to strongly associated with knee OA, while this is clearly not associated with hip OA. Kneeling and/or squatting must thus put a very specific load on the knee joint, while it does not at all put a burden on the hip joint.

Most reviews analyzed specific movements tied to specific joint OA (Jensen 2008; Lievense et al. 2001; McMillian and Nichols 2005; Mc Williams et al. 2011; Schouten et al. 2002; Vingård et al. 1996). These were included in tables 3, 4, and 5. There are a few general reviews that were not included. Most of those agree that some movements can lead to OA, although they do not elaborate on which ones.

3.2 Archaeological articles

3.2.1 Reviews

The first review I will discuss is Jurmain (1991). In this article Jurmain argues that the clinical literature has not yet proven the link between degenerative changes and occupational stress. The problem is that not all joints, or parts of joints, are equally subject to OA. As well, most clinical studies are cross-sectional rather than longitudinal. The problem with the archaeological sample is a lack of detailed information on the type and severity of occupational stress, even in recent samples.
The skeletal sample he analyzed previously (Jurmain 1977) shows that the expression of OA is different within and between joints, due to the multifactoral nature of osteoarthritis. Joints affected by occupational stress are the elbow, to some degree the knee, and to a lesser extent the shoulder and hip. The most behaviorally sensitive lesions are pitting and eburnation, not the marginal osteophytes.

Jurmain (1991) makes a few suggestions on how to search for a pattern in joints. Scoring all joints on several degenerative changes is the first step, followed by a few possibilities. The first is to compute a correlation coefficient of the total joint score with age. The second is to look for patterns of asymmetry. Third is use of well controlled comparative epidemiology and fourth is use of multivariate analysis. Jurmain concludes that in certain cases we can assume that mechanical stress is the primary cause of OA, but we must always remain cautious in attempting to correlate this with specific activities.

The second review is also by Jurmain (Jurmain and Kilgore 1995). This is a general article on osteoarthritis with a small mention of activity as an etiological factor. Jurmain and Kilgore argue the same as Jurmain (1991), that there is not enough behavioral data (no details on intensity and specific movements), even from ethnohistorical documentation, to be drawing conclusions from skeletal samples. Sometimes there is a pattern distinguishable in certain population groups, such as more knee OA in Medieval Nubian groups than in Inuits, but specific behavior or movements cannot be related to this. There is however a pattern visible in the spine, as lumbar degeneration probably results from compression caused by weight bearing.

The last review is again by Weiss and Jurmain (2007). It is an update on the review by Jurmain (1991) with new insights on the etiology of osteoarthritis. There has been a focus in the research on activity and age as causes of OA but in the clinical literature other factors have been identified such as genetics and obesity. In extensive research by Jurmain (1999), it is shown that evidence from clinical articles on activity and OA is not clear-cut, results are mixed. Jurmain (1999) is an extensive review I did not mention here, as most of the opinions the author gives in there, are here in this article and this article is also more up-to-date. Studies focusing on specific risk groups engaged in a mechanically stressful activity, give slightly more encouraging results. Some good results are shown in studies about farming increasing the risk of hip OA. Mostly there is no explanation for this in clinical studies. Osteologists though, believe that this has to do with the early age at which farmers start working but this has only been proven in a few studies. Osteoarthritis is thus “not an ideal indicator of the overall level of activity nor is it at all a good predictor of specific activities." (Weiss and Jurmain 2007, 444). In some cases though, osteoarthritis is more likely to develop, especially when stresses are frequent and high and if they begin early in life. Future directions discussed include within-body comparisons, animal studies, and examining patterns in large populations.

These reviews (Jurmain 1991; Jurmain and Kilgore 1995; Weiss and Jurmain 2007) all agree that there is not yet a convincing and clear cut relationship of OA and different activities in the clinical record. As well, the archaeological record does not have enough detail on the type and severity of stress that the persons endured. However, studies focusing on specific risk groups engaged in a mechanically stressful activity, give slightly encouraging results.

3.2.2 Case studies

Here I will present six case studies, five from the UK and one from the US. See table 1 in chapter 2 for an overview of these case studies.

Jurmain (1977) is about the only population from the US that I will use. The author looked at four different populations (both medieval and 20th century) and four joints: the elbow, shoulder, knee, and hip. Occupations were unknown. The author states that local mechanical effects influence OA and that epidemiological studies also show a clear association between occupational stress and the incidence of OA. "One should be able to correlate specific information concerning different life styles with degenerative joint disease in those parts of the body most under functional stress" (Jurmain 1977, 356).
Interesting results were that that Eskimo males show a greater frequency of right knee OA at an early age, probably due to powerful stress factors acting on this group since a young age. Pecos Indians are generally less affected than the rest. In the hip, again Eskimo males are earlier and more frequently affected by OA. In the shoulder Black women have an early onset of OA, possibly due to sex-associated occupational practices such as domestic cleaning. Eskimo males also show a greater involvement at an early age in the right shoulder, probably related to stress factors. Finally at the elbow joint, again the Eskimo males show an early

onset on the right side, as did males in all other populations. For females, the Pecos Indians, Blacks, and the Eskimos all show early onset: the Black females on the right, the others on the left side. Concluding, Jurmain's article indicates that "age of onset, frequency, and location of degenerative changes are directly related to the nature and degree of environmentally associated stress" (1977, 353).

The next case study is by Knüsel et al. (1997) of a medieval English cemetery in York. Degenerative changes were analyzed on the vertebral column in the different sub-populations in the cemetery, divided according to status and occupational differences. All analyzed skeletons were male. The three sub-groups were Gilbertine canons, with a sedentary lifestyle, working men with domestic activities (a physically active lifestyle) and priests and wealthy people, buried inside the buildings of the priory. It was expected that there would be a difference in the severity and pattern of the three sub-populations studied, since they had different occupations and status. However, this was not the case: there were no differences, contrary to the previously noticed difference in historical, osteological, and archaeological evidence. The pattern of degenerative changes that was found is probably due to biological factors (such as the natural curvature of the spine) and not activity. The authors advise to be skeptical about the use of degenerative changes in the vertebral column for activity studies.

The third case study is from the UK, where a population from the Middle Ages from mainland Wharram Percy is compared to a population from post-Medieval Ensay island (Sofaer-Derevenski 2000). The material was the complete vertebral column or complete segments of it (the cervical, thoracic (T1-T6 and T7-T12) or lumbar spine). There is a known gendered division of occupation at both sites and activity related stresses on the spine are also known (lifting and heavy physical work). The author explains that the extent to which past occupations can be reconstructed with activity markers is debated, but in this study detailed ethnographic and historical data was used. In Ensay, the women show a different distribution pattern than the men for facet remodeling and pitting. Most affected is the upper thoracic region for the females and lower thoracic region for the males. In Wharram Percy, females have the same pattern but they are less affected than the males, they have the lowest percentage of both sites. For osteophytes and pitting, only slights differences are seen in the Ensay sample, and Wharram Percy skeletons. Overall, the results show that the sample from Ensay has more degenerative changes than Wharram Percy, suggesting a greater level of skeletal stress. Ensay women and men were subject to similar overall levels of stress, but because of the different patterns in the spine, they were possibly submitted to different forms of stress. Males and females in Wharram Percy were probably under the same form and level of stress, as seen in the broadly similar patterns of distribution of degenerative changes in the spine. Important is that all these results are in line with the known occupational patterns and the division of labor between the sexes.

Waldron's (1996) case study looked at the hand bones from many sites in the UK, from both the Medieval and post-Medieval periods. Hands were all (almost) complete and both left and right had to be present. He determined whether there were differences between number of joints affected by OA in men and women. Overall, males mostly suffered from unifocal and females from multifocal disease. There also seems to have been a change overtime in the amount of diseased joints. The Medieval period is mostly unifocal and the post-Medieval mostly multifocal. Comparing the two time periods, for the most commonly affected joints, a greater proportion from the post-Medieval group was involved. Differences between the two time periods can be attributed to several sources of bias (selection bias, diagnostic bias, etc.) or a change in prevalence of OA over time. The most plausible explanation seems to be a change in activity but what this change is, has yet to be determined. Also interesting is the relative frequency of OA at the second and third metacarpophalangeal joint: this is not common in modern populations and could as well be attested to a high level of manual labor.

Stirland and Waldron's article (1996) analyzes commingled remains from the ship the *Mary Rose*. Here, vertebrae are analyzed and compared to a Medieval cemetery in Norwich. Only men were on the ship so from the cemetery, only men were examined. The authors are cautious about conclusions on OA and activity as the relationship between the two is complicated. Overall, there was a similar distribution of degenerative changes to the vertebral column but there were some differences in prevalence. OA of the facet joints was more common in the Norwich spines, as was the prevalence of Schmorl's nodes. The prevalence of marginal osteophytes was higher in the cervical and lumbar regions at Norwich while the prevalence of ossification into the ligamentum flavum was higher in the *Mary Rose* spines. The differences between the two sets of spines are slight but as the crew from the *Mary Rose* was much younger, it seems that age related changes were accelerated. Possibly this occurred because of the activities they were involved in on the ship, such as heavy lifting and working in a stooped position.

Waldron and Cox's case control (1989) involves a post-Medieval cemetery in east London. Sex, age, and name were obtained from still legible coffin plates (367 skeletons). Osteoarthritis was assessed at all joints and occupation was found through different records. With these remains and information about their activities, the authors assessed if there was a relationship between weaving and OA of the hands, a relationship was not found and there was no other relationship between OA and occupation. For unknown reasons though, non-manual work did show a significant association with spinal OA. The sample was too small to do a case control on another occupation and OA.

Overall, the case studies show varying results. Four studies have positive results and two have negative results. Knüsel et al. (1997) saw no differences in OA of the spine of three different occupational groups. Waldron and Cox (1989) tried to prove a link between OA of the hands and weaving but this was not found in their case control study. Jurmain (1977) has only one interesting result, that White males show an early onset of right elbow OA.

Positive and promising results are Sofaer-Derevenski (2000), where degenerative changes to the spine are linked with stress on the vertebral column (especially lifting and heavy physical labor). Stirland and Waldron (1996) found an early onset of degenerative changes in the spines from the *Mary Rose*, probably due to a response to the activities on board of the ship (lifting and working in a bended position). Waldron (1996) attributed differences of OA of the hands between the Medieval and post-Medieval periods to a probable change in occupation. Thus, OA of the spine is, although Knüsel et al. (1997) did not find anything, the most promising result.

Chapter 4 – Discussion

In this chapter I will be discussing the results from chapter 3, the problems I encountered and especially whether clinical and archaeological records can be compared. The latter I will do with help of the osteological paradox theory.

Overall, both the results from the clinical studies and the general reviews are alike. Some movements seem to cause OA, other movements are shown be unlikely causes of OA. Some movements will need more research done as they have only been shown to cause or not cause OA in one study. There is also a need for more research on the movements that have inconclusive results.

4.1 Discussion of clinical studies

In the clinical setting there are a few things that need to be considered. These may influence the results of the articles that I have presented. Different factors can influence a study and complicate the comparison between different researches.

Results may differ due to use of different methods of measuring OA, for example radiographs vs. hip or knee replacement. Radiographs can diagnose OA in an early stage, whereas knee or hip replacement surgery is reserved for severe cases. This difference in stages of OA may make it difficult to compare results. This was reduced to a minimum by mostly using articles that use a threshold in radiographs, excluding the less severe cases. This was useful in selecting only the more severe cases of OA, the ones with bony changes, which will be the ones observable in an archaeological setting.

For clinical articles, the cohort study design is best (Lievense et al. 2001). Unfortunately, Toivanen (2010) was the only one of this kind. It would be good to have more of these studies as we do not know beforehand which individuals will get OA. Also, there is a data baseline from which to start. The biggest advantage to this method of study is that all factors are closely monitored during life and researchers do not need to rely on memory of the studied person, unlike the case-control design. Case-control design can thus lead to recall bias (Lievense et al. 2001).

Different results may also come from biases. A few named in Heneghan and Badenoch (2006) are publication bias (the tendency for negative results to be unequally reported in the literature), interviewer bias (systematic error due to interviewer's subconscious or conscious gathering of selective data) or the above named recall bias. Sometimes sample size (not big enough), losses to follow-up (in cohort studies), and atypical patient groups can lead to varying results.

There are a few general issues that must be considered with the reviews used. Limitations due to the literature search may include the missing of relevant literature because of unclear abstracts or using the wrong search methods or words. Also, I only included articles that were written in languages I could read and articles I could access. Certain articles were of restricted access through the Leiden University database.
Not all articles used are from the same time period. As medicine is a fast evolving research area, medical researchers may consider the older articles to be somewhat dated. These researches were included since solid research stays solid research. Most of these older articles have laid the foundation for future researches and must certainly be looked at. The fact that there were not much recent articles on this specific subject should particularly encourage more research in the field. The same can be said about archaeological articles, which I will discuss in the next part of this chapter.

4.2 Discussion of archaeological results

Earlier in this thesis, it was mentioned that there is no consensus on the relationship between OA and activity in the clinical record (Jurmain 1999). The previous part of this chapter has indeed demonstrated that there is no clear cut relationship; however, some activities have proven to cause some sorts of OA. This is also what the latest review (Weiss and Jurmain 2007) shows: results are mixed, but some studies give somewhat promising outcomes, especially when a group performing specific activities is analyzed. Perhaps this thesis focusing on North Western Europe contributes to the difference between these results and

Jurmain's negative results (1991) on clinical association of certain movements to OA.

Jurmain (1999, 51) mentions that many archaeological researchers assume that chronic overuse is a major cause of OA. Jurmain says this is far from accepted in the clinical setting. Some authors of the case studies do question the link between OA and activity, which proves that not all archaeological researchers assume this link. On the other hand, a few believe for example Sofaer-Derevenski (2000), that their specific data is sufficient to still make such conclusions. Others assume that there is a link (Knüsel et al. 1997) or they just ignore the questionable link after all (Stirland and Waldron 1997). Jurmain himself made the mistake of assuming this relationship in his article from 1977, to which he admits in Weiss and Jurmain (2007). Only Waldron (1996) and Waldron and Cox (1989) seem to be somewhat careful with their conclusions.

Reviews (Jurmain and Kilgore 1995; Weiss and Jurmain 2007) agree that there is not enough behavioral data, even from ethnohistorical documentation, to be drawing conclusions from skeletal samples. I agree with this statement. Although four of the six case studies have data of the occupations of the subjects they researched, this is only somewhat detailed in two of the six cases (Sofaer-Derevenski 2000; Waldron and Cox 1989). Even then, the information is not as detailed as in the clinical setting. Information on the occupations of the persons studied may be useful but must be handled with care, especially when drawing conclusions from these.

In the case studies, I noticed that there was no standard method of research, as there is in the clinical studies. Some looked at records such as annals or the Anthony Roll, while others did not. Some researched two different time eras (Jurmain, 1977; Waldron 1996), while others tried to compare only samples from the same time (Stirland and Waldron 1996). Some compared samples from the same area (Knüsel et al. 1997), while others did the opposite (Sofaer-Derevenski 2000; Waldron 1996). Only one study showed some structure in the form of a case control study (Waldron and Cox 1989).

Ideally, the solution would be to make a standard and use it for every new research on this subject. However, this is difficult due to the variable nature of archaeological data. For example, there are always differences in which bones are preserved. Some researches may have mostly knee joints to work with, while others have recovered more hip or hand joints. As well, some data may not be recorded at all, e.g. occupation.

Overall, the results of the archaeological articles are quite divided. Some results such as lifting and spinal OA seem promising (see paragraph 3.2.2). A few of the problems are that methods are used differently and assumptions are made on the relationship between OA and activity. This research area is in need of more and better structured research on skeletal samples. Ethnographic information or data from records on occupations must be handled with care and conclusion cannot be drawn solely on these.

4.3 Comparing the clinical and archaeological record

One of the major problems I had in this thesis, is that clinical and archaeological records are not well linked to each other and comparing the two is quite difficult. I will discuss a few issues and reasons why they exist.

The first problem arose during the comparison of osteoarthritis found in osteological material with the clinical setting. As mentioned, osteological methods are focused on bone changes while medical researchers use radiographs, specifically joint space narrowing. These two methods are not exactly comparable. For this thesis I tried to bring these together by using thresholds and studies with joint replacements (only severe cases). Videman et al. (1991) is a good study to bridge the gap, as both radiographs and osteological methods are used on cadaveric material. Unfortunately the osteological method was used on a different part of the spine as the radiographical method, which makes them incomparable. A standard to compare these two records could be very useful, for example a standard from study of cadaveric material. The advantage of the use of cadaveric material is that information on the patient and radiographs of them during life are present. Osteological changes can be used to assess osteoarthritis and these can be compared to the radiographic evidence, producing a standard between the two. Of course, the bones will not have the same weathering and decomposition effects as archaeological material but it is the closest we can find without having to wait for years of decomposition. In the future material from decomposition labs or farms may be used to solve this problem.

The comparison of the two records reveals a different prevalence of OA between archaeological and modern populations. There is an ongoing discussion whether the prevalence is lower in the archaeological or clinical record. Most researchers believe the prevalence is underrepresented in archaeological settings because of the absence of cartilage. Osteoarthritis limited to the cartilage cannot be seen and this will make for a lower prevalence of OA in archaeology (Crubézy et al. 2002, 582; Ortner 2003, 547). One article did mention the exact opposite (Lovell 1994). It states that “radiological studies typically under-represent joint changes when compared to autopsy and archaeological studies, since slight and moderate changes can be seen on dry bone but do not usually appear radiologically” (Lovell 1994, 160). These differences may be due to the material studied. Ortner and Crubézy both spoke for all joints, while Lovell only studied the spine, which has a different kind of cartilage as the synovial joints (the intervertebral discs) and a different range of motion.

Another discovery was that the types of OA most commonly treated and studied in modern times are not the same as the ones most commonly found in archaeological settings. This can clearly be seen in the differences between the clinical articles, where knee and hip are very prominent and the archaeological articles, where OA of the spine is particularly common. One explanation is that OA of the spine can be present in a patient and be symptomless (Kumar and Clark 2009, 510). In this way, OA of the spine can be found in the osteological setting but not in the clinical record. Since knee and hip OA produce discomfort and handicap, especially at the workplace, they may be more common in the clinical literature. One last explanation is that the most common symptom of spinal OA is back pain, which is quite aspecific. Spinal OA may thus be misdiagnosed more often than other sorts of OA, which have quite specific symptoms (see chapter 1).

4.3.1 The osteological paradox

Finally, how the archaeological sample and the population that they belonged to relate to each other, can explain the difficulties that researchers experience when comparing archaeological and modern populations. This relationship and its problems are considered in a theory that was first synthesized in the 1990's: the osteological paradox. This theory was first presented by Wood et al. (1992) for prehistoric samples, but it can be applied to any archaeological sample. In the osteological paradox, the three major problems in establishing a relationship between statistics calculated from archaeological skeletal material and the health status of the population they belonged to are demographic non-stationarity, selective mortality, and hidden heterogeneity in the risks of disease and death (Wood et al. 1992).

Demographic non-stationarity refers to populations where age-at-death distribution is very sensitive to changes in fertility instead of changes in mortality due to their non-stationary nature. Non-stationary means not of constant size. A demographic reconstruction is thus more based on fertility than mortality. As Wright and Yoder describe "the age distribution of skeletons in a cemetery reveals more about fertility levels than it does about mortality patterns" (Wright and Yoder 2003, 45). OA is not related to fertility or mortality, so this is not of further relevance for this thesis.

Selective mortality means that not all individuals are at risk of disease or death at a certain age in a skeletal sample. This is because they did not all die at a certain moment, only a few did. The example from Wood et al. (1992, 344) is that the only 20 year olds that we find in archaeology are the ones that died. Others may also have been at risk of disease or death at 20 but did not die until 60 years old. Thus we see only a highly selective sample of disease at 20 years old. Direct extrapolations from the clinical record to mortality samples (the archaeological sample) cannot be made due to this. The distinction between active and healed lesions in paleopathology can be very helpful in solving this bias.

In osteoarthritis the lesions are degenerative, which means that cartilage does not heal when it has been destroyed. This also means that we will eventually find all people who were at risk for this disease at a certain age, regardless of the age-at- death. Other issues may of course prevent us from finding every single person from a population but as a theoretical problem, it is less of a point for OA.

Hidden heterogeneity in risks of disease or death means that not everyone in a population has the same chance or susceptibility for disease or death (also known as frailty). Heterogeneity arises from all kinds of genetic and environmental factors that are hard to predict. This makes it almost impossible to interpret population-level mortality rates in terms of individual risks of death (Wood et al. 1992, 345). Archaeological populations cannot be compared if the distribution of this chance differs in an unknown way.

This is certainly the case with osteoarthritis. As this is a multifactorial disease, the chance of one individual being affected is not the chance of another individual. Individuals will thus vary in their risk of OA because of heterogeneity and it will obscure the analysis of the association of OA with activity.

All these problems make it hard to obtain direct estimates of demographic or epidemiological rates from archaeological samples (Wood et al. 1992, 345). This is because we do not know the exact amount of exposure or their susceptibility to disease per individual in an archaeological sample to calculate these rates, just as it is hard to know the amount of activity and how long someone has been exposed to it. Individuals are thus so different from one another that the individual does not tell us much about health or disease in a population.

Wright and Yoder (2003) responded to Wood et al. (1992) in the form of a review of recent literature on several topics such as paleodemography, age and sex estimation, biodistance, growth disruption, paleopathology, and paleodiet. The authors use these areas of research to address the problems in the osteological paradox and to search for solutions. Accurate demographic models are important to interpret the impact of the pathological lesions on the well-being of the whole population. Wright and Yoder (2003) explain that the solution to the paradox lies in “a better integration of paleodemography and paleopathology” (Wright and Yoder 2003, 49). Research on biodistance can help in the field of the hidden heterogeneity. Movement between different populations can result in differences in genetics and thus in frailty. Paleodiet may help us by looking specifically at individual changes in the diet during life. Diet of children directly influences their frailty and chance of survival through childhood. Growth disruption can also contribute to a solution to the osteological paradox. Enamel hypoplasia can for example provide us with “a record of childhood illness that can be compared to morbidity and mortality at later ages” (Wright and Yoder 2003, 53). Finally, one of the solutions to the hidden heterogeneity is to examine the dimensions that contribute to frailty in paleopathology, mostly from studies on living people. For OA this would mean that we need to explore the causes and to get a better view of the multifactorial nature of this disease.

5 - Conclusion

Osteoarthritis is a multifactorial disease and activity is certainly one of the contributing factors to this illness. To what extent it causes OA is not yet clearly defined in the clinical record. Some movements such as kneeling or lifting show strong evidence of causing knee and hip OA. Some movements are clearly not causing OA (e.g. standing and knee OA) and others have inconclusive results. More research is needed in order to investigate the inconclusive results and also the movements that have only been minimally examined.

The main research question addressed in this thesis was "*Can activity be detected in archaeological human skeletal remains in the Middle Ages of North-Western Europe?".* Archaeological results show that there is no standard in analyzing whether osteoarthritis was caused by activity. It must always be kept in mind while researching OA and activity, that there is an ambiguous relationship between the two that cannot be assumed to be present. I think it is difficult to relate OA to activity in the archaeological sample due to limitation in knowledge of the occupations and movements but also because of the limitations of the skeletal sample itself, as seen in the osteological paradox, especially hidden heterogeneity. This research area is in need of more and better structured research on skeletal samples. A more standard methodological approach would be useful to make the comparison between sites possible but the variable nature of archaeological data may make this difficult.

The sub-question *"What types of activity cause the most frequent or severe osteoarthritis in groups from the Medieval and post-Medieval period of North Western Europe?"* is influenced by the fact that results from the archaeological literature are divided. Four articles found positive results and two did not. As we are looking at different joints and different movements, it is difficult to pinpoint one activity that caused the most OA of a certain joint. However, it is worth noting that the spine was the most named joint. As heavy lifting was named twice with spinal OA (Sofaer-Derevenski 2000; Stirland and Waldron 1996) and no other movement has been named twice, this is likely to be an activity that indeed causes OA. However, caution must be taken because samples are small .

The second sub-question was *“To what extent does the clinical data support the findings from the archaeological record?”* and it can be answered as follows. The archaeological record can be supported by the clinical record when it concerns activities that are already proven to cause OA in the clinical record, thus not in all cases. As the joints in which OA is found in the clinical record and the archaeological record differ, this may prove to be difficult. One promising result is that spinal OA is linked in both archaeological and clinical record to lifting, working in a bended position and heavy work load. However additional research is needed on other populations.

5.1 Future directions

As a first step to make the archaeological and the clinical record more comparable, a standard should be established in which bony changes and radiological changes are linked. Of course more issues, such as hidden heterogeneity in the risk of disease, must be solved as well but Wright and Yoder (2003) made some good suggestions how to solve a part of the problem.

Other directions for future research on activity in archaeological samples are discussed in the book by Jurmain (1999). He suggests looking at enthesopathies, the skeletal manifestations of tendinous or ligamanentous insertions, often termed musculoskeletal stress markers (MSM). These bone markers are said to be caused by mechanical factors. These are being studied by researchers such as Molar (2006) and results are promising.

Abstract

Nederlands

Artrose is de meest voorkomende degeneratieve gewrichtsziekte in populaties uit het heden en het verleden. Het is een ziekte die door meerdere factoren wordt veroorzaakt zoals leeftijd, geslacht en genetica. Een factor die artrose kan veroorzaken is activiteit (oftewel bewegingen). Met behulp van klinische artikelen wordt onderzocht of activiteit daadwerkelijk een oorzaak is van artrose in de hedendaagse populatie. Daarna wordt er gekeken naar archeologische literatuur, om te zien of de relatie tussen activiteit en artrose kan worden teruggevonden in populaties uit het verleden. Er is in de klinische literatuur gezocht naar knie, heup en wervelkolom artrose. In de archeologische literatuur is er voornamelijk gekeken naar wervelkolom en handen artrose. Uit het onderzoek komen een aantal bewegingen naar voren die zeer waarschijnlijk artrose veroorzaken (zoals de link tussen knielen en knie artrose), maar ook een groot aantal bewegingen waar meer onderzoek bij nodig is. In de archeologische literatuur is geen eenduidige conclusie. Er zijn een aantal veelbelovende onderzoeken die aantonen dat activiteit terug te vinden is met artrose maar ook onderzoeken die dit tegenspreken. Als laatste wordt ook een aantal problemen besproken over het vergelijken van klinische en archeologische literatuur, waaronder “the osteological paradox”. Concluderend worden sommige vormen van artrose in de kliniek door activiteit veroorzaakt maar dit is lastig in de archeologie terug te vinden. Meer onderzoek naar standaarden voor onderzoek naar de link tussen OA en activiteit is nodig.

English

Osteoarthritis is the most common degenerative joint disease in both modern and past populations. It is a disease caused by several factors such as age, sex, and genetics. Activity is a factor which possibly causes osteoarthritis. By using clinical literature, it is examined if activity is truly a cause of osteoarthritis in modern populations. Archaeological literature is then examined, to determine the relationship between activity and osteoarthritis in past populations. The clinical

literature is assessed for knee, hip, and spinal column osteoarthritis. In the archaeological literature spinal and hand osteoarthritis were particularly common. In this research, a number of movements were found to be associated with osteoarthritis, such as the link between kneeling and knee osteoarthritis. Many movements were found to be in need of more research. In the archaeological literature no distinct conclusion was found. While there are some promising studies which show that activity is related to osteoarthritis, there are also studies which contradict this. Finally, a number of problems are discussed on comparing clinical and archaeological literature, among others the osteological paradox. Concluding, some sorts of osteoarthritis in the clinical setting are caused by activity but finding this in the archaeological record is difficult. There is more research needed on standards for research on the link between activity and OA.

Bibliography

Angel, J.L., 1966. *Early Skeletons from Tranquility, California*. Washington DC: Smithsonian Press.

Brothwell, D.R., 1981. *Digging up bones*. London: Oxford University Press/British Museum of Natural History.

Coggon, D., S. Kellingray, H. Inskip, P. Croft, L. Campbell and C. Cooper, 1998. Osteoarthritis and Occupational Lifting. *American Journal of Epidemiology* 147(8), 523-8.

Coggon, D., P. Croft, S. Kellingray, D. Barrett, M. McLaren and C. Cooper, 2000. Occupational Physical Activities and Osteoarthritis of the Knee. *Arthritis and Rheumatism* 43(7), 1443-9.

Cooper, C., T. McAlindon, D. Coggon, P. Egger and P. Dieppe, 1994. Occupational activity and osteoarthritis of the knee. *Annals of the Rheumatic Diseases* 53, 90-3.

Cooper, C., L. Campbell, P. Byng, P. Croft and D. Coggon, 1996. Occupational activity and the risk of hip osteoarthritis. *Annals of the Rheumatic Diseases* 55, 680-682.

Croft, P., C. Cooper, C. Wickham and D. Coggon, 1992. Osteoarthritis of the hip and occupational activity. *Scandinavian Journal of Work, Environment and Health* 18(1), 59-63.

Crubézy, E., J. Goulet, J. Bruzek, J. Jelinek, D. Rougé and B. Ludes, 2002. Epidemiology of osteoarthritis and enthesopathies in a European population dating back 7700 years. *Joint Bone Spine* 69, 580-8.

Felson, D.T., 1994. Do occupation-related physical factors contribute to arthritis? *Baillières Clinical Rheumatology* 8(1), 63–77.

Felson, D.T., 2000. Osteoarthritis: new insights. Part 1: The disease and its risk factors. *Annals of Internal Medicine* 133, 635-46.

Genti, G., 1989. Occupation and osteoarthritis*. Bailliere's Clinical Rheumatology* 3(1) 193-204.

Heneghan, C. and D. Badenoch, 2006. *Evidence- based Medicine Toolkit*. Oxford: Blackwell Publishing Ltd.

Hough, Jr. A., 2001. Pathology of osteoarthritis, in W. Koopman (eds), *Arthritis and Allied Conditions*. Philadelphia: Lippincott Williams and Wilkins, 2167-94.

Jensen, L.K., 2008. Hip osteoarthritis: influence of work with heavy lifting, climbing stairs or ladders, or combining kneeling/squatting with heavy lifting. *Occupational and Environmental Medicine* 65, 6-19.

Jurmain, R.D., 1975. *Distribution of Degenerative Joint Disease in Skeletal Populations*. *PhD Thesis*. Cambridge: Harvard University.

Jurmain, R.D., 1977. Paleoepidemiology of Degenerative Knee Disease. *Medical Anthropology* 1, 1-14.

Jurmain, R.D., 1977. Stress and the Etiology of Osteoarthritis. *American Journal of Physical Anthropology* 46, 353-66.

Jurmain, R.D., 1999. *Stories from the skeleton: Behavioural Reconstruction in Human Osteology*. The Netherlands: Gordon and Breach Publishers.

Jurmain, R.D. and L. Kilgore, 1995. Skeletal evidence of osteoarthritis: a palaeopathological perspective. *Annals of the Rheumatic Diseases* 52, 443-50.

Kellgren, J. H. and J.S. Lawrence, 1963. *Atlas of standard radiographs: the epidemiology of chronic rheumatism*. Oxford: Blackwell Scientific.

Kieser, J.A., C.B. Preston and W.G. Evans, 1983. Skeletal age at death: an evaluation of the Miles method of ageing. *Journal of Archaeological Science* 10, 9–12.

Klussmann, A., H. Gebhardt, M. Nübling, F. Liebers, E. Quirós Perea, W. Cordier, L. V. Von Engelhardt, M. Schubert, A. Dávid, B. Bouillon and M. A. Rieger, 2010. Individual and occupational risk factors for knee osteoarthritis: results of a case-control study in Germany. *Arthritis Research & Therapy* 12, 88-103.

Knüsel, C.J., S. Göggel and D. Lucy, 1997. Comparative Degenerative Joint Disease of the Vertebral Column in the Medieval Monastic Cemetery of the Gilbertine Priory of St. Andrew, Fishergate, York, England. *American Journal of Physical Anthropology* 103, 481-95.

Kumar, P. and M. Clark, 2009. *Clinical Medicine*. Edinburgh: Saunders Elsevier.

Lievense, A., S. Bierma-Zeinstra, A. Verhagen, J. Verhaar and B. Koes, 2001. Influence of work on the development of osteoarthritis of the hip: a systematic review. *Journal of Rheumatology* 28(11), 2520-8.

Lovell, N.C., 1994. Spinal Arthritis and Physical Stress at Bronze Age Harappa. *American Journal of Physical Anthropology* 93, 149-64.

Manninen, P. , M. Heliövaara, H. Riihimäki and O. Suomalainen, 2002. Physical workload and the risk of severe knee osteoarthritis. *Scandinavian Journal of Work, Environment and Health* 28(1), 25–32.

McMillan, G. and L. Nichols, 2005. Osteoarthritis and meniscus disorders of the knee as occupational diseases of miners. *Occupational and Environmental Medicine* 62, 567–75.

McWilliams, D.F., B.F. Leeb, S.G. Muthuri, M. Doherty and W. Zhang, 2011. Occupational risk factors for osteoarthritis of the knee: a meta-analysis. *Osteoarthritis and Cartilage* 19, 829-39.

Merbs, C.F., 1983. *Patterns of activity-induced pathology in a Canadian Inuit population*. National Museum of Man: Maercury Series 119.

Miles, A.E.W., 1962. Assessment of the ages of a population of Anglo-Saxons from their dentitions. *Proceeding of the Royal Society of Medicine* 55, 881–6.

Miles, A.E.W., 1963. The dentition in the assessment of individual age in skeletal material, in D.R. Brothwell (eds), *Dental anthropology*. London: Pergamon Press.

Molnar, P., 2006. Tracing prehistoric activities: Musculoskeletal stress marker analysis of a stone-age population on the Island of Gotland in the Baltic sea. *American Journal of Physical Anthropology* 129(1), 12-23.

Ortner, D.J., 2003. *Identification of Pathological Conditions in Human Skeletal Remains.* London: Academic Press.

Outerbridge, R.E., 1961. The etiology of chondromalacia patellae**.** *Journal of Bone and Joint Surgery British Volume* 43(B), 752-7.

Perera, R., C. Heneghan and D. Badenoch, 2008. *Statistics Toolkit*. Oxford: BMJ Books.

Petersson, I.F. and L.T.H. Jacobsson, 2002. Osteoarthritis of the peripheral joints. *Best Practice & Research Clinical Rheumatology* 16 (5), 741-60.

Rogers, J. and T. Waldron (eds), 1995. *Field Guide to Joint Disease.* Chichester: John Wiley and Sons.

Rogers, J., T. Waldron, P. Dieppe and I. Watt, 1987. Arthropathies in palaeopathology: the basis of classification according to most probable cause. *Journal of Archaeological Science* 14, 179-93.

Sandmark, H., C. Hogstedt and E. Vingård, 2000. Primary osteoarthrosis of the knee in men and women as a result of lifelong physical load from work. *Scandinavian Journal of Work, Environment and Health* 26(1), 20-5.

Schouten, J.S.A.G., R. A. de Bie and Gerard Swaen, 2002. An update on the relationship between occupational factors and osteoarthritis of the hip and knee. *Current Opinion in Rheumatology* 14, 89–92.

Seidler, A., U. Bolm-Audorff, H. Heiskel, N. Henkel, B. Roth-Küver, U. Kaiser, R. Bickeböller, W.J. Willingstorfer, W. Beck and G. Elsner, 2001. The role of cumulative physical work load in lumbar spine disease: risk factors for lumbar osteochondrosis and spondylosis associated with chronic complaints. *Occupational and Environmental Medicine* 58, 735–46.

Seidler, A., U. Bolm-Audorff, N. Abolmaali and G. Elsner, 2008. The role of cumulative physical work load in symptomatic knee osteoarthritis – a case-control study in Germany. *Journal of Occupational Medicine and Toxicology* 3, 14-22.

Sofaer-Derevenski, J.R., 2000. Sex Differences in Activity-Related Osseous Change in the Spine and the Gendered Division of Labor at Ensay and Wharram Percy, UK. *American Journal of Physical Anthropology* 111, 333-54.

Spector, T. D., C. Cooper, J. Cushnaghan, D.J. Hart and P.A. Dieppe, 1992. *A radiograph atlas of knee osteoarthritis*. London: Springer Verlag.

Stewart, T., 1947. Racial patterns in vertebral osteoarthritis. *American Journal of Physical Anthropology* 5, 230-1.

Stewart, T.D., 1976. Identification by the skeletal structures, in F.E. Camps (eds), *Gradwohl's legal medicine*. Bristol: Wright, 109–35.

Stirland, A.J. and T. Waldron, 1997. Evidence for Activity Related Markers in the Vertebrae of the Crew of the Mary Rose*. Journal of Archaeological Science* 24, 329–35.

Toivanen, A.T., M. Heliövaara, O. Impivaara, J.P.A. Arokoski, P. Knekt, H. Lauren and H. Kröger, 2010. Obesity, physically demanding work and traumatic knee injury are major risk factors for knee osteoarthritis—a population-based study with a follow-up of 22 years. *Rheumatology* 49, 308–314.

Verhaar, J.A.N. and A.J. van der Linden, 2003. *Orthopedie*. Houten: Bohn Stafleu van Loghum.

Videman, T., M. Nurminen and J.D.G. Troup, 1990. Lumbar Spinal Pathology in Cadaveric Material in Relation to History of Back Pain, Occupation, and Physical Loading. *Spine* 15(8), 728-40.

Vingård, E., 1996. Osteoarthrosis of the knee and physical load from occupation. *Annals of the Rheumatic Diseases* 55, 677-84.

Vingård, E., C. Hogstedt, L. Alfredsson, E. Fellenius, I. Goldie and M. Koster, 1991. Coxarthrosis and physical work load. *Scandinavian Journal of Work, Environment and Health* 17(2), 104-9.

Waldron, H.A. and M. Cox, 1989. Occupational arthropathy: evidence from the past. *British Journal of Industrial Medicine* 46, 420-2.

Waldron, H.A., 1996. Osteoarthritis of the Hands in Early Populations. *Bristish Journal of* Rheumatology 35, 1292-8.

Waldron, T., 1997. Osteoarthritis of the Hip in Past Populations. *International Journal of Osteoarchaeology* 7, 186-9.

Weiss, E. and R.D. Jurmain, 2007.Osteoarthritis Revisited: A Contemporary Review of Aetiology*. International Journal of Osteoarchaeology* 17: 437-450.

Wood, J.W., G.R. Milner, H.C. Harpending and K.M. Weiss, 1992. The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples. *Current Anthropology* 33(4), 343-70.

Wright, L.E. and C.J. Yoder, 2003. Recent Progress in Bioarchaeology: Approaches to the Osteological Paradox. *Journal of Archaeological Research* 11(1), 43-70.

Zhang, Y., L. Xu, M.C. Nevitt et al., 2001. Comparison of the prevalence of knee osteoarthritis between the elderly Chinese population in Beijing and whites in the United States: The Beijing Osteoarthritis Study. *Arthritis and Rheumatism* 44, 2065-71.

List of figures

List of tables