Using the Osteoarthritic Femur to Identify Impairment Potential in Archaeological Populations

Janet Young

Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements
for the Doctorate degree in Population Health

Population Health

Faculty of Graduate and Postdoctoral Studies

University of Ottawa

Table of Contents

List of Appendices

List of Figures

List of Tables

List of Abbreviations

ACL: anterior cruciate ligament

BMI: body mass index

CAOS: clinical archaeological osteoarthritis scale

CNI: combined notch index

FIPS: functional impact probability score

HDIS: health determinants impact score

ICD: International Statistics Classification of Disease and Related Health Problems

ICF: International Classification of Functioning Disability and Health

KOII: knee osteoarthritis impact index

KOOS: Knee Outcomes in Osteoarthritis Survey

MRI: magnetic resonance imaging

NDI: notch depth index

NWI: notch width index

OA: osteoarthritis

OAI: Osteoarthritis Initiative

WHO: World Health Organization

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index

List of Definitions

Disability: From the World Health Organization, disability is an umbrella term, covering impairments, activity limitations, and participation restrictions. Impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations. Thus disability is a complex phenomenon, reflecting an interaction between features of a person's body and features of the society in which he or she lives.

FIPS: The Functional Impairment Probability Score uses published probabilities related to lifestyle and functional outcome variables to calculate a single probability score. A single score is calculated by averaging the probabilities of all the relevant outcome variables by knee. This operationalizes individual level measures for populations.

Function: The manner in which an individual is able to successfully perform an action or activity proper to that person.

HDIS: The Health Determinants Impact Score is a scoring system for the determinants of health, included under the broad categories of social environment, physical environment, health interventions, and individual responses. Each determinant category is divided into subcategories: seven for social environment, six for physical environment, one for health interventions, and two for individual responses. These 16 subcategories are defined by four descriptions, with 0 defining the least and 3 defining the most impact on positive outcomes. The most applicable description for each determinant subcategory is identified and the relevant score noted. Summing the scores for all the factors provides a population level measure (HDIS-sum).

ICF: The International Classification of Functioning, Disability and Health is a classification of health and health-related domains that classify from not only body but also individual and societal perspectives using a list of body functions and structure, environmental factors, and domains of activity and participation.

ICD-10: The International Classification of Diseases is a diagnostic tool used in epidemiology, health management, and clinical situations to classify and record diseases and health problems including death certificates and health records.

Impairment: A loss or abnormality of biological structure of function.

KOII: The Knee Osteoarthritis Impact Index combines the quantified determinants of health data (HDIS-sum) and the clinical outcome data (FIPS) into a single score that quantifies the potential impact of knee OA in an archaeological population. This is a population level measure.

Acknowledgements

“…we are simply passing through history. This, this *is* history”
(Belloq, Raiders of the Lost Ark, 1981).

I am privileged everyday to have the opportunity to become acquainted with those who have passed through history; their physical remains providing a glimpse into vibrant and productive lives. It was the prospect of furthering my capacity to understand those lives, to better represent people long since passed that lead me to and through this thesis research. A difficult and long road, researching and writing a thesis is a product of many hands both guiding the research and supporting the researcher.

I would sincerely like to acknowledge and thank my thesis supervisor, Dr. Edward Lemaire, who accepted me as a student despite my background being outside the normal purview for the field of population health. Without his consistent guidance, constructive criticism, and expertise this thesis could never have been completed. I would like to thank the Canadian Museum of Civilization for supporting my thesis research and all my colleagues both inside and outside the institution who provided me with guidance, helpful suggestions, and a shoulder to lean on, especially Dr. Jean-Luc Pilon whose editing skills were always made available and provided with great encouragement. I would like to thank my evaluation committee, Dr. Louise Bouchard, Dr. Mary Egan, Dr. Lucie Brosseau, and Dr. Michèle Drapeau, for their thought comments and valuable input.

I am very grateful to my cohort who offered much needed insight, collegiality, and perspective during the long process of thesis preparation. The many coffee and lunch meetings mitigated the sense of isolation and pushed me forward.

I am very thankful for all the support provided by my family and friends. They could not fully comprehend what I was experiencing but were thoughtful, understanding, and empathetic when I needed it most.

A significant amount of my thanks and appreciation goes to my husband, Steve, who was a constant source of support, patience, and encouragement, and my children Jesse and Cassidy who provided abundant distraction and ample hugs and kisses to preserve my sanity.

Abstract

Background: Osteoarthritis (OA) is the leading cause of disability in North American and has major economic consequences for society. People with knee OA experience the worst quality of life, among musculoskeletal conditions, with function and mobility being influenced by symptoms such as pain and stiffness. However, the impact of OA symptoms varies due to intrinsic and extrinsic factors. This has lead many researchers to employ biopsychosocial and other population health frameworks to study the disease. These approaches have not been adopted for knee OA in bioarchaeology, where a limited biological lens prevails due to the sole reliance on skeletal remains.

Purpose: The purpose of this research was to identify the impairment potential of knee OA in archaeological populations using a clinical sample and population health approaches.

Methods: Clinical studies have the advantage of assessing not only the biological implications of knee OA but also the functional outcomes. To bring this information into the study of skeletal populations, a link to a clinical sample of knee OA patients had to be established. First, to explore the viability of clinical frameworks for the study of disease in archaeological populations, a pilot study adapted two medical classification systems of health and disease (ICD and ICF) to the documentation of disease in bioarchaeology. Secondly, a clinical population of knee OA patients with diagnostic images of the distal femur and impairment and disability outcome measures was identified. A grading system of knee OA severity was created that examines changes in the distal femur for both clinical and archaeological populations. The relationship between impairment and disability outcome measures and the categories of knee OA severity for the clinical population were identified and operationalized. Population health frameworks were employed by revising the multiple determinants of health model for its application to knee OA in archaeological populations. Finally, the operationalized outcome data and determinants of health data were applied to select archaeological populations.

Results: The adaptation of two medical classification systems for documentation of human skeletal remains was successful and established the viability of using clinical frameworks in bioarchaeology. The Osteoarthritis Initiative (OAI) provided a clinical population of knee osteoarthritis sufferers with both MRI images of the distal femur and lifestyle/functional outcome data for the creation of two grading systems of knee OA severity, one linked to the morphological changes of the distal femur (Clinical Archaeological Osteoarthritis Score or CAOS) and the other linked to the size of the intercondylar femoral notch. The CAOS measure was the best predictor of impairment while the intercondylar notch measure showed little correlation. The four CAOS grades were operationalized by linking grades (0 = no change to 3 = severe changes) to specific functional tasks and outcomes (e.g., walking, bending, running, light chores, etc.). The resulting probability profiles provided sex specific probabilities of having poor outcomes when completing specific tasks. For example, the probability of a female having difficulty kneeling with CAOS grade 3 knee OA would be 0.91. The revised Multiple Determinants of Health model was used to frame the collection of information from two archaeological populations, the 17^{th} century Huron and the 19^{th} century Inuit from the Igloolik region of Nunavut. The information on impairment potential was then combined with the determinants of health data to demonstrate the increased impairment potential of knee OA in the Inuit versus the Huron population.

Conclusion: Population health frameworks and models conceptualize impairment due to knee OA as a product of factors that are intrinsic or extrinsic to the individual. With the CAOS system providing a link between present and past populations, the dialogue on knee OA can be expanded beyond the biological to include other determinants of health. This is a paradigm shift in bioarchaeology that clarifies the importance of including both physical and social environments when interpreting skeletal populations.

Chapter 1. Introduction

The study of health and disease in past populations relies on the interpretation of skeletal changes due to pathology or injury. Complementing bioarchaeological analyses with current medical research allows more informed interpretations (Faccia & Williams, 2008, p. 28). Clinical information provides a guide for quantification, description, diagnosis of disease, and identification of prevalence rates in past populations (Roberts, 1999).
In modern society, musculoskeletal conditions like knee osteoarthritis (OA) have a direct impact on the individual and a peripheral affect on overall health, functional capacity during work, and participation in a social environment (Yelin & Felts, 1990; Yelin & Callahan, 1995; Kramer et al., 2001; Woolf, 2001; Stewart et al., 2003; Woolf & Pfleger, 2003). The same limitations should hold true for earlier populations. However, few studies have sought to correlate level of impairment and its ramifications, both personally and socially, to the expression of skeletal lesions. This information is fundamental for understanding health since level of impairment affects functional independence, social contribution, access to resources, and other factors needed for positive health outcomes.

1.1. Statement of the Problem: Limitations of Current Bioarchaeological Approaches

To study impairment and its personal and social ramifications in bioarchaeology, a broadening of the current interpretation of skeletal health, which is primarily focused on the biological, is required. Generally, bioarchaeologists refer to health as the physical manifestation of biological stress expressed through various skeletal and dental features (Bush, 1991; Bush & Zvelebil, 1991; Goodman & Martin, 2002; Larsen, 2002); including, adult stature, sub-adult growth rates, dental crowding, dental enamel defects, osteoporosis, and skeletal lesions related to anaemia (Bush & Zvelebil, 1991).

The World Health Organization defines health as a state of complete physical, mental and social wellbeing where an individual or group can identify and realize aspirations, satisfy needs, and change or cope with the environment (WHO, 1986). While this is only one of many definitions of health (Bush, 1991), the WHO definition moves beyond the absence of disease and embraces the biopsychosocial approach, recognizing the interaction of individual, social, and environmental factors (Gignac et al., 2008). Bioarchaeological analysis typically stops at the physical disease state.

Clinical and bioarchaeological health definitions are characterized by the type of information available for study. For the bioarchaeologist, a human skeleton holds much information about diet, activity patterns, disease processes, violence, and trauma but provides little information about outcomes generated by skeletal changes (Cohen & Armelagos, 1982; Verano & Ubelaker, 1992, Ortner, 1994; Aufderheide & Rodriguez-Martin, 1998; Lovel, 2000; Goodman & Martin, 2002; Steckel & Rose, 2002; Ortner, 2003, Mann & Hunt, 2005; Roberts & Manchester, 2007). In other words, "knowing why someone had a particular disease does not tell us much about how that disease affected everyday life for the person concerned" (Metzler, 1999, p. 58). In fact, few have attempted to describe functional consequences from the skeletal manifestation of disease (Goodman & Martin, 2002).

In modern society, musculoskeletal disorders are common and have extensive economic consequences for society (Mantyselka et al., 2002). While it is generally believed that bone changes have an effect on work capacity and reproduction, which in turn affects social and economic status, current bioarchaeology methods cannot tell us how an individual's life was affected by these lesions (Metzler, 1999). The lack of methods that relate boney changes to lifestyle makes it difficult to assess the impact of impairment on the individual and society. Roberts (1999) emphasized the importance of using clinical data to assess how normal function was affected by disease, stating that "if disease or injury states are to be considered as potentially disabling, reference to the clinical record for these conditions (i.e., how they affected a person) is essential". Without this data, impairment cannot be interpreted; however, little has been done to address this need.

The proposed research seeks to fill this void by introducing population health models that link the disease to determinants of health, encouraging a paradigm shift in the field of bioarchaeology. Currently, in bioarchaeology, the impact of a disease on outcomes is assumed homogeneous across cultural, geographical, and temporal contexts. New methods for moving beyond disease-based outcomes to include the individual's or population's environment provides a means to introduce heterogeneity into the dialogue of disease impact in archaeological populations.

A myriad of skeletal lesions can create functional limitations; however, only a single condition was explored in this thesis. The general category of degenerative joint disease has been chosen due to its prevalence in skeletal populations and its known impact on affected modern groups. OA has been cited as the most common joint disease in both modern and ancient populations (Rogers & Waldron, 1995). OA will therefore be the focus of the present research work. More specifically, knee OA was chosen because it is one of the leading causes of mobility impairment and also impacts psychological variables like depression and social consequences like isolation.

1.2. Research Question, Contribution to the Advancement of Knowledge and the Field of Population Health

This thesis assessed the individual experience of living with knee OA, how this experience relates to the bone changes associated with disease progression, the impact of the determinants of health on the knee OA experience, and the implications of knee OA for archaeological populations. The principle research question is:

> How can bone changes in the osteoarthritic femur be used to inform our understanding of impairment and disability for archaeological populations?

A solution to this research question can provide a new understanding of knee OA's impact and relevance to the overall health outcomes for ancient populations by including determinants of health in the discussion, which are not currently utilized in bioarchaeological analysis. Framed by the biopsychosocial theory of health, such determinants would include physical, social, and attitudinal environment factors. By incorporating population health concepts into the discourse on ancient populations, current health models can be applied to populations whose life contexts were not entirely dissimilar to those of today. This incorporation will also demonstrate the utility of population health concepts for research fields currently outside conventional application. By demonstrating the applicability of population health models to ancient populations, the impact and evolution of the determinants of health over the course of human history can be explored.

1.2.1 Limitations

Although the thesis research answered the principle research question, various limitations and shortcomings should be considered. First, there is no gold standard for evaluating the use of clinical data for archaeological populations. Relating clinical samples to archaeological population is limited by the ability to match population samples, the available information that is common to both populations, and the environmental context between modern and ancient societies. Second, this research focused only on a single dataset provided by the Osteoarthritis Initiative (OAI). Research with additional data sets would help with model validation and help with matching populations. Third, the theoretical application of the data was conducted on only two contrasting archaeological populations. No case studies were included due to the population level approach to the question. Fourth, since data collection was conducted by the author, interobserver error was not assessed. Fifth, due to the unique nature of the research, no other studies were available for comparison. Therefore the techniques developed and employed require further research on reliability and generalizability.

1.3. Background

1.3.1. Osteoarthritis: General Considerations

"The most common diseases of the musculoskeletal system among degenerative and inflammatory rheumatic disorders are osteoarthritis (OA) and rheumatoid arthritis (RA), respectively" (Ay et al., 2008, p.159). These articular disorders have the capacity to cause disability, produce activity limitations, and negatively affect quality of life (Ayis et al., 2007; Ay et al., 2008). OA is the most common of the two arthritic diseases and the leading cause of disability in North America and developed countries (Spector et al., 1996; Marra et al., 2007; Rosemann et al., 2007). Caused by a range of disorders and characterized by degeneration of cartilage and subchondral bone (Fautrel et al., 2005), OA manifests when the mechanism of joint tissue breakdown and repair is overwhelmed, leading to structural and functional failure of the synovial joints (Hunter et al., 2008). This progressive joint failure may cause pain, physical disability, impairment, psychological distress, limit activities of daily living, and reduce quality of life, although many persons who have structural changes consistent with OA are, for reasons unknown, asymptomatic (Hunter et al., 2008; Rapp et al., 2000).

Diet is believed to play a role in OA progression. The effect is twofold, having both a positive and a negative impact. Obesity contributes to OA development and progression since excessive weight increases stresses in load bearing joints, leading to increased wear of the structures. Obesity is also believed to lead to systemic inflammation, another factor linked to OA progression (Brunner et al., 2012; McAlindon and Felson, 1997). However, certain vitamins such as K or certain polyunsaturated fatty acids have been shown to mitigate the progression and symptom expression of OA (McAlindon and Felson, 1997; Oka et al., 2009; Knott et al., 2011; Baker et al., 2012; Brunner et al., 2012).

1.3.1.1. Knee Osteoarthritis

The knee is a biological unit of hard and soft tissue structures that function as a mechanism for mobility and a pathway for load transfer. Knee OA is a complex interaction between biological and biomechanical factors that lead to imbalances in degeneration and repair of articular cartilage, producing mechanically induced knee joint failure (Biscevic et al., 2008; Maly, 2008). Though knee OA is almost always symptomatic, its symptoms are diverse and heterogeneous; including, reduced function, stiffness after inactivity (short lived), joint instability (limiting task performance), buckling or giving way, and psychological and emotional distress (including depression) related to chronic pain (Cooper et al., 2000; Dieppe, 2000; Breedveld, 2004; Fitzgerald et al., 2004; Parmelee et al., 2007; Hunter et al., 2008). In some cases, these symptoms initiate limb use modifications, with the main changes identified during sitting, standing, bending, and walking (Hall et al., 2008).

OA related knee pain can be activity related or mechanical, deep, aching, and not well localized. This pain is often cited as the predominant symptom and the main reasons for disability. OA knee pain is related to a person's perception of their ability rather than with their actual ability to perform (Lethbridge-Cejku, 1995; Hopman-Rock et al., 1998; Bennell et al., 2003; Williams et al., 2004; Peters et al., 2005; van der Waal et al., 2005; Maly et al., 2006; Rosemann et al., 2006; Parmelee et al., 2007; Tuzun, 2007; Hunter et al., 2008; Maly et al., 2008; and Maly, 2009). Pain slows activity and leads to several functional consequences, including not only pain but a lack of trust in the knee, especially during challenging pursuits (Maly, 2009).

1.3.2. Osteoarthritis: Bone Changes

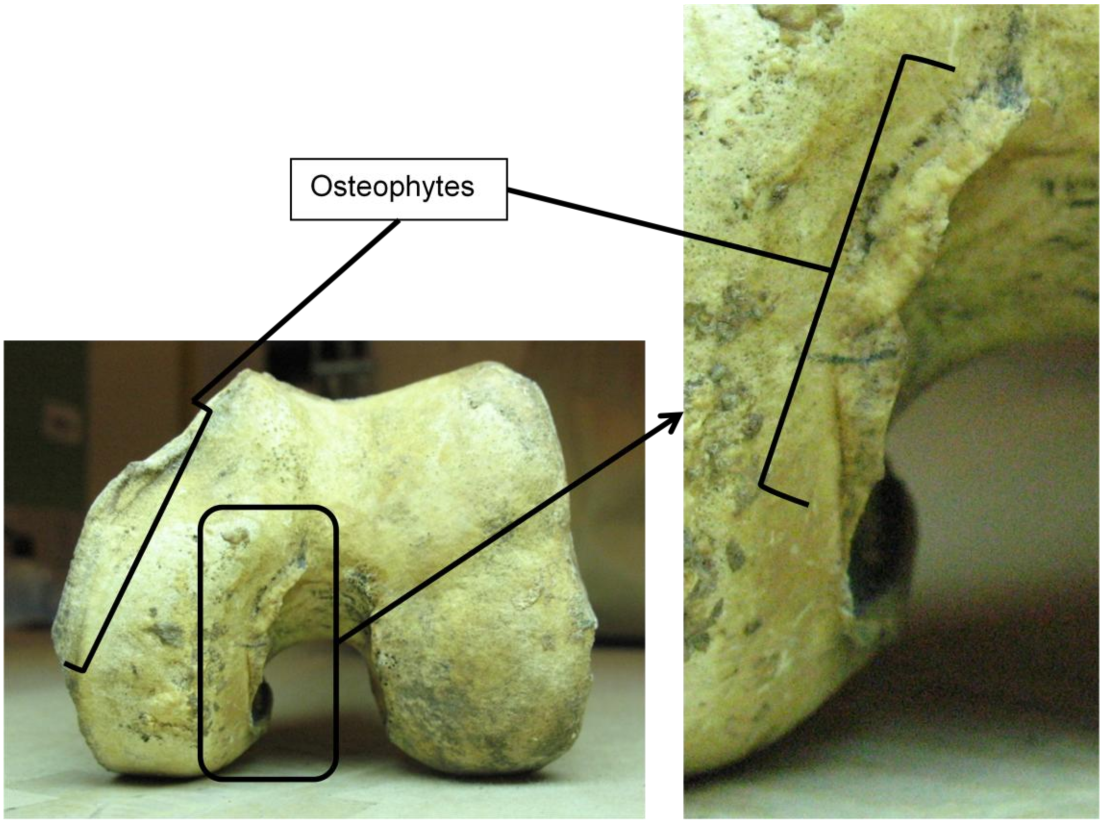
In clinical settings, osteoarthritis is primarily assessed through radiographs (Oka et al., 2008). Bone changes due to OA were defined by Schiphof et al. (2008) and Lethbridge-Cejku (1995):

a) formation of osteophytes (bone projections) on the joint margins (Figures 1.1) or in ligamentous attachments, as on the tibial spines,
b) narrowing of joint space associated with sclerosis of subchondral bone,
c) cystic areas with sclerotic walls situated in the subchondral bone, and
d) altered shape of the bone ends

The Kellgren-Lawrence Grading Scale is one of the most cited instruments to grade severity of radiographic changes associated with knee OA (Kellgren & Lawrence, 1957). This tool grades the three main physical features associated with OA (i.e., osteophytes formation, joint space narrowing, subchondral sclerosis) into five categories identified as grades 0-4 (Salaffi et al., 2005). Definite knee OA has a Kellgren-Lawrence grade of two or higher (Lethbridge-Cejku, 1995).

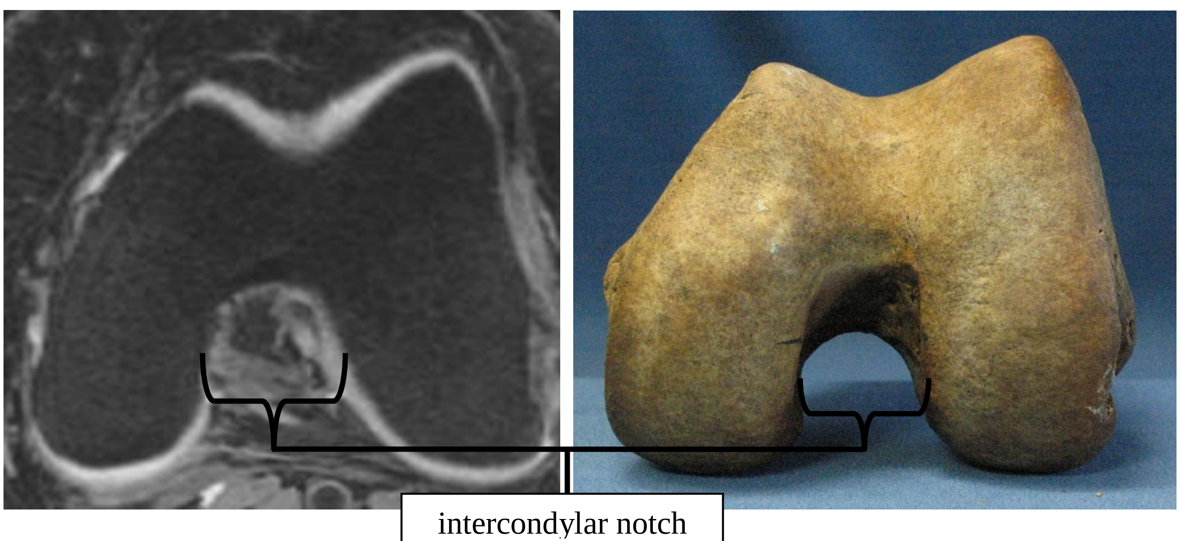
1.3.2.1. Femoral Intercondylar Notch

Studies have suggested that the shape of the distal femur, which is changed in knee OA, is pertinent to the condition's etiology (Wada et al., 1999; Shepstone et al., 2001). Of particular interest is intercondylar notch narrowing (Figure 1.2). This feature has been associated with OA severity and deterioration of the anterior cruciate ligament (Shepstone et al., 2001; and Quasnichka et al., 2005). Notch narrowing is thought to be a product of osteophyte formation (Quasnichka et al., 2005).



a. b.

Figure 1.1: Distal articular surface of a left femur with marginal osteophytes visible along the medial edge of both the entire joint surface (a) and along the intercondylar notch (b) (photos by J. Young).

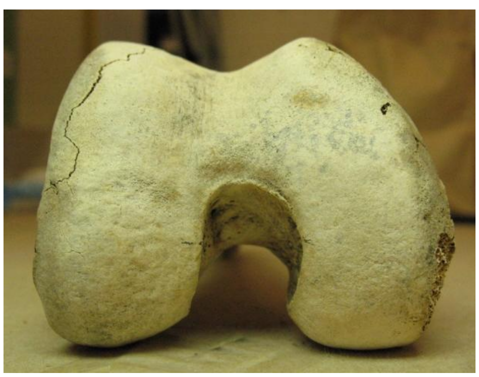


a. b.

Figure 1.2: Location of the intercondylar notch in a MRI slice (a) and a photo of a dry bone sample (b) (MRI courtesy of the Osteoarthritis Initiative and photo by J. Young).

Though osteophytes are seen in advanced knee OA, marginal osteophytes around the intercondylar notch are considered an early sign of knee OA (Shepstone et al., 2000) and a compensatory mechanism that allows bone to press against a degenerated or slackened anterior cruciate ligament (ACL) to increase stability. In some cases, a decreased intercondylar notch width may cause cruciate ligament damage and further knee instability, leading to further osteophytosis and other OA features (Shepstone et al., 2000). It is not surprising that smaller intercondylar notches are found in individuals with severe OA, when compared to notches in individuals with normal knees (Figures 1.3) (Wada et al., 1999; Shepstone et al., 2001).

Significant statistical differences in the shape of the intercondylar notch between osteoarthritic and non-osteoarthritic femora were found by Shepstone et al. (2001). "The difference was largely in the lateral aspect of the medial condyle, with the non-OA group exhibiting, on average, a wave shaped notch, whereas the OA group exhibited a more inverted U shaped notch" (Shepstone et al., 2001, p. 972).



a.

b.

Figure 1.3: Distal articular surface of two different femora with a) depicting a normal intercondylar notch and b) depicting a narrowed notched due to osteoarthritic changes, especially intercondylar notch osteophytes (photos by J. Young).

Preliminary studies (Wada et al., 1999; Shepstone et al., 2001) have suggested that the intercondylar notch may be a valid tool for assessing knee OA, but the region still requires more thorough exploration. Three dimensional images from magnetic resonance imaging (MRI) should make the intercondylar notch region accessible for study (Shepstone et al., 2000).

1.3.2.2. Symptoms

Linking knee OA symptoms to physical changes in the knee joint and associated disability has met with mixed results, ranging from a distinct association between joint changes and symptoms (Lethbridge-Cejku, 1995; Spector et al., 1996; Szebenyi et al., 2006; Neogi et al., 2008; and Zhai et al., 2008) to poor correlations (Altman et al., 1986; Rogers et al., 2004; and Roseman et al., 2007), to discordance between pain and x-ray features (Barker et al., 2004; Faucher et al., 2004; van der Kraan et al., 2007; Maly et al., 2008; and Oka et al., 2008). Though more radiographic evidence is present for those with chronic pain (Hopman-Rock et al., 1998), the relationship between pain and degenerative structural joint changes is poorly understood (Thorp et al., 2007). Bone features associated with radiographic characteristics of knee OA and ever-and-current pain include osteophytosis, subchondral sclerosis, and bone marrow lesions (Altman et al., 1986; Lethbridge-Cejku, 1995; Spector et al., 1996; and Zhai et al., 2008).

1.3.3. Osteoarthritis: Outcomes

People with knee OA report "the worst quality of life among people with musculoskeletal diseases" (Tukker et al., 2008, p.361). They have more difficulty performing daily activities and exhibit progressive loss of function, leading to increased dependency in walking, stair climbing, and other lower extremity tasks" (Hopman-Rock et al., 1998; Miller et al., 2001; Maly et al., 2005; Salaffi et al., 2005; van der Esch et al., 2006; Maly & Krupa, 2007; Ay et al., 2008; and Hall et al., 2008). The fear of falling, loss of sleep, rising and sitting down, getting into and out of bed, squatting, and kneeling were also cited as factors related to the knee OA experience (Steultjens et al., 1999; Bennell et al., 2003; Maly & Krupa 2007; Hall et al., 2008).

1.3.3.1. Gait Changes

Individuals with mild to moderate knee OA have unique gait characteristics, including reduced walking speed, reduced stride length, and increased stance time (Mundermann et al., 2005; Astephen et al., 2007; and Thorp et al., 2007). These gait alterations appear to be adaptive responses to chronic pain and structural pathology and therefore act as a mechanism to limit pain and/or improve function (Briema & Snyder-Mackler, 2009).

1.4. Osteoarthritis in Bioarchaeology

1.4.1. General Considerations

OA has affected animals from the earliest of times and most likely affected humans from the point where there lifespan permitted its development. Throughout time, the morphological characteristics of the disease have remained consistent (Waldron, 2012). In bioarchaeology OA is a marker of biomechanical stress caused by strains placed upon the human skeleton through habitual use, which is often impacted by human adaptation and cultural change (Goodman & Martin, 2002; Watkins, 2010). As such, skeletal lesions attributable to OA have been studied to interpret the type of work, occupation, or repetitive activities completed by individuals that could have caused OA (Goodman & Martin, 2002; Jurmain et al., 2012). This work is influenced by the interplay of lifestyle, culture, and environment (Larsen, 2002). Therefore, OA severity and its distribution in the skeleton can vary between societies and with different roles individuals fulfill within a society; roles that are often dictated by sex or social status (Ortner 2003).

Though subsistence pattern has been linked to OA distribution and severity, differences in diet and nutritional content have not been discussed as a causal factor by bioarchaeologists. Rather the type of work a subsistent pattern requires, and its effect on the development of OA, has been discussed (Inoue et al., 2001; Larsen, 2002; Weiss and Jurmain et al., 2012). Little to no dialogue could be found in the literature on OA ramifications, given social and physical environmental factors.

Comparing prevalence rates between earlier and modern populations is virtually impossible since an accurate prevalence rate cannot be determined from archaeological remains (Waldron, 2012). There are multiple reasons for this; including,

1. The amount of OA is underestimated because analysis relies solely on bone lesions,
2. Bones are not always preserved so exact distributions are difficult to assess,
3. There are no standard definitions or diagnosing criteria for OA,
4. There is no common OA measurement standard; skeletons, adults, joints have all been used (Inoue et al., 2001; Crubézy et al., 2002; Waldron, 2012).

Reasons 3 and 4 make it virtually impossible to pool data from different studies.

1.4.2. Bioarchaeological Definition

OA in the study of skeletal remains is defined by characteristic changes visible on joint surfaces. Rogers et al. (1987) defined these features as: 1) formation of marginal osteophytes; 2) subchondral bone reaction, including the presence of eburnation, sclerosis, and cysts; 3) joint surface pitting; 4) joint contour alterations in severe cases. In the absence of marginal osteophytes and subchondral bone reaction, changes cannot be classified as osteoarthritic because osteophytes alone may be a product of age.

1.4.3. Scoring

Various scoring systems have been developed and usually follow a progression from no sign of degenerative disease; to initial osteophytes or deterioration of the joint surfaces; to major osteophyte formation and/or destruction of the joint surface, such as eburnation; to joint immobilization (Steckel et al., 2002).

1.4.4. Interpretation

OA identification has often been used to discern activity patterns and sometimes used with other skeletal features to infer quality of life and general health status. Dettwyler (1991) recognized that "the paleopathological analysis of skeletal remains can tell us about physical impairment, from which we may be able to infer the extent of an individual's disability"; however, little has been done to inform this discussion for knee OA.

1.5. Theoretical Framework

The theoretical framework for this research is the biopsychosocial theory of health (Figure 1.4). Developed by Engel (1977), this conceptual model proposes a focus on health, an interaction between individual, social, and environmental factors (Gignac et al., 2008). This approach follows the paradigm of population health where positive health outcomes are based on a number of factors, including those external to the individual. The biopsychosocial lens is often used in OA research because OA symptoms and related outcomes are a product of multiple influences engaged in a dynamic interaction (Duncan, 2000; Bennell et al., 2003; Peters et al., 2005; Maly et al., 2006; Gignac et al., 2008). OA is not simply a disease of the body but "a health condition caused by the interrelationships of factors both within the affected individual and between the individual and the surrounding environment" (Hunt et al., 2008, p. 55). This is exemplified by knee OA sufferers who exhibit similar physiological abnormalities in their knee joints, but express different symptoms (Hunt et al., 2008).

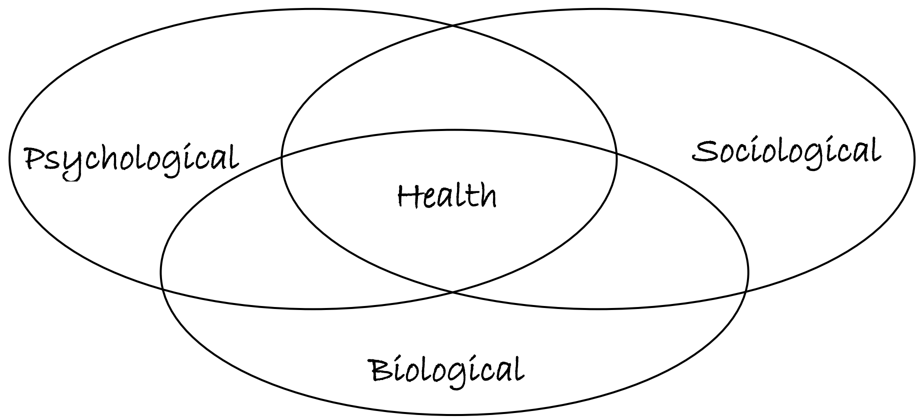


Figure 1.4: Conceptual model of Engel's biopsychosocial theory of health.

The biopsychosocial factors implicated in arthritis pain and disability may include (Keefe et al., 2002; Wang et al., 2005):

- **Biological**: cartilage damage, joint degeneration, inflammation, swelling, deconditioning, age, sex, comorbidities
- **Psychological**: helplessness, depression, coping, self-efficacy, pessimism, personality, hardiness
- **Social**: social support, socio-economic status, spouse/caregiver responses

The biological factors play a large role in the development and progression of knee OA while psychosocial factors could have a greater impact on an individual's overall level of disability (Hunt et al., 2008). Since this thesis is concerned with the identification of physical impairment, the use of the biopsychosocial theory is necessitated by the factors external to the biological changes associated with knee OA that contribute to physical limitations.
The biopsychosocial framework is also the principle structure for the International Classification of Functioning, Disability and Health (ICF).

1.5.1. International Classification of Function Disability and Health (ICF)

The ICF is a WHO endorsed classification system that provides a standard terminology and structure for classifying health and health-related states. ICF includes four main components: body functions, body structures, activities and participation, and environmental factors. Environmental factors, those extrinsic to the individual, include physical, social, and attitudinal environment (Wang et al., 2005). These components provide a means to classify, organize, and study information obtained from individuals manifesting a health condition. ICF's functioning and disability constructs and definitions have been used as building blocks for modeling OA induced disability from a biopsychosocial approach (Wang et al., 2005).

Within the ICF framework (Figure 1.5), an activity may lead to impairment (Gagné et al., 2009). The person with this impairment may experience an activity limitation or participation restriction, depending on the interaction between the different ICF domains (i.e., impairment, specific activity, physical and social environment in which the activity takes place, personality characteristics of people involved in the activity).

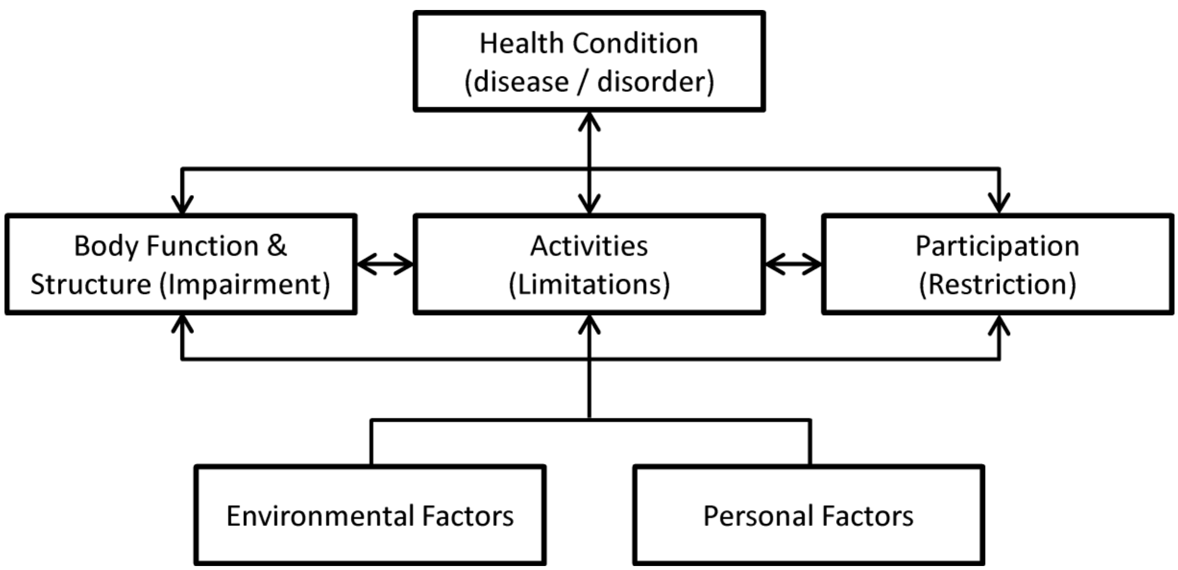


Figure 1.5: International Classification of Function Disability and Health (ICF) framework.

Though still establishing itself as an efficient tool for clinical practice, ICF has already been adapted by researchers to improve its efficacy. These "ICF Core Sets" were developed by leading researchers in specific fields to improve usage efficiency of a classification system that comprises almost 300 pages of text. To produce a core set, the ICF descriptive codes are reviewed for relevancy and, if deemed applicable, are included in a list of possibly useful descriptors (Cieza et al., 2004; Dreinhöfer et al., 2004; Stucki & Cieza, 2004; Stucki et al., 2004; Scheuringer et al., 2005; Stoll et al., 2005; and Grill et al., 2007). For OA, the long list of ICF codes were reviewed, graded, and the most relevant codes were selected as an OA core set. The OA ICF core set will be used to guide part of the thesis research.

1.5.2. International Statistics Classification of Diseases and Related Health Problems (ICD)

ICD is a classification system used to record diseases and related health problems on death certificates and in hospital records. The information generated by ICD has been used to determine the health status of populations, examine disease incidence and prevalence rates, and study variables associated with disease susceptibility (WHO, 2010.

1.5.3. Determinants of Health

Biopsychosocial theory can be used to define the determinants of health. The determinants of health are “the range of personal, social, economic and environmental factors which determine the health status of individuals or populations” (WHO, 1998, p.6). Since the determinants of health play an important role in knee OA outcomes, the potential impact for archaeological populations must be explored. The multiple determinants of health model developed by Evans et al (1994) will drive the choice of applicable determinants of health for this study.

1.5.4. Summary

Engel’s biopsychosocial theory, the determinants of health, ICD, and the ICF framework assert that health is a complex condition with multiple influences and outcome states related to a myriad of factors, both within and beyond the individual’s control. Assuming that this position reflects reality, the study of human skeletal remains is lacking a large component in the interpretation of health, because health in bioarchaeology is primarily assessed through biological remains. The influence of physical, social, and psychological environments on health for ancient populations has been mostly unexplored.

1.6. Research Strategy

Using the osteoarthritic femur to identify impairment potential in archaeological populations required the development of a multi-step research approach. Defined by a list of objectives, the strategy necessitated the completion of a series of steps each building on the information produced by the previous. The key objectives were as follows:

1. Explore the viability of using clinical frameworks in the study of disease in archaeological populations.
2. Identify a clinical population of osteoarthritic knee participants with available diagnostic images of the distal femur and impairment and disability outcome measures.
3. Establish a grading system for knee OA severity, based on changes in the distal femur that can be assessed in both clinical and archaeological populations.
4. Identify the relationship between "impairment and disability outcomes measures" and the "categories of knee OA severity" for the clinical population.
5. Operationalize the relationship between knee OA severity and outcomes for application to archaeological populations.
6. Revise the multiple determinants of health model for its application to knee OA in archaeological populations.
7. Use the operationalized outcome data and determinants of health data to interpret select archaeological populations.

1.6.1. Completed Objectives

1.6.1.1. Objective 1: The Viability of Using Clinical Frameworks

The International Classification of Functioning, Disability and Health (ICF) and the International Statistics Classification of Disease and Related Health Problems (ICD) are two systems that are used in the health care field for classifying disease states. Working in tandem, they are both well established and recognized methods for organizing data so that it is easy to understand and compare. A study of ICF and ICD for organizing disease related information in archaeological populations established the utility of clinical frameworks in the study of paleopathology and supported their use in future research. The establishment of this clinical- archaeological link assisted in the selection of outcome variables for later stages of the thesis research.

1.6.1.2. Objective 2: The Clinical Population and Ethics

The Osteoarthritis Initiative (OAI) is ideal for examining lifestyle, activity, and participation limitations based on knee joint changes associated with OA. OAI is a multi-center, longitudinal, cohort, prospective observational study focusing primarily on knee OA. The overall aim of the OAI is to create a public archive resource of data to facilitate the scientific evaluation of biological samples and images of OA, for use as possible surrogate endpoints for disease evaluation (Nevitt et al., 2006).

The OAI study consists of 4607 male and female participants of various ethnicities ranging in age from 45 to 79, with women slightly more represented than men. This cohort continues to be evaluated on a yearly basis with data available for baseline, 12, 24, 36, and 48 month follow-ups. The data includes a set of knee OA status and outcome measurements (clinical and imaging), pain, physical function, patient global assessment, and joint imaging (Nevitt et al., 2006).

The clinical variables include frequent knee symptoms, knee pain severity scale, participant global assessment, WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index), Knee Outcomes in Osteoarthritis Survey (KOOS), limitation in activity due to pain, general health and functional status, walking ability and endurance, upper leg strength, and Kellgren-Lawrence grade of OA severity. The available data for knee imaging includes MRIs of the knees and thighs, and knee joint radiographs.

Although clinical variable information is available online, after a registration process, the MRI images are only available after formal application and approval. Once approved, a series of MRI imaging sets are shipped on a hard drive from the OAI centre in California. Six image datasets are available: baseline, 12-month follow-up, 18-month follow-up, 24-month follow-up, non-exposed controls only, and thigh MRIs only. Within the 24-month follow-up set, three sub-groupings were available: Group A with 200 progression and incidence cohort participants, Group B with 160 progression cohort participants, and Group C with the first half of the entire cohort (2,686 participants).

Group A participants were chosen by OAI as follows: "There were four gender x subcohort strata within each Recruitment Center (16 strata in all), from each of which 13 participants were randomly picked, giving a total of 208 to choose from. The number of image types missing for each participant was then calculated and 8 participants eliminated who had the most missing images, while keeping the number of participants from each Recruitment Center equal (25 each), the subcohorts balanced (100 of each), and the genders balanced (100 of each)" (Nevitt et al., 2006, p. 9). The subcohorts consist of two different populations, a progressive subcohort of individuals with symptomatic knee OA at baseline with worsening of disease (Nevitt et al., 2006) and an incidence cohort with individuals without symptomatic knee OA, but having specific characteristics that gave them an increased risk of developing symptomatic knee OA during the study (Nevitt et al., 2006). The clinical diagnosis of symptomatic knee OA required both the presence of frequent knee symptoms and radiographic findings (Nevitt et al., 2006, p.9). The age, gender, and ethnicity breakdown of Group A are shown in Tables 1.1 and 1.2.

Table 1.1: Ethnic breakdown of participants by gender.

	White or Caucasian	Non-White	Total
Male	90	10	100
Female	79	21	100
Total	169	31	200

Table 1.2: Age breakdown of participants by gender.

	45-49 years	50-59 years	60-69 years	70-79 years	Total
Male	11	24	27	38	100
Female	11	29	35	25	100
Total	22	53	62	63	200

The OAI data is de-identified (i.e., MRI and lifestyle information are not linked to specific individuals). Also, prior to the usage of any OAI data, the researcher is required to sign a data user agreement (Appendix A) that stipulates the terms and conditions for use of the OAI information.

1.6.1.3. Objective 3: Establishing a Grading System of Knee OA Severity Based on the Distal Femur

Two methods, one quantitative (metric analysis) and the other qualitative (morphologic analysis), were developed. Changes in the distal femur due to degeneration were captured from the OAI MRI images. The majority of the images from the sample of 200 participants were used. However, some MRI's had to be excluded due to over or under exposure, making landmarks, surface structures, and bone margins difficult to discern. Excluding the MRI resulted in knee exclusion for all analyses.

Quantitative analysis focused on the femoral intercondylar notch width, depth, and overall size indices calculated from MRI images. This metric approach was employed because previous research indicated that intercondylar notch size decreases as degeneration increases. Morphological analysis was completed by creating a new grading system that combined osteological features visible in both MRI and denuded bone analysis. Named the Clinical Archaeological Osteoarthritis Scale (CAOS) this four point system graded osteophyte development, contour changes, and the presence of porosities at the distal femur.

1.6.1.4. Objective 4: Identifying the Relationship between Outcome Impairment/Disability and Knee OA Severity

The distal femora evaluations outlined in objective 2 were related to outcome data available on the OAI website. Of the over 1200 outcome variables available, only a small portion that included not only summative indices, but also individual activity variables were chosen for this study. Fifteen indices were chosen to quantify outcomes these included those related to pain (at normal activity level and at higher activity levels), joint stiffness, physical function, disability, symptoms, function in sport and recreation, and health status. For individual activity 14 variables were chosen; including, light chores, walking, standing, downstairs, stand from sitting, bending, heavy chores, walking upstairs, twisting/pivoting, running, jumping, kneeling, squatting, and having more difficulty with knee, limited in kind of work, accomplish less, limited with several flights of stairs, limited in moderate activities, and modified lifestyle to avoid activities that may damage knee. The outcome variables were related to the distal femora assessment results.

1.6.1.5. Objective 5: Operationalize the Relationship between Knee OA Severity and Outcomes

Results from completion of objective 3 established the significant relationships between OA changes in the distal femur and the lifestyle and activity outcome variables. Understanding these relationships was useful; however, this approach did not provide a means for direct application to archaeological populations, the primary goal of this research. Therefore, frequency distributions for each activity related outcome variable were used to estimate the probability of having difficulty at each CAOS grade. Establishing these probabilities, which were also estimated for each sex, allowed for direct application of the probabilities to archaeological samples.

1.6.1.6. Objective 6: Revise Population Health Model to Apply to Knee OA in Archaeological Populations

The population health model chosen to guide the application of the determinants of health to archaeological populations was the Multiple Determinants of Health Model established by Evans et al. (1994) (Figure 1.6). This model, whose determinates include

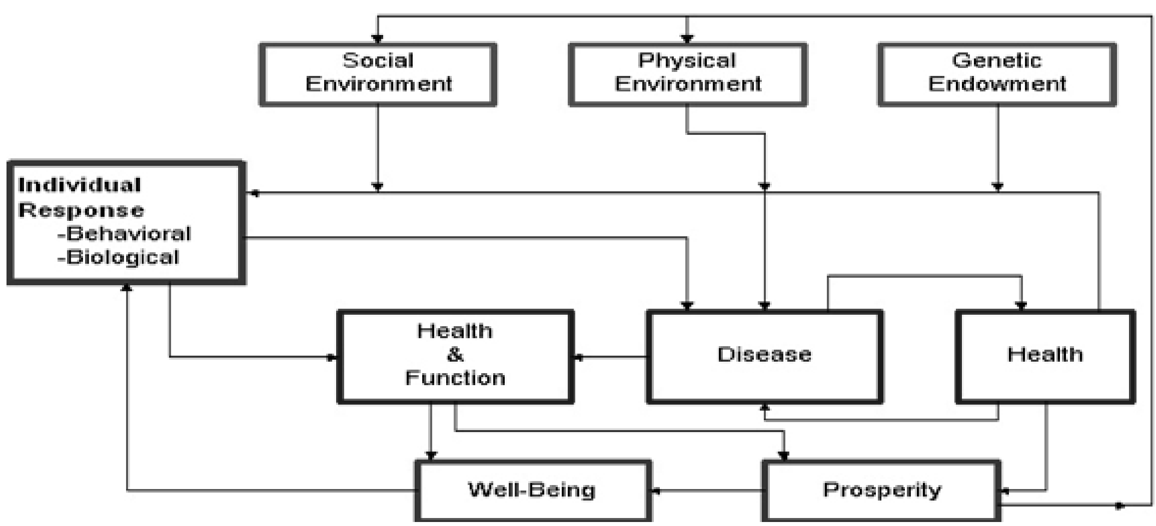


Figure 1.6: Multiple Determinants of Health Model.

social environment, physical environment, genetic endowment, health care, disease, health and function, individual response (behavioural and biological), well-being, and prosperity, was modified to only include determinants that could be informed through the clinical, archaeological, ethnographic, and historic record. The determinants included in the new model were social environment, physical environment, health interventions, health and function, disease (knee OA), and individual responses.

1.6.1.7. Objective 7: Use Operationalized Outcome Data and Determinants of Health Data to Interpret Archaeological Populations

Using the information produced by the completion of the previous objectives, two archaeological populations were examined to evaluate the potential impact of knee OA. A system was developed to incorporate the determinants of health and the operationalized clinical data into an applicable format. To quantify the impact of the determinants of health, a scoring system, identified as the Health Determinants Impact Score (HDIS), was developed. Individual HDIS factors can be summed to create an overall health determinates score (HDIS-sum).

The Functional Impact Probability Score (FIPS) was developed to generate a single measure that represented the probability of functional problems related to knee OA, across various activities of daily living. FIPS and HDIS-sum can be combined to create the Knee OA Impact Index (KOII), which provides an index of OA impact in a given population. The KOII was applied to generate an impairment potential scale for the osteoarthritic femur in two archaeological populations.

1.7. Conclusions

Studying clinical populations to inform our understanding of past populations is a necessity in the field of bioarchaeology. Knee OA is one disease where clinical data can help identify impairment in archaeological populations. However, health and function are also a construct of factors external to the individual. Therefore, to fully grasp the potential impact of knee OA, the individual’s environment information must also be considered. Population health frameworks allow for the exploration of these broader influences and assist in providing a more comprehensive understanding of impediments to function. This study seeks to embrace this encompassing approach by moving the dialogue of knee OA in archaeological populations beyond the biological. The results of this exploration are detailed in the research presented in chapters two, three, four, and five.

1.8. Literature Cited

1. Altman, R., Asch, E., Bloch, D., Bole, G., Borenstein, D., Brandt, K., Christy, W., Cooke, T., Greenwald, R., Hochberg, M., Howell, D., Kaplan, D., Koopman, W., Longley, S., Mankin, H., McShane, D., Medsger, T., Meenan, R., Mikkelsen, W., Moskowitz, R., Murphy, W., Rothschild, B., Segal, M., Sokoloff, L., & Wolfe, F. (1986). Development of Criteria for the Classification and Reporting of Osteoarthritis: Classification of Osteoarthritis of the Knee. *Arthritis and Rheumatism, 29*(8), 1039-1049.
2. Astephen, J., Deluzio, K., Caldwell, G., & Dunbar, M. (2008). Biomechanical Changes at the Hip, Knee, and Ankle Joint during Gate are Associated with Knee Osteoarthritis Severity. *Journal of Orthopaedic Research, 26*, 332-341.
3. Aufderheide, A., & Rodriguez-Martin, C. (1998). *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge: Cambridge University Press.
4. Ay, S., Tur, B., & Kucukdeveci, A. (2008). Evaluation of Disability in Patients with Degenerative and Inflammatory Arthritis. *International Journal of Rehabilitation Research, 31*, 159-163.
5. Ayis, S., Ebrahim, S., Williams, S., Juni, P., & Dieppe, P. (2007). Determinants of Reduced Walking Speed in People with Musculoskeletal Pain. *Journal of Rheumatology, 34*,1905-1912.
6. Barker, K., Lamb, S., Toye, F., Jackson, S., & Barrington, S. (2004). Association Between Radiographic Joint Space Narrowing, Function, Pain and Muscle Power in Severe Osteoarthritis of the Knee. *Clinical Rehabilitation, 18*, 793-800.
7. Baker, K., Matthan, N., Lichtenstein A., Niu, J., Guermazi, A., Roemer, F., Grainger, A., Nevitt, M., Clancy, M., Lewis, C., Torner, J., & Felson, D. (2012). Association of Plasma n-6 and n-3 Polyunsaturated Fatty Acids with Synovitis in the Knee: the Most Study. *Osteoarthritis and Cartilage, 20*, 382-387.

8. Bennell, K., Hinman, R., Mecalf, B., Crossley, K., Buchbinder, R., Smith, M., & McColl, G. (2003). Relationship of Knee Joint Proprioception to Pain and Disability in Individuals with Knee Osteoarthritis. *Journal of Orthopaedic Research, 21,* 792-797.
9. Biščević, M., Ljuca, F., Biščević, A., Gavrankapetanović, I., Smrke, B., Ozturk, C., & Smrke, D. (2008). Morphometric Alteration of Femoral Condyles Due to Knee Osteoarthritis. *Collegium Antropologicum, 32*(3), 875–879.
10. Breedveld, F. (2004). Osteoarthritis – the Impact of a Serious Disease. *Rheumatology, 43*(Suppl.1), i4-i8.
11. Briem, K., & Snyder-Mackler, L. (2009). Proximal Gait Adaptations in Medial Knee OA. *Journal of Orthopaedic Research, 27*, 78-83.
12. Brunner, A., Henn, C., Drewniak, E., Lesieur-Brooks, A., Machan, J., Crisco, J., & Ehrlich, M. (2012). High Dietary Fat and the Development of Osteoathritis in a Rabbit Model. *Osteoarthritis and Cartilage, 20,* 584-592.
13. Bush, H. (1991). Concepts of Health and Stress. In Past Societies: An Introduction. H. Bush & M. Zvelebil (Eds.), Health in Past Societies: Biocultural Interpretations of Human Skeletal Remains in Archaeological Contexts. *BAR International Series, 567*:11-22.
14. Bush, H., & Zvelebil, M. (1991). Pathology and Health. In Past Societies: An Introduction. In H. Bush & M. Zvelebil (Eds.), Health in Past Societies: Biocultural Interpretations of Human Skeletal Remains in Archaeological Contexts. *BAR International Series, 567,* 3-10.
15. Cieza, A., Ewert, T., Ustun, B., Chatterji, S., Kostanjsek, N., & Stucki, G. (2004). Development of ICF Core Sets for Patients with Chronic Conditions. *Journal of Rehabilitation Medicine, Suppl,44,* 9-11.
16. Cohen, M.N., & Armelagos, G.J. (Eds). (1982). *Paleopathology at the Origins of Agriculture*. Florida: Academic Press, Inc.
17. Cooper, C., Snow, S., McAlindon, T., Kellingray, S., Stuart, B., Coggon, D., & Dieppe, P. (2000). Risk Factors for the Incidence and Progression of Radiographic Knee Osteoarthritis. *Arthritis & Rheumatism, 43*(5), 995-1000.
18. Crubézy, E., Goulet, J., Bruzek, J., Jelinek, J., Rougé, D., & Ludes, B. (2002). Epidemiology of Osteoarthritis and Enthesopathies in a European Population Dating Back 7700 Years. *Joint Bone Spine, 69,* 580-588.

19. Dettwyler, K. (1991). Can Paleopathology Provide Evidence for “Compassion”? *American Journal of Physical Anthropology, 84*, 375-384.
20. Dieppe, P. (2000). Towards a Better Understanding of Osteoarthritis of the Knee Joint. *The Knee 7*, 135-137.
21. Dreinhöfer, K., Stucki, G., Ewert, T., Huber, E., Ebenbichler, G., Gutenbrunner, C., Kostanjsek, N., & Cieza, A. (2004). ICF Core Sets for Osteoarthritis. *Journal of Rehabilitation Medicine Suppl, 44*, 75-80.
22. Duncan, G. (2000). Mind-Body Dualism and the Biopsychosocial Model of Pain: What Did Descartes Really Say? *Journal of Medicine and Philosophy, 25*(4), 485-513.
23. Engel, G. (1977). The Need for a New Medical Model. *Science, 196(4286)*, 129-36.
24. Faccia, K., & Williams, R. (2008). Schmorl’s Nodes: Clinical Significance and Implications for the Bioarchaeological Record. *International Journal of Osteoarchaeology, 18,* 28-44.
25. Faucher, M., Poiraudeau, S., Lefevre-Colau, M., Rannou, F., Fermanian, J., & Revel, M. (2004). Assessment of the Test-retest Reliability and Construct Validity of a Modified WOMAC Index in Knee Osteoarthritis. *Joint Bone Spine, 71*, 121-127.
26. Fautrel, B., Hilliquin, P., Rozenberg, S., Allaert, F., Coste, P., Leclerc, A., & Rossignol, M. (2005). Impact of Osteoarthritis: Results of a Nationwide Survey of 10,000 Patients Consulting for OA. *Joint Bone Spine, 72*, 235-240.
27. Fitzgerald, G., Piva, S., & Irrgang, J. (2004). Reports of Joint Instability in Knee Osteoarthritis: Its Prevalence and Relationship to Physical Function. *Arthritis & Rheumatism, 51*(6), 941-646.
28. Gagné, J., Jennings, M., & Southall, K. (2009). The ICF: A Classification System and Conceptual Framework Ideal for Audiological Rehabilitation. *Perspectives on Aural Rehabilitation and Its Instrumentation, 16*(1), 8-14.
29. Gignac, M., Backman, C., Davis, A., Lacaille, D., Mattison, C., Montie, P., & Badley, E. (2008). Understanding Social Role Participation: What Matters to People with Arthritis? *Journal Rheumatology, 35*, 1655-1663.

30. Goodman, A., & Martin, D. (2002). Reconstructing Health Profiles from Skeletal Remains. In R.H. Steckel & J.C. Rose (Eds). *The Backbone of History: Health and Nutrition in the Western Hemisphere* (pp. 11-60). Cambridge: Cambridge University Press.
31. Grill, E., Zochling, J., Stucki, G., Mittrach, R., Scheuringer, M., Liman, W., Kostanjsek, N., & Braun, J. (2007). International Classification of Functioning, Disability and Health (ICF) Core Set for Patients with Acute Arthritis. *Clinical and Experimental Rheumatology, 25*, 252-258.
32. Hall, M., Migay, A., Persad, T., Smith, J., Yoshida, K., Kennedy, D., & Pagura, S. (2008). Individuals' Experience of Living with Osteoarthritis of the Knee and Perceptions of Total Knee Arthroplasty. *Physiotherapy Theory and Practice, 24*(3), 167-181.
33. Hopman-Rock, M., Kraaimaat, F., Odding, E., & Bijlsma, J. (1998). Coping with Pain in the Hip or Knee in Relation to Physical Disability in Community-Living Elderly People. *Arthritis Care and Research, 11*(4), 243-252.
34. Hunt, M., Birmingham, T., Skarakis-Doyle, E., & Vandervoort, A. (2008). Towards a Biopsychosocial Framework of Osteoarthritis of the Knee. Disability *& Rehabilitation, 1*, 54-61.
35. Hunter, D., Niu, J., Zhang, Y., LaValley, M., McLennan, C., Hudelmaier, M., Echstein, F., & Felson, D. (2008). Premorbid Knee Osteoarthritis is not Characterised by Diffuse Thinness: the Framingham Osteoarthritis Study. *Annals of the Rheumatic Diseases, 67,* 1545-1549.
36. Inoue, K., Hukuda, S., Fardellon, P., Yang, Z., Nakai, M., Katayama, K., Ushiyama, T., Saruhashi, Y., Huang, J., Mayeda, A., Catteddu, I., & Obry, C. (2001). Prevalence of Large-Joint Osteoarthritis in Asian and Caucasian Skeletal Populations. *Rheumatology, 40*, 70-73.
37. Jurmain, R., Cardoso, F., Henderson, C., & Vilotte, S. (2012). Bioarchaeology's Holy Grail: The Reconstruction of Activity. In A. Grauer (Ed) *A Companion to Paleopathology,* (531-552). Wiley-Blackwell Publication.

38. Keefe, F., Smith, S., Buffington, A., Gibson, J., Studts, J., & Caldwell, D. (2002). Recent Advances and Future Directions in the Biopsychosocial Assessment and Treatment of Arthritis. *Journal of Consulting and Clinical Psychology, 70*(3), 640-655.
39. Kellgren, J., & Lawrence, J. (1957). Radiological Assessment of Osteo-arthrosis. *Annals of Rheumatic Diseases*, *16*, 494-502.
40. Knott, L., Avery, N., Hollander, A., & Tarlton, J. (2011). Regulation of Osteoarthritis by Omega-3 (n-3) Polyunsaturated Fatty Acids in a Naturally Occurring Model of Disease. *Osteoarthritis and Cartilage*, *19*, 1150-1157.
41. Kramer, J., Yelin, E., & Epstein, W. (2001). Social and Economic Impacts of Four Musculoskeletal Conditions. *Arthritis & Rheumatism, 44*(5), 1160-1169.
42. Larsen, C. (2002). Bioarchaeology: The Lives and Lifestyles of Past Peoples. *Journal of Archaeological Research*, *10*(2), 119-166.
43. Lethbridge-Cejku, M., Scott, W., Reichle, R., Ettinger, W., Zonderman, A., Costa, P., Plato, C., Tobin, J., & Hochberg, M. (1995). Association of Radiographic Features of Osteoarthritis of the Knee with Knee Pain: Data from the Baltimore Longitudinal Study of Aging. *Arthritis Care & Research*, *8*(3), 182-188.
44. Lovell, N. (2000). Paleopathological Description and Diagnosis. In M.A. Katzenberg & S.R. Saunders (Eds). *Biological Anthropology of the Human Skeleton* (pp. 217-248). USA: Wiley-Liss Publishers.
45. Maly, M. (2008). Abnormal and cumulative loading in knee osteoarthritis. *Current Opinion in Rheumatology, 20*, 547–552.
46. Maly, M. (2009). Linking Biomechanics to Mobility and Disability in People with Knee Osteoarthritis. *Exercise and Sport Sciences Review, 37*(1), 36-42.
47. Maly, M., & Krupa, T. (2007). Personal Experiences of Living with Knee Osteoarthritis Among Older Adults. *Disability and Rehabilitation, 29*(18), 1423-1433.
48. Maly, M., Costigan, P., & Olney, S. (2005). Contribution of Psychosocial and Mechanical Variables to Physical Performance Measures in Knee Osteorthritis. *Physical Therapy, 85*(12), 1318-1328.
49. Maly, M., Costigan, P., & Olney, S. (2006). Determinants of Self-Report Outcome Measures in People with Knee Osteoarthritis. *Archives of Physical Medicine and Rehabilitation, 87*(1), 96-104.

50. Maly, M., Costigan, P., & Olney, S. (2008). Mechanical Factors Relate to Pain in Knee Osteoarthritis. *Clinical Biomechanics, 23*(6), 796-805.
51. Mann, R., & Hunt, D. (2005). *Photographic Regional Atlas of Bone Disease*. Illinois: Charles C Thomas Publisher Ltd.
52. Mantyselka, P., Kumpusalo, E., Ahonen, R., & Takala, J. (2002). Direct and Indirect Costs of Managing Patients with Musculoskeletal Pain – Challenge for Health Care. *European Journal of Pain, 6*, 141-148.
53. Marra, C., Civere, J., Tsuyuki, R., Soon, J., Esdaile, J., Gastonguay, L., Oteng, B., Embley, P., Colley, L., Enenajor, G., & Kok, R. (2007). Improving Osteoarthritis Detection in the Community: Pharmacist Identification of New, Diagnostically Confirmed Osteoarthritis. *Arthritis & Rheumatism, 57*(7), 1238 – 1244.
54. McAlindon, T. & Felson, D. (1997). Nutrition: Risk Factors for Osteoarthritis. *Annals of Rheumatic Disease, 56*, 397-400.
55. Metzler, I. (1999). The Paleopathology of Disability in the Middle Ages. In N. Finlay (Ed), Disability and Archaeology. *Archaeological Review from Cambridge, 15*(2), 55-67.
56. Miller, M., Rejeski, W., Messier, S., & Loeser, R. (2001). Modifiers of Change in Physical Functioning in Older Adults with Knee Pain: the Observational Arthritis Study in Seniors (OASIS). *Arthritis Care & Research, 45*(4), 331-339.
57. Mundermann, A., Dyrby, C., & Andriacchi, T. (2005). Secondary Gait Changes in Patients with Medial Compartment Knee Osteoarthritis Increased Load at the Ankle, Knee, and Hip During Walking. *Arthritis & Rheumatism, 52*(9), 2835-2844.
58. Neogi, T., Felson, D., Niu, J., Nevitt, M., Lewis, C., Aliabadi, P., Sach, B., Torner, J., Bradley, L., & Zhang, Y. (2008). 327 Radiographic Features of Osteoarthritis are Strongly Associated with Knee Pain in Two Cohorts: Most and Framingham. *Osteoarthritis and Cartilage, 16*(Supplement 4), S144-S145
59. Nevitt, M., Felson, D., & Lester, G. (2006). The Osteoarthritis Initiative: Protocol for the Cohort Study. Retrieved from http://www.oai.ucsf.edu/datarelease/docs/StudyDesignProtocol.pdf .

60. Oka, H., Muraki, S., Akune, T., Mabuchi, A., Suzuki, T., Yoshida, H., Yamamoto, S., Nakaruma, K., Yoshimura, N., & Kawaguchi, H. (2008). Fully Automatic Quantification of Knee Osteoarthritis Severity on Plain Radiographs. *Osteoarthritis and Cartilage, 16*, 1300-1306.
61. Oka, H., Akune, T., Muraki, S., En-Yo, Y., Yoshida, M., Saika, A., Sasaki, S., Nakaruma, K., Kawaguchi, H., & Yoshimura, N. (2009). Association of Low Dietary Vitamin K Intake with Radiographic Knee Osteoarthritis in the Japanese Elderly Population: Dietary Survey in a Population-Based Cohort of the ROAD Study. *Journal of Orthopaedic Science, 14*, 687-692.
62. Ortner, D. (1994). Descriptive Methodology in Paleopathology. In D.E. Owsley & R.L. Jantz (Eds), *Skeletal Biology in the Great Plains: Migration, Warfare, Health and Subsistence* (pp. 73-80), Washington: Smithsonian Institution Press.
63. Ortner, D. (2003). *Identification of Pathological Conditions in Human Skeletal Remains*. California: Academic Press.
64. Parmelee, P., Harralson, T., Smith, L., Schumacher, H. (2007). Necessary and Discretionary Activities in Knee Osteoarthritis: Do They Mediate the Pain–Depression Relationship? *Pain Medicine, 8*(5), 449-462.
65. Peters, T., Sanders, C., Dieppe, P., & Donovan, J. (2005). Factors Associated with Change in Pain and Disability over Time: A Community-based Prospective Observational Study of Hip and Knee Osteoarthritis. *British Journal of General Practice, 55*(512), 205–211.
66. Quasnichka, H., Anderson-MacKenzie, J., Tarlton, J., Sims, T., Billingham, M., & Bailey, A. (2005). Cruciate Ligament Laxity and Femoral Intercondylar Notch Narrowing in Early-stage Knee Osteoarthritis. *Arthritis & Rheumatism, 52*(10), 3100-3109.
67. Rapp, S., Rejeski, W., & Miller, M. (2000). Physical Function Among Older Adults with Knee Pain: The Role of Pain Coping Skills. *Arthritis Care & Research, 13*(5), 270-279.
68. Roberts, C., & Manchester, K. (2007). *The Archaeology of Disease*. New York: Cornell University Press.
69. Rogers, J., & Waldron, T. (1995). *A Field Guide to Joint Disease in Archaeology*. England: John Wiley & Sons Ltd.

70. Rogers, J., Waldron, T., Dieppe, P., & Watt, I. (1987). Arthropathies in Paleopathology: The Basis of Classification According to Most Probable Cause. *Journal of Archaeological Science, 14*, 179-193.

71. Rogers, J., Shepstone, L., & Dieppe, P. (2004). Is Osteoarthritis a Systemic Disorder of Bone? *Arthritis & Rheumatism, 50*(2), 452-457.

72. Roberts, C. (1999). Disability in the Skeletal Record: Assumptions, Problems and Some Examples. In N. Finlay (Ed), Disability and Archaeology. *Archaeological Review from Cambridge, 15*(2), 79-97.

73. Rosemann, T., Kuehlein, T., Laux, G., & Szecsenyi, J. (2006). Factors Associated with Physical Activity of Patients with Osteoarthritis of the Lower Limb. *Journal of Evaluation in Clinical Practice, 14*, 288-293.

74. Rosemann, T., Keuhlein, T., Laux, G., & Szecsenyi, J. (2007). Osteoarthritis of the Knee and Hip : A Comparison of Factors Associated with Physical Activity. *Clinical Rheumatology, 26*, 1811-1817.

75. Salaffi, F., Carotti, M., & Grassi, W. (2005). Health-related Quality of Life in Patients with Hip or Knee Osteoarthritis: Comparison of Generic and Disease-Specific Instruments. *Clinical Rheumatology, 24*(1), 29-37.

76. Scheuringer, M., Stucki, G., Huber, E., Brach, M., Schwarzkopf, S., Kostanjsek, N., & Stoll, T. (2005). ICF Core Set for Patients with Musculoskeletal Conditions in Early Post-Acute Rehabilitation Facilities. *Disability and Rehabilitation*, *27*(7/8), 405-410.

77. Schiphof, D., Boers, M., & Bierma-Zeinstra, S. (2008). Differences in Descriptions of Kellgren and Lawrence Grades of Knee Osteoarthritis. *Annals of the Rheumatic Diseases, 67*(7), 1034-1036.

78. Shepstone, L., Rogers, J., Kirwan, J., & Silverman, B. (2000). Distribution of Distal Femoral Osteophytes in a Human Skeletal Population. *Annals of the Rheumatic Diseases*, *59*(7), 513-520.

79. Shepstone, L., Rogers, J., Kirwan, J., & Silverman, B. (2001). Shape of the Intercondylar Notch of the Human Femur: A Comparison of Osteoarthritic and Non-osteoarthritic Bones from a Skeletal Sample. *Annals of the Rheumatic Diseases, 60,* 968-973.

80. Spector, T., Harris, P., Hart, D., Cicuttini, F., Nandra, D., Etherington, J., Wolman, R., & Doyle, D. (1996). Risk of Osteoarthritis Associated with Long-term Weight-bearing Sports: A Radiologic Survey of the Hips and Knees in Female Ex-athletes and Population Controls. *Arthritis & Rheumatism, 39*(6), 988-995.
81. Steckel, R., Rose, J., Spencer Larsen, C., & Walker, P. (2002). Skeletal Health in the Western Hemisphere from 4000 B.C. to the Present. *Evolutionary Anthropology, 11*(4), 142-155.
82. Steckel, R., & Rose, J. (Eds.). (2002). *The Backbone of History: Health and Nutrition in the Western Hemisphere: Health and Nutrition in the Western Hemisphere*. Cambridge: Cambridge University Press.
83. Steultjens, M., Dekker, J., van Baar, M., Oostendorp, R., & Bijlsma, J. (1999). Internal Consistency and Validity of an Observational Method for Assessing Disability in Mobility in Patients with Osteoarthritis. *Arthritis Care & Research, 12*(1), 19-25.
84. Stewart, W., Ricci, J., Chee, E., Morganstein, D., & Lipton, R. (2003). Lost Productive Time and Cost Due to Common Pain Conditions in the US Workforce. *Journal of the American Medical Association, 290*, 2443-2454.
85. Stoll, T., Brach, M., Huber, E., Scheuringer, M., Schwarzkopf, S.R., Konstanjsek, N., & Stucki, G. (2005). ICF Core Set for Patients with Musculoskeletal Conditions in the Acute Hospital. *Disability and Rehabilitation, 27*(7/8), 381-387.
86. Stucki, G., & Cieza, A. (2004). The International Classification of Functioning, Disability and Health (ICF) Core Sets for Rheumatoid Arthritis: A Way to Specify Functioning. *Annals of Rheumatic Diseases, 63*, 40-45.
87. Stucki, G., Cieza, A., Gehy, S., Battistella, L., Lloyd, J., Symmons, D., Kostanjsek, N., & Schouten, J. (2004). ICF Core Sets for Rheumatoid Arthritis. *Journal of Rehabilitation Medicine, Suppl. 44*, 87-93
88. Szebeny, B., Hollander, A., Dieppe, P., Quilty, B., Duddy, J., Clarke, S., & Kirwan, J. (2006). Associations Between Pain, Function, and Radiographic Features in Osteoarthritis of the Knee. *Arthritis & Rheumatism, 54*(1), 230-235.
89. Thorp, L., Sumner, D., Wimmer, M., & Block, J. (2007). Relationship Between Pain and Medial Knee Joint Loading in Mild Radiographic Knee Osteoarthritis. *Arthritis Care & Research, 57*(7), 1254-1260.

90. Tukker, A., Visscher, T., & Picavet, H. (2008). Overweight and Health Problems of the Lower Extremities: Osteoarthritis, Pain and Disability. *Public Health Nutrition*, *12*(3), 359-368.
91. Tuzun, E. (2007). Quality of Life in Chronic Musculoskeletal Pain. *Best Practice & Research in Clinical Rheumatology, 21*(3), 567-579.
92. Wada, M., Tatsuo, H., Baba, H., Asamoto, K., & Nojyo, Y. (1999). Femoral Intercondylar Notch Measurements in Osteoarthritic Knees. *Rheumatology, 38*, 554-558.
93. Waldron, T. (2012). Joint Disease. In A. Grauer (Ed) *A Companion to Paleopathology* (513-530). Wiley-Blackwell Publication.
94. Wang, T., Chern, H., & Chiou, Y. (2005). A Theoretical Model for Preventing Osteoarthritis-related Disability. *Rehabilitation Nursing*, *30*(2), 62-67.
95. Watkins, R. (2012). Variation in Health and Socioeconomic Status within the W. Montague Cobb Skeletal Collection: Degenerative Joint Disease, Trauma and Cause of Death. *International Journal of Osteoarchaeology*, *22*, 22-44.
96. Weiss, E. & Jurmain, R. (2007). Osteoarthritis Revisited: A Contemporary Review of Aetiology. *International Journal of Osteoarchaeology*, *17*, 437-450.
97. Williams, D., Farrell, M., Cunnigham, F., Gracely, R., Ambrose, K., Cupps, T., Mohan, N., & Clauw, D. (2004). Knee Pain and Radiographic Osteoarthritis Interact in the Prediction of Levels of Self-Reported Disability. *Arthritis & Rheumatism, 51*(4), 558-561.
98. Wolfe, F., Hawley, D., Peloso, P., Wilson, K., & Anderson, J. (1996). Back Pain in Osteoarthritis of the Knee. *Arthritis Care & Research, 9*(5), 376-383.
99. Woolf, A. (2001). Understanding the Burden of Musculoskeletal Conditions. *BMJ, 322*(7294), 1079-80.
100. Woolf, A., & Pfleger, B. (2003). Burden of Major Musculoskeletal Conditions. *Bulletin of the World Health Organization, 81*(9), 646-656.
101. World Health Organization (WHO). (1986). *Ottawa Charter for Health Promotion*. Geneva.
102. World Health Organization (WHO). (1998). *Health Promotion Glossary*. Geneva.
103. World Health Organization (WHO). (2001). *International Classification of Functioning, Disability and Health: IC*F. Geneva.

104. World Health Organization (WHO). (2010). Classifications: International Classification of Disease (ICD). Retrieved from http://www.who.int/classifications/icd/en/.

105. Van der Esch, M., Steultjens, M., Knol, D., Dinant, H., & Dekker, J. (2006). Joint Laxity Modifies the Relationship between Muscle Strength and Functional Ability in Patients with Osteoarthritis of the Knee. *Annals of the Rheumatic Diseases, 65*(Suppl. 2), 408-408.

106. Van der Kraan, P., & Van den Berg, W. (2007). Osteophytes: Relevance and Biology. *Osteoarthritis and Cartilage*, *15*(3), 237-244.

107. Van der Waal, J., Terweel, C., van der Windt, W., Bouter, L., & Dekker, J. (2005). The Impact of Non-traumatic Hip and Knee Disorders on Health-related Quality of Life as Measured with the SF-36 or SF-12. A Systematic Review. *Quality of Life Research, 14*(4), 1141-1155.

108. Verano, J., & Ubelaker, D. (1992). *Disease and Demography in the Americas*. Washington: Smithsonian Institution Press.

109. Yelin, E., & Callahan, L. (1995). The Economic Cost and Social and Psychological Impact of Musculoskeletal Conditions. National Arthritis Data Work Groups. *Arthritis & Rheumatism*, *38*(10), 1351-1362.

110. Yelin, E., & Felts, W. (1990). A Summary of the Impact of Musculoskeletal Conditions in the United States. *Arthritis & Rheumatism*, *33*(5), 750-755.

111. Zhai, G., Blizzard, L., Srikanth, V., Ding, C., Cooley, H., Cicuttini, F., & Jones, G. (2008). Correlates of Knee Pain in Older Adults: Tasmanian Older Adult Cohort Study. *Arthritis Care & Research, 55*(2), 264-271.

Chapter 2. Cross-disciplinary Adaptation of Classification Systems: Exploring Knowledge Transfer between Medicine and Anthropology

This chapter discusses the utility of using modern health frameworks to improve organization and understanding of disease in past populations. Examining the link between clinical and archaeological populations is the basic premise of this thesis and this chapter reveals that the concept is viable. This research has been submitted for publication.

Cross-disciplinary Adaptation of Classification Systems: Exploring Knowledge Transfer between Medicine and Anthropology

Janet L. Young and Edward D. Lemaire

Keywords = ICF, ICD-10, paleopathology, disease, standardization

2.1. Abstract

This chapter investigates the capabilities of two medical classification systems of health and disease, the International Classification of Disease 10th Edition (ICD-10) and the International Classification of Function, Disability and Health (ICF), for documenting disease in human skeletal populations (paleopathology). A small portion of these medical classification systems were applicable to paleopathological analysis, but these sections could be easily adapted for use during, or subsequent to, data collection. Adapting the relevant portions of ICD-10 and ICF required new guidelines for code choice, highlighting the need for a formal process to map these systems into the study of skeletal remains. ICF/ICD-10 coding of skeletal features provided a means of easily aggregating data for the identification of paleopathological trends and patterns.

2.2. Introduction

Documenting human remains prior to repatriation has become a familiar task in many museums and universities. Information on metrics, non-metrics, skeletal anomalies, and pathological lesions is vital to understanding past populations. Collecting such information on human remains that are soon to be lost to the scientific record requires standardization since differences in data collection methods, data manipulation, data categorization, and data archiving may preclude valid aggregation. In the "global village", comparing and contrasting populations based on temporal, geographical, and cultural origins would increased our knowledge of the past. Also, in a world where skeletal populations are being repatriated and reburied, or found and reburied, standardization helps to ensure that a range of appropriate data is collected in a usable fashion. Standardized recording methods exist for documenting human remains prior to repatriation. 'Standards for Data Collection from Human Skeletal Remains' (Buikstra & Ubelaker, 1994) is one example of a system adopted for such a use. Despite this and other resources, definition and classification in paleopathology has remained a popular issue for discussion.

The study of disease in past populations is not new. Principally a field of description, paleopathology traces its roots back at least 150 years (Ortner, 1991). Drawing heavily upon medical knowledge, but more specifically the subdisciplines of pathology, orthopaedics and radiology, paleopathologists use clinical studies to define and quantify disease expression in the remains of the dead (Ortner, 1994; Roberts & Manchester, 2007). In fact, "the use of clinical data to diagnose disease in a skeleton is the base from which all paleopathologists work" (Roberts & Manchester, 2007). With such a reliance on medical syntheses and an acknowledged need for standardization, it is surprising that paleopathology has not incorporated standard classificatory systems from medicine and healthcare as documentation tools (Ortner, 1994; Brickley, 2004; Ortner, 2005; Roberts & Manchester, 2007).

Health and disease in modern populations can be categorized using various systems, but only a few systems were developed as global classification tools. These include the International Classification of Disease 10th Edition (ICD-10) and the International Classification of Function, Disability and Health (ICF). Both systems were developed and endorsed by the World Health Organization (WHO) and are a potential means of addressing the issue of standardized classification for cross usage of information in paleopathology.

This paper explores the potential use of ICD-10 and ICF as classificatory tools for paleopathology in the context of data collection prior to repatriation. The prospect of incorporating widely used and accepted medical classificatory systems into anthropology explores a link to the modern world of disease identification, diagnosis and interpretation.

2.3. Paleopathology: Standardization and Classification

The need for standardization in the field of paleopathology has been recognized for some time due to the lack of consistency in the way skeletal lesions are described and recorded (Ortner, 1991; Ortner, 1996; Roberts & Manchester, 2007). Discrepancies in lesion documentation often preclude the use of data amalgamation from multiple studies (Ortner, 1991; Ortner, 2005). However, the push to repatriate curated human remains from institutional holdings has increased the need for researchers to focus on description rather than diagnosis. These documentation issues have spurred dialogue concerning accepted terminology and standardization of descriptive approaches (Ortner, 1991; Ortner, 1994; Thillaud, 1994; Buikstra & Ubelaker, 1994; Ortner, 1996; Roberts & Connell, 2004; Roberts & Manchester, 2007).

Presently, the literature used for interpreting skeletal lesions follows two main formats. The first is based on causation; such as, determining if the lesion is traumatic, infectious, or congenital (Steinbock, 1976; Rose et al., 1991; Roberts & Connell, 1994;

Rogers & Waldron, 1995; Aufderheide & Rodriguez-Martin, 1998; Ortner, 2003; Roberts & Manchester, 2007). The second is organized by lesion location; such, as skull, vertebra, or rib (Mann & Murphy, 1990; Mann & Hunt, 2005). Both approaches have their merits and are useful when conducting a skeletal analysis. The literature in this area, along with published classification systems, stress a standard descriptive approach to the recording of skeletal pathology, with an emphasis on detailed description first and diagnosis second (Buikstra & Ubelaker, 1994; Thillaud, 1994).

Developed for the recording of repatriatable collections, "Standards for Data Collection from Human Skeletal Remains" (Buikstra & Ubelaker, 1994) endorses a coded system for recording skeletal lesions. Buikstra & Ubelaker proposed three main sections: location (separated by side, section, and aspect), bone, and pathology. Each section is subdivided into numerically coded qualifiers. For example, under Bone, skull is 2.0.0 and frontal 2.0.1.

Other classificatory systems have been developed for categorizing conditions (Ortner, 1968; Grmek, 1975/1976; Rogers, 1987; Rogers et al., 1987; Thillaud, 1994; Steckel et al., 2005); however, these systems are less widely cited, as compared to Buikstra and Ubelaker (1994). This may be because the Buikstra and Ubelaker system arose to address the need for documentation of skeletal collections due to repatriation in the United States (NAGPRA, Native American Graves Protection and Repatriation Act). Despite these efforts to provide a framework for classifying skeletal pathology, the issue of standardization is still cited as a problem in the field.

2.4. Clinical Practice: Standardization and Classification

In the fields of health and disease there has been a long-standing tradition, dating back to the18th century, of using globally accepted classification standards (WHO, 1990). The World Health Organization and its members now endorse ICD-10 and ICF for classifying health and disease. Both are coded systems that provide a common definition, measurement, and policy-making framework for health and disability. These systems can be used in tandem to increase understanding of disease and its affects on the individual and the population in which they live.

2.4.1. International Statistics Classification of Diseases and Related Health Problems (ICD)

Initiated in 1893 as a list of causes of death, ICD is now in its 10th edition (ICD-10) and has expanded to cover all diseases. ICD "was endorsed by the Forty-third World Health Assembly in May 1990 and came into use in WHO Member States as from 1994" (WHO, 1990). ICD-10 is an international medical classification system that has been used to determine the health status of populations, to examine disease incidence and prevalence rates, and to identify variables related to susceptibility. The classification system is used to record information on death certificates and hospital records and is a vital tool for coding information for improved storage and retrieval. This provides the mechanism for aggregating mortality and morbidity statistics by WHO member states.

The classification system is divided into twenty-two chapters, each representing a type of disease or related health problem. One chapter of interest to osteological analysis is XIII "Diseases of the musculoskeletal system and connective tissue". Each chapter is separated into blocks (Chapter XIII is identified as M00-M99). Each block of numbers is divided into subsections, each representing one condition. ICD-10 employs a hierarchical system with each level building on the information provided by the one above, with the associated alphanumeric code showing the relationship. For example, an ICD-10 code for knee osteoarthritis could be M17.2 (Gonarthrosis [arthrosis of knee], Post-traumatic gonarthrosis, bilateral).

2.4.2. International Classification of Functioning, Disability and Health (ICF)

Revised from the International Classification of Impairments, Disabilities, and Handicaps (ICIDH), ICF was "endorsed by the Fifty-fourth World Health Assembly for international use on 22 May 2001" (WHO, 2001). Based on medical and social models (WHO, 2002), the new version sought to move away from a "consequences of disease" focus to a "components of health" perspective (WHO, 2001). The 191 WHO member states agreed to use this tool to globally standardize data on health and disability (WHO, 2002) with the aim "to provide a unified and standard language and framework for the description of health and health-related states" (WHO, 2001).

ICF was developed to serve various fields of study. The ICF aims are relevant to anthropology research:

- provide a scientific basis for understanding and studying health and health-related states, outcomes, and determinants;
- establish a common language for describing health and health-related states to improve communication between different users;
- permit data comparison across countries, health care disciplines, services, and time;
- provide a systematic coding scheme for health information systems (WHO, 2001).

ICF is separated into health and health-related domains that are grouped into two main sections “Body Functions and Structures” and “Activities and Participation” and four main headings: “Body functions”, “Body structures”, “Activities and participation” and “Environmental factors”. Beneath each heading are chapters, eight in body functions, eight in body structures, nine in activities and participation, and five in environmental factors. This classification system organizes pertinent information for an individual with a specific health condition. ICF seeks to move beyond the physical to include an individual’s living environment and the impact of their social structure. “Thus, ICF attempts to achieve a synthesis, in order to provide a coherent view of different perspectives of health from a biological, individual and social perspective” (WHO, 2001).

As with ICD-10, ICF has limited utility for paleopathology since it was developed to study living populations. Out of ICF’s many chapters, only a few sections in “Body Structure” are presently applicable to the study of human skeletal remains: Chapter 7 titled “Structures related to movement”, coded as s7 (‘s’ for body structure and ‘7' for chapter 7) and Chapter 3 titled “Structures involved in voice and speech”, coded as s3. As an example, s730 codes upper extremity structure, s7300 - upper arm structure, s73001 - elbow joint. As can be seen, each additional number added to the sequence provides an extra level of information. However, even the basic codes offer a degree of classification capability. Three additional numbers, called qualifiers, are added to these primary codes. The first is a generic qualifier related to impairment (e.g. 1=mild, 2=moderate, 3=severe). The second qualifier is used to indicate the nature of the change in the respective body structure (e.g. 0=no change, 1=total absence, 2=partial absence, 3=additional part, etc.). The third qualifier indicates localization (e.g.

1=right, 2=left, 3=both sides, 4=front, etc.). An ICF code for a musculoskeletal condition could read s73001.153, with s73001=elbow joint, 1=mild, 5=discontinuity, 3=both sides.

2.5. Can Medicine and Paleopathology use Common Ground?

Perhaps a better question than “Can medicine and paleopathology use common ground?” would be “Should two distinct fields of study try to establish a common classificatory link”? A positive response is supported since many of the diagnoses from human skeletal remains are derived from data collected on modern populations. Some have argued that “the paleopathologist also needs to develop a classificatory system that takes full advantage of the data available in the material being studied. We need ongoing dialogue between paleopathologists and medical colleagues to ensure as much overlap as possible with medical terminology and classificatory (diagnostic) categories” (Ortner, 1991). A common system could use common coding as a gateway to information severely lacking in past population research, such as how a person functioned with impairment.

As a means of exploring the hypothesis that an overlapping classificatory system is possible, the application of ICD-10 and ICF models for categorizing paleopathological lesions was adopted into the data collection protocols for human remains being repatriated from the collections of the Canadian Museum of Civilization. These protocols are based on ‘the Standards for Data Collection from Human Skeletal Remains’ (Buikstra & Ubelaker, 1994) but are constantly being broadened to include a wider variety of observations.

2.6. Methods

A column based data collection form was developed to capture information on lesion location, description, ICD-10 code, and ICF codes. A reference book with information on ICD-10 and ICF codes relevant to musculoskeletal conditions was created to facilitate coding. For the ICF classification system, the reference book was comprised of two chapters from the ‘body structures’ section, Chapter 7 – Structure related to movement and Chapter 3 – Structures involved in voice and speech. For ICD-10, Chapter XIII – Diseases of the musculoskeletal system and connective tissue, part of Chapter XI – Diseases of the digestive system, and portions of Chapter XIX – Injury, poisoning and certain other consequences of external causes were included.

From a single repatriation in the Ottawa valley, 15 skeletons of varying degrees of completeness (crania to almost complete skeletons) were examined. Descriptive and visual recording of all pathological lesions was undertaken. This primary documentation was reviewed and ICD-10 and ICF codes were recorded using the code collection forms. For each skeleton examined, descriptive and coded information was provided for both individual lesions and general pathological conditions. While coding the data, decisions on code selection were made and noted in a log to maintain consistent coding practice.

2.7. Results

For this pilot study, features are defined as skeletal lesions (areas of pathologically alteration) or anomalies (deviations from normal). All features from the skeletal remains were successfully coded using ICD-10 and ICF (e.g. Table 2.1).

The number of features coded for each case ranged from 1 to 24, with the most codes produced by the most complete set of remains. The sample as a whole generated 82 codes per classification system, with complimenting ICF and ICD-10 codes for each feature (i.e., 82 codes for ICF, 82 codes for ICD-10). The pathological codes were grouped into eight categories for comparison (Table 2.2). The degenerative joint disease category (excluding spinal changes) accounted for the largest percentage of total codes at 33.83%; dental pathology was second at 26.46%, and spinal changes third at 19.13% (Table 2.3).

Other features, not considered lesions in paleopathology but falling under the anomalies description, were also classified using ICF and ICD-10. Table 2.4 presents ICD-10 codes that can be used for such skeletal analyses.

Table 2.1: Example of ICF and ICD-10 coding for skeletal remains.

Location	Description	ICD Code	ICD Code Description	ICF Code	ICF Code Description
Mandible	M3s congenitally absent	K00.0	anodontia	S3200.123	teeth / mild / partial absence / both sides
	dental attrition	K03.0	excessive attrition of teeth	s3200.170	teeth / mild / qualitative changes in structure / more than one region
	periodontal disease	K05.3	chronic perodontitis	s7101.120	bones of face / mild / partial absence/ more than one region
	LM2 odd wear pattern	K03.1	abrasion of teeth	s3200.242	teeth / moderate / aberrant dimensions / left

	dental calculus	K03.6	deposits (accretionss) on teeth	s3200.130	teeth / mild / additional part / more than one region
	torus	K10.0	developmental disorders of jaws (torus)	s7101.133	bones of face / mild / additional part / both sides
Maxilla	M3s congenitally absent	K00.0	anodontia	s3200.122	teeth / mild / partial absence / left
	dental attrition	K03.0	excessive attrition of teeth	s3200.170	teeth / mild / qualitative changes in structure / more than one region
	periodontal disease	K05.3	chronic perodontitis	s7101.220	bones of face / moderate / partial absence / more than one region
	dental crowding	K07.3	anomalies of tooth position	s3200.161	teeth / mild / deviating position / right
	peg shaped RM3	K00.2	abnormalities of size and form of teeth	s3200.141	teeth / mild / aberrant dimensions / right
	dental calculus	K03.6	deposits (accretions) on teeth	s3200.130	teeth / mild / additional part / more than one region
Cranium - TMJ	DJD	K07.6	temporomandibular joint disorders	s7103.151	joints of head and neck region /mild / discontinuity / right
Cranium - occipital condyle	DJD	M19.0	primary arthrosis of other joints	s7103.143	joints of head and neck region / mild / abberant dimensions / both sides
Scapulae - glenoid fossae	DJD	M19.0	primary arthrosis of other joints	s7201.14(5)3	joints of shoulder region / mild / abberant dimensions(discontinuity) / both sides
Humerus - distal end	DJD	M19.0	primary arthrosis of other joints	s73001.153	elbow joint / mild / discontinuity / both sides
Ulna - proximal end	DJD	M19.0	primary arthrosis of other joints	s73001.143	elbow joint / mild / abberant dimensios / both sides
Spine - cervical	DJD	M47.8	other spondylosis	s76000.140	cervical vertebral column / mild / abberant dimensions / more than one region
Spine - atlas	ossified ligament	M46.0	spinal enthesopathy	s76000.137	cervical vertebral column / mild / additional part / distal
Spine - thoracic	DJD	M47.8	other spondylosis	s76001.140	thoracic vertebral column / mild / abberant dimensions / more than one region
Spine - thoracic	ossified ligament	M46.0	spinal enthesopathy	s76001.230	thoracic vertebral column / moderate / additional part / more than one region
Spine - lumbar	DJD	M47.8	other spondylosis	s76002.140	lumbar vertebral column / mild / abberant dimensions / more than one region
Spine - L6	spondylolysis	M43.0	spondylolysis	s76002.423	lumbar vertebral column / complete / partial absence / both sides
Rib - heads	DJD	M47.8	other spondylosis	s7608.140	structures of trunk, other specified / mild / abberant dimensions / more than one region
Tarsal / Metatarsal	DJD	M19.0	primary arthrosis of other joints	s75021.152	ankle joint, joints of foot and toes/mild/discontinuity/left

Table 2.2: The ICD-10 pathological codes grouped into eight categories.

Category	ICD Code	Description
Arthrosis	K07.6	Temporomandibular joint disorders
	M15.0	Polyarthrosis
	M16.7	Other secondary coxarthrosis
	M16.9	Coxarthrosis, unspecified
	M17.4	Other secondary gonarthrosis, bilateral
	M18.9	Arthrosis of first carpometacarpal joint, unspecified
	M19.0	Primary arthrosis of other joints
	M19.9	Arthrosis, unspecified
Dental pathology	K00.0	Anodontia - hypodontia
	K00.2	Abnormalities of size and form of teeth
	K00.4	Disturbances in tooth formation
	K01.0	Embedded teeth
	K04.6	Periapical abscess with sinus
	K05.3	Chronic periodontitis
	K05.6	Periodontal disease, unspecified
	K07.3	Anomalies of tooth position
	K08.1	Loss of teeth due to accident, extraction or local periodontal disease
Spine	M43.0	Spondylolysis
	M46.0	Spinal enthesopathy
	M47.8	Other spondylosis
	M50.3	Other cervical disc degeneration
	M51.3	Other specified intervertebral disc degeneration
	M51.4	Schmorl's nodes
Fracture	S02.0	Fracture of skull vault
	S62.3	Fracture of other metacarpal bone
	S62.8	Fracture of other and unspecified parts of wrist and hand
Development disorders of jaws (tori)	K10.0	Development disorders of jaws
Osteochondritis dessicans	M93.2	Osteochondritis dessicans
Osteonecrosis	M87.9	Osteonecrosis, unspecified
Enthesopathy	M76.9	Enthesopathy of lower limb, unspecified

Table 2.3: Percentage of ICD-10 pathological codes falling within various groupings.

Description	Percentage
Arthrosis	33.83%
Dental pathology	26.46%
Spine	19.13%
Development disorders of jaws (tori)	5.88%
Fracture	4.41%
Osteochondritis dessicans	4.41%
Osteonecrosis	2.94%
Enthesopathy	2.94%

Table 2.4: ICD-10 codes identified for factors considered anomalous and non-pathological in skeletal analyses.

Category	ICD Code	Description
Anomalies	K03.6	Deposits on teeth
	K03.0	Excessive attrition of teeth
	K03.1	Abrasion of teeth
	K03.4	Hypercementosis

2.8. Discussion

The use of ICD-10 was successful, although some decisions on proper code employment were required. For example, degenerative changes at the rib/vertebral articulation were coded as M47.8 (other spondylosis) instead of M19.0 (primary arthrosis of other joints) as ICD-10 did not have precise codes for this region. The spondylosis code was chosen because it was more specific to the area in the skeleton as compared with the non-descript qualifier ‘general arthrosis’.

The primary coding for ICF was also straightforward. However, using the first, second, and third qualifiers proved challenging. The first qualifier deals with degree of impairment, which cannot be assessed from archeological remains. Therefore, this qualifier was used as degree of expression. The second qualifier is a quality measure; however, one skeletal lesion may have multiple features that cannot be catalogued using one code. Two procedures were employed to address this issue: 1) the most prominent feature was coded and identified in the log; 2) Secondary features were given separate codes. For example, when categorizing degenerative changes to a joint surface, including peripheral osteophytes and surface erosion, additional part (3), aberrant dimensions (4), discontinuity (5), or qualitative changes in structure (7) are applicable. Both secondary qualifier 4 (aberrant dimensions - produced at the joint by the marginal bone proliferation) and 5 (discontinuity – mainly produced by islands of porosity on the surface of the joint) were found to be more applicable, though arguably “additional part” and “aberrant dimensions” and “discontinuity and “qualitative changes in structure” can refer to similar features. The third qualifier, location, was easily coded for all remains.

Despite the limitations, specific conditions and lesions could be coded and the amount of time needed to do so decreased as familiarity with the system improved. The coded results simplified the data and allowed for quick entry into a database. This electronic resource permitted the simple aggregation of features and created a system for categorizing and archiving data from repatriated human remains. This suggests that the streamlined coding system could be useful in creating and examining pathological datasets producing a research tool for the future where curated collections may no longer be available. However, the full potential of this system cannot be tested until the ICD-10 and ICF frameworks are adequately developed for the field of paleopathology, which will require the establishment of mapping rules for consistent coding.

2.9 Conclusions

Fields of paleopathology and medicine have worked to address issues of standardization and classification. The success of the medical world can be attributed to the global framework in which the systems are developed and implemented. Paleopathology does not have the luxury of such an apparatus. Since paleopathology is a field that relies heavily on clinical study, healthcare models deserve further consideration as a means of classifying data accumulated during analysis prior to repatriation. ICF and ICD-10 are two complementary systems that can provide a classification structure for the documentation of skeletal remains.

As in this repatriation scenario, where the categorization occurred subsequent to the data collection, categorization can be used as a complementary system for synthesis (i.e., in conjunction with the primary recording system for human remains). In this way, classification can be a useful link in the knowledge transfer and data aggregation chains.

2.10 Acknowledgements

The authors would like to acknowledge the support of the Canadian Museum of Civilization and The Ottawa Hospital Rehabilitation Centre. Dr. Jerome Cybulski is acknowledged for his comments on an earlier draft.

2.11 Literature Cited

1. Aufderheide A and Rodriguez-Martin C. (1998). *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge: Cambridge University Press.
2. Brickley, M., (2004). Introduction. In Guidelines to the Standards for Recording Human Remains. In M. Brickley & J. McKinley (Eds.). *Institute of Field Archaeologists, Paper 7*, 5-6.
3. Buikstra, J., & Ubelaker, D. (1994). *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archaeological Survey Research Series No.44.
4. Grmek, M. (1975/76). La paleopathologie des tumeurs osseuses malignes: Proposition d'une classification a l'usage de L'osteo-archeologie, revue des exemples publies et presentation de deux cas inedits. *Histoire des Sciences Medicales 9(1)*, 21-50.
5. Mann, R., & Hunt, D. (2005). *Photographic Regional Atlas of Bone Disease*. Illinois: Charles C Thomas Publisher Ltd.
6. Mann, R. & Murphy, S. (1990). *Regional Atlas of Bone Disease*. Illinois: Charles C Thomas Publisher Ltd.
7. Ortner. D. (1968). Description and Classification of Degenerative Bone Changes in the Distal Joint Surfaces of the Humerus. *American Journal of Physical Anthropology 28*, 139-156.
8. Ortner, D. (1991). Theoretical and Methodological Issues in Paleopathology. In D. Ortner, & A. Aufderheide (Eds.), *Human Paleopathology: Current Syntheses and Future Options* (pp.5-11). Washington, DC: Smithsonian Institution.
9. Ortner, D. (1994). Descriptive Methodology in Paleopathology. In D. Owsley & R. Jantz (Eds.), *Skeletal Biology in the Great Plains: Migration, Warfare, Health and Subsistence* (pp.73-80), Washington, DC: Smithsonian Institution Press.
10. Ortner, D. (1996). *Classification of Bone Lesions*. Papers presented at the 23rd Annual Meeting of the Paleopathology Association. Durham.
11. Ortner, D. (2003). Identification of Pathological Conditions in Human Skeletal Remains. California: Academic Press.
12. Ortner, D. (2005). Introduction. In R. Mann & D. Hunt (Eds.), *Photographic Regional Atlas of Bone Disease* (pp. vii-x), Illinois: Charles C Thomas Publisher Ltd.

13. Roberts, C. & Connell, B. (2004). Guidance on Recording Paleopathology. In M. Brickley & J. McKinley (Eds.), *Guidelines to the Standards for Recording Human Remains, Institute of Field Archaeologists Paper 7* (pp. 34-39).
14. Roberts, C. & Manchester, K. (2007). The Archaeology of Disease. New York: Cornell University Press.
15. Rogers,J. (1987). *Erosive Arthritis in Skeletal Material: Recognition and Classification*. Papers presented at the 14th Annual Meeting of the Paleopathology Association. New York.
16. Rogers, J. & Waldron, T. (1995). *A Field Guide to Joint Disease in Archaeology*. England: John Wiley & Sons Ltd.
17. Rogers, J., Waldron, T., Dieppe, P., & Watt, I. (1987). Arthropathies in Paleopathology: The Basis of Classification According to Most Probable Cause. *Journal of Archaeological Science 14,* 179-193.
18. Rose, J., Anton, S., Aufderheide, A., Eisenberg, L., Gregg, J., Neiburger, E., & Rothschild, B. (1991). Skeletal Database Committee Recommendations, *Paleopathology Newsletter*. Detroit, Michigan.
19. Steinbock, T. (1976). *Paleopathological Diagnosis and Interpretation*. Illinois: Charles C Thomas Publisher Ltd.
20. Steckel, R., Larsen, C., Sciulli, P., & Walker, P. (2005). *The Global History of Health Project: Data Collection Codebook*. Retrieved from http://global.sbs.ohio-state.edu.
21. Thillaud, P. (1994). Lesions Osteo-Archeologiques: Recueil et Identification. Sceaux: Kronos B.Y. Editions.
22. World Health Organization (WHO). (1990). *International Classification of Disease.* Retrieved from http://www.who.int/classifications/icd/en/.
23. World Health Organization (WHO). (2001). International Classification of Functioning, Disability and Health: ICF. Geneva.
24. World Health Organization (WHO). (2002). *Towards a Common Language for Functioning, Disability and Health.* Retrieved from http://www.who.int/classifications/icf/training/icfbeginnersguide.pdf.

Chapter 3. Linking Bone Changes in the Distal Femur to Functional Deficits

This chapter, published in the International Journal of Osteoarchaeology, discusses the qualitative approach to grading knee OA severity by developing the Clinical Archaeological Osteoarthritis Score (CAOS) grading system and relates this new system to specific outcome variables to create a means of applying the relation between bone changes and outcomes to archaeological populations.

Young, J. L. & Lemaire, E. D. (2012), Linking Bone Changes in the Distal Femur to Functional Deficits. *International Journal of Osteoarchaeology*.. doi: 10.1002/oa.2257

Linking Bone Changes in the Distal Femur to Functional Deficits

Janet L. Young and Edward D. Lemaire

Keywords = degeneration, osteoarthritis, knee, impairment, MRI, bioarchaeology, Osteoarthritis Initiative

3.1. Abstract

Knee osteoarthritis is a condition that leads to functional deficits in the afflicted. Quantifying these deficits in a clinical population and relating them to bone changes in the distal femur is crucial to identifying potential impairment in archaeological populations. This study provides a knee osteoarthritis grading system linking MRI observations of clinical populations and direct bone observations on skeletal populations. This grading system is then related to 28 pain, disability, and activity limitation outcome variables provided by the Osteoarthritis Initiative (OAI) through frequency distributions, probability profiles, and Spearman's rank correlations. The results suggest that while the five outcome variables with the highest probabilities were common to males and females, bone changes in knee osteoarthritis impact males and females differently.

3.2. Introduction

Bioarchaeologists often assume that archaeological human bone with advanced pathological changes would have caused intense symptoms, including pain and disability. Unfortunately, there is little empirical evidence to support this view. Osteoarthritis (OA) is one condition where advanced bone changes arouse empathy for the afflicted. OA is one of "the most common diseases of the musculoskeletal system among degenerative and inflammatory rheumatic disorders", along with rheumatoid arthritis (Ay et al., 2008, p.159). OA can cause pain, disability, and psychological distress. OA can also limit activity, negatively affect quality of life, and is the leading cause of disability in North America and developed countries (Spector et al., 1996; Ayis et al., 2007; Marra et al., 2007; Rosemann et al., 2007; Ay et al., 2008). In archaeological populations, OA is cited as the commonest joint disease (Rogers & Waldron, 1995); however, research is needed to determine the potential impact of this pathological condition on these archaeological populations.

OA is caused by cartilage and subchondral bone degeneration (Fautrel et al., 2005), which is believed to occur when the natural balance of deterioration and repair of the joint tissues is disproportionate, resulting in structural and functional joint failure (Hunter et al., 2008). While this progressive joint failure can cause pain and adversely affect activities of daily living, many people who have structural changes consistent with OA are, for reasons unknown, asymptomatic (Rapp et al., 2000; Hunter et al., 2008).

While OA affects many joints, knee OA has a direct effect on functioning and mobility, two important characteristics for archaeological populations reliant on physical capacity for subsistence. The knee is also considered one of the major locations for OA in archaeological populations (Rogers & Waldron, 1995). Knee OA is progressive and eventually leads to mechanically induced knee joint failure (Biscevic et al., 2008; Maly et al., 2008). Functional symptoms include stiffness, instability, and buckling; sensory symptoms include chronic pain; and psychological symptoms can include emotional distress and depression (Cooper et al., 2000; Dieppe, 2000; Breedveld, 2004; Fitzgerald et al., 2004; Parmelee et al., 2007; Hunter et al., 2008). In some cases, the functional and sensory symptoms may lead to modified knee biomechanics in an attempt to limit sensory intensity. These movement modifications mainly occur during sitting, standing, bending, and walking (Hall et al., 2008).

Linking knee OA symptoms to physical changes in the knee joint, and associated disability, has met with mixed results that range from a distinct association between joint changes and symptoms (Lethbridge-Cejku, 1995; Spector et al., 1996; Szebenyi et al., 2006; Neogi et al., 2008; Zhai et al., 2008) to poor correlation (Altman et al., 1986; Rogers et al., 2004; Roseman et al., 2007), to discordance between pain and x-ray features (Barker et al., 2004; Faucher et al., 2004; van der Kraan et al., 2007; Maly et al., 2008; Oka et al., 2008). Though more radiographic evidence is present for those with chronic pain (Hopman-Rock et al., 1998), the "relationship between pain and degenerative structural changes in joints is poorly understood" (Thorp et al., 2007, p.1257). Pain is often cited as the predominant symptom and the main reasons for disability in knee OA and relates to a person's perception of their ability rather than their actual ability to perform (Lethbridge-Cejku, 1995; Hopman-Rock et al., 1998; Bennell et al., 2003; Williams et al., 2004; Peters et al., 2005; van der Waal et al., 2005; Maly et al., 2006; Rosemann et al., 2006; Parmelee et al., 2007; Tuzun, 2007; Hunter et al., 2008; Maly et al., 2008; Maly, 2009). Knee OA pain can be activity related or mechanical, deep, aching, and non- localized. This pain slows activity and leads to a lack of trust in the knee, especially during challenging pursuits (Maly, 2009).

In clinical settings, OA is primarily assessed through radiographs (Oka et al., 2008). The bone features associated with knee OA radiographs and chronic pain include osteophytosis, subchondral sclerosis, and bone marrow lesions (Altman et al., 1986;

Lethbridge-Cejku, 1995; Spector et al., 1996; and Zhai et al., 2008). Schiphof et al. (2008) and Lethbridge-Cejku (1995) identified osteophyte (bone projections) formation on the joint margins or in ligamentous attachments (ex., tibial spines), joint space narrowing associated with subchondral bone sclerosis, cystic areas with sclerotic walls situated in the subchondral bone, and altered shape of the bone ends as OA indicators. One of the most cited instruments to grade these radiographic changes is the Kellgren-Lawrence Grading Scale (Kellgren & Lawrence, 1957). This tool grades the three main physical features associated with OA: osteophytes formation, joint space narrowing, and subchondral sclerosis, from 0-4 (Salaffi et al., 2005). Definite knee OA has a Kellgren-Lawrence grade of two or higher (Lethbridge-Cejku, 1995).

Not all the features used in the Kellgren-Lawrence model are available bioarchaeologically; therefore, for archaeological bone OA is defined by characteristic changes visible on joint surfaces. Rogers et al. (1987, p. 185) defined these features as "(1) the formation of true, marginal osteophytes; (2) subchondral bone reaction (eburnation, sclerosis, cysts); (3) pitting of joint surfaces; and in severe cases (4) alterations in the joint contours."

This paper proposes a method for relating impairments with bone changes due to knee OA. This information is currently not accessible in the bioarchaeological dialogue. However, creating such a correlate to impairment could allow researchers to move beyond descriptive text to identifying potential limitations related to movement and activities of daily living for archaeological populations.

3.3. Material and Methods

A clinical population is needed to establish the link between bone degeneration and functional outcomes. The Osteoarthritis Initiative (OAI) is ideal for examining lifestyle, activity, and participation limitations based on changes of the knee joint associated with OA. OAI is a multi-center, longitudinal, cohort, prospective observational study focusing primarily on knee OA (Nevitt et al., 2006).

The OAI study consists of 4607 male and female participants of various ethnicities ranging in age from 45 to 79 at baseline, with women slightly more represented than men. This cohort continues to be evaluated on a yearly basis with data available for baseline, 12, 24, 30, 36, and 48 month follow-ups. These data include a set of knee OA status and outcome measurements (clinical and imaging) including pain, physical function, patient global (overall impact of knee problems), and joint assessments (Nevitt et al., 2006). "Data used in the preparation of this article were obtained from the Osteoarthritis Initiative (OAI) database, which is available for public access at http://www.oai.ucsf.edu/ " (OAI, 2006, p. 2). The specific dataset used for our research was a random sample of 200 participants from the 12 month follow-up that was selected from a strata of gender, subcohort assignment ("knee symptoms" and "no symptoms but have risk factors for their development"), and clinic (four recruitment centers). This sample was one of several MRI packages made available through OAI.

Since MRI images depicting bone are known to be accurately related to the macroscopic appearance of denuded bone (Cohen et al., 1999; Iwaki et al., 2000; Woodhead et al., 2001; Leitzes et al., 2005; Boileau et al., 2008; Louis et al., 2010; Ochiai et al., 2010), a grading system that is equally applicable to clinical and archaeological skeletal populations was developed. This new system, the Clinical Archeological Osteoarthritis Scale (CAOS), was used to grade the degree of knee OA visible in MRIs and focused on features previously identified as significant in the Kellgren-Lawrence (1957) and Rogers et al. (1987) grading systems: marginal osteophyte formation and alterations in joint contours. Pitting (micro/macroporosities) or cysts were also selected since they are readily detectable on both denuded bone and MRIs and are accepted as important indicators of disease progression for archaeological populations.

The CAOS grading system, based on the femur's distal articular surface, was developed to capture the degree of bone change with the progression of knee OA (Table 3.1). Consisting of four grades, 0 represents no changes (Figure 3.1), 1 represents very mild changes in the form of minimal marginal bone exostosis that may produce minor irregularities to the joint margin (Figure 3.2), 2 represents possible surface microporosities with distinct osteophytes along the articular margins producing evident contour irregularities (Figure 3.3), and 3 represents deterioration of the articular surface shown by the presence of porosities and/or cysts and completely irregular articular surface margins produced by excessive osteophyte formation (Figure 3.4).

Table 3.1: The CAOS grading system.

	Features of the Distal Femoral Articular Surface			
CAOS Grade	Marginal Bone Proliferation	Irregular Surface Margins	Porosities	Predominant Feature
0	none	none	none	smooth articular surface with well defined rounded joint margins
1	minor bony exostosis usually seen in region of intercondylar notch	minimal	none	smooth articular surface with slightly irregular margins due to minor marginal bone proliferation creating a sharpening of the edge in some areas
2	minimal to moderate osteophyte formation	minimal to moderate	microporosities may be present	marginal bone proliferation in the form of distinctive osteophytes creating irregular and sharp margins in some areas
3	moderate to excessive osteophyte formation	distinctive irregular joint surface margins	distinctive microporosities present; macroporosities and/or cysts may be present	articular surface has obvious porosities; joint contours are sharp and irregular along most of the margin due to advanced bone proliferation (osteophytosis)

The MRIs for each knee were reviewed using DICOMWORKS (v1.3.5 © 2000, 2001 Philippe Puech-Loïc Boussel). Of the 200 participants available for study (400 knees) not all had the required clinical data or adequate MRI images. A total of 357 knees comprised the study sample with 190 male knees and 167 female knees. Individual knees were chosen as the unit of analysis because many of the outcome variables are specific to either the right knee or the left knee. The participants ranged in age from 46 to 80 years with a mean of 64.34 years (±9.8) and ranged in Body Mass Index (BMI) from 18.7 to 42.6 with a mean of 29 (±4.6). Of the 357 knees, 84.5% belonged to Caucasians, 13.4% belonged to African Americans, 1.05% belonged to Asians and 1.05% belonged to other non-Caucasian. CAOS grading outcomes were generated for all knees.

Variables related to pain, disability, and activity limitations were collected by OAI using a series of self-administered questionnaires. The Western Ontario and McMaster

Universities Arthritis Index (WOMAC) questionnaire assessed pain during daily activities, joint stiffness, and physical function (Bellamy et al., 1988). The Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire assessed pain at higher intensity movement, symptoms, function in sport and recreation, and knee related quality of life (Roos et al., 1998). The Health Survey Short Form 12 (SF-12®) questionnaire measured physical status (Ware et al., 1996).

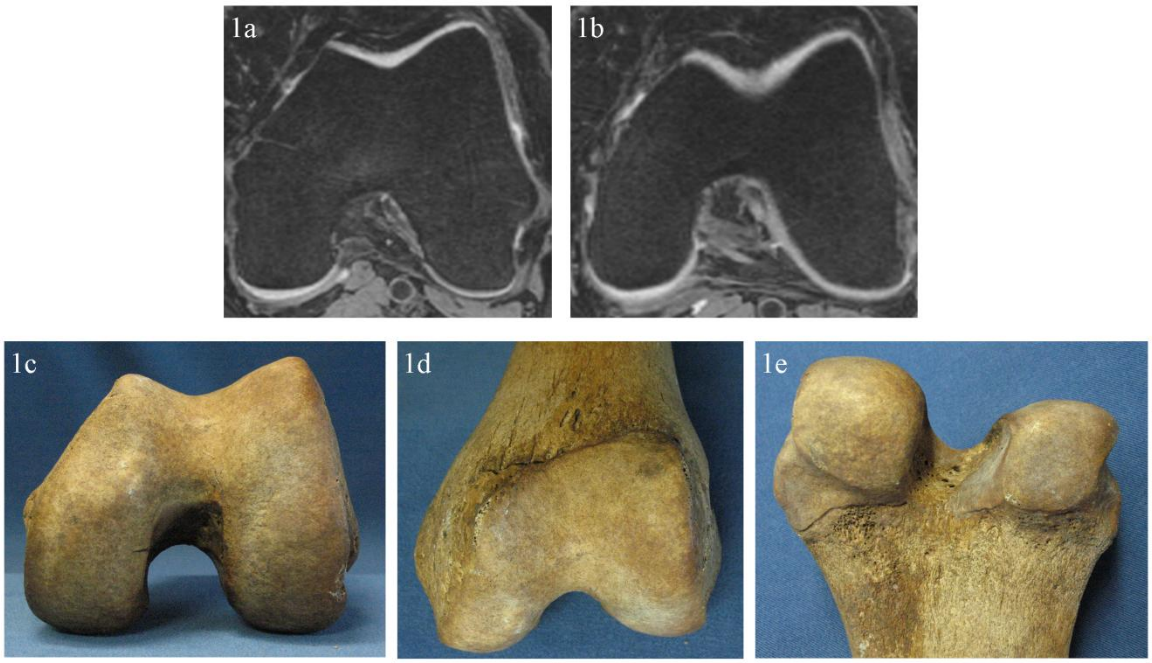


Figure 3.1: CAOS grade 0 as represented by two (1a and 1b) MRI proximal to distal cross-sections of the distal femur from the OAI clinical sample exhibiting a smooth youthful appearance. Three photographs of an archaeological bone sample with views of the distal surface (1c), anterior surface of the distal end (1d), and posterior surface of distal end (1e) exhibiting no degenerative bone changes.

Outcome variables were chosen from OAI for their relevance to archaeological populations. OAI graded most variables on a 5 point Likert scale, a point scale that measures participant attitude based on level of agreement to specific survey questions or statements (Uebersax, 2006). This 5-point scale was reduced to dichotomous data, with outcomes recorded as present or absent. Nine variables were used to assess pain (straightening knee fully, twisting/pivoting, standing, in bed, walking, bending knee fully, stair ascent or descent, sitting or lying down, interference with normal work), 14 variables were used to assess disability (light chores, walking, standing, downstairs, stand from sitting, bending, heavy chores, walking upstairs, twisting/pivoting, running, jumping, kneeling, squatting, having more difficulty with knee), and five variables were used to assess activity limitations (limited in kind of work, accomplish less, limited with several flights of stairs, limited in moderate activities, modified lifestyle to avoid activities that may damage knee).

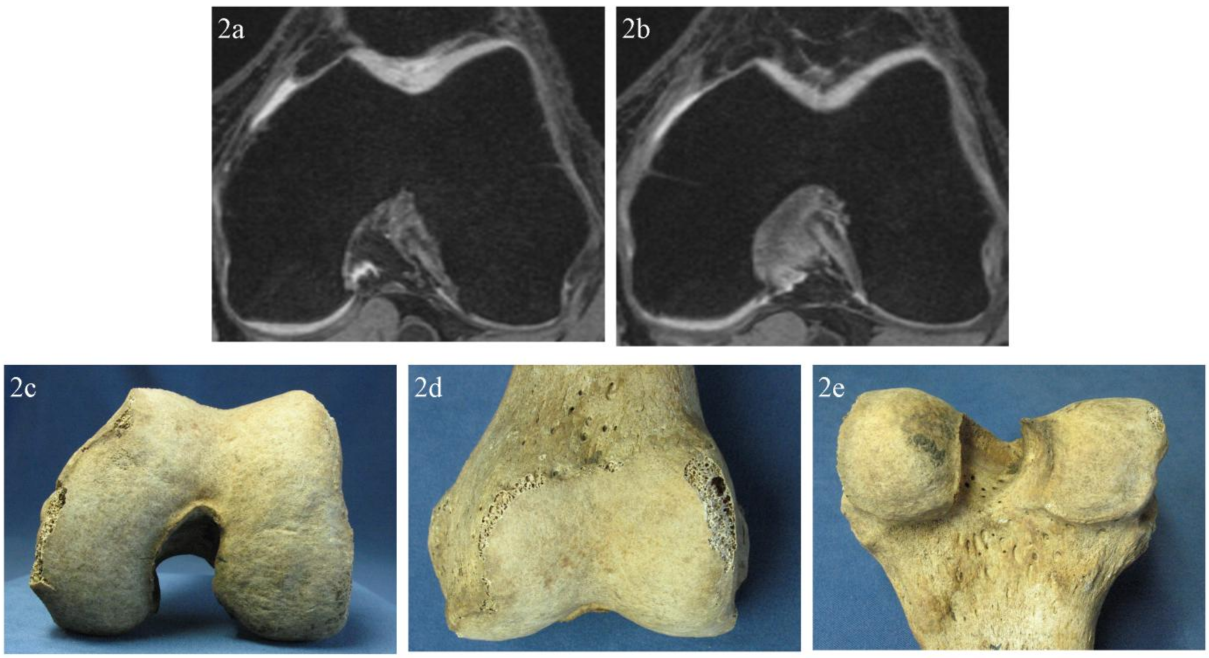


Figure 3.2: CAOS grade 1 as represented by two (2a and 2b) MRI proximal to distal cross-sections of the distal femur from the OAI clinical sample exhibiting slight bone proliferation along the margins of the intercondylar notch. Three photographs of an archaeological bone sample with views of the distal surface (2c), anterior surface of the distal end (2d), and posterior surface of distal end (2e) exhibiting minor marginal bone proliferation most evident along the intercondylar notch.

Linking OAI outcome variables to activities completed by archaeological populations will depend on the population chosen. However, certain generalities can be considered. For instance, climbing hills or navigating a hilly terrain could be equivalent to stair ascent/descent; crouching while hunting or squatting while preparing food could be linked to the bending knee fully, kneeling, or squatting variables; knee mobility when chasing prey or when tilling fields could be linked to twisting/pivoting variables or the running/walking variables.

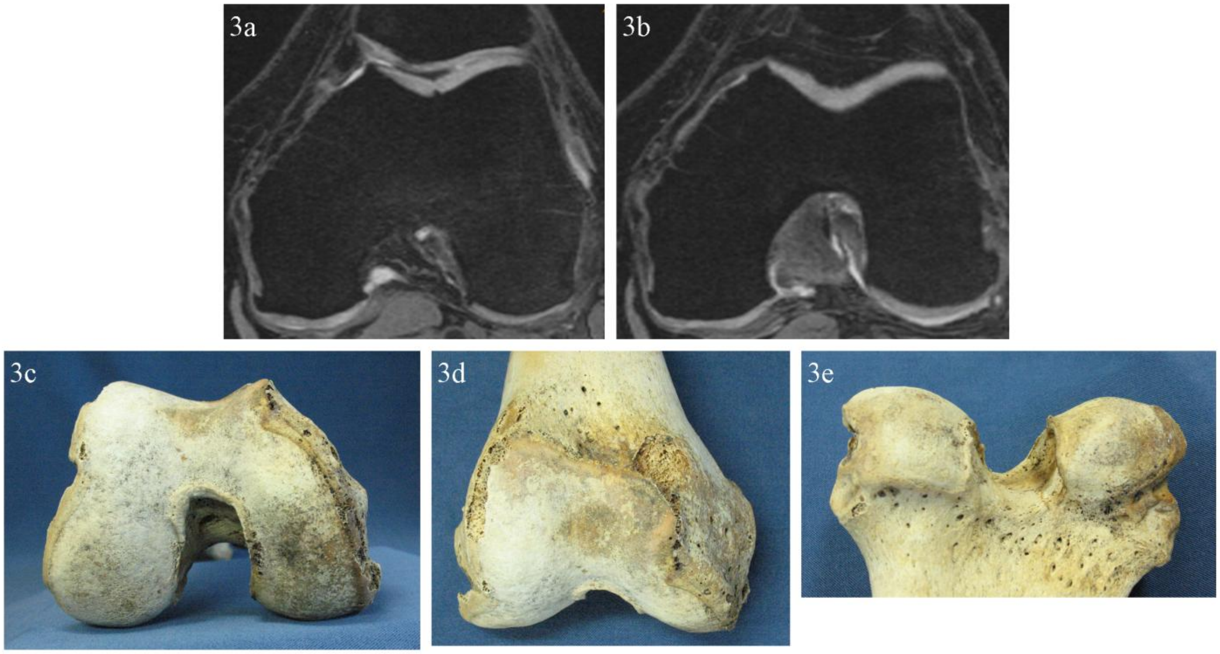


Figure 3.3: CAOS grade 2 as represented by two (3a and 3 b) MRI proximal to distal cross-sections of the distal femur from the OAI clinical sample exhibiting moderate osteophyte formation around the articular surface periphery creating irregular margins. Three photographs of an archaeological bone sample with views of the distal surface (3c), anterior surface of the distal end (3d), and posterior surface of distal end (3e) exhibiting similar bone proliferation distribution and irregular articular margins.

Frequency distributions for each OAI outcome variable were used to calculate the probability of having a functional deficit at each CAOS grade. These probabilities were generated for males, females, and the population as a whole. Spearman's rank correlations were calculated to determine if the probabilities were significantly related to the CAOS grade.

Since the sample population is clinical in nature, medication usage was also assessed to determine if medication might have had a masking effect on the outcomes, thereby affecting the bioarchaeology relevance of any findings.

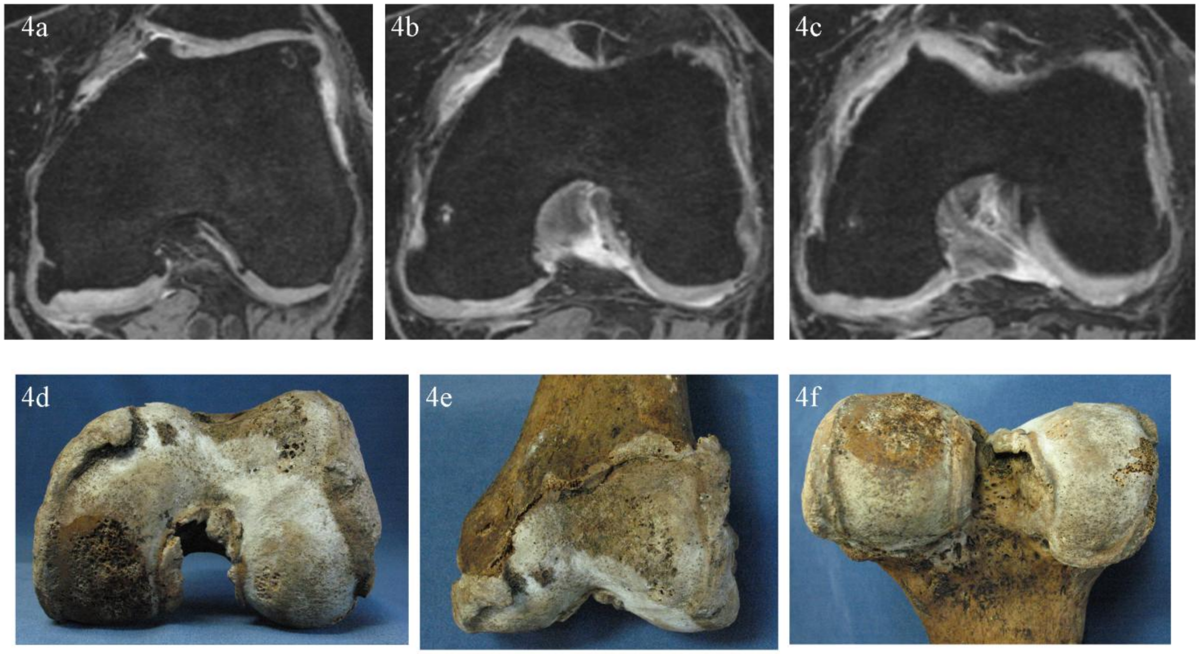


Figure 3.4: CAOS grade 3 as represented by three (4a, 4b, and 4c) MRI proximal to distal cross-sections of the distal femur from the OAI clinical sample exhibiting macroporosities/cysts and excessive osteophyte formation around the articular surface periphery creating distinctly irregular margins. Three photographs of an archaeological bone sample with views of the distal surface (4d), anterior surface of the distal end (4e), and posterior surface of distal end (4f) exhibiting surface porosities, widespread bone proliferation, and very irregular articular margins.

3.4. Results

The complete list of probabilities for each outcome variable at each CAOS grade can be found in the Appendix (section 3.9). The significant female probabilities can be found in Table 3.2 and the significant male probabilities in Table 3.3. The probability data can also be used to generate probability profiles for specific cases of right knee / left knee combinations (see Table 3.4 for an example). Significant correlations ($p \leq 0.01$) between the probability of having a functional deficit and CAOS grade were found in 61% of the outcome variables for the entire sample, 73% of the outcome variables for males, and 30% of the outcome variables for females. The probability for each outcome was compared between males and females, for each CAOS grade. At CAOS grade 0, females had a greater probability value for 93% of the cases. Female probability results were also greater than males for 75% of the variables at CAOS grade 1. Male and female probability results were similar for CAOS grades 2 and 3.

Table 3.2: Functional deficit probabilities for each outcome variable and the associated significant Spearman's rank correlations (r) for females.

`	CAOS grade				
OAI Variable	0	1	2	3	*r*
moderate activities	0.25	0.31	0.37	0.53	1
climbing several flights of stairs	0.37	0.56	0.77	0.93	1
accomplish less	0.59	0.66	0.67	0.8	1
left pain with stairs	0.54	0.59	0.62	0.73	1
left pain in bed	0.2	0.31	0.32	0.4	1
right pain bending knee fully	0.37	0.39	0.52	0.8	1
left pain twisting/pivoting	0.43	0.45	0.47	0.67	1
right disability bending	0.39	0.56	0.72	0.91	1
right disability light chores	0.49	0.54	0.7	0.91	1
left disability down stairs	0.44	0.48	0.6	0.8	1
difficulty running	0.06	0.15	0.27	0.6	1
right disability standing	0.39	0.39	0.52	0.6	0.949
right disability walking	0.27	0.31	0.6	0.6	0.949

When the five highest probabilities for the OAI outcome variables at each CAOS grade were compared by sex, similar results were found (Table 3.5) with "overall difficulty with knee", "pain interferes with work", "modify lifestyle to avoid damaging knee", stairs, kneeling, sitting from standing, and walking being common to both.

Table 3.6 lists medication usage by CAOS grade for OA sufferers. Medications ranged from homeopathic treatments to over the counter drugs such as acetaminophen and ibuprofen to prescription medications such as non-steroidal anti-inflammatories like Bextra and Celebrex to steroid injections. As the degree of OA increased medication usage also increased, with the worst OA grade having the highest percentage of medication usage.

Table 3.3: Functional deficit probabilities adjusted for non-bone influences for each significant outcome variable and the associated Spearman's rank correlations (r) with significant correlations highlighted, for males.

	CAOS grade				
OAI Variable	0	1	2	3	*r*
limited in kind of work	0.3	0.38	0.57	0.64	1
right pain walking	0.09	0.39	0.52	0.73	1
left pain walking	0.13	0.29	0.5	0.64	1
left pain with stairs	0.35	0.46	0.63	0.73	1
left pain in bed	0.13	0.16	0.33	0.45	1
left pain sitting or lying down	0.17	0.25	0.37	0.55	1
left pain standing	0.17	0.44	0.46	0.64	1
right pain straightening knee fully	0	0.21	0.35	0.64	1
right pain bending knee fully	0	0.36	0.43	0.64	1
left pain twisting/pivoting	0.17	0.35	0.48	0.64	1
left pain straightening knee fully	0.09	0.2	0.39	0.45	1
left pain bending knee fully	0.17	0.36	0.43	0.64	1
right disability sit from stand	0.26	0.46	0.67	0.73	1
right disability standing	0.13	0.33	0.37	0.45	1
right disability walking	0.13	0.2	0.37	0.55	1
right disability light chores	0.22	0.28	0.59	0.7	1
right disability heavy chores	0.09	0.16	0.4	0.5	1
left disability down stairs	0.09	0.28	0.57	0.64	1
left disability up stairs	0.17	0.35	0.57	0.64	1
left disability sit from stand	0.22	0.42	0.63	0.64	1
left disability standing	0.13	0.3	0.46	0.55	1
left disability bending	0.26	0.32	0.44	0.6	1
left disability walking	0.17	0.24	0.46	0.64	1
left disability light chores	0.26	0.32	0.43	0.7	1
left disability heavy chores	0.17	0.19	0.4	0.7	1
difficulty squatting	0.13	0.4	0.48	0.64	1
difficulty running	0.09	0.23	0.24	0.27	1
difficulty jumping	0.09	0.15	0.26	0.27	1
modify lifestyle to avoid damaging knee	0.39	0.56	0.65	0.73	1
overall difficulty with knee	0.61	0.74	0.85	1	1
right pain twisting/pivoting	0.05	0.28	0.45	0.45	0.949
right disability bending	0.22	0.32	0.6	0.6	0.949

Table 3.4: Probability profile of a male with right knee CAOS grade 3 and left knee CAOS grade 2.

OAI Variable	Grade 2	OAI Variable	Grade 3
left pain with stairs	0.63	overall difficulty with knee	1.00
left disability sit from stand	0.63	right pain walking	0.73
right disability bending	0.60	right disability sit from stand	0.73
left disability down stairs	0.57	modify lifestyle to avoid damaging knee	0.73
left disability up stairs	0.57	pain interferes with work	0.73
left pain walking	0.50	difficulty kneeling	0.73
left pain twisting/pivoting	0.48	right pain with stairs	0.73
left pain standing	0.46	right disability light chores	0.70
left disability standing	0.46	limited in kind of work	0.64
left disability walking	0.46	right pain straightening knee fully	0.64
left disability bending	0.44	right pain bending knee fully	0.64
left pain bending knee fully	0.43	difficulty squatting	0.64
left disability light chores	0.43	accomplish less	0.63
left disability heavy chores	0.40	right disability bending	0.60
left pain straightening knee fully	0.39	right disability walking	0.55
left pain sitting or lying down	0.37	right disability heavy chores	0.50
left pain in bed	0.33	difficulty twisting/pivoting	0.46
		right disability standing	0.45
		right pain twisting/pivoting	0.45
		climbing several flights of stairs	0.45
		right pain standing	0.45
		right disability up stairs	0.36
		right disability down stairs	0.28
		difficulty running	0.27
		difficulty jumping	0.27
		moderate activities	0.27
		right pain sitting or lying down	0.09
		right pain in bed	0

Table 3.5: The number of outcome variables, of the 44 examined, that fall within the parameters of three probability thresholds.

Outcome Probability Thresholds	CAOS Grade 0		CAOS Grade 1		CAOS Grade 2		CAOS Grade 3	
	Female	Male	Female	Male	Female	Male	Female	Male
≥ .50	15 (34%)	2 (5%)	12 (27%)	4 (9%)	26 (59%)	19 (43%)	34 (77%)	30 (68%)
≥ .75	0	1 (2%)	0	0	5 (11%)	2 (5%)	12 (27%)	1 (2%)
≥ .90	0	0	0	0	0	0	5 (11%)	1 (2%)

Table 3.6: Medication usage by CAOS grade for the research sample.

CAOS Grade	% of patients on medication in the last 12 months	% of patients on medication more than 1/2 a month in the last 12 months
0	40.9	19.7
1	50.8	24.6
2	64.2	29.6
3	91	52

3.5. Discussion

Clinical studies have reported that people with knee OA have a poorer quality of life than other groups with musculoskeletal diseases (Tukker et al., 2008). People with knee OA have more difficulty performing daily activities, exhibit progressive loss of function, and increased dependency for walking, stair climbing, and other lower extremity tasks (Hopman-Rock et al., 1998; Miller et al., 2001; Maly et al., 2005; Salaffi et al., 2005; van der Esch et al., 2006; Maly and Krupa, 2007; Ay et al., 2008; Hall et al., 2008). Fear of falling, loss of sleep, rising and sitting down, getting into and out of bed, squatting, and kneeling have also been associated with knee OA (Steultjens et al., 1999; Bennell et al., 2003; Maly & Krupa 2007; Hall et al., 2008). The functional deficits included in this study are consistent with the clinical literature. However, quantifying the limitations experienced for each outcome variable at each CAOS grade through the use of probabilities operationalizes the information and provides a tool to interpret human skeletal remains. This tool is exemplified by the development of probability profiles.

If we take the example of a male with right knee CAOS grade 3 and left knee CAOS grade 2 (Table 3.6) since the right knee had the highest CAOS grade the individual would have had overall difficulty with their knee. There is a high probability (≥0.7) that the right knee would have generated pain with specific tasks such as walking or when climbing/descending hills; would have produced general pain that would interfere with work; would have made sitting from a standing position, kneeling and light chores difficult; and would have been an impetus for activity modification to prevent further symptom advancement. There is a moderate probability (0.5 - 0.65) that the symptoms would have limited the kind or amount of work accomplished, produced pain when bending or extending the knee joint, made it difficult to squat, or produced disability when walking or conducting heavy chores. The left knee at CAOS grade 2 would have produced less difficulty but would have had a moderate probability of causing pain and disability with hills, and pain while walking. Creating such probability profiles is an important step in understanding the impact of bone changes on the lives of people and can broaden our interpretation of past populations. They also allow for contrasting populations.

As an example, a female with CAOS grade 3 has a 0.93 probability of having difficulty climbing several flights of stairs while the probability for males of the same grade and the same task is much lower at 0.45. For archaeological populations, this may mean that most females would experience problems when going up and down hills with CAOS grade 3 while more than half of males would not experience this functional deficit.

This contrast between males and females illustrates the variability among sexes and highlights the need for a sex-based interpretation for knee OA. Though the 'entire sample' results could be used to interpret the effect of degenerative bone changes of the distal femur for non-sexed human skeletal remains, this analysis should be done with caution because an under or over statement of the impact could be derived. Interestingly, poor outcomes are still associated with knees that exhibit no bone changes to the distal femoral articular surface. This demonstrates the dynamic relationship between soft and hard tissue changes associated with OA and exemplifies the loss of information when dealing solely with skeletal remains. Caution is required when analyzing skeletal remains that do not show bone changes but belong to an individual older than 45 years at death since they would still have a probability of functional limitations. This is especially relevant for females who experienced substantially more functional deficits than their male counterparts at CAOS grade 0. Females demonstrated a less predictable relationship between the probability of having a functional deficit and increasing CAOS grade since only 30% of these correlations were significant, while 73% of these correlations were significant for males. This unpredictability suggests that the outcome variables, which encapsulate a portion of the experience of living with knee OA, could be influenced by factors that were not considered in this study.

For example, influences that lead to the differences between males and females may be simple differences in work type and/or intensity or complex interactions between multiple influences. These may include sexual dimorphic differences in joint biology (ligament laxity, bone density, cartilage thickness since articular cartilage thinner in women), joint structure (surface size), biomechanics (limb alignment, muscle strength), hormones (depressed levels of insulin factor 1, estrogen loss), and social norms (more negative feelings in women than men regardless of severity or disability) (Sims et al., 2009; Lerner, 2010; Maleki-Fischback & Jordan, 2010; O'Connor, 2010). Studies have shown contradictory results for the influence of "different biomechanics, gait, and structural and morphometric properties" (Maleki-Fischback & Jordan, 2010: 4) leaving the underlying cause of the sex differences in knee OA unclear (Sudo et al., 2008). Smaller joint surfaces in women are an unlikely explanation for sex differences in knee OA" (Maleki-Fischback & Jordan, 2010, p. 2). Nevertheless, functional deficits related to knee OA should be considered as sex specific. While differences in outcome probabilities between sexes must be acknowledged, males and females also exhibit a commonality for the outcome variables with the five highest probabilities for each CAOS grade, including stairs and "overall difficulty with knee".

Exploring the effects of knee OA on past populations relies on inferential data from clinical studies. This study established a hybrid grading system that combines aspects of clinical and bioarchaeological standards (CAOS). The CAOS grading system provided an osteological correlate to link the experience of living with knee OA to bone features that could be present in archaeological samples. However, the use of this clinical data is not without its drawbacks including the age and BMI profile of the sample and the participant's access to modern interventions available to help mitigate physical barriers and symptoms.

On average, the clinical sample had an elevated BMI, a state that is different from most archaeological populations. BMI not only leads to increased symptoms but is also a risk factor for knee OA (Felson et al., 1992; Felson, 1996; Coggon et al., 2001; Macfarlane et al., 2011; Richette et al., 2011; Wilson et al., 2011) since it increases the load across the knee joint, producing increased stress on the articular cartilage and inducing structural breakdown (Felson, 1996; Richette et al., 2011). "The knee joint is exposed to high compressive and shear forces during weight bearing. Compressive loads can exceed three times body weight during walking and six times body weight during stair climbing in healthy-weight individuals. As body weight increases, the loads to which the knee joint is subjected also increase" (Russell & Hamill, 2010, p. 1). Therefore, it is not surprising that higher BMI leads to worse symptoms, with obesity as a risk factor for knee pain (Felson, 1996; Elbaz et al., 2011; Macfarlane et al.,2011; Nguyen et al., 2011). However the exact mechanism involved in this BMI-OA relationship is uncertain. For instance, people could have a high BMI because they are not moving due to knee pain (Rogers & Wilder, 2008). Also, high BMI may put an individual at risk for systemic inflammation which may in itself be a cause for OA or its symptoms (Richette et al., 2011). Therefore BMI could have a metabolic or biomechanical effect on the knee joint (Lerner, 2010; Wilson et al., 2011). For our sample, increasing BMI was not correlated with the outcome variables examined. The highest correlation was r = .336 which pertained to a general health question.

The sample population is older (45-79 years) than typically expected in an archaeological sample. Since knee OA is a progressive condition, a large clinical sample can only be acquired from the mid to upper age ranges. While increased age has been reported to increase the risk of OA symptoms (Nguyen et al., 2011; Elbaz et al., 2011; Robbins et al., 2011), increasing age did not correlate with increasing symptoms in our sample. However this does not mute the question: is an older clinical sample equivalent to a younger archaeological sample? An older sample may be more symptomatic due to age (though the mechanism is not certain) but are most individuals in this age range less active, engaging in less physically demanding work, and carrying less loads than their younger archaeological counterparts? It could be argued that, since increased activity is known to cause increased symptoms (Hall et al., 2008; Hunter et al., 2008), the activity requirements of a younger archaeological population may off-set the age related increase in symptoms of an older clinical population.

Medication may provide a masking effect over the true impact of knee OA, especially common for those with the worst bone changes. Therefore, a larger number of functional deficits could be present, especially at CAOS grade 3, for a population with few available medical interventions. Despite the impact of medication, quantification of the knee OA experience via the outcome variables provides a quantitative base to improve our dialogue on the impact of disease on past populations.

3.6. Conclusions

This study provides a link between bone and the experience of living with knee OA. This experience varies between sexes. For males, most outcome variables were significantly linked to the CAOS grade, with bone appearing to contribute significantly to the experience. For females, few outcome variables were significantly correlated to CAOS grade and there was a greater probability, when compared to males, of experiencing functional deficits with few or no bone changes at the distal femur. Overall, males had a lower probability than females of having a functional deficit in the chosen variables when suffering from knee OA. The activity limitations and functional barriers identified in this study provide insight when interpreting the impact of knee OA in past populations.

3.7. Acknowledgements

The authors would like to thank the OAI for the use of their data. "The OAI is a public-private partnership comprised of five contracts (N01-AR-2-2258; N01-AR-2-2259; N01-AR-2-2260; N01-AR-2-2261; N01-AR-2-2262) funded by the National Institutes of Health, a branch of the Department of Health and Human Services, and conducted by the OAI Study Investigators. Private funding partners include Merck Research Laboratories; Novartis Pharmaceuticals Corporation, GlaxoSmithKline; and Pfizer, Inc. Private sector funding for the OAI is managed by the Foundation for the National Institutes of Health. This manuscript was prepared using an OAI public use data set and does not necessarily reflect the opinions or views of the OAI investigators, the NIH, or the private funding partners" (OAI, 2006). The authors would also like to thank Jean-Luc Pilon for comments on earlier drafts and the Canadian Museum of Civilization for supporting the research.

3.8. Literature Cited

1. Altman, R., Asch, E., Bloch, D., Bole, G., Borenstein, D., Brandt, K., Christy, W., Cooke, T., Greenwald, R., Hochberg, M., Howell, D., Kaplan, D., Koopman, W., Longley, S., Mankin, H., McShane, D., Medsger, T., Meenan, R., Mikkelsen, W., Moskowitz, R., Murphy, W., Rothschild, B., Segal, M., Sokoloff, L., & Wolfe, F. (1986). Development of Criteria for the Classification and Reporting of Osteoarthritis: Classification of Osteoarthritis of the Knee. *Arthritis and Rheumatism, 29*(8), 1039-1049.
2. Ay, S., Tur, B., & Kucukdeveci, A. (2008). Evaluation of Disability in Patients with Degenerative and Inflammatory Arthritis. *International Journal of Rehabilitation Research, 31*, 159-163.

3. Ayis, S., Ebrahim, S., Williams, S., Juni, P., & Dieppe, P. (2007). Determinants of Reduced Walking Speed in People with Musculoskeletal Pain. *Journal of Rheumatology, 34*,1905-1912.
4. Barker, K., Lamb, S., Toye, F., Jackson, S., & Barrington, S. (2004). Association Between Radiographic Joint Space Narrowing, Function, Pain and Muscle Power in Severe Osteoarthritis of the Knee. *Clinical Rehabilitation*, *18*, 793-800.
5. Bellamy, N., Buchanan, W., Goldsmith, C., Campbell, J., & Stitt, L. (1988). Validation Study of WOMAC: A Health Status Instrument for Measuring Clinically Important Patient Relevant Outcomes to Antirheumatic Drug Therapy in Patients with Osteoarthritis of the Hip or Knee. *Journal of Rheumatology,* 15(12), 1833-1840.
6. Bennell, K., Hinman, R., Mecalf, B., Crossley, K., Buchbinder, R., Smith, M., & McColl, G. (2003). Relationship of Knee Joint Proprioception to Pain and Disability in Individuals with Knee Osteoarthritis. *Journal of Orthopaedic Research, 21*, 792-797.
7. Biščević, M., Ljuca, F., Biščević, A., Gavrankapetanović, I., Smrke, B., Ozturk, C., & Smrke, D. (2008). Morphometric Alteration of Femoral Condyles Due to Knee Osteoarthritis. *Collegium Antropologicum*, *32*(3), 875-879.
8. Boileau, C., Martel-Pelletier, J., Abram, F., Raynauld, J., Troncy, E., D'Anjou, M., Moreau, M., & Pelletier, J. (2008). Magnetic Resonance Imaging can Accurately Assess the Long-Term Progression of Knee Structural Changes in Experimental Dog Osteoarthritis. *Annals of Rheumatic Disease, 67*, 926-932.
9. Breedveld, F. (2004). Osteoarthritis – the Impact of a Serious Disease. *Rheumatology, 43*(Suppl.1), i4-i8.
10. Coggon, D., Reading, I., Croft, P., McLaren, M., Barrett, D., & Cooper, C. (2001). Knee Osteoarthritis and Obesity. *International Journal of Obesity, 25*, 622-627.
11. Cohen, Z., McCarthy, D., Kwak, S., Legrand, P., Fogarai, F., Ciaccio, E., & Ateshian, G. (1999). Knee Cartilage Topography, Thickness, and Contact Areas from MRI: In-vitro Calibration and In-vivo Measurements. *Osteoarthritis and Cartilage,* 7, 95-109.
12. Cooper, C., Snow, S., McAlindon, T., Kellingray, S., Stuart, B., Coggon, D., & Dieppe, P. (2000). Risk Factors for the Incidence and Progression of Radiographic Knee Osteoarthritis. *Arthritis & Rheumatism, 43*(5), 995-1000.

13. Dieppe, P. (2000). Towards a Better Understanding of Osteoarthritis of the Knee Joint. *The Knee, 7*, 135-137.

14. Elbaz, A., Debbi, E., Segal, G., Haim, A., Halperin, N., Agar, G., Mor, A., & Debi, R. (2011). Sex and Body Mass Index Correlate with Western Ontario and McMaster Universities Osteoarthritis Index and Quality of Life Scores in Knee Osteoarthritis. *Archives of Physical Medicine and Rehabilitation, 92*, 1618-1623.

15. Faucher, M., Poiraudeau, S., Lefevre-Colau, M., Rannou, F., Fermanian, J., & Revel, M. (2004). Assessment of the Test-retest Reliability and Construct Validity of a Modified WOMAC Index in Knee Osteoarthritis. *Joint Bone Spine, 71*, 121-127.

16. Fautrel, B., Hilliquin, P., Rozenberg, S., Allaert, F., Coste, P., Leclerc, A., & Rossignol, M. (2005). Impact of Osteoarthritis: Results of a Nationwide Survey of 10,000 Patients Consulting for OA. *Joint Bone Spine, 72*, 235-240.

17. Felson, D. (1996). Weight and Osteoarthritis. *American Journal of Clinical Nutrition 63*, 430S-432S.

18. Felson, D., Zhang, Y., Anthony, J., Naimark, A., & Anderson, J. (1992). Weight Loss Reduces the Risk for Symptomatic Knee Osteoarthritis in Women: The Framingham Study. *Annals of Internal Medicine, 116,* 535-539.

19. Fitzgerald, G., Piva, S., & Irrgang, J. (2004). Reports of Joint Instability in Knee Osteoarthritis: Its Prevalence and Relationship to Physical Function. *Arthritis & Rheumatism, 51*(6), 941-646.

20. Hall, M., Migay, A., Persad, T., Smith, J., Yoshida, K., Kennedy, D., & Pagura, S. (2008). Individuals' Experience of Living with Osteoarthritis of the Knee and Perceptions of Total Knee Arthroplasty. *Physiotherapy Theory and Practice, 24*(3), 167-181.

21. Hinterwimmer, S., Graichen, H., Vogl, T., & Abolmaali, N. (2008). An MRI-based Technique for Assessment of Lower Extremity Deformities – Reproducibility, Accuracy, and Clinical Application. *European Radiology, 18*, 1497-1505.

22. Hopman-Rock, M., Kraaimaat, F., Odding, E., & Bijlsma, J. (1998). Coping with Pain in the Hip or Knee in Relation to Physical Disability in Community-Living Elderly People. *Arthritis Care and Research, 11*(4), 243-252.

23. Hunter, D., Niu, J., Zhang, Y., LaValley, M., McLennan, C., Hudelmaier, M., Echstein, F., & Felson, D. (2008). Premorbid Knee Osteoarthritis is not Characterised by Diffuse

Thinness: the Framingham Osteoarthritis Study. *Annals of the Rheumatic Diseases, 67,* 1545-1549.

24. Iwaki, H., Pinskerova, V., & Freeman, M. (2000). Tibiofemoral Movement 1: The Shapes and Relative Movements of the Femur and Tibia in the Unloaded Cadaver Knee. *Journal of Bone and Joint Surgery [Br], 82-B(8),* 1189-1195.
25. Kellgren, J., & Lawrence, J. (1957). Radiological Assessment of Osteo-arthrosis. *Annals of Rheumatic Diseases, 16,* 494-502.
26. Leitzes, A., Potter, H., Amaral, T., Marx, R., Lyman, S., & Widmann, R. (2005). Reliability and Accuracy of MRI Scanogram in the Evaluation of Limb Length Discrepancy. *Journal of Pediatric Orthopedics, 25,* 747-749.
27. Lerner, A. (2010). *Gender Differences and Obesity as Risks for Knee Osteoarthritis: Using Biomechanical Models to Develop Understanding*. University of Rochester. Paper presented at the Society for Women's Health Research. Retrieved from http://www.womenshealthresearch.org/site/DocServer/womens_health_Congress_briefing_-_Lerner.pdf?docID=3521.
28. Lethbridge-Cejku, M., Scott, W., Reichle, R., Ettinger, W., Zonderman, A., Costa, P., Plato, C., Tobin, J., & Hochberg, M. (1995). Association of Radiographic Features of Osteoarthritis of the Knee with Knee Pain: Data from the Baltimore Longitudinal Study of Aging. *Arthritis Care & Research, 8*(3), 182-188.
29. Louis, O., Cattrysse, E., Scafoglieri, A., Luypaert, R., Clarys, J., & de Mey. (2010). Accuracy of Peripheral Quantitative Computed Tomography and Magnetic Resonance Imaging in Assessing Cortical Bone Cross-Sectional Area: A Cadaver Study. *Journal of Computer Assisted Tomography, 34*(3), 469-472.
30. Macfarlane, G., de Silva, V., & Jones, G. (2011). The Relationship Between Body Mass Index Across the Life Course and Knee Pain in Adulthood: Results from the 1958 Birth Cohort Study. *Rheumatology, 50,* 2251-2256.
31. Maleki-Fischbach, M., & Jordan, J. (2010). Sex Differences in Magnetic Resonance Imaging-Based Biomarkers and in those of Joint Metabolism. *Arthritis Research & Therapy, 12*(212), 1-8.
32. Maly, M. (2009). Linking Biomechanics to Mobility and Disability in People with Knee Osteoarthritis. *Exercise and Sport Sciences Review, 37*(1), 36-42.

33. Maly, M., & Krupa, T. (2007). Personal Experiences of Living with Knee Osteoarthritis Among Older Adults. *Disability and Rehabilitation, 29*(18), 1423-1433.
34. Maly, M., Costigan, P., & Olney, S. (2005). Contribution of Psychosocial and Mechanical Variables to Physical Performance Measures in Knee Osteorthritis. *Physical Therapy, 85*(12), 1318-1328.
35. Maly, M., Costigan, P., & Olney, S. (2006). Determinants of Self-Report Outcome Measures in People with Knee Osteoarthritis. *Archives of Physical Medicine and Rehabilitation, 87*(1), 96-104.
36. Maly, M., Costigan, P., & Olney, S. (2008). Mechanical Factors Relate to Pain in Knee Osteoarthritis. *Clinical Biomechanics, 23*(6), 796-805.
37. Marra, C., Civere, J., Tsuyuki, R., Soon, J., Esdaile, J., Gastonguay, L., Oteng, B., Embley, P., Colley, L., Enenajor, G., & Kok, R. (2007). Improving Osteoarthritis Detection in the Community: Pharmacist Identification of New, Diagnostically Confirmed Osteoarthritis. *Arthritis & Rheumatism, 57*(7), 1238-1244.
38. Miller, M., Rejeski, W., Messier, S., & Loeser, R. (2001). Modifiers of Change in Physical Functioning in Older Adults with Knee Pain: the Observational Arthritis Study in Seniors (OASIS). *Arthritis Care & Research, 45*(4), 331-339.
39. Neogi, T., Felson, D., Niu, J., Nevitt, M., Lewis, C., Aliabadi, P., Sach, B., Torner, J., Bradley, L., & Zhang, Y. (2008). 327 Radiographic Features of Osteoarthritis are Strongly Associated with Knee Pain in Two Cohorts: Most and Framingham. *Osteoarthritis and Cartilage, 16*(Supplement 4), S144-S145
40. Nevitt, M., Felson, D., & Lester, G. (2006). The Osteoarthritis Initiative: Protocol for the Cohort Study. Retrieved from http://www.oai.ucsf.edu/datarelease/docs/StudyDesignProtocol.pdf .
41. Nguyen, U., Zhang, Y., Zhu, Y., Niu, J., Zhang, B., & Felson, D. (2011). Increasing Prevalence of Knee Pain and Symptomatic Knee Osteoarthritis: Survey and Cohort Data. *Annals of Internal Medicine, 155,* 725-732.
42. OAI (Osteoarthritis Initiative). (2006). Osteoarthritis Initiative (OAI) Guidelines for Publications Using Public Use Data Sets. Retrieved from http://oai.epi-ucsf.org/datarelease/Docs/OAIPubsGuidePublicData.pdf.

43. Ochiai, N., Sasho, T., Tahara, M., Watanabe, A., Matsuki, K., Yamaguchi, S., Miyake, Y., Nakaguchi, T., Wada, Y., & Moriya, H. (2010). Objective Assessments of Medial Osteoarthritic Knee Severity byMRI: New Computer Software to Evaluate Femoral Condyle Contours. *International Orthopaedics*, *34*, 811-817.

44. O'Connor, M. (2010). *Sex and Gender Differences in Knee Osteoarthritis*. Mayo Clinic. Paper presented at the Society for Women's Health Research. Retrieved from http://www.womenshealthresearch.org/site/DocServer/Knee_OA_Sex_Gender_Diff_Cong_Brief_-_OConnor.pdf?docID=3503; last accessed May 2012-05-25.

45. Oka, H., Muraki, S., Akune, T., Mabuchi, A., Suzuki, T., Yoshida, H., Yamamoto, S., Nakaruma, K., Yoshimura, N., & Kawaguchi, H. (2008). Fully Automatic Quantification of Knee Osteoarthritis Severity on Plain Radiographs. *Osteoarthritis and Cartilage, 16*, 1300-1306.

46. Parmelee, P., Harralson, T., Smith, L., Schumacher, H. (2007). Necessary and Discretionary Activities in Knee Osteoarthritis: Do They Mediate the Pain–Depression Relationship? *Pain Medicine, 8*(5), 449-462.

47. Peters, T., Sanders, C., Dieppe, P., & Donovan, J. (2005). Factors Associated with Change in Pain and Disability over Time: A Community-based Prospective Observational Study of Hip and Knee Osteoarthritis. *British Journal of General Practice, 55*(512), 205-211.

48. Rapp, S., Rejeski, W., & Miller, M. (2000). Physical Function Among Older Adults with Knee Pain: The Role of Pain Coping Skills. *Arthritis Care & Research*, *13*(5), 270-279.

49. Richette, P., Poitou, C., Garnero, P., Vicaut, E., Bouillot, J., Lacorte, J., Basdevant, A., Clement, K., Bardin, T., & Chevalier, X. (2011). Benefits of Massive Weight Loss on Symptoms, Systemic Inflammation and Cartilage Turnover in Obese Patients with Knee Osteoarthritis. *Annals of Rheumatic Disease, 70*, 139-144.

50. Robbins, S., Birmingham, T., Callaghan, J., Jones, G., Chesworth, B., & Maly, M.. (2011). Association of Pain with Frequency and Magnitude of Knee Loading in Knee Osteoarthritis. *Arthritis Care & Research*, *63*(7), 991-997.

51. Rogers, J., & Waldron, T. (1995). *A Field Guide to Joint Disease in Archaeology*. England: John Wiley & Sons Ltd.

52. Rogers, J., Waldron, T., Dieppe, P., & Watt, I. (1987). Arthropathies in Paleopathology: The Basis of Classification According to Most Probable Cause. *Journal of Archaeological Science, 14*, 179-193.

53. Rogers, J., Shepstone, L., & Dieppe, P. (2004). Is Osteoarthritis a Systemic Disorder of Bone? *Arthritis & Rheumatism, 50*(2), 452-457.

54. Rogers, M., & Wilder, F. (2008). The Association of BMI and Knee Pain among Persons with Radiographic Knee Osteoarthritis: A Cross-sectional Study. *BMC Musculoskeletal Disorders*, *9*, 163-168.

55. Roos, E., Roos, H., Lohmander, L., Ekdahl, C., & Beynnon, B. (1998). Knee Injury and Osteoarthritis Outcome Score (KOOS) - Development of a Self-administered Outcome Measure. *Journal of Orthopaedic & Sports Physical Therapy, 28*(2), 88-96.

56. Rosemann, T., Kuehlein, T., Laux, G., & Szecsenyi, J. (2006). Factors Associated with Physical Activity of Patients with Osteoarthritis of the Lower Limb. *Journal of Evaluation in Clinical Practice, 14*, 288-293.

57. Rosemann, T., Keuhlein, T., Laux, G., & Szecsenyi, J. (2007). Osteoarthritis of the Knee and Hip : A Comparison of Factors Associated with Physical Activity. *Clinical Rheumatology*, *26*, 1811-1817.

58. Russell, E., & Hamill, J. (2010). Knee OA and Obesity: A Cyclical Clinical Challenge. *Lower Extremity Review*. July (35). Retrieved from http://www.lowerextremityreview.com/article/knee-oa-in-obese-patients-a-cyclical-clinical-challenge.

59. Salaffi, F., Carotti, M., & Grassi, W. (2005). Health-related Quality of Life in Patients with Hip or Knee Osteoarthritis: Comparison of Generic and Disease-Specific Instruments. *Clinical Rheumatology, 24*(1), 29-37.

60. Schiphof, D., Boers, M., & Bierma-Zeinstra, S. (2008). Differences in Descriptions of Kellgren and Lawrence Grades of Knee Osteoarthritis. *Annals of the Rheumatic Diseases, 67*(7), 1034-1036.

61. Sims, E., Carland, J., Keefe, F., Kraus, V., Guilak, F., & Schmitt, D. (2009). Sex Differences in Biomechanics Associated with Knee Osteoarthritis. *Journal of Women Aging*, *21*(3), 159-170.

62. Spector, T., Harris, P., Hart, D., Cicuttini, F., Nandra, D., Etherington, J., Wolman, R., & Doyle, D. (1996). Risk of Osteoarthritis Associated with Long-term Weight-bearing Sports: A Radiologic Survey of the Hips and Knees in Female Ex-athletes and Population Controls. *Arthritis & Rheumatism, 39*(6), 988-995.
63. Steultjens, M., Dekker, J., van Baar, M., Oostendorp, R., & Bijlsma, J. (1999). Internal Consistency and Validity of an Observational Method for Assessing Disability in Mobility in Patients with Osteoarthritis. *Arthritis Care & Research, 12*(1), 19-25.
64. Sudo, A., Miyamoto, N., Horikawa, K., Urawa, M., Yamakawa, T., Yamada, T., & Uchida, A. (2008). Prevalence and Risk Factors for Knee Osteoarthritis in Elderly Japanese Men and Women. *Journal of Orthopaedic Science, 13,* 413-418.
65. Szebeny, B., Hollander, A., Dieppe, P., Quilty, B., Duddy, J., Clarke, S., & Kirwan, J. (2006). Associations Between Pain, Function, and Radiographic Features in Osteoarthritis of the Knee. *Arthritis & Rheumatism, 54*(1), 230-235.
66. Thorp, L., Sumner, D., Wimmer, M., & Block, J. (2007). Relationship Between Pain and Medial Knee Joint Loading in Mild Radiographic Knee Osteoarthritis. *Arthritis Care & Research, 57*(7), 1254-1260.
67. Tukker, A., Visscher, T., & Picavet, H. (2008). Overweight and Health Problems of the Lower Extremities: Osteoarthritis, Pain and Disability. *Public Health Nutrition, 12*(3), 359-368.
68. Tuzun, E. (2007). Quality of Life in Chronic Musculoskeletal Pain. *Best Practice & Research in Clinical Rheumatology, 21*(3), 567-579.
69. Uebersax, J. (2006). *Likert Scales: Dispelling the Confusion*. Retrieved from http://www.john-uebersax.com/stat/likert.htm.
70. Ware, J., Kosinski, M., & Keller, S. (1996). A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care, 34*(3), 220-233.
71. Williams, D., Farrell, M., Cunnigham, F., Gracely, R., Ambrose, K., Cupps, T., Mohan, N., & Clauw, D. (2004). Knee Pain and Radiographic Osteoarthritis Interact in the Prediction of Levels of Self-Reported Disability. *Arthritis & Rheumatism, 51*(4), 558-561.

72. Wilson, J., Deluzio, K., Dunbar, M., Caldwell, G., & Hubley-Kozey, C. (2011). The Association Between Knee Joint Biomechanics and Neuromuscular Control and Moderate Knee Osteoarthritis Radiographic and Pain Severity. *Osteoarthritis and Cartilage, 19*, 186-193.
73. Woodhead, H., Kemp, A., Blimkie, C., Briody, J., Duncan, C., Thomspon, M., Lam, A., Howman-Giles, R., & Cowell, C. (2001). Measurement of Midfemoral Shaft Geometry: Repeatability and Accuracy Using Magnetic Resonance Imaging and Dual-Energy X-ray Absorptiometry. *Journalof Bone and Mineral Research, 16*(12), 2251-2259.
74. Van der Esch, M., Steultjens, M., Knol, D., Dinant, H., & Dekker, J. (2006). Joint Laxity Modifies the Relationship between Muscle Strength and Functional Ability in Patients with Osteoarthritis of the Knee. *Annals of the Rheumatic Diseases, 65*(Suppl. 2), 408-408.
75. Van der Kraan, P., & Van den Berg, W. (2007). Osteophytes: Relevance and Biology. *Osteoarthritis and Cartilage, 15*(3), 237-244.
76. Van der Waal, J., Terweel, C., van der Windt, W., Bouter, L., & Dekker, J. (2005). The Impact of Non-traumatic Hip and Knee Disorders on Health-related Quality of Life as Measured with the SF-36 or SF-12. A Systematic Review. *Quality of Life Research, 14*(4), 1141-1155.
77. Zhai, G., Blizzard, L., Srikanth, V., Ding, C., Cooley, H., Cicuttini, F., & Jones, G. (2008). Correlates of Knee Pain in Older Adults: Tasmanian Older Adult Cohort Study. *Arthritis Care & Research, 55*(2), 264-271.

3.9. Appendix: Functional deficit probabilities for each outcome variable and the associated Spearman's rank correlations

	Female Sample					Male Sample					Entire Sample				
	CAOS Grade					CAOS Grade					CAOS Grade				
OAI Variable	0	1	2	3	*r*	0	1	2	3	*r*	0	1	2	3	*r*
moderate activities	0.25	0.31	0.37	0.53	1	0.26	0.27	0.35	0.27	0.64	0.25	0.28	0.36	0.43	1
climbing several flights of stairs	0.37	0.56	0.77	0.93	1	0.26	0.31	0.57	0.45	0.8	0.33	0.4	0.66	0.75	1
accomplish less	0.59	0.66	0.67	0.8	1	0.39	0.41	0.65	0.63	0.8	0.53	0.5	0.66	0.79	0.8
limited in kind of work	0.49	0.58	0.62	0.53	0.4	0.3	0.38	0.57	0.64	1	0.43	0.44	0.59	0.61	1
pain interferes with work	0.63	0.61	0.7	0.93	0.8	0.35	0.59	0.74	0.73	0.8	0.54	0.63	0.72	0.86	1
right pain walking	0.61	0.42	0.5	0.6	-0.2	0.09	0.39	0.52	0.73	1	0.31	0.4	0.51	0.64	1
right pain with stairs	0.62	0.63	0.75	0.73	0.8	0.78	0.49	0.75	0.73	-0.4	0.49	0.54	0.75	0.89	1
right pain in bed	0.18	0.16	0.35	0.6	0.8	0	0.18	0.37	0	0.11	0.12	0.18	0.36	0.36	0.95
right pain sitting or lying down	0.2	0.18	0.35	0.47	0.8	0	0.25	0.39	0.09	0.4	0.14	0.22	0.37	0.32	0.8
right pain standing	0.37	0.35	0.6	0.6	0.73	0.09	0.3	0.52	0.45	0.8	0.28	0.32	0.56	0.54	0.8
left pain walking	0.41	0.32	0.3	0.53	0.2	0.13	0.29	0.5	0.64	1	0.32	0.3	0.41	0.61	0.8
left pain with stairs	0.54	0.59	0.62	0.73	1	0.35	0.46	0.63	0.73	1	0.48	0.51	0.63	0.75	1
left pain in bed	0.2	0.31	0.32	0.4	1	0.13	0.16	0.33	0.45	1	0.18	0.18	0.33	0.43	0.95
left pain sitting or lying down	0.37	0.26	0.32	0.33	-0.2	0.17	0.25	0.37	0.55	1	0.31	0.25	0.35	0.43	0.8
left pain standing	0.35	0.37	0.37	0.33	-0.31	0.17	0.44	0.46	0.64	1	0.29	0.35	0.42	0.5	1
right pain twisting/pivoting	0.4	0.39	0.34	0.89	0.2	0.05	0.28	0.45	0.45	0.95	0.28	0.32	0.53	0.63	1
right pain straightening knee fully	0.25	0.21	0.32	0.8	0.8	0	0.21	0.35	0.64	1	0.17	0.21	0.33	0.71	1
right pain bending knee fully	0.37	0.39	0.52	0.8	1	0	0.36	0.43	0.64	1	0.25	0.37	0.48	0.71	1
left pain twisting/pivoting	0.43	0.45	0.47	0.67	1	0.17	0.35	0.48	0.64	1	0.43	0.43	0.48	0.64	0.95
left pain straightening knee fully	0.25	0.21	0.32	0.4	0.8	0.09	0.2	0.39	0.45	1	0.2	0.2	0.36	0.43	0.95
left pain bending knee fully	0.43	0.39	0.4	0.4	-0.31	0.17	0.36	0.43	0.64	1	0.33	0.37	0.42	0.5	1
right disability down stairs	0.4	0.46	0.65	0.6	0.8	0.09	0.27	0.59	0.28	0.8	0.3	0.34	0.62	0.64	1
right disability up stairs	0.54	0.48	0.67	0.47	-0.4	0.17	0.32	0.59	0.36	0.8	0.42	0.38	0.63	0.68	0.8
right disability sit from stand	0.55	0.55	0.77	0.73	0.74	0.26	0.46	0.67	0.73	1	0.46	0.49	0.62	0.82	1
right disability standing	0.39	0.39	0.52	0.6	0.95	0.13	0.33	0.37	0.45	1	0.31	0.25	0.44	0.5	0.8
right disability bending	0.39	0.56	0.72	0.91	1	0.22	0.32	0.6	0.6	0.95	0.33	0.4	0.66	0.7	1
right disability walking	0.27	0.31	0.6	0.6	0.95	0.13	0.2	0.37	0.55	1	0.22	0.24	0.48	0.54	1
right disability light chores	0.49	0.54	0.7	0.91	1	0.22	0.28	0.59	0.7	1	0.4	0.38	0.65	0.74	0.8
right disability heavy chores	0.41	0.39	0.45	0.73	0.8	0.09	0.16	0.4	0.5	1	0.31	0.21	0.42	0.59	0.8

left disability down stairs	0.44	0.48	0.6	0.8	1	0.09	0.28	0.57	0.64	1	0.32	0.35	0.58	0.75	1
left disability up stairs	0.58	0.56	0.57	0.61	0.4	0.17	0.35	0.57	0.64	1	0.45	0.42	0.57	0.65	0.8
left disability sit from stand	0.57	0.48	0.6	0.73	0.8	0.22	0.42	0.63	0.64	1	0.46	0.44	0.62	0.68	0.8
left disability standing	0.49	0.26	0.42	0.33	-0.4	0.13	0.3	0.46	0.55	1	0.31	0.29	0.44	0.43	0.6
left disability bending	0.5	0.48	0.5	0.73	0.63	0.26	0.32	0.44	0.6	1	0.42	0.38	0.47	0.68	0.8
left disability walking	0.41	0.31	0.37	0.4	-0.2	0.17	0.24	0.46	0.64	1	0.25	0.26	0.42	0.5	1
left disability light chores	0.53	0.47	0.51	0.67	0.4	0.26	0.32	0.43	0.7	1	0.44	0.38	0.47	0.67	0.8
left disability heavy chores	0.39	0.29	0.4	0.53	0.8	0.17	0.19	0.4	0.7	1	0.32	0.22	0.4	0.59	0.8
difficulty squatting	0.6	0.5	0.57	0.6	0.11	0.13	0.4	0.48	0.64	1	0.62	0.44	0.52	0.64	0.4
difficulty running	0.06	0.15	0.27	0.6	1	0.09	0.23	0.24	0.27	1	0.07	0.2	0.26	0.39	1
difficulty jumping	0.1	0.03	0.14	0.26	0.8	0.09	0.15	0.26	0.27	1	0.1	0.11	0.21	0.32	1
difficulty twisting/pivoting	0.39	0.31	0.52	0.87	0.8	0.13	0.41	0.31	0.46	0.8	0.29	0.37	0.43	0.54	1
difficulty kneeling	0.62	0.39	0.65	0.91	0.8	0.48	0.5	0.48	0.73	0.63	0.57	0.46	0.56	0.71	0.4
modify lifestyle to avoid damaging knee	0.55	0.53	0.75	0.8	0.8	0.39	0.56	0.65	0.73	1	0.5	0.55	0.7	0.75	1
overall difficulty with knee	0.73	0.66	0.82	0.73	0.32	0.61	0.74	0.85	1	1	0.69	0.71	0.84	0.96	1

Chapter 4. Quantitative and Qualitative Assessment of the Degenerative Distal Femur: Identifying Optimal Indicators of Poor Outcomes in Skeletal Populations

This chapter, prepared for submission to a peer reviewed journal, identifies the optimal means of relating functional outcomes to changes in the distal femur by contrasting two methods of capturing knee OA severity: the qualitative method developed in chapter 3 and a quantitative method based on the femoral intercondylar notch.

.

Quantitative and Qualitative Assessment of the Degenerative Distal Femur: Identifying Optimal Indicators of Poor Outcomes in Skeletal Populations

Janet L. Young and Edward D. Lemaire

Keywords = degeneration, osteoarthritis, knee, impairment, MRI, intercondylar notch, Osteoarthritis Initiative

4.1. Abstract

The shape of the distal femur in a clinical population, which changes with the progression of knee osteoarthritis (OA), was examined both quantitatively and qualitatively in a clinical population and related to health, function, pain, symptom, stiffness, disability, and quality of life outcome indices for the sample. The purpose of this examination was to determine which distal femur assessment approach was more related to these outcome indices. The intercondylar notch was quantitatively assessed with particular focus on notch depth, notch width, and general notch size. The clinical and archaeological outcome score (CAOS) was used to qualitatively grade knee OA severity. Results suggested that intercondylar femoral notch metrics are poor indicators of OA outcomes while CAOS grading of morphological changes in the distal femur can be a useful tool to capture poor outcome potential among the various lifestyle variables. A viable osteological correlate allows for the application of clinical data to archaeological populations.

4.2. Introduction

Knee osteoarthritis (OA) is a complex interaction between biological and biomechanical factors that leads to cartilage degeneration, producing mechanically induced knee joint failure (Biscevic et al., 2008; Maly, 2008). Though knee OA is almost always symptomatic, the symptoms are varied and include reduced function, stiffness after inactivity, joint instability, buckling, and psychological and emotional distress related to chronic pain (Cooper et al., 2000; Dieppe, 2000; Breedveld, 2004; Fitzgerald et al., 2004; Parmelee et al., 2007; Hunter et al., 2008). These symptoms can lead to limb use modifications, with the main changes during sitting, standing, bending, and walking (Hall et al., 2008).

The relationship between joint pain and degenerative structural changes is poorly understood (Thorp et al., 2007), with mixed results reported in studies that link OA symptoms to physical changes in the knee (Altman et al., 1986; Lethbridge-Cejku, 1995; Spector et al., 1996; Barker et al., 2004; Faucher et al., 2004; Rogers et al., 2004; Szebenyi et al., 2006; Roseman et al., 2007; van der Kraan et al., 2007; Maly et al., 2008; Neogi et al., 2008; Oka et al., 2008; and Zhai et al., 2008). However, many radiographic bone features are associated with chronic pain, including osteophytosis, subchondral sclerosis, and bone marrow lesions (Altman et al., 1986; Lethbridge-Cejku, 1995; Spector et al., 1996; Hopman-Rock et al., 1998; Zhai et al., 2008).

Studies have suggested that distal femur shape, which changes with knee OA, is pertinent to the condition's etiology (Wada et al., 1999; Shepstone et al., 2001; Quasnichka et al., 2005). Intercondylar notch narrowing has been associated with OA severity and deterioration of the anterior cruciate ligament (ACL) (Shepstone et al., 2001; and Quasnichka et al., 2005). Notch narrowing is thought to be a product of osteophyte formation (Quasnichka et al., 2005), with osteophytes seen in advanced knee OA. Marginal osteophytes around the intercondylar notch are considered an early sign of knee degeneration (Shepstone et al., 2000) and a compensatory mechanism that increases stability by allowing bone to press against the slackened ACL. In some cases, a decreased intercondylar notch width may cause cruciate ligament damage and further knee instability, leading to additional osteophytosis and other OA features (Shepstone et al., 2000). It is not surprising that smaller intercondylar notches due to stenosis are found in individuals with severe OA, as compared with normal knees (Wada et al., 1999; Shepstone et al., 2001). Therefore, the femur's distal articular surface may be a valid feature for assessing physical impairment due to knee OA.

This paper compares two techniques, one based on quantitative changes and the other on qualitative changes in degenerative distal femora of a clinical sample, to determine which is most significantly related to potential barriers to optimum function. Determining the best link between osteological change and pain, disability, and functional outcomes is crucial for identifying impairment potential in skeletal populations. This link will allow bioarchaeologists to move beyond the description of pathological changes to consider the impact these physical changes may have had on not only the individual but also the society in which they participated.

4.3. Subjects and Methods

4.3.1. Subjects

"Data used in the preparation of this article were obtained from the Osteoarthritis Initiative (OAI) database, which is available for public access at http://www.oai.ucsf.edu/" (OAI, 2006, p. 2). OAI is a multi-center, longitudinal, cohort, prospective observational study focusing primarily on knee OA, consisting of 4607 male and female participants of various ethnicities, ranging in age from 45 to 79 at baseline, with women slightly more represented than men (Nevitt et al., 2006). The OAI data includes knee OA status and outcome measurements; such as, pain and physical function, overall physical assessment indices, and joint imaging assessments collected at baseline and subsequent 12 month intervals (Nevitt et al., 2006).

OAI provides randomized subsets of MRI images for research purposes. For this study, a subset of 279 knees were selected from the 12 month interval, including individuals from the progression (i.e., individuals with symptomatic knee OA) and the incidence (i.e., individuals without symptomatic knee OA but having specific characteristics that predispose them to developing symptomatic knee OA) cohorts. The clinical diagnosis of symptomatic knee OA required both the presence of frequent knee symptoms and radiographic findings (Nevitt et al., 2006).

The sample of 279 knees was represented by: 139 right and 140 left knees, 141 males,138 females, 46 to 80 years of age (mean 64 years ± 9.7), BMI from 18.7 to 42.6 (mean 29.4 ± 4.7), weight from 43.5 to 121 kg (mean 83.6 ±15.1). Eighty-four percent of the knees belonged to Caucasians, 14% to African Americans, 1% to Asians, and 1% to other non-Caucasians. Of the male subjects, the average age was 65.3 ±9.4 years, average BMI was 28.6 ±4.1, and average weight was 88 ±14.5 kg. Of the female subjects, the average age was 62.8 ±9.9 years, average BMI was 30.2 ±5.2, and average weight was 78.9 ±14.4 kg.

4.3.2. Instruments

The International Classification of Functioning, Disability and Health (ICF) was used as the framework for choosing the OAI variables most relevant to knee OA. This WHO endorsed system provides standard terminology and structure for classifying health and health-related states. ICF includes four main components: 1) body functions, 2) body structures,3) activities and participation, and 4) environmental factors. Environmental factors, extrinsic to the individual, include physical, social, and attitudinal environments (Wang et al., 2005). ICF’s functioning and disability constructs and definitions have been used as building blocks for modeling OA induced disability (Wang et al., 2005).

Though still establishing itself as a tool in clinical practice, ICF has already been adapted by researchers to produce “ICF Core Sets” for specific fields, to improve usage efficiency for a classification system that includes almost 300 pages of text. To produce a core set, the descriptive codes within ICF are reviewed for relevancy by experts in the field and, if deemed applicable, are included in a list of descriptors (Cieza et al., 2004; Dreinhöfer et al., 2004; Stucki & Cieza, 2004; Stucki et al., 2004; Scheuringer et al., 2005; Stoll et al., 2005; Grill et al., 2007). The OA ICF core set was used as a guide in this study.

Since the OA core set is general to all OA, not just knee OA, seven ICF categories most relevant to knee OA were chosen from the OA core set: b280 – Sensation of Pain, b710 – Mobility of Joint Functions, d410 – Changing Basic Body Position, d450 – Walking, d455 – Moving Around, d640 – Doing Housework, and d920 – Recreation and Leisure. Of the approximately 1200 variables recorded by the OAI, 15 variables were identified based on the ICF core set framework and their possible relevance to ancient populations (Table 4.1). These 15 OAI variables, collected by OAI via a series of self-administered questionnaires, are indexes that include scores from multiple questions related to outcome variables.

The Western Ontario and McMaster Universities Arthritis Index (WOMAC) questionnaires were used to assess pain, joint stiffness, and physical function using three subscales: pain, stiffness, disability (Bellamy *et al*., 1988). The individual items in the pain subscale are walking, stairs, in bed, sit or lie down, and standing. The stiffness subscale measures stiffness in the morning and later in the day. The disability subscale measures disability experienced when walking down stairs, up stairs, stand from sitting, standing, bending, walking, getting in car/out of car, shopping, donning socks, getting out of bed, doffing socks, lying down, getting in/out of bathtub, sitting, getting on/off toilet, doing heavy chores, and doing light chores. All the subscales were measured on a 5-point scale with 0 equaling none and 4 equaling extreme. The WOMAC total score combines results from the three subscales to assess overall impact of knee OA.

Table 4.1: Demographic and OAI variables used in the analysis along with the correlation results

Quantitative/Qualitative/Population Variables		NWI			NDI			CNI			CAOS Grade		
		All	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male
Notch Width Index	NWI	1.000	1.000	1.000	0.057	-0.029	0.126	-0.108	*0.699	*0.736	-0.025	0.009	-0.084
Notch Depth Index	NDI	0.057	-0.029	0.126	1.000	1.000	1.000	0.044	*0.695	*0.764	-0.088	-0.057	-0.150
Combined Notch Index	CNI	-0.108	*0.699	*0.736	0.044	*0.695	*0.764	1.000	1.000	1.000	*-0.154	0.063	-0.132
CAOS Grade	Degree	-0.058	-0.036	-0.088	-0.091	0.000	*-0.167	*-0.133	-0.026	*-0.171	1.000	1.000	1.000
Age	age	-0.113	*-0.174	-0.066	*-0.201	*-0.213	*-0.168	0.082	*-0.277	-0.157	0.090	*0.181	0.019
Body Mass Index	bmi	*-0.1203	-0.015	*-0.23	0.008	0.015	-0.010	0.044	0.000	-0.155	*0.215	0.140	*0.248
Weight	weight	0.005	0.101	-0.148	0.058	0.081	-0.003	0.017	0.131	-0.098	*0.158	0.087	*0.216
OAI Variable													
Health survey physical summary score	hspss	0.061	0.097	0.011	*0.249	*0.399	0.108	0.052	*0.355	0.081	*-0.300	*-0.231	*-0.376
KOOS function, sports, and recreational activities	koosfsr	-0.005	-0.204	0.162	*0.165	*0.249	0.052	0.129	0.032	0.141	*-0.386	*-0.373	*-0.430
KOOS pain score left knee	kooskpl	-0.076	*-0.179	0.006	0.083	*0.212	-0.045	*0.139	0.023	-0.026	*-0.178	-0.079	*-0.264
KOOS pain score right knee	kooskpr	0.085	-0.023	0.156	*0.224	*0.278	0.157	0.071	*0.182	*0.208	*-0.395	*-0.317	*-0.506
KOOS quality of life	koosqol	0.002	*-0.170	0.149	0.107	*0.218	-0.001	0.171	0.034	0.096	*-0.358	*-0.363	*-0.364
KOOS symptoms score left knee	koosyml	*-0.150	*-0.327	0.012	0.110	0.106	0.118	*0.122	-0.159	0.088	*-0.221	-0.125	*-0.328
KOOS symptoms score right knee	koosymr	0.006	-0.091	0.067	*0.175	0.241	0.085	*0.138	0.107	0.102	*-0.385	*-0.400	*-0.389
WOMAC disability score left knee	womadll	0.105	*0.203	0.036	-0.099	*-0.170	-0.018	*-0.150	0.024	0.012	*0.231	0.168	*0.285
WOMAC disability score right knee	womdlr	-0.067	0.044	-0.126	*-0.210	*-0.202	*-0.223	-0.059	-0.112	*-0.234	*0.377	*0.345	*0.436
WOMAC pain score left knee	womkpl	0.055	0.119	0.009	-0.060	*-0.200	0.075	*-0.139	-0.058	0.057	*0.187	0.080	*0.281
WOMAC pain score right knee	womkpr	*-0.123	-0.010	*-0.21	*-0.228	*-0.285	-0.149	-0.052	*-0.211	*-0.238	*0.381	*0.292	*0.511
WOMAC stiffness score left knee	womstfl	0.085	*0.276	-0.077	*-0.152	*-0.198	-0.107	-0.030	0.056	-0.123	*0.245	0.146	*0.348
WOMAC stiffness score right knee	womstfr	-0.067	0.059	-0.153	*-0.175	*-0.203	-0.118	-0.013	-0.103	*-0.180	*0.361	*0.373	*0.415
WOMAC total score left knee	womstl	0.096	*0.197	0.020	-0.099	*-0.184	-0.005	*-0.142	0.011	0.010	*0.231	0.168	*0.301
WOMAC total score right knee	womtsr	-0.083	0.035	-0.159	*-0.219	*-0.227	*-0.210	-0.055	-0.137	*-0.247	*0.402	*0.368	*0.497

* significant *p* values

The Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaires were used to assess pain, symptoms, function in sport and recreation, and knee related quality of life (Roos et al., 1998). Using the same 5-point scale as WOMAC, KOOS measures pain while twisting/pivoting, straightening, and bending the knee fully. Difficulty with function is measured during sport and recreational activities; including, squatting, running, jumping, twisting/pivoting, and kneeling. KOOS also measures symptoms for swelling, clicking or noise in knee, knee catching or hanging up, straightening knee fully, and bending knee fully, with 0 equaling never and 4 equaling always. The quality of life index measures awareness of knee problems, modifying lifestyle to avoid potentially damaging activities, lack of confidence in the knee, and overall degree of difficulty with the knee.

The Health Survey Short Form 12 questionnaire(SF-12®) was used to measure overall physical health status by assessing opinions on overall health, activity limitations, ability to accomplish tasks, pain with normal work, and health interfering with social activities (Ware et al., 1996).

4.3.3. MRI Assessment

The validity of using MRIs as surrogates for direct bone observations has been shown in previous studies (Cohen et al., 1999; Iwaki et al,. 2000; Woodhead et al,. 2001; Leitzes et al., 2005; Louis et al., 2010; Ochiai et al., 2010). The bone features chosen for this study, accessible through both clinical imaging and direct osteological analysis, were the size of the intercondylar femoral notch (quantitative assessment) and the overall morphology of the distal femur (qualitative assessment). For quantitative analysis, the intercondylar notch was measured and scaled to control for size differences amongst individuals. Using MRIs from the OAI study, femoral notch width index (NWI, notch width divided by epicondylar width) and femoral notch depth index (NDI, notch depth divided by condylar depth) were calculated using the parameters established by Wada et al. (1999). NWI represents a wide or narrow notch and NDI a deep or shallow notch; however, neither represents large or small notches. Therefore, a third index was developed by averaging NWI and NDI to produce an area-related index called the combined notch index (CNI). DicomWorks software (v1.3.5 © 2000, 2001, Philippe Puech-Loïc Boussel) was used to complete all MRI analyses for the notch measures.

The notch measurement procedure involved analyzing MRI slices from the most distal end of the femur toward the proximal end (Sagittal 3D DESS with Water Excitation, Axial Plane Multi-planar reformatting). The notch measurements were taken from the slice where the notch's upper rim emerged complete. A base line was inserted along the inferior margin of the condyles. Notch depth was taken from the base line to the notch ceiling. Notch width was taken at two-thirds notch depth (Figure 4.1). Condylar measurements were taken from the slice that exhibited the largest epicondylar width and tallest condylar height (Figure 4.2).

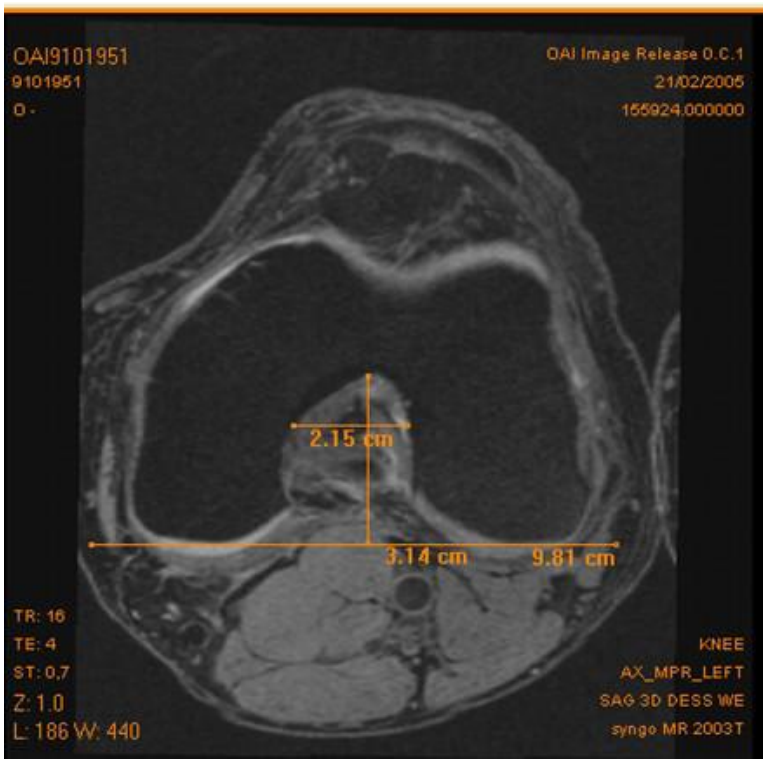


Figure 4.1: MRI slice showing the location of the notch width measures.

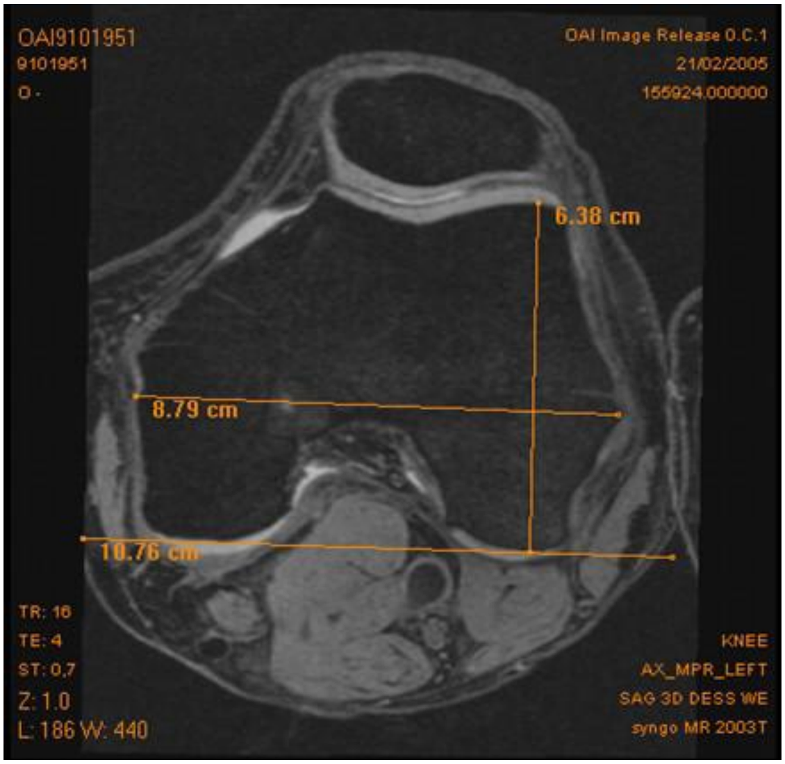


Figure 4.2: MRI slice showing the location of the condylar measurements

The Clinical Archeological Osteoarthritis Scale (CAOS), a grading system for knee OA severity, was used for qualitative assessments (Young & Lemaire, 2012). The CAOS system (Table 4.2) was developed on a clinical population but uses measures common to both clinical and bioarchaeological fields. The scale focuses on features that are indicative of the OA degenerative process and are recognizable in both MRI and direct bone observations. These features include osteophyte formation, shape contour changes, and the presence of micro/macroporosities and/or cysts. In this study, each distal femur was graded on the CAOS with 0 representing no bony changes, 1 representing minimal marginal osteophyte formation, 2 representing increased marginal osteophyte formation and changes in the joint contour, and 3 representing advanced bony changes including excessive osteophyte formation causing distinctive changes in the joint contour and the presence of micro/marcroporosities and/or cysts.

Table 4.2: The CAOS grading system.

	Features of the Distal Femoral Articular Surface			
CAOS Grade	Marginal Bone Proliferation	Irregular Surface Margins	Porosities	Predominant Feature
0	none	none	none	smooth articular surface with well defined rounded joint margins
1	minor bony exostosis usually seen in region of intercondylar notch	minimal	none	smooth articular surface with slightly irregular margins due to minor marginal bone proliferation creating a sharpening of the edge in some areas
2	minimal to moderate osteophyte formation	minimal to moderate	microporosities may be present	marginal bone proliferation in the form of distinctive osteophytes creating irregular and sharp margins in some areas
3	moderate to excessive osteophyte formation	distinctive irregular joint surface margins	distinctive microporosities present; macroporosities and/or cysts may be present	articular surface has obvious porosities; joint contours are sharp and irregular along most of the margin due to advanced bone proliferation (osteophytosis)

4.3.4. Statistical Analysis

Microsoft Excel was used to calculate the notch indices based on the femoral measurements. Each femur was considered separately because most OAI outcome variables assess right and left knees as individual units. Microsoft Access was used to collate data from the notch measures, grade assessments, and the OAI outcome variables. NCSS 2007 was used to calculate correlations between the distal femoral observations and the 15 OAI outcome variables. Pearson's ranked correlations were used for the continuous (quantitative) data and Spearman's ranked correlations were used for the categorical (qualitative) data.

4.4. Results

4.4.1. Quantitative Assessment

Pearson's ranked correlation coefficients with identified significant *p* values are reported in Table 4.1 and the average notch measurements are reported in Table 4.3. Correlations showed that notch height decreases as age increases and that overall notch size decreases in females as they age. Increasing BMI and decreasing notch width were significantly correlated for males. However, there were no significant correlations between any of the notch measures and weight.

Table 4.3: The average notch measures with standard deviations and the percentage of subjects for each CAOS grade of knee OA for the entire population, males, and females.

	Notch Measure			Knee Grade (% of subjects)			
	NWI	NDI	CNI	0	1	2	3
All	0.217±0.03	0.439±0.04	0.328±0.02	23	44	26	7
Male	0.220±0.03	0.442±0.03	0.331±0.02	15	52	28	5
Female	0.215±0.03	0.435±0.03	0.325±0.02	32	35	24	9

Few significant correlations were discovered when relating the OAI outcome variables to the notch measures. The most interesting results were found for females, where a decreasing NDI was weakly, but significantly ($p < .05$ to $p < .0001$), correlated to increased problems with pain, stiffness, disability, physical health, functioning during sports and recreation, and quality of life. In some cases, this was despite notch widening. For the entire sample, NDI was weakly but significantly ($p < .05$ to $p < .0001$) correlated with right knee pain, stiffness, disability, symptoms, physical health, and functioning during sports and recreation. For males, a decreasing CNI correlated weakly but significantly ($p < .05$ to $p < .01$) with right knee pain, stiffness, and disability variables.

4.4.2. Qualitative Assessment

CAOS grade frequencies are reported in Table 4.3. Spearman's ranked correlation coefficients (Table 4.1) suggested that age does not correlate significantly with grade of bony changes in the overall sample. However, the age – grade relationship was statistically significant for females ($p < .05$). There was also a significant correlation ($p < .05$ to $p < .001$) between increased CAOS grade and increased BMI and between CAOS grade and weight for the sample as a whole and males, but not females. Decreasing CNI correlated significantly with CAOS grade, indicating that the overall notch size (CNI) decreased as the CAOS grade worsened, supporting the findings of Wada et al. (1999) and Shepstone et al. (2001).

When relating knee OA grade to the OAI outcome variables, many statistically significant relationships were found. All activity, quality of life, right knee pain, disability, stiffness, and symptom outcome variables were weakly to moderately, but significantly ($p < .0001$), correlated with CAOS grades for the population as a whole, males, and females. There were also significant correlations ($p < .01$ to $p < .0001$) between left knee pain, disability, stiffness, and symptom outcome variables for the entire sample and males, but not for females.

Comparing the five outcome variables with the highest Spearman rank correlation values by sex (Table 4.4) revealed that males and females had only two outcome variables in common, WOMAC total score right knee" and "KOOS function, sports, and recreational activities". In addition, males had significant correlations for right knee pain (WOMAC and KOOS) and right knee disability variables, which are predominately task based. Females had significant correlations with quality of life, right knee symptom, and right knee stiffness variables, which were more general and lifestyle based. As expected, both groups had increasing problems with high intensity movements, as measured by the KOOS "function, sports, and recreational activities". Interestingly, pain was not in the top five Spearman ranked correlation values for females.

4.4.3. Quantitative vs. Qualitative Assessments: Comparing the Significant Relationships

The strongest links between osteological features and outcomes were determined by comparing significant relationships between OAI variables and distal femoral measures. Table 4.5 reports the percentage of significant relationships between the various distal femur assessment tools and the 15 OAI variables. For the sample as a whole, and males in particular, morphological assessment via CAOS grade had the best linear relationship with the outcome variables. However, NDI had the strongest relationships between OAI variables for females. The sample as a whole and the male sub-sample had a similar relational pattern between CAOS grade and the various OAI variable breakdowns (i.e., right only, left only, non-sided only).

Table 4.4: Comparison of the highest ranked OAI variables by sex as determined by Spearman correlations.

Females	
OAI Variable	**Items Measured**
KOOS function, sports, and recreational activities	function during sports and recreational activities while squatting, running, jumping, twisting/pivoting, and kneeling.
KOOS quality of life	measures awareness of problems with knee, modifying lifestyle to avoid potentially damaging activities, lack of confidence in knee, and overall degree of difficulty with knee
KOOS symptoms score right knee	swelling, clicking or noise in knee, knee catching or hanging up, straightening knee fully, and bending knee fully
WOMAC stiffness score right knee	stiffness in the morning and later in the day
WOMAC total score right knee	combines results from the three subscales assessing overall impact of knee OA
Males	
OAI Variable	**Items Measured**
KOOS function, sports, and recreational activities	function during sports and recreational activities while squatting, running, jumping, twisting/pivoting, and kneeling.
KOOS pain score right knee	pain while twisting/pivoting, straightening and bending the knee fully
WOMAC disability score right knee	disability experienced when completing the following activities; down stairs, up stairs, stand from sitting, standing, bending, walking, in car and out of car, shopping, socks on, get out of bed, socks off, lying down, get in and out of bathtub, sitting, on and off toilet, heavy chores, and light chores
WOMAC pain score right knee pain	pain subscale are walking, stairs, in bed, sit or lie down, and standing.
WOMAC total score right knee	combines results from the three subscales assessing overall impact of knee OA

The female sub-sample exhibited varying results for different OAI variables (Table 4.1). When looking at just the right knee, most of the strongest correlations were with CAOS grade. However, left OAI variables had an equal number of strong correlations with NDI and NWI, but no strong correlations with CAOS grade. When the non-sided OAI variables were examined, an equal number of significant correlations were found for NDI and CAOS outcomes.

Comparing the five outcome variables with the highest Spearman rank correlation values by sex (Table 4.5) revealed that males and females had only two outcome variables in common, “WOMAC total score right knee” and “KOOS function, sports, and recreational activities”. In addition, males had significant correlations ($p<0.05$) for right knee pain (WOMAC and KOOS) and right knee disability variables, which are predominately task based. Females had significant correlations with quality of life, right knee symptom, and right knee stiffness variables, which were more general and lifestyle based. As expected, both groups had increasing problems with high intensity movements, as measured by the KOOS “function, sports, and recreational activities”. Interestingly, pain was not in the top five Spearman ranked correlation values for females.

Table 4.5: The percentage of significant relationships for OAI variables by measure for the entire sample, females, and males.

	% of Significant Relationships with all OAI Variables			% of Significant Relationships with Right OAI Variables			% of Significant Relationships with Left OAI Variables			% of Significant Relationships with Non-sided OAI Variables		
	All	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male
NWI	13	40	7	17	0	17	17	83	0	0	33	0
NDI	60	87	13	83	83	33	17	83	0	67	100	0
CNI	40	20	33	17	33	83	83	0	0	0	33	0
CAOS	100	60	100	100	100	100	100	0	100	100	100	100

4.5. Discussion

People with knee OA report “the worst quality of life among people with musculoskeletal diseases” (Tukker et al., 2008) with cited problems including difficulty performing daily activities; progressive loss of function; dependency in walking, stair climbing, and other lower extremity tasks; fear of falling; loss of sleep; and difficulty rising and sitting down, getting into and out of bed, squatting, and kneeling (Hopman-Rock et al., 1998; Steultjens et al., 1999; Miller et al., 2001; Bennell et al., 2003; Maly et al., 2005; Salaffi et al., 2005; van der Esch et al., 2006; Maly & Krupa, 2007; Ay et al., 2008; and Hall et al., 2008). This study focused on quantitative and qualitative measures at the distal femur as a means of linking osseous changes to functional impediments. In the literature, conflicting results were reported when linking physical changes in the knee with knee OA outcome measures. Results from this study showed differences in the effectiveness of quantitative and qualitative measures when relating physical changes to clinical and life-related outcomes associated with knee OA.

Femoral intercondylar notch stenosis has been related to knee OA, with notch size decreasing as OA progresses (Shepstone et al., 1999; Wada et al., 1999). Notch size was therefore used as a surrogate for knee OA progression to investigate its utility when relating bone changes to activity limitations. This research is the first to use femoral intercondylar notch size to investigate the relationship between symptoms and patient outcomes. Our findings suggest that outcomes for females are predominately related to decreasing notch depth while outcomes for males are more related to decreasing CNI. However, standard deviations for NDI, NWI, and CNI were less than 0.04 (Table 4.3). While these standard deviations were 6-14% of the mean measures, notch size may not be sensitive enough to be a useful tool when linking bone changes to functional outcomes.

The CAOS grading method was, for the most part, superior to the quantitative measures for identifying poor functional outcomes in skeletal populations. Although it is intuitive to assume that increased degeneration creates worse symptoms, this simple linear relationship is not entirely supported, especially when comparing the variability of statistically significant outcomes between males and females.

Apart from males and females exhibiting differences in their outcome variables ranked by highest Spearman correlation, an additional point of contrast was the lack of significant relationships between the left knee outcome variables and CAOS grade for the female population, while the male population demonstrated significant correlations for all variables. These findings may be related to several factors, including the type and/or intensity of activities performed by females in the represented age range and the divergent biomechanical role played by the dominant versus non-dominant leg. Previc's theory (1991) dictates "that antigravity extension (postural support) on the left side of the body emerges before voluntary motor control (mobilization) on the contralateral (right) side. This suggests that the dominant foot for either unilateral or bilateral task behaviors is the left one for most individuals" (Sadeghi et al., 2000, p.38). Therefore, the non-dominant knee, the right knee in most individuals, is the preferential weight-bearing knee (Kranjc et al., 2010).

In a study of athletes, degenerative changes consistent with OA in the non-dominant knee are more symptomatic in later life than cases with dominant side degeneration, despite having no more evidence of knee OA (Kranjc et al., 2010). Our CAOS results were consistent with those seen in Kranjc et al. (2010), with the right knee having more reportable symptoms than the left. Therefore, the different male/female symptom profiles could be related to leg dominance and weight-bearing roles and thus may be linked to internal (body structure or weight) or external (work requirements, etc.) biomechanical stressors that are unique to each sex. However, leg dominance does not explain why NDI was significantly correlated with almost all the outcome variables for females.

The differences in outcomes from the CAOS tool and NDI measure may be explained by two different mechanisms. The CAOS tool evaluates degenerative changes in the distal femur from soft tissue break down, inflammation, and possible bone on bone contact. Therefore, this tool may capture knee symptoms related to load bearing and leg dominance functions. NDI, NWI, and CNI evaluate osteophyte formation around the intercondylar notch, which may be related to a slackened ACL. Thus, these notch measures may capture symptoms related to knee joint hypermobility and instability. If this reasoning is valid, the greater number of significant correlations for females between NDI and the outcome measures, especially for the left knee, may be more related to knee instability than load bearing and leg dominance biomechanics. Studies have shown that females are more susceptible to ACL injuries (Adachi et al., 2008; Hewett, 2010), which may support the greater number of correlations between notch measures and symptoms for females in our sample population.

Despite the possibility that two different symptom generation mechanisms are captured by the quantitative and qualitative evaluation systems, the CAOS grading approach did exhibit superior overall correlation. This qualitative system was the optimal indicator of poor OA outcomes.

4.6. Conclusions

Studies examining the relationship between functional difficulties and degree of knee OA have met with mixed results. This study, using the ICF system for guidance, examined quantitative and qualitative analyses of the distal femur as useful indicators of functional outcomes. The findings showed that, overall, quantitative indices based on the femoral intercondylar notch were not sufficiently correlated or sensitive to identify impairment and are thus an inefficient bridge between clinical findings and their direct application to archaeological populations. However, statistically significant correlations between CAOS grading of the qualitative bone changes in the distal femur and outcomes from clinical evaluations confirmed that macroscopic osteological features are a viable option to link clinical and archaeological populations and accessing this information may help identify functional barriers related to the disease state.

Increased distal femur bone degeneration, as reflected by CAOS grade, lead to overall and sex-specific increases in pain, stiffness, disability, symptoms, and decreased quality of life, physical health, and functional capacity when performing sports and recreational activities. Understanding that sex specific symptom profiles and outcome experiences exist will improve interpretation in archaeological populations where symptoms and their functional impact can no longer be inferred onto all members of a population equally.

Statistically significant correlations between the bone changes and the outcome variables support the use of the ICF system as a mechanism for choosing variables related to a disease state. This study also highlights ICF's validity as a tool for investigating disease impact both in clinical and archaeological populations.

4.7. Acknowledgements

The authors would like to thank the OAI for the use of their data. **"**The OAI is a public-private partnership comprised of five contracts (N01-AR-2-2258; N01-AR-2-2259; N01-AR-2-2260; N01-AR-2-2261; N01-AR-2-2262) funded by the National Institutes of Health, a branch of the Department of Health and Human Services, and conducted by the OAI Study Investigators. Private funding partners include Merck Research Laboratories; Novartis Pharmaceuticals Corporation, GlaxoSmithKline; and Pfizer, Inc. Private sector funding for the OAI is managed by the Foundation for the National Institutes of Health. This manuscript was prepared using an OAI public use data set and does not necessarily reflect the opinions or views of the OAI investigators, the NIH, or the private funding partners" (OAI, 2006).

4.8. Literature Cited

1. Adachi, N., Nawata, K., Maeta, M., & Kurozawa, Y. (2008). Relationship of the Menstrual Cycle Phase to Anterior Cruciate Ligament in Teenaged Female Athletes. *Archives of Orthopaedic and Trauma Surgery, 128*, 473-478.
2. Altman, R., Asch, E., Bloch, D., Bole, G., Borenstein, D., Brandt, K., Christy, W., Cooke, T., Greenwald, R., Hochberg, M., Howell, D., Kaplan, D., Koopman, W., Longley, S., Mankin, H., McShane, D., Medsger, T., Meenan, R., Mikkelsen, W., Moskowitz, R., Murphy, W., Rothschild, B., Segal, M., Sokoloff, L., & Wolfe, F. (1986). Development of Criteria for the Classification and Reporting of Osteoarthritis: Classification of Osteoarthritis of the Knee. *Arthritis and Rheumatism*, *29*(8), 1039-1049.
3. Ay, S., Tur, B., & Kucukdeveci, A. (2008). Evaluation of Disability in Patients with Degenerative and Inflammatory Arthritis. *International Journal of Rehabilitation Research, 31*, 159-163.
4. Barker, K., Lamb, S., Toye, F., Jackson, S., & Barrington, S. (2004). Association Between Radiographic Joint Space Narrowing, Function, Pain and Muscle Power in Severe Osteoarthritis of the Knee. *Clinical Rehabilitation, 18*, 793-800.
5. Bellamy, N., Buchanan, W., Goldsmith, C., Campbell, J., & Stitt, L. (1988). Validation Study of WOMAC: A Health Status Instrument for Measuring Clinically Important Patient Relevant Outcomes to Antirheumatic Drug Therapy in Patients with Osteoarthritis of the Hip or Knee. *Journal of Rheumatology*, *15*(12): 1833-1840.
6. Bennell, K., Hinman, R., Mecalf, B., Crossley, K., Buchbinder, R., Smith, M., & McColl, G. (2003). Relationship of Knee Joint Proprioception to Pain and Disability in Individuals with Knee Osteoarthritis. *Journal of Orthopaedic Research, 21*, 792-797.
7. Biščević, M., Ljuca, F., Biščević, A., Gavrankapetanović, I., Smrke, B., Ozturk, C., & Smrke, D. (2008). Morphometric Alteration of Femoral Condyles Due to Knee Osteoarthritis. *Collegium Antropologicum*, *32*(3), 875–879.
8. Breedveld, F. (2004). Osteoarthritis – the Impact of a Serious Disease. *Rheumatology*, *43*(Suppl.1), i4-i8.
9. Cieza, A., Ewert, T., Ustun, B., Chatterji, S., Kostanjsek, N., & Stucki, G. (2004). Development of ICF Core Sets for Patients with Chronic Conditions. *Journal of Rehabilitation Medicine, Suppl, 44*, 9-11.

10. Cohen, Z., McCarthy, D., Kwak, S., Legrand, P., Fogarai, F., Ciaccio, E., & Ateshian, G. (1999). Knee Cartilage Topography, Thickness, and Contact Areas from MRI: In-vitro Calibration and In-vivo Measurements. *Osteoarthritis and Cartilage, 7,*95-109.

11. Cooper, C., Snow, S., McAlindon, T., Kellingray, S., Stuart, B., Coggon, D., & Dieppe, P. (2000). Risk Factors for the Incidence and Progression of Radiographic Knee Osteoarthritis. *Arthritis & Rheumatism, 43*(5), 995-1000.

12. Dieppe, P. (2000). Towards a Better Understanding of Osteoarthritis of the Knee Joint. *The Knee, 7*, 135-137.

13. Dreinhöfer, K., Stucki, G., Ewert, T., Huber, E., Ebenbichler, G., Gutenbrunner, C., Kostanjsek, N., & Cieza, A. (2004). ICF Core Sets for Osteoarthritis. *Journal of Rehabilitation Medicine Suppl, 44*, 75-80.

14. Faucher, M., Poiraudeau, S., Lefevre-Colau, M., Rannou, F., Fermanian, J., & Revel, M. (2004). Assessment of the Test-retest Reliability and Construct Validity of a Modified WOMAC Index in Knee Osteoarthritis. *Joint Bone Spine, 71*, 121-127.

15. Fitzgerald, G., Piva, S., & Irrgang, J. (2004). Reports of Joint Instability in Knee Osteoarthritis: Its Prevalence and Relationship to Physical Function. *Arthritis & Rheumatism, 51*(6), 941-946.

16. Grill, E., Zochling, J., Stucki, G., Mittrach, R., Scheuringer, M., Liman, W., Kostanjsek, N., & Braun, J. (2007). International Classification of Functioning, Disability and Health (ICF) Core Set for Patients with Acute Arthritis. *Clinical and Experimental Rheumatology, 25*, 252-258.

17. Hall, M., Migay, A., Persad, T., Smith, J., Yoshida, K., Kennedy, D., & Pagura, S. (2008). Individuals' Experience of Living with Osteoarthritis of the Knee and Perceptions of Total Knee Arthroplasty. *Physiotherapy Theory and Practice, 24*(3), 167-181.

18. Hewett, T. (2010). Why Women Have an Increased Risk of ACL Injury. AAOS Now. American Academy of Orthopaedic Surgeons. Nov. last retrieved July 2012 from http://www.aaos.org/news/aaosnow/nov10/research3.asp.

19. Hopman-Rock, M., Kraaimaat, F., Odding, E., & Bijlsma, J. (1998). Coping with Pain in the Hip or Knee in Relation to Physical Disability in Community-Living Elderly People. *Arthritis Care and Research, 11*(4), 243-252.

20. Hunter, D., Niu, J., Zhang, Y., LaValley, M., McLennan, C., Hudelmaier, M., Echstein, F., & Felson, D. (2008). Premorbid Knee Osteoarthritis is not Characterised by Diffuse Thinness: the Framingham Osteoarthritis Study. *Annals of the Rheumatic Diseases, 67*, 1545-1549.
21. Iwaki, H., Pinskerova, V., & Freeman, M. (2000). Tibiofemoral Movement 1: The Shapes and Relative Movements of the Femur and Tibia in the Unloaded Cadaver Knee. *Journal of Bone and Joint Surgery [Br], 82-B(8),* 1189-1195.
22. Leitzes, A., Potter, H., Amaral, T., Marx, R., Lyman, S., & Widmann, R. (2005). Reliability and Accuracy of MRI Scanogram in the Evaluation of Limb Length Discrepancy. *Journal of Pediatric Orthopedics, 25,* 747-749.
23. Lethbridge-Cejku, M., Scott, W., Reichle, R., Ettinger, W., Zonderman, A., Costa, P., Plato, C., Tobin, J., & Hochberg, M. (1995). Association of Radiographic Features of Osteoarthritis of the Knee with Knee Pain: Data from the Baltimore Longitudinal Study of Aging. *Arthritis Care & Research, 8*(3), 182-188.
24. Louis, O., Cattrysse, E., Scafoglieri, A., Luypaert, R., Clarys, J., & de Mey. (2010). Accuracy of Peripheral Quantitative Computed Tomography and Magnetic Resonance Imaging in Assessing Cortical Bone Cross-Sectional Area: A Cadaver Study. *Journal of Computer Assisted Tomography, 34*(3), 469-472.
25. Maly, M. (2008). Abnormal and cumulative loading in knee osteoarthritis. *Current Opinion in Rheumatology, 20,* 547–552.
26. Maly, M., & Krupa, T. (2007). Personal Experiences of Living with Knee Osteoarthritis Among Older Adults. *Disability and Rehabilitation, 29*(18), 1423-1433.
27. Maly, M., Costigan, P., & Olney, S. (2005). Contribution of Psychosocial and Mechanical Variables to Physical Performance Measures in Knee Osteorthritis. *Physical Therapy, 85*(12), 1318-1328.
28. Maly, M., Costigan, P., & Olney, S. (2008). Mechanical Factors Relate to Pain in Knee Osteoarthritis. *Clinical Biomechanics, 23*(6), 796-805.
29. Miller, M., Rejeski, W., Messier, S., & Loeser, R. (2001). Modifiers of Change in Physical Functioning in Older Adults with Knee Pain: the Observational Arthritis Study in Seniors (OASIS). *Arthritis Care & Research, 45*(4), 331-339.

30. Neogi, T., Felson, D., Niu, J., Nevitt, M., Lewis, C., Aliabadi, P., Sach, B., Torner, J., Bradley, L., & Zhang, Y. (2008). 327 Radiographic Features of Osteoarthritis are Strongly Associated with Knee Pain in Two Cohorts: Most and Framingham. *Osteoarthritis and Cartilage, 16*(Supplement 4), S144-S145.
31. Nevitt, M., Felson, D., & Lester, G. (2006). The Osteoarthritis Initiative: Protocol for the Cohort Study. Retrieved from http://www.oai.ucsf.edu/datarelease/docs/StudyDesignProtocol.pdf.
32. OAI (Osteoarthritis Initiative). 2006. Osteoarthritis Initiative (OAI) Guidelines for Publications Using Public Use Data Sets. Retrieved from http://oai.epi-ucsf.org/datarelease/Docs/OAIPubsGuidePublicData.pdf.
33. Ochiai, N., Sasho, T., Tahara, M., Watanabe, A., Matsuki, K., Yamaguchi, S., Miyake, Y., Nakaguchi, T., Wada, Y., & Moriya, H. (2010). Objective Assessments of Medial Osteoarthritic Knee Severity byMRI: New Computer Software to Evaluate Femoral Condyle Contours. *International Orthopaedics, 34*, 811-817.
34. Oka, H., Muraki, S., Akune, T., Mabuchi, A., Suzuki, T., Yoshida, H., Yamamoto, S., Nakaruma, K., Yoshimura, N., & Kawaguchi, H. (2008). Fully Automatic Quantification of Knee Osteoarthritis Severity on Plain Radiographs. *Osteoarthritis and Cartilage, 16*, 1300-1306.
35. Parmelee, P., Harralson, T., Smith, L., Schumacher, H. (2007). Necessary and Discretionary Activities in Knee Osteoarthritis: Do They Mediate the Pain–Depression Relationship? *Pain Medicine, 8*(5), 449-462.
36. Quasnichka, H., Anderson-MacKenzie, J., Tarlton, J., Sims, T., Billingham, M., & Bailey, A. (2005). Cruciate Ligament Laxity and Femoral Intercondylar Notch Narrowing in Early-stage Knee Osteoarthritis. *Arthritis & Rheumatism, 52*(10), 3100-3109.
37. Rogers, J., Shepstone, L., & Dieppe, P. (2004). Is Osteoarthritis a Systemic Disorder of Bone? *Arthritis & Rheumatism, 50*(2), 452-457.
38. Rosemann, T., Keuhlein, T., Laux, G., & Szecsenyi, J. (2007). Osteoarthritis of the Knee and Hip : A Comparison of Factors Associated with Physical Activity. *Clinical Rheumatology, 26*, 1811-1817.

39. Roos, E., Roos, H., Lohmander, L., Ekdahl, C., & Beynnon, B. (1998). Knee Injury and Osteoarthritis Outcome Score (KOOS) - Development of a Self-administered Outcome Measure. *Journal of Orthopaedic & Sports Physical Therapy, 28*(2): 88-96.
40. Salaffi, F., Carotti, M., & Grassi, W. (2005). Health-related Quality of Life in Patients with Hip or Knee Osteoarthritis: Comparison of Generic and Disease-Specific Instruments. *Clinical Rheumatology, 24*(1), 29-37.
41. Scheuringer, M., Stucki, G., Huber, E., Brach, M., Schwarzkopf, S., Kostanjsek, N., & Stoll, T. (2005). ICF Core Set for Patients with Musculoskeletal Conditions in Early Post-Acute Rehabilitation Facilities. *Disability and Rehabilitation, 27*(7/8), 405-410.
42. Shepstone, L., Rogers, J., Kirwan, J., & Silverman, B. (2000). Distribution of Distal Femoral Osteophytes in a Human Skeletal Population. *Annals of the Rheumatic Diseases, 59*(7), 513-520.
43. Shepstone, L., Rogers, J., Kirwan, J., & Silverman, B. (2001). Shape of the Intercondylar Notch of the Human Femur: A Comparison of Osteoarthritic and Non-osteoarthritic Bones from a Skeletal Sample. *Annals of the Rheumatic Diseases, 60,* 968-973.
44. Spector, T., Harris, P., Hart, D., Cicuttini, F., Nandra, D., Etherington, J., Wolman, R., & Doyle, D. (1996). Risk of Osteoarthritis Associated with Long-term Weight-bearing Sports: A Radiologic Survey of the Hips and Knees in Female Ex-athletes and Population Controls. *Arthritis & Rheumatism, 39*(6), 988-995.
45. Steultjens, M., Dekker, J., van Baar, M., Oostendorp, R., & Bijlsma, J. (1999). Internal Consistency and Validity of an Observational Method for Assessing Disability in Mobility in Patients with Osteoarthritis. *Arthritis Care & Research, 12*(1), 19-25.
46. Stoll, T., Brach, M., Huber, E., Scheuringer, M., Schwarzkopf, S.R., Konstanjsek, N., & Stucki, G. (2005). ICF Core Set for Patients with Musculoskeletal Conditions in the Acute Hospital. *Disability and Rehabilitation, 27*(7/8), 381-387.
47. Stucki, G., & Cieza, A. (2004). The International Classification of Functioning, Disability and Health (ICF) Core Sets for Rheumatoid Arthritis: A Way to Specify Functioning. *Annals of Rheumatic Diseases, 63,* 40-45.
48. Stucki, G., Cieza, A., Gehy, S., Battistella, L., Lloyd, J., Symmons, D., Kostanjsek, N., & Schouten, J. (2004). ICF Core Sets for Rheumatoid Arthritis. *Journal of Rehabilitation Medicine, Suppl. 44,* 87-93.

49. Szebeny, B., Hollander, A., Dieppe, P., Quilty, B., Duddy, J., Clarke, S., & Kirwan, J. (2006). Associations Between Pain, Function, and Radiographic Features in Osteoarthritis of the Knee. *Arthritis & Rheumatism, 54*(1), 230-235.
50. Thorp, L., Sumner, D., Wimmer, M., & Block, J. (2007). Relationship Between Pain and Medial Knee Joint Loading in Mild Radiographic Knee Osteoarthritis. *Arthritis Care & Research, 57*(7), 1254-1260.
51. Tukker, A., Visscher, T., & Picavet, H. (2008). Overweight and Health Problems of the Lower Extremities: Osteoarthritis, Pain and Disability. *Public Health Nutrition, 12*(3), 359-368.
52. Van der Esch, M., Steultjens, M., Knol, D., Dinant, H., & Dekker, J. (2006). Joint Laxity Modifies the Relationship between Muscle Strength and Functional Ability in Patients with Osteoarthritis of the Knee. *Annals of the Rheumatic Diseases, 65*(Suppl. 2), 408-408.
53. Van der Kraan, P., & Van den Berg, W. (2007). Osteophytes: Relevance and Biology. *Osteoarthritis and Cartilage, 15*(3), 237-244.
54. Wada, M., Tatsuo, H., Baba, H., Asamoto, K., & Nojyo, Y. (1999). Femoral Intercondylar Notch Measurements in Osteoarthritic Knees. *Rheumatology, 38*, 554-558.
55. Wang, T., Chern, H., & Chiou, Y. (2005). A Theoretical Model for Preventing Osteoarthritis-related Disability. *Rehabilitation Nursing, 30*(2), 62-7.
56. Ware, J., Kosinski, M., & Keller, S. (1996). A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care, 34*(3), 220-233.
57. Woodhead, H., Kemp, A., Blimkie, C., Briody, J., Duncan, C., Thompson, M., Lam, A., Howman-Giles, R., & Cowell, C. (2001). Measurement of Midfemoral Shaft Geometry: Repeatability and Accuracy Using Magnetic Resonance Imaging and Dual-Energy X-ray Absorptiometry. *Journal of Bone and Mineral Research, 16*(12), 2251-2259.
58. Young J and Lemaire E.D. (2012). Linking Bone Changes in the Distal Femur to Functional Deficits. *International Journal of Osteoarchaeology*. Early view (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1212/earlyview).

59. Zhai, G., Blizzard, L., Srikanth, V., Ding, C., Cooley, H., Cicuttini, F., & Jones, G. (2008). Correlates of Knee Pain in Older Adults: Tasmanian Older Adult Cohort Study. *Arthritis Care & Research*, *55*(2), 264-271.

Chapter 5. A Population Health Approach to Paleopathology: The Case of Impairment in Knee Osteoarthritis

Chapter 5, prepared for submission to a peer reviewed journal, uses the operationalized data from chapter 3 and the determinants of health tool detailed in objective 5 of the introduction to investigate the impairment potential of knee OA in two distinct archaeological populations.

A Population Health Approach to Paleopathology: The Case of Impairment in Knee Osteoarthritis

Janet L. Young and Edward D. Lemaire

Keywords = determinants of health, physical environment, social environment, Huron, Inuit, mobility, disability

5.1. Abstract

Paleopathology, the study of disease in past populations, focuses on the biological expression of disease. However, current population health models show that health outcomes are related not only to biology but to factors external to the individual. This study considers the potential impact of knee OA on the 17th century Huron of Ontario and the 19th century Inuit from the Igloolik region of Nunavut by examining factors such as the social environment, physical environment, health interventions, individual responses, and health and function, known collectively as determinants of health. The results suggest that environmental factors have a great impact on the potential for impairment in knee OA but also that the impact of knee OA varies between males and females.

5.2. Introduction

The study of health and disease in past populations relies on the interpretation of changes in the normal morphology of the human skeleton. The human skeleton holds much information about diet, activity patterns, disease processes, violence, and trauma (Aufderheide & Rodriguez-Martin, 1998; Goodman & Martin, 2002; Steckel & Rose, 2002; Ortner, 2003; Roberts & Manchester, 2007). This information is often interpreted using clinical data since "analyses with current medical research allows more informed interpretations" (Faccia & Williams, 2008, p.28). Clinical information has provided the bioarchaeologist with a framework for quantification, description, disease diagnosis, and identification of prevalence rates in past populations (Roberts, 1999). However, clinical information also informs us that living with a health condition involves more than just its biological expression, it also includes dynamic interactions with social and physical environments, healthcare interventions, and how we cope with the disease state. This expanded idea of health, an interaction of individual, social, and physical environmental factors (Gignac et al., 2008) dictates that a broader approach be adopted to fully grasp disease impact in archaeological populations, thereby requiring a paradigm shift in paleopathology from viewing the skeleton as the entire representation of the individual to the biological component of a complex entity. Population health theories and frameworks that focus on internal and external factors to the individual, also known as the determinants of health, provide the necessary tools for exploring this shift.

Osteoarthritis (OA) is caused by an imbalance in the destruction and repair of joint tissues, which leads to cartilage and subchondral bone degeneration (Fautrel et al., 2005; Hunter et al., 2008). In knee OA, this degeneration affects function and mobility through symptoms such as pain, stiffness, and instability (Cooper et al., 2000; Dieppe, 2000; Breedveld, 2004; Fitzgerald et al., 2004; Parmelee et al., 2007; Hunter et al., 2008). Movement modifications during sitting, standing, bending, and walking can occur when attempting to limit functional and sensory symptoms (Hall et al., 2008). Beyond the biological aspect, the psychological and societal influences are often studied since OA is believed to be a dynamic interaction between multiple factors, including the physical and social environments (Duncan, 2000; Bennell et al., 2003; Peters et al., 2005; Maly et al., 2006; Gignac et al., 2008; Hunt et al., 2008). These interrelationships have been cited as the probable reason why individuals with the same biological expression of knee OA often have different symptoms (Hunt et al., 2008).

While it is generally believed that bone changes have an effect on the individual, current bioarchaeological methods are only now exploring how an individual's life could be affected by lesions (Young & Lemaire, 2012). This deficiency makes it difficult to assess the impact of impairments on the individual and society. Roberts (1999, p.92) emphasized the importance of using clinical data to assess how normal function was affected by disease, indicating that "if disease or injury states are to be considered as potentially disabling, reference to the clinical record for these conditions (i.e., how they affected a person) is essential". It can further be argued that understanding the environment in which the individual is embedded is also an essential component in understanding the disability or impairment potential of a disease.

This study is a population based assessment to identify how a range of knee OA grades could affect archaeological populations. Using data from a clinical population and current population health models, this paper theorizes the potential impact knee OA could have had on two identified archaeological populations.

5.3. Theoretical Framework

5.3.1. Population Health

Population health recognizes that, instead of a state of being, health is a capacity or resource allowing an individual to pursue their goals, acquire skills and education, and grow. This broader notion of health moves beyond the absence of disease by recognizing the range of social, economic, and physical environmental factors that impact or buffer health (PHAC, 2012). This health concept can be articulated as "the capacity of people to adapt to, respond to, or control life's challenges and changes" (Frankish et al., 1996). A population health approach thus takes into consideration not only the range of individual and group factors and conditions but also their interactions (PHAC, 2001). Known as the determinants of health, these factors and conditions include social support networks, working conditions, social environments, physical environments, personal health practices and coping skills, biology, gender, and culture (PHAC, 2001).

Applying this holistic health approach to paleopathology requires adaptation of current population health frameworks. For this study, the Multiple Determinants of Health Model (Evans et al., 1994c) was chosen to guide development of a health framework that is useful for archaeological populations. Health determinants included in this revised model are social environment, physical environment, health interventions, disease profile, health and function, and individual responses (Figure 5.1). For this study, data to inform these determinants were from clinical and historic sources.

5.3.2. Health Determinants

Archaeological and ethnographic records provided data for the majority of the determinants of health used in this study since the social environment, physical environment, health interventions, and individual responses are population specific. Clinical data provided a framework for the health and function portion of the determinants model because activity information for specific movements or tasks is difficult to extrapolate from archival sources, yet remains an important factor to be considered.

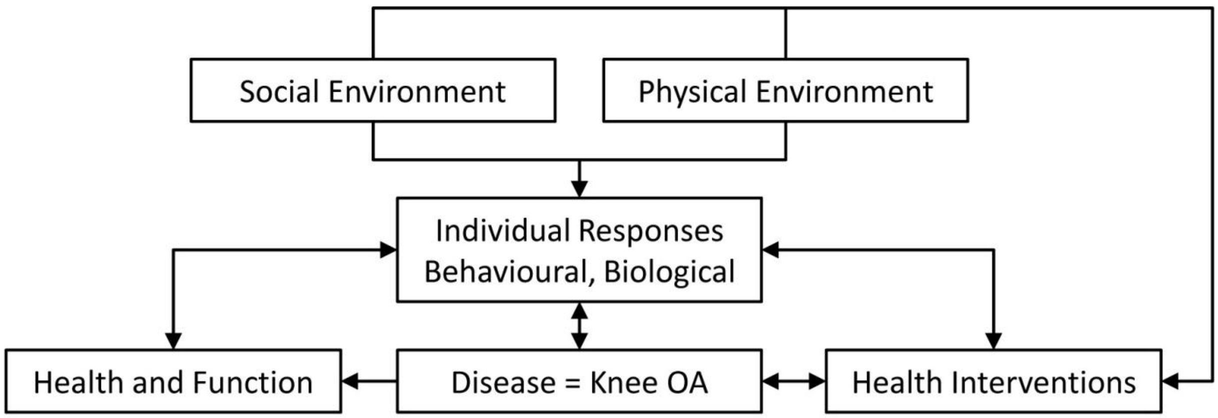


Figure 5.1: Adapted Multiple Determinants of Health Model.

5.3.2.1. Social Environment

Social environment is the human-built social construct in which people are nested and influences and shapes them as individuals and as the collective whole (Corin, 1994; Renaud, 1994). Cultural influences provide a means for the individual to reference themselves in this world and provide a framework to understand what is meaningful. These influences include norms, beliefs, and values that encompass a way of life where individuals share in behaviours and are guided by social institutions (Corrin, 1994). The framework created by the social environment also defines ill-health, the causes of ill-health, and societal perception and reaction to illness. The social environment may, through the determinants of health, heighten ill-health's effects or buffer and protect from them (Evans et al., 1994b).

Social organizations, including social networks, affect social support and isolation, emotional deprivation, stress and stress' relation to the individual's learned coping capacity (Hertzman et al., 1994). The availability of large social networks during illness can provide a buffer to poor outcomes (Evans et al., 1994a). Small family units could also supply this buffer but larger family based communities provide a wider support system with built in redundancies to compensate for failure. However, once communities grow too large, gradients in social positioning will have a negative effect on health for individuals in the least affluent echelons due to fewer resources (Evans et al., 1994a). Therefore, moderate sized family based communities could provide the necessary access to resources, varied types of work, and accommodation of individuals with mobility deficits due to knee OA.

Cultural norms and values have an impact on the concepts of health and weakness, resource sharing practices, and the role of sex and gender, including constraints on opportunities provided to men and women (e.g., culturally dictated work and duties for which each sex is deemed responsible; Corrin, 1994). Cultural norms direct when and how those with knee OA would be perceived and helped.

Social power gives people freedom to make decisions, carry out their will, and help themselves. Studies have shown that decision making power is positively correlated with health outcomes (Bosma, 1997). In the case of knee OA, social power could improve an individual's value in society, thereby making them less dispensable and more supportable if impaired. However, support for those with impairment is not only a product of social frameworks but is also dependent on the latitude that resource availability and accessibility provide.

5.3.2.2. Physical Environment

The physical environment includes both natural (air, water, food, soil, land management, flora, fauna, and climate) and built environments (housing, indoor air quality, design of communities, and transportation) (PHAC, 2003). The logistics of navigating various physical environments would be complicated by having knee OA, despite social constructs. The impact of subsistence patterns and available resources would also affect individuals whose mobility and work capacity are lessened and access to resources impeded.

5.3.2.3. Health Interventions

Health interventions are a means of interfering in the course of a disease by influencing the biological, social, or physical environment of the afflicted to improve their situation. The success of interventions for knee OA in earlier populations would depend on degree of symptom expression, the group's capacity to intervene, and the effectiveness of the interventions.

5.3.2.4. Individual Responses

Individual responses are comprised of two components, behavioural and biological. Behavioural responses are influenced by personal health practices and coping skills such as self care, self-reliance, and freedom to make choices. These coping mechanisms can be conceptualized as an individual's inherent characteristics, acquired skills, or external buffers that are naturally available (e.g., supportive families) or purposefully introduced to provide support (e.g., self-help groups or similar social support networks) (Evans et al., 1994a). The social environment plays a key role in providing supportive communities and in forming a conceptual framework in which an individual learns how to cope, based on the acceptability of expressing symptoms.

Biological responses are linked to general health status, sex, age, and social feedback. In the context of knee OA symptoms, biological and behavioural components are framed by psychological and social factors (Edwards et al., 2001; PHAC, 2003). Such factors include ethnicity and sex. Ethnicity is known to influence how pain is appraised and responded to emotionally and behaviourally (Edwards et al., 2001). Sex has an effect on pain tolerance, depending on psychological factors that are socially constructed, but does not have an effect on pain threshold (how the body processes pain perception) (Bates et al., 1993; Schiefenhovel, 1995; Nayak et al., 2000).

For the purposes of this study, the behavioural component of individual responses can be related to societal norms on physical weakness while the biological component may be determined through direct observations of a population's general health. These latter observations provide insight into "overall health capacity and outlook on life" or "general disposition", while also providing insight into the presence of adequate coping styles with positive attitude translating into positive symptom outcomes.

5.3.2.5. Health and Function

Health and function outcome probability profiles for knee OA, based on clinical populations, have been published by Young and Lemaire (2012). Knees are categorized by degree of bone change at the distal femur (0=no change to 3=advance changes) for different physical activities and states of being. These profiles are used to estimate the probability of archaeological populations experiencing impairment from knee OA.

5.4. Populations

Population selection for this study was based on two criteria, sufficient archaeological and ethnographic information to populate the determinant categories and contrasting populations of different subsistence patterns and/or geographic profiles. The 17th century Ontario Huron and the 19th century Inuit population of the Igloolik region of Nunvaut were chosen.

5.4.1. 17th Century Huron

5.4.1.1. Social Environment

The Huron engaged in a clan based society, with representatives from eight matrilineal clans present in most villages. This organizational structure formed the foundation of the village, including the functioning of political life, marital selections, support systems, and distribution of resources (Anderson, 1985). All members of each village society were guaranteed access to both the means of production and the products of social labor through this gender-based kinship (Anderson, 1985).

The Huron economy was centered on horticulture (corn, squash, beans) while fishing, hunting and gathering, and barter were of less importance (Anderson, 1985). Women controlled horticulture through matrilocal production units with matrilineal decent groups ensuring the continued management of resource production (Dannin, 1982). This made the matrilineal extended family not only the basic social group but also the main economic unit (Heidenreich, 1978).

A village was made up of several longhouses, with each longhouse forming a unit of familial, social, and economic cooperation (Heidenreich, 1978). A longhouse held three to six related family groups, with each family having a dedicated space (Heidenreich, 1978; Anderson, 1985; Trigger 1987). Women were the charge of the longhouse daily activities.

The central figures, decision makers, ritual position holders, and ceremonial leaders were mature men who, in youth, had proven themselves worthy (Heindenreich, 1978; Trigger 1987). Women did not take part in councils, the group's decision making bodies, which were primarily attended by 'old' men (those over 30 years) and clan chiefs (Heidenreich, 1978). However, given their positions in the longhouse, mature women were the strongest voices in all matters of the family (Trigger, 1987).

Huron cultural norms not only framed how individuals lived but also created a strong sense of responsibility towards the community (Trigger, 1987, p. 50). Huron society emphasized individual freedoms for both men and women while expecting each individual to maintain a gentle and considerate air and repress their feelings, especially of anger or frustration (Trigger, 1987). Strength in the face of pain, torture, war, and childbirth was admired and respected (Champlain, 1608-1613; Trigger, 1987) with an expectation that a Huron was "to die as bravely as he had lived" (Trigger, 1987, p. 52). To this end, children, especially boys, were encouraged to become self-reliant, courageous, and to endure misfortune with strength and resilience. Public displays of emotion were viewed with scorn by the community (Trigger, 1987).

When circumstances allowed, all Huron were expected to share their wealth freely and without complaint with hospitality, gift giving, and exchange not only playing important roles but also providing strong social approval and accruing social status (Heidenreich, 1978; Trigger, 1987). Though each woman could maintain a cache of goods, individuals who hoarded met with village disapproval, accusations of witchcraft, or even expulsion. No person was permitted to go hungry if food remained in the household (Heidenreich, 1978; Trigger, 1987).

Amongst the Huron, the division of labour was gender based (Anderson, 1985). Men hunted, fished, cleared new land, built lodges, left on trading and war expeditions, were responsible for safety and order, and created links with the outside world (Herman, 1956; Langton & Ganong, 1971; Heidenreich, 1978; Anderson, 1985; Trigger, 1987). During the summer, some men would stay close to the village to protect against raids, but they would also help with odd jobs or go fishing and hunting close by (Heidenreich, 1978).

Women provided almost all the horticultural labour; including, planting, hoeing, harvesting, pulling weeds, and chasing away pests (Herman, 1956; Heidenreich, 1978; Anderson 1985). They also gathered all the firewood and performed domestic work; such as child care, making household goods, clothing, pottery, thread, and fishing-nets, and preparing food (Langton & Ganong, 1971; Heidenreich, 1978; Anderson, 1985). Women could also assist in the hunts by driving, butchering, and transporting game (Heidenreich, 1978; Trigger, 1987). Women typically did not travel outside Huron territory, especially for lengthy canoe trips (Trigger, 1987).

5.4.1.2. Physical Environment

The 17th century Huron occupied a narrow stretch of land in southern Ontario, measuring approximately thirty-five miles long and twenty miles wide, bounded by Georgian Bay on the west and Lake Simcoe on the east (Anderson, 1985, p. 51). This area, known as Huronia, was a region of arable soils surrounded by water and low-lying untouched swamp (Heidenreich, 1978). The four occupied upland areas were generally bounded by steep, boulder-strewn, recessional shorelines.

Huron communities were large, averaging four to five acres, with approximately 800 people or less. A few villages grew to over 1,000 or 1,600 (Heidenreich, 1978). A village is defined by a cluster of longhouses, usually three to four yards apart, with small open areas scattered throughout. Apart from the main village, temporary camps were seasonally employed for hunting, fishing or tending corn fields (Ramsden, 1990). Archaeological evidence suggests that some seasonal sites were mainly occupied by women and children. Satellite short and long-term hamlets were also found close to the major villages.

The Huron's principle subsistence, horticulture, allowed them to create larger, economically self-sufficient, agricultural settlements (Heidenreich, 1978). Hunting and fishing were less important, with gathering only important in times of famine, presumably due to crop failure. Famine rarely occurred, perhaps every 10 years, making agricultural subsistence very stable.

A system of extensive walking trails constituted the main transportation routes. Water transportation was not used within Huronia but canoe travel was often used by men who ventured outside the territory. Travel in winter was difficult and largely avoided, except for ice fishing and some socializing with nearby villages (Heidenreich, 1978). During winter, loads were pulled on wooden sleds (Langton & Ganong, 1971).

5.4.1.3. General Health and Health Interventions

The 17th century Huron's concept of health mirrors the current WHO definition as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 2003). As such, the Huron believed that an individual's health was not restricted to the physical but encompassed all things affecting happiness, personal fulfillment, or luck (good or bad) (Trigger, 1987).

Historic reports suggested that the Huron were unusually healthy, generally happy, and believed that they had an excellent life (Langton & Ganong, 1971; Heidenreich, 1978). The Shaman were males and were considered important and prominent. Shaman intervened when illness occurred, using herbal medicine, good sense, and community supported ceremonies to heal their charges (Heidenreich, 1978; Trigger, 1987).

5.4.2. 19th Century Inuit from Igloolik Region of Nunavut

5.4.2.1. Social Environment.

In the 19th century, the Inuit from the Igloolik region of Nunavut had little political or social unity. Composed principally of simple family units that allowed for rapid mobility, they followed rules established by custom, habit, and tradition, in particular taboos passed from generation to generation (Mathiasson, 1928; Fitzhugh, 1997). Though often dispersed, these smaller groups maintained distant kin relations and trading partners to engage in information sharing and hospitality (Fitzhugh, 1997). These extended family groups not only lived together but formed the principal unit of cooperation, exchange, and distribution (Mary-Rousselière, 1984). Any meat was distributed throughout the community as it was their practice to share (Rasmussen, 1930). If group customs were not followed, an individual could be eliminated from the community (Mary-Rousselière, 1984). Males were dominant in the household, with older males making the decisions and coordinating group activities (Mathiasson, 1928; Mary-Rousselière, 1984).

Traditionally men hunted, sometimes requiring long trips to procure food and skins. They also fished, built houses, scraped skins, and made sledges and implements. Women stayed mostly indoors during the day, sewing clothes and preparing skins. They fished infrequently and rarely helped in the hunt, but could periodically assist by carrying meat (Mathiasson, 1928; Rasmussen, 1930).

Inuit cultural norms were a product of circumstances. When resources were plentiful a communism prevailed. The family had a duty to care for all helpless persons, including fatherless children, widows, and old men and women who could no longer keep up on the constant hunting expeditions (Mathiasson, 1928; Rasmussen, 1930). Individuals who lacked immediate family became the responsibility of the extended group, who could choose to take care of the person or leave them to their fate. The latter was the frequent outcome for old women who were thought to be useless (Rasmussen, 1930).

When resources were meagre and people struggled to subsist, which occurred frequently, the weak and dependent often became disposable to reduce the number of mouths to feed. “Orphan children were blocked up in snow huts and left there, buried alive … Old and worn-out folk would be left behind on the road when unable to keep up with the rest on a journey … Sometimes also, the party would simply neglect to take them along when first setting out from the old site” (Rasmussen, 1930, p.159).The same would apply to those considered crippled (Low, 1906). The choice of leaving someone behind was often made on the hope that this would secure the survival of the remainder of the group (Low, 1906). These actions were so culturally accepted that the weak or old would often choose to commit suicide rather than to be a burden on their family (Low, 1906).

5.4.2.2. Physical Environment

During winter, there is a sameness to the landscape with an absence of trees or tall vegetation and the entirety covered in a blanket of snow (Mathiasson , 1928; Stager & McSkimming, 1984). In summer, the coasts are rocky with many loose fragments lying at odd angles and little vegetation (Mathiasson, 1928; Merbs, 1983; Maxwell, 1985). This ‘shingled’ terrain makes walking difficult and falling a possible hazard (Merbs, 1983).

"Few conditions in world history … imposed environmental stresses on the hunters and their communities as severe as those of the Eastern Arctic" (Maxwell, 1985, p. 2). This applies to the 19th century Inuit who adopted a roaming lifestyle, with the pursuit of food being the primary goal (Mary-Rousselière, 1984; Maxwell, 1985). Housing for these nomadic groups consisted of tents in the summer and snow houses in the winter. The small familial groups could sometimes come together for certain hunting pursuits. These usually occurred in winter, making the transient settlements more populated in winter than in summer when populations scatter for hunting and fishing, the primary subsistence (Mathiasson, 1928).

Marine and terrestrial animals formed most of the Inuit diet. Resource failure was a constant threat in an Arctic system that, compared to temperate climate ecological systems, had few species (Fitzhugh, 1997). This made the Arctic less stable, requiring those reliant on northern subsistence strategies to have methods for rapid adjustment (Fitzhugh, 1997). Despite their adaptability, sudden disappearances of game lead to periods of Inuit starvation (Maxwell, 1985).

With the sea covered in ice and the ground covered in snow 9-10 months of the year, sledges pulled by dogs were the most frequently used mode of transportation (Mary-Rousselière, 1984). In times without snow, the Inuit walked, carrying what they needed or loading packs on their dogs. The summer was considered to be a poor time to travel due to the terrain (Maxwell, 1985). Kayaks were used in open water (Mathiasson, 1928).

5.4.2.3. General Health and Health Interventions

The contact Inuit, as with the 17th century Huron, had a very holistic view of health "where mind, body, and spirit are intrinsically linked and a weakness in one will surface as a weakness in another aspect" (Black et al., 2008, p. 157). As such, their healing techniques incorporated not only an extensive knowledge of the human body but of the person, with the body being viewed as a whole in relation with its social environment (Tipula et al., 2001).

The Inuit were fatalistic, believing themselves powerless. A complex system of taboo and propitiatory rites and sacrifices was considered necessary to maintain a balanced life (Rasmussen, 1930). Overseeing this realm was the Angakut or Shaman (healer) who promoted physical, emotional, and spiritual wellness by a strict set of rules that governed each person's behaviour and established each individual's relationship with the community (Rasmussen, 1930). The importance of family was emphasised for personal and community integrity (Gray, 1996). The more concrete forms of intervention for aches and pains were ointments, heated cloths containing clay, or broths (Gray, 1996; Tipula et al., 2001; Black et al., 2008).

By nature, the Inuit appeared to have been proud, independent, have a sense of gratitude, slow to anger, and good natured, but capable of ungovernable bursts of rage when roused (Low, 1906). Accounts of survival attest to their resiliency and determination (Rasmussen, 1930). They appeared accustomed to the extreme cold, being described in harsh conditions as acting "as if there were no such thing as cold" (Rasmussen, 1930, p. 13) and "altogether unaffected by the cold" (Rasmussen, 1930, p. 14). Some people who were characterized as cripples were also considered hard workers, another indication of the Inuit's resiliency (Rasmussen, 1930).

5.5. Methods

Systematically combining the determinants of health, historic, archaeological, ethnographic, and clinical data into a useable format requires a system that quantifies the possible impact of knee OA on the selected populations. A new approach was developed to accomplish this goal.

5.5.1. Health determinants data

For this study, the determinants of health and their respective subcategories are:

- **Social environment**: social networks, societal values, norms for physical or mental weakness and access to resources, work, power distribution, social support for ill health
- **Physical environment**: terrain, resources, subsistence, climate, housing, transportation
- **Health intervention**
- **Individual responses**: reported group biological health, general disposition (life outlook)

A scoring system for these health determinant subcategories was created. The subcategories were defined by four descriptions, with 0 defining the least and 3 defining the most impact on positive outcomes (Table 5.1). The populations were examined by sex since certain determinants of health, such as work, are sex specific. The most applicable description for each determinant subcategory was identified and the relevant score noted. Summing the scores for all the factors provided a health determinant impact score (HDIS-sum).

5.5.2. Clinical Knee Osteoarthritis Data

The clinical data for this study, consisting of significantly correlated functional outcome probabilities, was derived from previous research by Young and Lemaire (2012).

Table 5.1**:** Scoring system for health determinant subcategories.

Determinant	Health Determinates Impact Score			
Social Environment	3	2	1	0
social networks	family and extended family	multiple family and extended family groups	multiple family and extended family groups with many social networks	many multiple family and extended family groups (moderate to large society) with many social networks
societal values and norms : weakness	expressing weakness punished	expressing weakness deterred and cajoled	expressing weakness tolerated	expressing weakness supported
societal values and norms: access to resources		resources not shared	resources shared when available	all resources shared
work	very physically demanding and extensive mobility requirements including running	physically demanding and moderate mobility (walking some distance)	physically demanding (e.g. squatting, lifting, bending, carrying loads) but little mobility	few physical demands, little mobility
social power female	males have all decision making power	males make major decisions and females have input in limited matters	males make major decisions but females have considerable input	equal power distribution or females have majority of power
social power male	females have all decision making power	females make major decisions and males have input in limited matters	females make major decisions but males have considerable input	equal power distribution or males have majority of power
social support for ill health	no support	intermittent support when resources allow	physical support	complete emotional and physical support

Physical Environment	3	2	1	0
terrain	hilly and rocky	hilly	flat but rocky	flat
resources	poor	intermittent	plentiful but occasional famine	plentiful
subsistence		hunter and gatherer	horticultural, hunter and gatherer	horticultural
climate	seasonal with short cool summer and extreme winter	seasonal with extreme summer and winter	seasonal with moderate summer and winter	temperate
housing	temporary	temporary with seasonally permanent	permanent with seasonal camping	permanent
transportation	mostly walking	mostly walking with some riding	mostly riding with some walking	mostly riding (canoe, sledge, horse, etc.)

Health Care	3	2	1	0
interventions available	none	shaman	shaman and natural healing methods	doctors and medicine

Individual Response	3	2	1	0
general disposition		mostly ill-tempered	happy and ill-tempered on occasion	happy and good tempered
reported group biological health	mostly ill	physically weak	healthy	unusually healthy

These probabilities were produced by correlating outcome variables to degree of knee OA as assessed using the Clinical and Archaeological Osteoarthritis Score (CAOS) grading system (Table 5.2). Given noted sex differences in outcome profiles, each sex within a given population was examined separately.

From the clinical data, only outcome variables related to activities applicable to the chosen archaeological populations were utilized (e.g., walking, running, standing, bending, light and heavy chores). For each outcome variable, probabilities at each CAOS grade were calculated for the right knee, left knee, or non-knee specific cases.

The functional impact probability score (FIPS) generates an overall measure that relates knee OA severity to functional impact. FIPS represents the functional component of the determinates of health model.

Probability scores for all knees, at the CAOS grade for each knee, are averaged. Since both knees may not have the same CAOS grade, the probability outcomes were dependent on how each knee was scored. The non-knee specific outcome variables (e.g., accomplish less) were scored by the highest CAOS grade of the right and left knees. For example, if the right knee was at CAOS grade 1 and the left at CAOS grade 3, the grade 3 probability for the non-specific outcome variable would be used.

Combining the health determinants and clinical data

Quantified determinants of health data (HDIS-sum) were multiplied by quantified clinical data (FIPS) to create a knee OA impact index (KOII).This score quantified the potential impact knee OA might have had on the identified archaeological populations. Various scenarios (e.g., right knee at CAOS grade one and left knee at CAOS grade three) for the two populations were then calculated and compared.

5.6. Results

The health determinants grading system was applied to the four population groups; 17th century Huron males, 17th century Huron females, 19th century Inuit males, 19th century Inuit females (Table 5.3). The 17th century Huron males had a HDIS-sum of 12 and females of the same population a similar score of 13. This score reflects a relatively large and stable society, plentiful resources, an easy physical environment, interventions available, and a generally happy and healthy population. The 19th century Inuit of Igloolik had much higher HDIS-sum scores of 25 for both males and females since the small family groups had limited resources, intermittent support for the weak, and existed in one of the harshest physical environments on the planet.

The FIPS results (Table 5.4) show a greater probability of females having poor functional outcomes than males. From the KOII results (Table 5.4), knee OA would have had a greater impact on health in the Inuit population but more specifically on females, who have worse expected outcomes than both Inuit males and females in the 17th century Huron population. The 17th century Huron males would expect the least impact from knee OA, amongst the populations considered.

Table 5.2: Probability profiles by sex for various OAI outcome variables at each CAOS grade.

	CAOS grade			
Female Sample - Outcome Variables	0	1	2	3
right disability bending	0.39	0.56	0.72	0.91
right disability light chores	0.49	0.54	0.7	0.91
accomplish less	0.59	0.66	0.67	0.8
right pain bending knee fully	0.37	0.39	0.52	0.8
left pain twisting/pivoting	0.43	0.45	0.47	0.67
right disability standing	0.39	0.39	0.52	0.6
right disability walking	0.27	0.31	0.6	0.6
difficulty running	0.06	0.15	0.27	0.6
moderate activities	0.25	0.31	0.37	0.53
left pain in bed	0.2	0.31	0.32	0.4
Male Sample - Outcome Variables	0	1	2	3
overall difficulty with knee	0.61	0.74	0.85	1
right pain walking	0.09	0.39	0.52	0.73
right disability sit from stand	0.26	0.46	0.67	0.73
modify lifestyle to avoid damaging knee	0.39	0.56	0.65	0.73
right disability light chores	0.22	0.28	0.59	0.7
left disability light chores	0.26	0.32	0.43	0.7
left disability heavy chores	0.17	0.19	0.4	0.7
limited in kind of work	0.3	0.38	0.57	0.64
left pain walking	0.13	0.29	0.5	0.64
left pain standing	0.17	0.44	0.46	0.64
right pain straightening knee fully	0	0.21	0.35	0.64
right pain bending knee fully	0	0.36	0.43	0.64
left pain twisting/pivoting	0.17	0.35	0.48	0.64
left pain bending knee fully	0.17	0.36	0.43	0.64
left disability sit from stand	0.22	0.42	0.63	0.64
left disability walking	0.17	0.24	0.46	0.64
difficulty squatting	0.13	0.4	0.48	0.64
right disability bending	0.22	0.32	0.6	0.6
left disability bending	0.26	0.32	0.44	0.6
left pain sitting or lying down	0.17	0.25	0.37	0.55
right disability walking	0.13	0.2	0.37	0.55
left disability standing	0.13	0.3	0.46	0.55
right disability heavy chores	0.09	0.16	0.4	0.5
left pain in bed	0.13	0.16	0.33	0.45
right pain twisting/pivoting	0.05	0.28	0.45	0.45
left pain straightening knee fully	0.09	0.2	0.39	0.45
right disability standing	0.13	0.33	0.37	0.45
difficulty running	0.09	0.23	0.24	0.27
difficulty jumping	0.09	0.15	0.26	0.27

Table 5.3: Health determinants grading scores (HDIS) and sums for the four population groups.

Determinants of Health	Populations			
Social Environment	Huron Male	Huron Female	Inuit Male	Inuit Female
social networks	0	0	3	3
societal values and norms : weakness	2	2	2	2
societal values and norms: access to resources	0	0	1	1
work	2	2	3	1
social power female		1		2
social power male	0		0	
social support for ill health	0	0	2	2
Physical Environment				
terrain	0	0	1	1
resources	1	1	2	2
subsistence	1	1	2	2
climate	1	1	3	3
housing	1	1	2	2
transportation	2	2	1	1
Health Care				
interventions available	1	1	1	1
Individual Response				
general disposition	1	1	1	1
reported group biological health	0	0	1	1
HDIS-sum	12	13	25	25

Table 5.4: FIPS and KOII results for the Huron and Inuit populations.

		Females			Males		
CAOS Grade		FIPS	KOII		FIPS	KOII	
Right	Left	Score	HDIS- sum Huron =13	HDIS- sum Inuit = 25	Score	HDIS- sum Huron =12	HDIS-sum Inuit = 25
0	0	0.33	4.29	8.25	0.21	2.52	5.25
0	1	0.36	4.68	9	0.26	3.12	6.5
0	2	0.38	4.94	9.5	0.33	3.96	8.25
0	3	0.45	5.85	11.25	0.41	4.92	10.25
1	0	0.37	4.81	9.25	0.29	3.48	7.25
1	1	0.4	5.2	10	0.34	4.08	8.5
1	2	0.42	5.46	10.5	0.41	4.92	10.25
1	3	0.49	6.37	12.25	0.48	5.76	12
2	0	0.45	5.85	11.25	0.36	4.32	9
2	1	0.48	6.24	12	0.4	4.8	10
2	2	0.5	6.5	12.5	0.48	5.76	12
2	3	0.57	7.41	14.25	0.55	6.6	13.75
3	0	0.56	7.28	14	0.41	4.92	10.25
3	1	0.59	7.67	14.75	0.45	5.4	11.25
3	2	0.6	7.8	15	0.52	6.24	13
3	3	0.67	8.71	16.75	0.6	7.2	15

5.7. Discussion

The effects of knee OA on the afflicted individual are symptom based. Pain, stiffness, and instability impact an individual's capacity for function and mobility, leading to movement modifications to avoid symptom intensity. Not surprising, the probability of having difficulty with certain activities has been correlated to an increasing degree of knee OA. It is also expected that social and physical environment variables are affected when coping with this affliction. The population examples chosen for this research were extremes, highlighting the different impact knee OA could have had on individuals, based on their life circumstances.

Results indicated that mobility limitations related to HDIS and knee OA would have had a greater impact on societies like the 19th century Inuit, whose nomadic lifestyle meant that all individuals had to keep up during the pursuit of food. The 17th century Huron, who had a relatively sedentary lifestyle, didn't have the same mobility requirements. Mobility was also impacted by the type of terrain individuals had to navigate and transportation methods used. Huronia was flat and well soiled, providing little resistance for tilling and travel, and the main transportation method was walking on a system of trails. Nunavut's Igloolik region was relatively flat and rocky (uneven surface), which made summer travel difficult and winter travel on sleds over snow covered terrain easier. As expected, the Inuit scored worse for all the physical environment factors except transportation.

The health determinant subcategory scores for social environment factors were less dichotomous than those for physical environment, with the Huron exhibiting better scores for four of seven factors (social networks, societal values and norms: access to resources, female social power, and social support for ill health), equivalent scores for two factors (societal values and norms: weakness, male social power), and split scores for one factor (work).

The movement modifications required to avoid or mitigate symptom intensity could have led to limitations in work capacity. For the Huron, males and females both required physical endurance for lower limb oriented tasks such as walking, running, bending, straightening, kneeling, twisting, and pivoting (health determinant subcategory scored of 2). However, this moderately large society was complex enough to provide options for activity requirements. For example, if a male had difficulties with travel, he could remain in the village and assist with small jobs and local hunting. For the Inuit, work by males required physical and mental endurance, with many tasks recruiting the lower limb, including walking and running on uneven and hazardous terrain (health determinant subcategory score of 3). Typical female tasks required less physical endurance though, when occasion presented, they could assist in transporting game or moving camps, which required load carriage (health determinant subcategory score of 1).

If movement modifications limited an individual's ability to work, they would need societal support to provide adequate access to living resources. Such support is linked to the society's size and its established norms for sharing resources. Entitlement to these resources could be based on an individual's political clout or power, the society's compassion, or simply access to resource surpluses. The 17th century Huron lived in large villages and relied on a fairly stable subsistence of horticulture. Both males and females had social power. The cultural norms of sharing and cooperation were emphasized. Resources were plentiful and sharing food ensured that no one would go hungry. Although famine could occur, this was relatively infrequent.

The 19th century Inuit from Nunavut's Igloolik region had an unstable food source, dictating that the majority of their time was spent in its pursuit. Their social structure was based on small family units that could expand to include multiple families, who would cooperate in certain hunting traditions. Males, especially older males, were the decision makers while older females were at times considered disposable. Sharing of food was the cultural norm, though famine was a common occurrence. Weakness due to age or illness was tolerated when resources allowed but when they were meagre those that exhibited weakness became expendable.

When dealing with knee OA symptoms, interventions would have been necessary to improve outcome potential, especially in the most severe cases. For both the Huron and Inuit, interventions were provided by a Shaman who used ritual and herbal remedies. These interventions were limited and their success unclear.

Beyond the symptoms generated by knee OA, research has shown that mobility or movement limitations are also a product of an individual's general health and overall outlook on life (Maly et al., 2006). A positive approach to knee OA leads to better functional outcomes, including performance. Both example populations exhibited a reputed hardiness and general positive nature, though the Huron scored slightly better on reported biological health.

The HDIS results demonstrated various non-biological differences impacting impairment outcomes for both groups. The scores reflected the contrasting environments surrounding the 19th century Inuit populations and the 17th century Huron groups and provided a quantification of the various influences affecting the populations. However, the biological aspect of OA, including functional outcome considerations (FIPS), also has an influence on impairment potential. Combining HDIS-sums and FIPS into KOII scores integrated multiple factors that contribute to function and overall health of the individual, with ‘health’ defined as a resource for living that provides a capacity to adopt and cope with life’s challenges. It is not surprising, given the variables considered in producing the KOII, that the Inuit female group had the worse KOII scores overall, with their male counterparts close behind. The environment in which the Inuit were embedded was extremely harsh, both socially and physically, leading to functional differences between societies.

5.8. Conclusion

Population health research has demonstrated that social and physical environmental factors impact people afflicted with different health conditions, including OA. It can be argued that this also applies to earlier populations where the human condition is not entirely dissimilar to that of today. Examining a disease state in archaeological populations without the benefit of contextual information limits our understanding to the biological aspect of the condition. However, individuals are more than simple biological entities, they are biopsychosocial composites born, shaped, and embedded in social and physical environments. To understand the impact of disease, bioarchaeological researchers must embrace this holistic view and not limit examinations to a restrictive biological lens that places every geographical and cultural group of varying circumstance on equal footing.
To optimize our understanding of health and disease in past populations, individuals must be considered as more than simply physical remains but complex biological entities, people, nested in dynamic physical and social environments. Though bioarchaeologists may not have all the information required to place a skeletal population in their full contextual environments, attempts should be made to assess the potential impact these external

influences may have had. Using the example of knee OA, a method was developed to incorporate many of these non-biological factors into the dialogue of disease impact in archaeological populations. This research demonstrates the potential for paleopathological analysis through a holistic lens and can act as a template for further assessments, with possible adaptations providing an allowance for missing data.

5.9. Acknowledgements

The authors would like to acknowledge the support of the Canadian Museum of Civilization and The Ottawa Hospital Rehabilitation Centre. Dr. Jean-Luc Pilon is acknowledged for his comments on an earlier draft.

5.10. Literature Cited

1. Anderson, K. (1985). Commodity Exchange and Subordination: Montagnais-Naskapi and Huron Women, 1600-1650. *Signs, 11*(1), 48-62.
2. Aufderheide, A., & Rodriguez-Martin, C. (1998). *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge: Cambridge University Press.
3. Bates, M., Edwards, W., & Anderson, K. (1993). Ethnocultural Influences on Variation in Chronic Pain Perception. *Pain, 52*, 101-112.
4. Bennell, K., Hinman, R., Mecalf, B., Crossley, K., Buchbinder, R., Smith, M., & McColl, G. (2003). Relationship of Knee Joint Proprioception to Pain and Disability in Individuals with Knee Osteoarthritis. *Journal of Orthopaedic Research, 21*, 792-797.
5. Black, P., Arnason, J., & Cuerrier, A. (2008). Medicinal Plants used by the Inuit of Qikiqtaaluk (Baffin Island, Nunavut). *Botany, 86*, 157-163.
6. Bosma H, Marmot M, Hemingway H, Nicholson A, Brunner E, Stansfeld S. 1997. Low Job Control and Risk of Coronary Heart Disease in Whitehall ii (Prospective Cohort) Study. *British Medical Journal, 314*, 558.
7. Breedveld, F. (2004). Osteoarthritis – the Impact of a Serious Disease. *Rheumatology, 43*(Suppl.1), i4-i8.
8. Champlain, S. (1608-1613). *The Works of Samuel de Champlain Volume II 1608-1613*. Translated by John Squair.

9. Cooper, C., Snow, S., McAlindon, T., Kellingray, S., Stuart, B., Coggon, D., & Dieppe, P. (2000). Risk Factors for the Incidence and Progression of Radiographic Knee Osteoarthritis. *Arthritis and Rheumatism, 43*(5), 995-1000.
10. Corin, E. (1994). The Social and Cultural Matrix of Health and Disease. In Evans, R., Morris, L., & Marmor, T. (Eds). *Why are some people health and others not?* (pp. 93-132). New York: Aldine de Gruyter.
11. Dannin, R. (1982). Forms of Huron Kinship and Marriage. *Ethnology, 21*(2), 101-110.
12. Dieppe, P. (2000). Towards a Better Understanding of Osteoarthritis of the Knee Joint. *The Knee, 7,* 135-137.
13. Duncan, G. (2000). Mind-Body Dualism and the Biopsychosocial Model of Pain: What Did Descartes Really Say? *Journal of Medicine and Philosophy, 25*(4), 485-513.
14. Edwards, C., Fillingim, R., & Keefe, F. (2001). Race, Ethnicity and Pain. *Pain 94*, 133-137.
15. Evans, R., Hodge, M., & Pless, I. (1994a). If not Genetics, then what? Biological Pathways and Population Health. In Evans, R., Morris, L., & Marmor, T., (Eds), Why are some people health and others not? (pp. 161-188). New York: Aldine de Gruyter.
16. Evans, R., Morris, L., & Marmor, T. (1994b). Preface. In Evans, R., Morris, L., & Marmor, T., (Eds), Why are some people health and others not? (pp. ix-xix). New York: Aldine de Gruyter.
17. Evans, R., & Stoddart, G. (1994c). Producing Health, Consuming Health Care. In Evans, R., Morris, L., & Marmor, T., (Eds), Why are some people health and others not? (pp. 27-66). New York: Aldine de Gruyter.
18. Faccia, K., & Williams, R. (2008). Schmorl's Nodes: Clinical Significance and Implications for the Bioarchaeological Record. *International Journal of Osteoarchaeology, 18,* 28-44.
19. Fautrel, B., Hilliquin, P., Rozenberg, S., Allaert, F., Coste, P., Leclerc, A., & Rossignol, M. (2005). Impact of Osteoarthritis: Results of a Nationwide Survey of 10,000 Patients Consulting for OA. *Joint Bone Spine, 72*, 235-240.
20. Fitzgerald, G., Piva, S., & Irrgang, J. (2004). Reports of Joint Instability in Knee Osteoarthritis: Its Prevalence and Relationship to Physical Function. *Arthritis and Rheumatism, 51*(6), 941-646.

21. Fitzhugh, W. (1997). Biogeographical Archaeology in the Eastern North American Arctic. *Human Ecology, 25*(3), 385-418.

22. Frankish, C., Green, L., Ratner, P., Chomik, T., & Larsen, C. (1996). *Health Impact Assessment as a Tool for Population Health Promotion and Public Policy*. Vancouver: Institute of Health Promotion Research, University of British Columbia.

23. Gignac, M., Backman, C., Davis, A., Lacaille, D., Mattison, C., Montie, P., & Badley, E. (2008). Understanding Social Role Participation: What Matters to People with Arthritis? Journal *Rheumatology, 35*, 1655-1663.

24. Goodman, A., & Martin, D. (2002). Reconstructing Health Profiles from Skeletal Remains. In Steckel, R. & Rose, J. (Eds). *The Backbone of History: Health and Nutrition in the Western Hemisphere* (pp. 11-60). Cambridge: Cambridge University Press.

25. Gray, G. (1996). Health Care in North Must Acknowledge Inuit Values, Traditional Medicine. *Canadian Medical Association Journal, 155*(11), 1613-1614.

26. Hall, M., Migay, A., Persad, T., Smith, J., Yoshida, K., Kennedy, D., & Pagura, S. (2008). Individuals' Experience of Living with Osteoarthritis of the Knee and Perceptions of Total Knee Arthroplasty. *Physiotherapy Theory and Practice, 24*(3), 167-181.

27. Herman, M. (1956). The Social Aspect of Huron Property. *American Anthropologist, New Series, 58*(6), 1044-1058.

28. Hertzman, C., Frank, J., & Evans, R. (1994). Heterogeneities in health status and the determinants of population health. In Evans, R., Morris, L., & Marmor, T. (Eds). *Why are some people health and others not?* (pp. 67-92). New York: Aldine de Gruyter.

29. Heidenreich, C. (1978). Huron. In Sturtevant, W. (Ed), *Handbook of North American Indians: Volume 15 Northeast* (pp.368-388).

30. Hunt, M., Birmingham, T., Skarakis-Doyle, E., & Vandervoort, A. (2008). Towards a Biopsychosocial Framework of Osteoarthritis of the Knee. Disability *& Rehabilitation, 1*, 54-61.

31. Hunter, D., Niu, J., Zhang, Y., LaValley, M., McLennan, C., Hudelmaier, M., Echstein, F., & Felson, D. (2008). Premorbid Knee Osteoarthritis is not Characterised by Diffuse Thinness: the Framingham Osteoarthritis Study. *Annals of the Rheumatic Diseases, 67*, 1545-1549.

32. Low, A. (1906). *The Cruise of the Neptune 1903-04*. Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on Board the D.G.S. Neptune 1903-1904.

33. Maly, M., Costigan, P., & Olney, S. (2006). Determinants of Self-Report Outcome Measures in People with Knee Osteoarthritis. *Archives of Physical Medicine and Rehabilitation, 87*(1), 96-104.

34. Mann, R., & Hunt, D. (2005). *Photographic Regional Atlas of Bone Disease*. Illinois: Charles C Thomas Publisher Ltd.

35. Mary-Rousselière, G. (1984). Iglulik. In Damas, D. (Ed). *Handbook of North American Indians*, Vol. V, Arctic, (pp.431-446). Washington: Smithsonian Institution.

36. Mathiasson, T. (1928). Material Culture of the Iglulik Eskimos. *Report of the Fifth Thule Expedition 1921-1924, Vol. 6*(1).

37. Maxwell, M. (1985). *Prehistory of the Eastern Arctic*. Academic Press, Inc. Harcourt Brace Jovanovich Publishers.

38. Merbs, C. (1983). *Patterns of Activity-Induced Pathology in a Canadian Inuit Population*. National Museum of Man Mercury Series, Archaeological Survey of Canada Paper #119.

39. Nayak, S., Shiflett, S., Eshun, S., & Levine, F. (2000). Culture and Gender Effects in Pain Beliefs and the Prediction of Pain Tolerance. *Cross-Cultural Research, 34*(2), 135-151.

40. Ortner, D. (2003). *Identification of Pathological Conditions in Human Skeletal Remains*. California: Academic Press.

41. Parmelee, P., Harralson, T., Smith, L., & Schumacher, H. (2007). Necessary and Discretionary Activities in Knee Osteoarthritis: Do They Mediate the Pain–Depression Relationship? *Pain Medicine, 8*(5), 449-462.

42. Peters, T., Sanders, C., Dieppe, P., & Donovan, J. (2005). Factors Associated with Change in Pain and Disability over Time: A Community-based Prospective Observational Study of Hip and Knee Osteoarthritis. *British Journal of General Practice, 55*(512), 205-211.

43. PHAC (Public Health Agency of Canada) (2012). *What is the Population Health Approach?* Retrieved from http://www.phac-aspc.gc.ca/ph-sp/approach-approche/index-eng.php.
44. PHAC (Public Health Agency of Canada) (2001). *What is the Population Health Approach*? Retrieved from http://www.phac-aspc.gc.ca/ph-sp/approach-approche/appr-eng.php#history).
45. PHAC (Public Health Agency of Canada) (2003). *What makes Canadian Healthy or Unhealthy?* Retrieved from http://www.phac-aspc.gc.ca/ph-sp/determinants/determinants-eng.php#physenviron.
46. Ramsden, P. (1990). The Hurons: Archaeology and Culture History. In Ellis, C. & Ferris, N., *The Archaeology of Southern Ontario to A.D. 160*. Occasional Publication of the London Chapter, OAS Number 5.
47. Rasmussen, K. (1930). *Intellectual Culture of the Hudson Bay Eskimos. Report of the Fifth Thule Expedition 1921-21 Vol. 3*(1).
48. Renaud, M. (1994). The Future: Hygeia Versus Panakeia? In Evans, R., Morris, L., & Marmor, T. (Eds). *Why are some people health and others not?* (pp. 317-334). New York: Aldine de Gruyter.
49. Roberts, C. (1999). Disability in the Skeletal Record: Assumptions, Problems and Some Examples. In Finlay, N. (Ed). *Disability and Archaeology* (pp.79-98). Archaeological Review of Cambridge 15(2).
50. Roberts, C., & Manchester, K. (2007). *The Archaeology of Disease*. New York: Cornell University Press.
51. Schiefenhövel, W. (1995). Perception, Expression, and Social Function of Pain: A Human Ethological View. *Source in Context, 8*(1), 31-46.
52. Stager, J. & McSkimming, R. (1984). Physical Environment. In Dumas, D. (Ed). *Handbook of North American Indians, Vol. V, Arctic* (pp.431-446). Washington: Smithsonian Institution.
53. Steckel, R., & Rose, J. (Eds.). (2002). *The Backbone of History: Health and Nutrition in the Western Hemisphere: Health and Nutrition in the Western Hemisphere*. Cambridge: Cambridge University Press.

54. The Champlain Society. (1929). *The Publications of the Champlain Society: The Works of Samuel de Champlain Volume III 1615-1618*. Translated and edited by H.H. Langton & W.F. Ganong. Reprinted 1971 by University of Toronto Press, Toronto.
55. Tipula, A., Alasi, A., Joamie, A., Pitseolak, J., Ootoova, E., & Ijjangiaq, T. (2001). Health Practices. In Therrien, M. & Laugrand, F. (Eds). *Interviewing Inuit Elders: Volume 5.*
56. Trigger, B. (1987). *The Children of Aataentsic: A History of the Huron People to 1660*. Kingston and Montreal: McGill-Queen's University Press.
57. World Health Organization (WHO). (2003). *Who Definition of Health*. Geneva. Retrieved from http://www.who.int/about/definition/en/print.html.
58. Young, J. & Lemaire, E.D. (2012). Linking Bone Changes in the Distal Femur to Functional Deficits. *International Journal of Osteoarchaeology*. Early view (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1212/earlyview).

Chapter 6. Integrated Discussion and Conclusions

For bioarchaeologists the study of disease in past populations, paleopathology, focuses on the identification, differential diagnosis, and cause of disease as discerned through the study of the biological remains of people long since dead. Bringing population health models into the paleopathology discussion provides a new way to view poor health in archaeological populations. This thesis is the first initiative to link the fields of bioarchaeology and population health to investigate knee OA and improve our understanding of impairment potential in ancient populations.

To create this approach, new innovative methods and procedures were required. The previous chapters described the newly developed processes and the products of their implementation. The findings are highlighted by the confirmation that population health approaches can be adapted to improve our understanding of disease in past populations. This chapter discusses the personal impetus behind this research and how adaptation to statistical findings improved the quality of the thesis results. The outcomes of the thesis research are also discussed by integrating the key components from the papers (Chapters 2-5) into seven sections, with aspects of the unique research detailed in Figure 6.1:

1. Purpose of this research and development of the approach
2. Techniques developed for this research
3. Unique information provided by this research
4. Contribution of this research to the fields of bioarchaeology and population health
5. Answering the research question
6. Future research
7. Concluding remarks

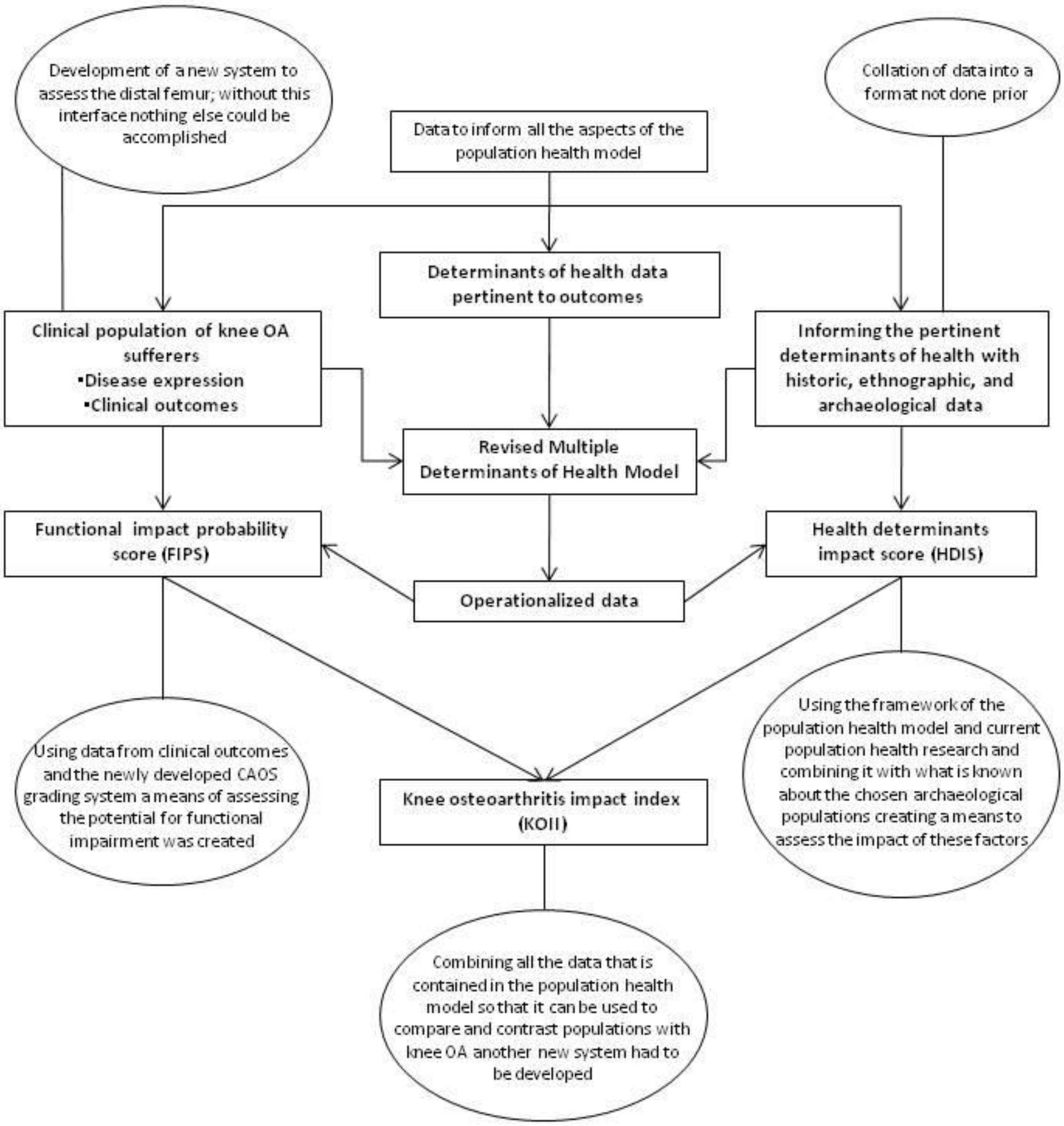


Figure 6.1**:** Outline of the thesis research highlighting original aspects.

6.1. Purpose of the Research and Strategic Approach

The purpose of this thesis research was to answer the question: How can bone changes in the distal femur be used to inform our understanding of impairment and disability for archaeological populations? To answer this question, three broad strategies were employed;

1. Create tools for the bioarchaeologist to broaden their interpretative capabilities of human skeletal remains.
2. Explore the potential of population health models and frameworks to produce tools for the bioarchaeologist to frame physical and social environment factors.
3. Investigate the applicability of these interpretive tools to archaeological samples.

Through the guidance of these strategies key finding were identified for the development of bioarchaeological tools. These findings include the identification of healthcare frameworks, ICD-10 and ICF, as a means to collate and compare data from paleopathological analysis; the utility of ICF to frame research parameters and assist in identifying factors relevant to a disease state; the ability of osteological features related to knee OA progression to be linked to lifestyle, activity, and functional outcomes; and the ability to adapt population health frameworks and models to create a template for application to archaeological populations.

6.2. Techniques Developed for this Research

The goal of this thesis research was to better understand physical impairment due to knee OA of the distal femur and the impact this disease process could have had on archaeological populations. Since this research is unique, different techniques and procedures had to be developed to achieve this goal, following the strategies outlined in response to the research question. A flow chart detailing the origin of the data used in the various aspects of the research can be found in figure 6.2.

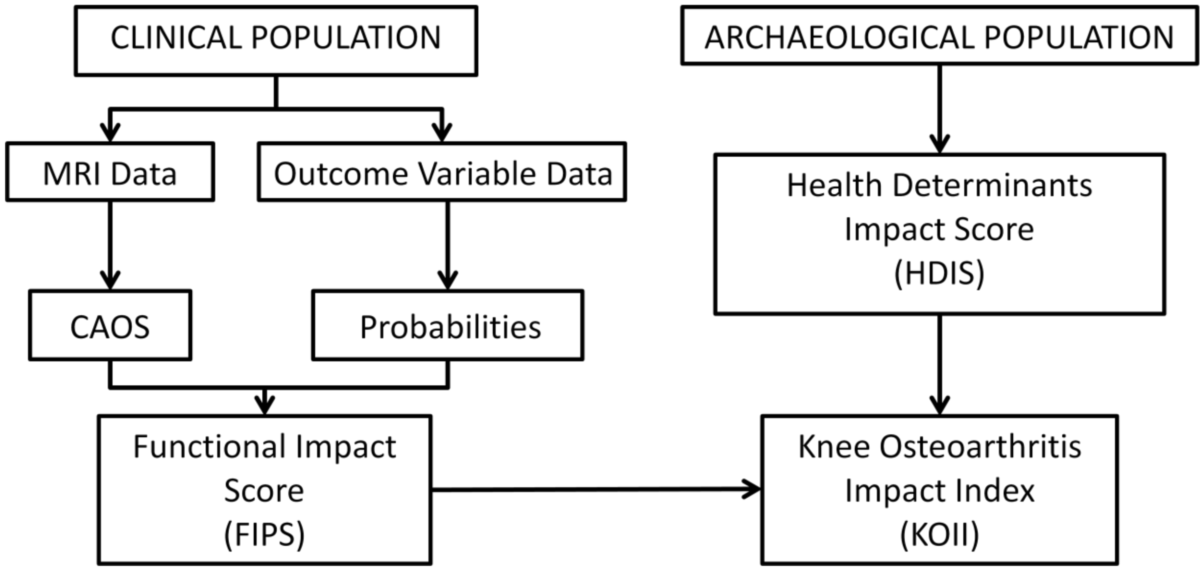


Figure 6.2**:** Flow chart of the data used in the research.

6.2.1. Development of Tools for the Bioarchaeologist

Bridging the gap between a clinical population with related lifestyle data and archaeological populations was accomplished using patient MRIs and their related outcome information from the Osteoarthritis Initiative (OAI) study. Since MR images of bone are accurately related to changes visible in denuded bone, a system that was equally applicable for both mediums could be developed. This allowed for the inference of outcomes that are directly linked to clinical MRIs, such as pain and disability, onto skeletal remains with similar changes.

Identifying the best mechanism to relate bone changes in the distal femur to outcome variables was the subject of Chapter 4. The chosen OAI outcome variables were grouped into multiple outcomes such as pain with stairs, light chores, heavy chores, etc.; under general subscales of pain, stiffness, disability, symptoms, function in sport; and recreation, quality of life, and overall health status (Appendix B and C). Focusing on bone features accessible through both clinical imaging and direct osteological analysis, one quantitative and one qualitative approach was examined. The quantitative assessment examined the intercondylar femoral notch size, which is believed to decrease as knee OA progresses (Appendix D). The qualitative analysis focused on morphological changes in the distal femur, concentrating on characteristics used in both clinical and archaeological knee OA assessment.

For the quantitative analysis, the intercondylar notch was measured and scaled to control for size differences among individuals. Notch width index (NWI) represents a wide or narrow notch and notch depth index (NDI) represents a deep or shallow notch. These measures pre-existed this thesis; however, neither adequately represented large or small notches. Therefore, a third index was developed for this study by averaging NWI and NDI to produce an area-related index called the combined notch index (CNI). Another novel aspect of this study was applying the notch measures originally developed for denuded bone to MR images. To standardize this process, the proper MRI slices from which to take the measurements were identified.

For the qualitative analysis, the chosen morphological features needed to be equally identifiable in archaeological and clinical populations. To develop this approach, systems for assessing knee OA progression for clinical populations or for archaeological populations were examined. Based on the main features of both systems, the Clinical Archeological Osteoarthritis Scale (CAOS), a grading system for knee OA severity, was developed for this study (Chapter 3). CAOS input includes osteophyte formation, shape contour changes, and the presence of micro/macroporosities and/or cysts. Chapter 4 compared the two assessment tools and found that the qualitative approach had more statistically significant correlations with the OAI outcome indices and was thus the superior method for linking outcome data to osseous changes at the distal femur.

6.2.2. Using the Osteological Correlate to Link to Specific Outcome Variables

In Chapter 3, the qualitative assessment tool (CAOS) was used to grade a sample of knees and then each knee was related to a list of OAI outcome variables. Statistically significant outcomes, frequency distributions, and probability assessments operationalized the data, making it directly applicable to skeletal populations (Appendix E). Separating these probabilities into males, females, and the population as a whole permitted easy application to any individual or sample (Appendix F).

6.2.3. Exploring the Potential of Population Health Models and Frameworks for Bioarchaeology

The techniques developed to produce probability results allowed for the application of outcome data to archaeological population scenarios. However, before applying this method, techniques were developed to pull the impact of population health factors into the discussion. Since interpreting archaeological populations using a combination of clinical, historic, ethnographic, and archaeological data had not been attempted, several new tools had to be devised. It was decided that these tools should be numeric since results could then easily be combined and compared (Chapter 5).

6.2.3.1. Health Determinants Impact Score (HDIS)

A population health model was identified that was relevant for the research and easily revised when limited information for the archaeological population was available. The Multiple Determinants of Health Model, was chosen and adapted to incorporate specific determinants of health; including, social environment (social networks, societal values and norms (physical or mental weakness and access to resources), work, power distribution, and social support for ill health), physical environment (terrain, resources, subsistence, climate, housing, and transportation), health interventions, and individual responses (reported group biological health and general disposition – life outlook) (fig.5.1). A scoring system was created, based on what is known about these determinants of health and how they can influence health outcomes. Using research gleaned from historic, ethnographic and archaeological sources, the designated populations were scored on a grid that estimated impact for each population health variable. Since sex has a bearing on many social determinants of health and on clinical outcomes, the sexes were considered separately (Chapter 5). The Health Determinants Impact Score (HDIS-sum) is the sum of scores for each population health factor, for each population, and by sex.

6.2.3.2. Functional Impact Probability Score (FIPS)

Once the majority of population health data was quantified, the remaining determinant data, falling within the health and function category and taking the form of probability estimates, was adapted so that it could be combined with the other determinants of health data. This step took the affected knee into account since probabilities could be knee specific. This step also considered each activity described in the outcome variable and only included those relevant to the populations. Once the outcome variables by knee and sex were identified, summary probability scores were calculated by adding and averaging all applicable probabilities (Chapter 5). This average was called the Functional Impact Probability Scores (FIPS), which was calculated for all the possible right/left knee pair CAOS grade composites.

6.2.3.3. Knee OA Impact Index

The HDIS-sum was combined with the FIPS to create a score that reflected both the clinical and population specific determinants data. Multiplication was the simplest and most straightforward method of combining scales, the product being a Knee OA Impact Index (KOII). The quantification of all the data into this streamlined numeric score allowed for easy comparison of populations but also comparisons of sex specific subpopulations.

6.2.4. Identifying Impairment Potential of Knee OA in Archaeological Samples

Two populations were considered in this research, the 17th century Huron and the 19th century Inuit from the Igloolik region. These distinct groups were chosen because they provided sufficient contrast in environmental data to demonstrate how the variability of these social and physical environmental factors contributes to functional and lifestyle outcomes. Collating data from clinical, archaeological, ethnographic, and historic sources was used to establish that Inuit females would have been the most impacted by knee OA. The disabling effects were supported by inadequate social circumstances and poor functional outcomes, while Huron males would have had the least impairment potential impact from knee OA.

6.3. Unique Information Provided by this Research

6.3.1. The CAOS Tool was Superior to NWI, NDI, and CNI for Creating an Osteological Correlate in Knee OA

From comparisons of the qualitative and quantitative measures, the CAOS approach was the best mechanism to link bone changes at the distal femur and functional outcome variables. Quantitative assessment of the femoral intercondylar notch captured through the NWI, NDI, and the CNI showed little variability over the range of the results, indicating that these measures are not sensitive enough to allow for the direct correlation with functional and lifestyle outcome measures. The CAOS grading system lead to a great number of statistically significant relationships with the selected outcome variables, confirming that macroscopic bone features are the best option for linking osteological and outcome data. This newly developed, unique method will allow bioarchaeologists and researchers to make inferences to skeletal populations via this osteological bridge.

Although there were a many statistically significant correlations between NDI and various outcome variables in the female population, these were not sensitive enough for direct application to archaeological populations. However, these results highlighted a possible difference in the biological mechanism of symptom production. Symptoms produced by the weight bearing function of the knee joint appeared to be captured by the CAOS grading system while symptoms produced by knee instability appeared to be captured by the intercondylar notch measures. The findings suggest that the biological differences between males and females have an impact on symptom production.

6.3.2. The CAOS Measure can be Linked to Outcome Data and can also be Operationalized to Better Interpret Skeletal Populations

The CAOS grading system was related to outcome data for specific activities, such as pain when navigating stairs. This relationship was established with frequency distribution data that was converted to probabilities, producing a probability score for each outcome variable at each CAOS grade of knee OA. The probabilities, reflecting the potential of having an issue with a particular outcome at a particular CAOS grade, were given for the whole population and male and female subpopulations. Research showed that males and females had distinct outcome probabilities. The example in Chapter 4 shows this best, where a female with CAOS grade 3 had a 0.93 probability of having difficulty climbing several flights of stairs and males with the same CAOS grade and the same task had a much lower probability at 0.45. Providing outcome data in such a manner is a unique contribution to the field that allows for applications to individual cases or population based scenarios.

6.3.3. Operationalized Outcome Data along with Population Health Approaches can Improve our Understanding of Disease Impact in Archaeological Populations

Though applying outcome probabilities derived from clinical populations to archaeological populations can assist the bioarchaeologist in understanding the impact of knee OA on functional capacity, it does not provide a complete picture of impairment potential. Bringing other population health considerations into the dialogue, as outlined in the revised Multiple Determinants of Health model, provides important details to improve interpretation. This study is unique in operationalizing population health, clinical, ethnographic, historic, and archaeological data into a system that considers all when interpreting potential outcome scenarios, given the degree of knee OA, the sex of the group, and the environments in which they are embedded.

6.4. Contribution of this Research to the Fields of Bioarchaeology and Population Health

6.4.1. Bioarchaeology

This study is unique in linking bone changes in the distal femur consistent with knee OA to lifestyle data, making this information accessible to the bioarchaeologist and allowing for the application of the clinical findings to archaeological populations. The research also confirmed that morphological assessments of the entire distal femur are better than metric analyses of the femoral intercondylar notch for exploring impairment potential. This confirmation was emphasized by the results that exemplified what is intuitive, that increased degeneration of at least one aspect of the knee joint leads to worse mobility and functional outcomes. However, the new method provides more precision in this analysis by providing probabilities of how the degree of knee OA can affect specific functional and lifestyle factors.

Another contribution to bioarchaeology was to highlight the importance of assessing males and females separately when considering the effects of a disease process and not to assume that the impact would be equal. Also, it is important to consider medication usage in clinical populations, which could provide a masking effect over the true impact of a disease process that might be found in archaeological populations.

Though all of these contributions are important, developing a method to introduce a population health lens through which paleopathology can be interpreted may the principle contribution. Population health determinants have been known, in modern health scenarios, to have a major impact on outcomes as they consider the individual as not simply a biological island but as a composite structure being influenced by, and influencing, the environments in which they are nested. Paleopathology often describes the biological aspect of disease in human bone but rarely moves beyond this description to include aspects of the individual's social and physical environments. This may be simply because population health approaches are not known to the bioarchaeologist or that the data needed to inform these environmental aspects are not available. This research has shown that failure to incorporate aspects of the physical and social environment can influence the accuracy of defining the impairment potential of a disease process. Therefore, even if some information about the skeletal population being studied is lacking, the environmental aspects that are known should be brought into the dialogue because they can have an impact on the accuracy of interpretations by the bioarchaeologist.

Using the population examples of the 17th century Huron and the 19th century Inuit from the Igloolik region of Nunavut, the validity of using population health models and determinants of health data to explore the differences in potential functional outcomes for each group was shown. This research shows that bioarchaeologists can no longer use blanket statements about the impact of knee OA but first must consider which populations are being examined and the known determinants of health for those groups.

6.4.2. Population Health

For the field of population health, expanding the use of its models and theories to arenas where they are not currently used and showing the application potential of their integration;

- expands the multi-disciplinary reach of the paradigm to new frontiers
- demonstrate the value of the population health approach
- encourages the experimentation of application of population health models and approaches to fields not currently exploring their potential
- demonstrates that discussion of health on either present or past populations is not complete without the consideration of all known variables both internal and external to the individual

6.5. Answering the Research Question

How can bone changes in the distal femur be used to inform our understanding of impairment and disability for archaeological populations?

Bone changes in the distal femur, when linked to functional and lifestyle outcome data, quantify impairment potential through outcome probabilities. With disability as a social construct, the social and physical environments in which populations are embedded provide a disability potential framework. Combining impairment and disability data for select populations allows bioarchaeologists to estimate knee OA’s impact on ancient groups. Therefore, through adaptation of clinical information and population health models, bone changes in the distal femur associated with progressive, degenerative changes from knee OA can now inform our understanding of impairment and disability for archaeological populations.

6.6. Future Research

The current research has shown the potential of incorporating population health models into the interpretation of health in skeletal populations. The results are exciting and validate the call for a paradigm shift in the field of paleopathology from viewing individuals as biological entities to viewing them as biopsychosocial constructs nested in various environments, adapting to the ebb and flow of the non-static world that surrounds them.

With this new understanding, the potential of applying population health frameworks, models, and general approaches become boundless. To expand on this initial research, additional research avenues could include:

- applying CAOS grading system to other clinical samples to verify findings generated from the OAI data
- inter and intraobserver reliability studies on the CAOS grading system
- applying the framework for examining the impairment potential of knee OA to other populations beyond the two explored in this thesis
- applying the framework to individual case studies
- applying portions of the framework, especially the health determinants section, to populations with limited ethnographic, historic, and/or archaeological data
- explore different diseases using the template developed by this research

With the realization that population health approaches can not only be incorporated into the field of bioarchaeology but provide an opportunity to increase the depth of the analysis of the impact of disease, the integration of these two fields opens a door to a vast increase in knowledge generation from skeletal samples.

6.7. Concluding Remarks

Knee OA is a chronic, progressive disease that, through imbalances in the damage and repair cycles, causes the breakdown of articular joint structures. In a clinical sample, this breakdown is primarily assessed through radiographic evidence of joint space narrowing, formation of osteophytes, subchondral bone sclerosis and cysts, and altered morphology of bone ends. In a skeletal sample, only the disarticulated osseous structures remain for appraisal with the primary assessment criteria, including osteophytes, articular surface pitting and/or eburnation, and articular surface contour changes.

Since the knee is a key biological structure in human mobility and load transfer, deterioration of the bone and soft tissue structures have many implications for movement and functional capacity. However, these implications are dependent on symptom expression since it is the avoidance of symptoms that leads to limb use modification.

This research provides a link between bone changes seen at the distal femur and symptom and impairment outcomes. Creating this link allows for the application of these results gleaned from clinical populations to skeletal populations. Using this data as a single aspect of the revised multiple determinants of health model and then using ethnographic, historic, and archaeological data to inform the remaining portions of that model allows for a broadened interpretation of the impact of knee OA in archaeological populations. Since this research is unique, new techniques and procedures were developed to achieve the goal.

To understand the importance of this line of research, we should consider the depth of what is lost when interpreting only the biological aspect of human remains. Let us consider how we experience ill health, how it affects all those around us, how it changes our interaction with our environment and people in our social circle, how the environment both physical and social impacts how we function, how those around us can judge us and make us feel small or support us and making us feel better. When you consider these factors, it is hard to look at skeletal remains from someone who has had a life and only report that the person had a pathological lesion, that they probably got the pathological lesion because they did something repeatedly as part of their daily routine, or they were exposed to a traumatic situation. This biological view excludes the humanity, the give and take with the environment, the psychological burden ill health can create, and the depth and breadth of the experience.

As a bioarchaeologist, I found the standard interpretation unacceptable, I wanted to say more, understand better, to be able to show that the experience of knee OA cannot be the same for everyone, but too many factors were involved. Population health models were the best mechanism to examine the humanness of the disease process on an individual and their community by bringing into the dialogue of skeletal remains factors beyond the biological, factors that research has shown interplay with the disease process through the biological.

The goal of the research was not simply to examine what factors affect an individual’s outcome in the presence of varying degrees of knee OA but to encourage a paradigm shift in the field of paleopathology. To argue that, for all disease processes, the biological description of ill health through skeletal lesions is only a single component in the interpretation process of the person who had the affliction. To fully understand any pathology in any individual or population it is imperative to consider the physical, social, and resource nest in which they are resting. While it has to be acknowledged that there are components of this broadened dialogue that can only be inferred and components that we can never fully comprehend, historic, ethnographic, archaeological, and even clinical data can provide some insight, an additional lens through which a disease process can be viewed.

The research presented in this thesis proves that isolating the dialogue of knee OA to the biological (i.e. applying the same standard of impairment potential equally across very different populations from very different geographical regions) is invalid. Understanding the impact a disease process could have through the examination of clinical populations is only the first step in a multi-step process of truly understanding a disease's influence on the outcomes of individuals and populations.

Appendix A: Osteoarthritis Initiative Data User Agreement

OSTEOARTHRITIS INITIATIVE
DATA USER AGREEMENT FOR RESEARCH IMAGE SETS

This Data User Agreement ("Agreement") is between the Osteoarthritis Initiative Coordinating Center, University of California, San Francisco and the Data Recipient (noted in Section #7) and is effective as of the "Effective Date" (noted in Section #7).

Both parties are committed to complying with local, state, and federal laws and regulations (including the Privacy Rule under the Health Insurance Portability and Accountability Act [HIPAA] of 1996) relating to privacy, security and confidentiality.

1. <u>Name of Entity Releasing the Research Image Set(s)</u>:

   Osteoarthritis Initiative Coordinating Center
   Department of Epidemiology and Biostatistics
   University of California, San Francisco
   San Francisco, California
   United States of America

   Principal Investigator: Michael C. Nevitt, PhD

Study Title:	Osteoarthritis Initiative (OAI)
Study Sponsor:	National Institute of Arthritis and Musculoskeletal & Skin Diseases / National Institutes of Health Agency award #: N01-AR-2-2258
UCSF IRB #:	H5254-20499-08 (Expiration date: 3-2-2010)

2. <u>Preparation of the Research Image Set(s)</u>. The OAI Research Image Set(s) provided under this Agreement do not contain any of the following elements:

- ☐ Names
- ☐ Street or postal address, other than town or city, state, or zip code
- ☐ Telephone numbers
- ☐ Fax numbers
- ☐ Electronic mail addresses
- ☐ Social security numbers
- ☐ Medical record numbers
- ☐ Health plan beneficiary numbers
- ☐ Account numbers
- ☐ Certificate/license numbers
- ☐ Vehicle identifiers and serial numbers, including license plate numbers
- ☐ Device identifiers and serial numbers
- ☐ Web Universal Resource Locators (URLs)
- ☐ Internet Protocol (IP) address numbers
- ☐ Full face photographic images and any other comparable images

3. Purpose of Data Set Disclosure. The Recipient of the Research Image Set(s) (named in Section #7) and the Agents to whom the Recipient provides the Research Image Set(s) to, are permitted to use and disclose the Research Image Set(s) for the following purpose(s):

[X] Human subjects research
[X] Educational activities (i.e., teaching activities, development of clinical guidelines)

4. Responsibilities of the Recipient. The Recipient of the Research Image Set(s) (named in Section #7) and the Agents to whom the Recipient provides the Research Image Set(s) to, agrees to:

a) Use or disclose the Research Image Set(s) only as permitted by this Agreement or as Required by Law.
b) Use appropriate safeguards to prevent the use or disclosure of the Research Image Set(s) other than as permitted by this Agreement.
c) All data Recipients must review and sign a Data User Agreement for Research Image Sets. If it is not feasible for all Agents (including subcontractors, students, fellows, analysts, etc.) to review and sign a Data User Agreement for Research Image Sets, the Recipient must ensure that any Agents to whom the Recipient provides the Research Image Set(s) agrees to the same conditions and restrictions on the use and disclosure of the Research Image Set(s) that apply to the Recipient through this Agreement. Individuals not working directly with the Recipient should obtain the Research Image Set(s) directly from the OAI Coordinating Center at the University of California, San Francisco and complete a Data User Agreement for Research Image Sets.
d) Not attempt to use the information in the Research Image Set(s) to identify or contact the persons from whom the data originated, their relatives, employers, or household members.
e) Accept all responsibility for data analysis, results from analyses, and any consequences resulting from breaching study participant privacy in connection with the analysis.
f) Obtain approval from the Recipient's local IRB, if required, before the initiation of any analyses.
g) Cite and acknowledge the OAI and its funding sources in all abstracts, presentations and publications, using language detailed in the OAI Publication Guidelines (posted on OAI Online website), and make a good faith effort to follow the other provisions of these guidelines.
h) Return any hard disks provided by the University of California, San Francisco, containing the Research Image Set(s) back to the University of California, San Francisco, within 10 working days after receipt.
i) Report any use or disclosure of the Research Image Set(s) not permitted by this Agreement in writing to OAIOnlineFeedback (E-mail: OAIOnlineFeedback@psg.ucsf.edu) within five (5) days after the Recipient becomes aware of the unauthorized use or disclosure.

5. Term and Termination

a) Term. The term of this Agreement shall commence on the Effective Date (noted in Section #7) and shall continue for as long as the Recipient and their Agents retains the Research Image Set(s), unless terminated sooner as set forth in this Agreement.

b) Termination by Recipient. The Recipient may terminate this Agreement at any time by notifying the University of California, San Francisco and returning and/or destroying the Research Image Set(s) and any copies of the Research Image Set(s).

c) Termination by University of California, San Francisco. The University of California, San Francisco may terminate this Agreement at any time by blocking the Recipient's access to the OAI Online website as well as access to any additional datasets, images and other study materials.

d) Termination for Cause. Upon the University of California, San Francisco's knowledge of a material breach of this Agreement by the Recipient (and/or the Recipient's Agents), the University of California, San Francisco shall either provide an opportunity for the Recipient to cure the breach or end the violation OR terminate this Agreement if the Recipient does not satisfactorily cure the breach or end the violation within the timeframe set forth and to the satisfaction of the University of California, San Francisco. The University of California, San Francisco may immediately terminate this Agreement if cure is not possible by blocking the Recipient's access to the OAI Online website as well as access to any additional datasets, images and other study materials.

6. Miscellaneous

a) *Regulatory references*. A reference in this Agreement to a section in the HIPAA Privacy Regulations means the section as in effect or as amended.

b) *Amendment*. The Parties agree to take action as is necessary to amend this Agreement from time to time as is necessary for the University of California, San Francisco to comply with changes in local, state and federal laws and regulations relating to privacy, security and confidentiality of the Research Image Set(s).

c) *Interpretation*. Any ambiguity in this Agreement shall be resolved to permit the University of California, San Francisco to comply with local, state and federal laws and regulations relating to privacy, security and confidentiality of the Research Image Set(s).

7. Agreement Execution. By signing your name below the Recipient is: a) certifying that he/she as well as any Agents to whom the Recipient provides the Research Image Set(s), agrees to use or disclose the information contained in the Research Image Set(s) only as permitted in Sections #3 and #4 in this Agreement, and if applicable b) certifying that he/she agrees to return the hard disk containing the Research Image Set(s) to the University of California, San Francisco, within 10 working days after receipt.

a) I agree to use or disclose the information contained in the Research Image Set(s) only as permitted in Sections #3 and #4 in this Agreement. I also certify that any Agents to whom I provide the Research Image Set(s) will use or disclose the information contained in the Research Image Set(s) only as permitted in Sections #3 and #4 in this Agreement.

Name of Recipient of Research Image Set(s): Janet Young
(PLEASE PRINT)

Signature of Recipient of Research Image Set(

April 17, 2009.
Date Signed (Effective Date of Data User Agreement)

By signing your name below the Recipient is: b) certifying that he/she agrees to return the hard disk containing the Research Image Set(s) to the University of California, San Francisco, within 10 working days after receipt.

b) I agree to return the hard disk containing the Research Image Set(s) to the University of California, San Francisco, at the specified address, within 10 working days after receipt.

Signature of Recipient of Research Image S

April 17, 2009.
Date Signed

Please thoroughly complete the ***Request for Research Image Set(s)*** form to request OAI x-ray and MRI images.

Appendix B: List of OAI indexed variables used in this thesis, their related codes, and descriptions

OAI Indexed Variables		Description	Assessed Factors Contributing to Overall Score
WOMAC stiffness score	womstfr = right knee womstfl = left knee	Stiffness evaluated for the past 7 days with 0=none and 4=extreme (the stiffness subscale possible score range is 0-8)	In morning, later in day
WOMAC pain score	womkpr = right knee womkpl = left knee	Pain evaluated for the past 7 days with 0=none and 4=extreme (the pain subscale possible score range is 0-20)	Down/up stairs, standing from sitting, standing, bending, walking, in/out car, shopping, socks on/off, get out of bed, lying down, in/out of bathtub, sitting, on/off toilet, heavy chores, light chores
WOMAC disability score	womdlr = right knee womdll = left knee	Disability evaluated for the past 7 days with 0=none and 4=extreme (the disability subscale possible score range is 0-68)	
KOOS symptoms score	koosymr = right knee koosyml = left knee	Symptoms during the past 7 days scored on a 4 point scale ranging usually ranging from always to never	Swelling, grinding/clicking, catch/hang up, straighten/bend knee fully
KOOS pain score	kooskpr = right knee kooskpl = left knee	In the past 7 days how much pain have you had doing the activities 0=none and 4=extreme	Twisting/pivoting on knee, straightening/bending knee fully
KOOS function, sports, and recreational activities score	koosfsr = both knees	Concerns physical function when being active on a higher level - what degree of difficulty in last 7 days 0=none and 4=extreme	Degree of difficulty when squatting, running, jumping, twisting/pivoting, kneeling

KOOS Quality of Life	koosqol	Concerns quality of life issues with questions being measured on different 5 point scales with 0 indicating no problem and 4 indicating excessive problems	Aware of problems, modify lifestyle to avoid problems, problems cause lack of confidence, general difficulty
Health survey (SF12) mental summary scale	hsmss	Survey asks for views about your health - how you feel	Any problems with work or daily activities due to emotional problems, feeling calm/peaceful/downhearted/depressed, energy level
Health survey (SF12) physical summary scale	hspss	Survey asks for views about your health - how well you are able to do your usual activities	Does your health limit you in moderate activities/stairs, accomplish less, limited in activities, pain interfering

Appendix C: List of the individual OAI variables that contribute to the indexed variables including their codes and general descriptions

Table 1. The individual OAI variables contributing to the KOOS indices and their respective codes.

Right knee: KOOS Pain Score KOOSKPR	
KPRKN1	Right knee pain: twisting/pivoting on knee, last 7 days
KPRKN2	Right knee pain: straightening knee fully, last 7 days
KPRKN3	Right knee pain: bending knee fully, last 7 days
Left knee: KOOS Pain Score KOOSKPL	
KPLKN1	Left knee pain: twisting/pivoting on knee, last 7 days
KPLKN2	Left knee pain: straightening knee fully, last 7 days
KPLKN3	Left knee pain: bending knee fully, last 7 days
Right knee: KOOS Symptoms Score KOOSYMR	
KSXRKN1	Right knee symptoms: swelling, last 7 days
KSXRKN2	Right knee symptoms: feel grinding, hear clicking or any other type of noise when knee moves, last 7 days
KSXRKN3	Right knee symptoms: knee catch or hang up when moving, last 7 days
KSXRKN4	Right knee symptoms: straighten knee fully, last 7 days
KSXRKN5	Right knee symptoms: bend knee fully, last 7 days
Left knee: KOOS Symptoms Score KOOSYML	
KSXLKN1	Left knee symptoms: swelling, last 7 days
KSXLKN2	Left knee symptoms: feel grinding, hear clicking or any other type of noise when knee moves, last 7 days
KSXLKN3	Left knee symptoms: knee catch or hang up when moving, last 7 days
KSXLKN4	Left knee symptoms: straighten knee fully, last 7 days
KSXLKN5	Left knee symptoms: bend knee fully, last 7 days
KOOS Function, Sports, and Recreational Activities Score KOOSFSR	
KOOSFX1	Either knee difficulty: squatting, last 7 days
KOOSFX2	Either knee difficulty: running, last 7 days
KOOSFX3	Either knee difficulty: jumping, last 7 days
KOOSFX4	Either knee difficulty: twisting/pivoting on injured knee, last 7 days
KOOSFX5	Either knee difficulty: kneeling, last 7 days
KOOS Quality of Life Score KOOSQOL	
KQOL1	Quality of life: how often aware of problems with knee(s)
KQOL2	Quality of life: modified lifestyle to avoid potentially damaging activities to knee(s)
KQOL3	Quality of life: how much troubled with lack of confidence in knee(s)
KQOL4	Quality of life: in general, how much difficulty have with knee(s)

Table 2. The individual OAI variables contributing to the WOMAC indices and their respective codes.

Right knee: WOMAC Pain Score WOMKPR	
WPRKN1	Right knee pain: walking, last 7 days
WPRKN2	Right knee pain: stairs, last 7 days
WPRKN3	Right knee pain: in bed, last 7 days
WPRKN4	Right knee pain: sit or lie down, last 7 days
WPRKN5	Right knee pain: standing, last 7 days
Left knee: WOMAC Pain Score WOMKPL	
WPLKN1	Left knee pain: walking, last 7 days
WPLKN2	Left knee pain: stairs, last 7 days
WPLKN3	Left knee pain: in bed, last 7 days
WPLKN4	Left knee pain: sit or lie down, last 7 days
WPLKN5	Left knee pain: standing, last 7 days
Right knee: WOMAC Stiffness Score WOMSTFR	
WSRKN1	Right knee stiffness: in morning, last 7 days
WSRKN2	Right knee stiffness: later in day, last 7 days
Left knee: WOMAC Stiffness Score WOMSTFL	
WSLKN1	Left knee stiffness: in morning, last 7 days
WSLKN2	Left knee stiffness: later in day, last 7 days
Right knee: WOMAC Disability Score WOMADLR	
DIRKN1	Right knee difficulty: down stairs, last 7 days
DIRKN2	Right knee difficulty: up stairs, last 7 days
DIRKN3	Right knee difficulty: stand from sitting, last 7 days
DIRKN4	Right knee difficulty: standing, last 7 days
DIRKN5	Right knee difficulty: bending, last 7 days
DIRKN6	Right knee difficulty: walking, last 7 days
DIRKN7	Right knee difficulty: in car/out of car, last 7 days
DIRKN8	Right knee difficulty: shopping, last 7 days
DIRKN9	Right knee difficulty: socks on, last 7 days
DIRKN10	Right knee difficulty: get out of bed, last 7 days
DIRKN11	Right knee difficulty: socks off, last 7 days
DIRKN12	Right knee difficulty: lying down, last 7 days
DIRKN13	Right knee difficulty: get in/out of bathtub, last 7 days
DIRKN14	Right knee difficulty: sitting, last 7 days
DIRKN15	Right knee difficulty: on/off toilet, last 7 days
DIRKN16	Right knee difficulty: heavy chores, last 7 days
DIRKN17	Right knee difficulty: light chores, last 7 days

Left knee: WOMAC Disability Score WOMADLL	
DILKN1	Left knee difficulty: down stairs, last 7 days
DILKN2	Left knee difficulty: up stairs, last 7 days
DILKN3	Left knee difficulty: stand from sitting, last 7 days
DILKN4	Left knee difficulty: standing, last 7 days
DILKN5	Left knee difficulty: bending, last 7 days
DILKN6	Left knee difficulty: walking, last 7 days
DILKN7	Left knee difficulty: in car/out of car, last 7 days
DILKN8	Left knee difficulty: shopping, last 7 days
DILKN9	Left knee difficulty: socks on, last 7 days
DILKN10	Left knee difficulty: get out of bed, last 7 days
DILKN11	Left knee difficulty: socks off, last 7 days
DILKN12	Left knee difficulty: lying down, last 7 days
DILKN13	Left knee difficulty: get in/out of bathtub, last 7 days
DILKN14	Left knee difficulty: sitting, last 7 days
DILKN15	Left knee difficulty: on/off toilet, last 7 days
DILKN16	Left knee difficulty: heavy chores, last 7 days
DILKN17	Left knee difficulty: light chores, last 7 days

Table 3. The individual OAI variables contributing to the SF-12 indices and their respective codes.

SF-12: physical summary scale for the MOS 12-item short-form health survey HSPSS	
SF-12: mental summary scale for the MOS 12-item short-form health survey HSMSS	
SF1	in general, how is health
SF2	how much health limit involvement in moderate activities (e.g., moving a table, pushing vacuum cleaner...)
SF3	how much health limit climbing several flights of stairs
SF4	how often physical health result in accomplishing less than would like with work or other activities, past 4 weeks
SF5	how often physical health result in being limited in kind of work or other activities, past 4 weeks
SF6	how often emotional problems result in accomplishing less than would like with work or other activities, past 4 weeks
SF7	how often emotional problems result in not doing work or activities as carefully as usual, past 4 weeks
SF8	how much did pain interfere with normal work (include work outside home and housework), past 4 weeks
SF9	how often felt calm and peaceful, past 4 weeks
SF10	how often had a lot of energy, past 4 weeks SF
SF11	how often felt downhearted and depressed, past 4 weeks
SF12	how often physical health or emotional problems interfered with social activities (like visiting with friends, relatives, etc.), past 4 weeks

Appendix D. Examples of calculated notch measures and notch indices and outcome variable scores for the study population

Table 1. Intercondylar notch measures, calculated indices, and OAI outcome information for SF1, SF2, SF3, SF4, and SF5.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	SF1	SF2	SF3	SF4	SF5
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	3	3	3	4	5
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	3	3	3	4	5
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	2	3	2	3	4
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	2	3	2	3	4
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	3	3	2	5	5
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	3	3	2	5	5
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	1	3	3	5	5
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	1	3	3	5	5
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	3	3	3	5	5
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	3	3	3	5	5
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	3	3	2	3	5
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	3	3	2	3	5
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	3	2	2	3	3
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	3	2	2	3	3
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	2	3	3	5	5
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	2	3	3	5	5
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	2	3	3	5	5
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	2	3	3	5	5
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	4	2	1	3	3
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	4	2	1	3	3
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	2	1	1	4	5
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	2	1	1	4	5
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	3	3	2	4	4
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	3	3	2	4	4
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	3	3	3	4	2
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	3	3	3	4	2
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	1	2	1	3	3
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	1	2	1	3	3
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	3	1	2	2	3
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	3	1	2	2	3
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	3	3	3	5	5

9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	3	3	3	5	5
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	2	3	3	3	3
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	2	3	3	3	3
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	2	3	3	5	4
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	2	3	3	5	4
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	2	2	2	4	4
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	2	2	2	4	4
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	2	3	2	4	2
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	2	3	2	4	2
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	3	3	3	5	5
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	3	3	3	5	5
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	2	3	3	5	5
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	2	3	3	5	5
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	3	3	3	5	5
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	3	3	3	5	5
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	2	2	1	1
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	2	2	1	1
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	3	2	1	2	3
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	3	2	1	2	3
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	4	2	2	4	4
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	4	2	2	4	4
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	2	3	3	5	5
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	2	3	3	5	5
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	3	3	1	2	2
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	3	3	1	2	2
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	2	3	3	5	5
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	2	3	3	5	5
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	3	3	2	4	4
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	3	3	2	4	4
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	3	3	3	4	4
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	3	3	3	4	4
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	3	3	2	4	4
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	3	3	2	4	4
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	2	3	3	4	5
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	2	3	3	4	5
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	2	3	3	5	5
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	2	3	3	5	5
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	3	1	1	3	2
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	3	1	1	3	2
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	2	3	3	5	5

9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	2	3	3	5	5
9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	3	3	2	3	3
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	3	3	2	3	3
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	3	2	2	3	3
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	3	2	2	3	3
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	1	3	3	5	5
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	1	3	3	5	5
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	3	2	2	4	4
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	3	2	2	4	4
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	2	3	3	5	5
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	2	3	3	5	5
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	2	3	2	4	5
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	2	3	2	4	5
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	2	2	3	5	5
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	2	2	3	5	5
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	2	3	2	4	4
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	2	3	2	4	4
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	2	3	3	5	5
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	2	3	3	5	5
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	2	2	2	3	3
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	2	2	2	3	3
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	3	2	1	3	3
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	3	2	1	3	3
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	4	3	2	2	3
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	4	3	2	2	3
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	4	3	2	3	4
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	4	3	2	3	4
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	2	3	3	5	5

Table 2. Intercondylar notch measures, calculated indices, and OAI outcome information for SF6, SF7, SF8, SF9, and SF10.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	SF6	SF7	SF8	SF9	SF10
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	4	5	2	4	4
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	4	5	2	4	4
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	5	5	2	2	2
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	5	5	2	2	2
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	5	4	2	3	3
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	5	4	2	3	3
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	5	5	1	2	2
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	5	5	1	2	2
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	5	5	1	2	2
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	5	5	1	2	2
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	5	5	1	2	4
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	5	5	1	2	4
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	4	4	3	2	2
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	4	4	3	2	2
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	4	4	2	1	2
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	4	4	2	1	2
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	5	5	1	2	3
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	5	5	1	2	3
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	4	5	3	3	4
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	4	5	3	3	4
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	4	5	3	2	5
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	4	5	3	2	5
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	5	5	2	3	2
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	5	5	2	3	2
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	3	3	2	3	3
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	3	3	2	3	3
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	5	5	2	2	2
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	5	5	2	2	2
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	2	4	3	3	5
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	2	4	3	3	5
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	5	5	1	2	2
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	5	5	1	2	2

9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	5	5	3	1	2
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	5	5	3	1	2
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	5	5	2	2	2
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	5	5	2	2	2
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	4	4	2	3	2
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	4	4	2	3	2
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	3	3	3	2	2
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	3	3	3	2	2
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	5	5	2	2	3
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	5	5	2	2	3
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	5	5	1	2	1
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	5	5	1	2	1
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	5	5	1	4	3
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	5	5	1	4	3
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	1	4	3	4
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	1	4	3	4
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	3	3	4	3	4
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	3	3	4	3	4
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	4	5	3	2	4
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	4	5	3	2	4
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	5	5	2	2	2
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	5	5	2	2	2
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	5	4	3	4	4
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	5	4	3	4	4
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	5	5	1	1	1
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	5	5	1	1	1
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	4	4	2	2	4
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	4	4	2	2	4
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	5	5	2	1	2
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	5	5	2	1	2
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	5	5	1	2	2
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	5	5	1	2	2
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	5	4	2	2	3
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	5	4	2	2	3
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	5	5	1	2	2
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	5	5	1	2	2
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	5	5	3	2	3
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	5	5	3	2	3
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	5	5	3	1	3
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	5	5	3	1	3

9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	5	5	3	2	3
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	5	5	3	2	3
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	5	5	4	4	5
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	5	5	4	4	5
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	5	5	2	2	2
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	5	5	2	2	2
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	5	5	3	3	4
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	5	5	3	3	4
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	5	5	2	1	2
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	5	5	2	1	2
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	5	5	2	2	2
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	5	5	2	2	2
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	5	5	1	2	2
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	5	5	1	2	2
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	5	5	2	2	2
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	5	5	2	2	2
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	5	5	2	2	2
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	5	5	2	2	2
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	5	5	3	2	2
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	5	5	3	2	2
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	3	3	4	4	4
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	3	3	4	4	4
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	5	3	3	2	3
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	5	3	3	2	3
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	4	5	2	2	2
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	4	5	2	2	2
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	5	5	2	3	3

Table 3. Intercondylar notch measures, calculated indices, and OAI outcome information for SF11, SF12, WPRKN1, and WPRKN2.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	SF11	SF12	WPRKN1	WPRKN2
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	5	5	1	1
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	5	5	1	1
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	5	5	0	1
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	5	5	0	1
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	4	5	0	2
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	4	5	0	2
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	5	5	0	2
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	5	5	0	2
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	5	5	0	1
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	5	5	0	1
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	4	5	1	1
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	4	5	1	1
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	4	4	1	1
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	4	4	1	1
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	5	5	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	5	5	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	3	3	1	2
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	3	3	1	2
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	5	5	0	0
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	5	5	0	0
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	4	5	1	1
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	4	5	1	1
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	3	3	1	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	3	3	1	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	5	5	1	3
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	5	5	1	3
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	3	4	1	2
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	3	4	1	2
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	4	5	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	4	5	0	0

9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	5	5	3	1
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	5	5	3	1
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	5	5	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	5	5	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	4	4	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	4	4	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	5	5	0	2
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	5	5	0	2
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	5	5	0	1
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	5	5	0	1
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	4	5	2	3
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	4	5	2	3
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	3	5	0	1
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	3	5	0	1
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	3	2	3
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	3	2	3
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	3	2	1	1
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	3	2	1	1
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	5	5	1	1
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	5	5	1	1
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	5	5	1	1
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	5	5	1	1
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	4	4	2	3
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	4	4	2	3
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	5	5	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	5	5	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	4	5	1	1
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	4	5	1	1
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	5	5	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	5	5	1	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	5	5	1	2
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	5	5	1	2
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	4	5	2	0
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	4	5	2	0
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	4	5	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	4	5	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	4	4	2	2
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	4	4	2	2
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	5	5	0	2
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	5	5	0	2

9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	5	5	2	3
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	5	5	2	3
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	4	5	0	1
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	4	5	0	1
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	5	5	0	1
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	5	5	0	1
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	4	5	1	1
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	4	5	1	1
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	4	5	1	1
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	4	5	1	1
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	4	5	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	4	5	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	5	5	0	1
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	5	5	0	1
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	5	5	0	1
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	5	5	0	1
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	5	5	0	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	5	5	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	5	5	1	2
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	5	5	1	2
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	4	2	4	3
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	4	2	4	3
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	4	5	0	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	4	5	0	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	3	4	1	1
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	3	4	1	1
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	4	4	1	1
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	4	4	1	1
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	4	5	1	2

Table 4. Intercondylar notch measures, calculated indices, and OAI outcome information for WPRKN3,WPRKN4, and WPRKN5.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	WPRKN3	WPRKN4	WPRKN5
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	1	1
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	1	1
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	0	0	0
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	0	0	0
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	0	0	0
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	0	0	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	0	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	0	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	0	0	0
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	0	0	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	0	0	1
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	0	0	1
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	0	1	1
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	0	1	1
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	2	2	2
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	2	2	2
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	0	0	1
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	0	0	1
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	0	0	2
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	0	0	2

9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	1	1	1
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	1	1	1
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	3	3	1
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	3	3	1
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	0	0	1
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	0	0	1
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	0	1
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	0	1
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	0	0	0
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	0	0	0
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	1	1	1
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	1	1	1
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	0	0	1
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	0	0	1
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	3	3	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	3	3	0
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	1	1	1
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	1	1	1
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	0	0	2
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	0	0	2
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	0	0	1
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	0	0	1
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	0	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	0	1	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	1	2	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	1	2	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	2	2	2
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	2	2	2
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0

9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	1	2	1
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	1	2	1
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	2	2	0
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	2	2	0
9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	0	0	0
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	0	0	0
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	0	0	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	0	0	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	0	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	0	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	1	1	2
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	1	1	2
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	1	1	1
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	1	1	1
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	0	0	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	0	0	0
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	0	0	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	0	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	1	1	1
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	1	1	1
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	0	0	1
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	0	0	1
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	0	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	0	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	1	0	1
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	1	0	1
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	0	1	1
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	0	1	1

Table 5. Intercondylar notch measures, calculated indices, and OAI outcome information for KPRKN1,KPRKN2, and KPRKN3.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	KPRKN1	KPRKN2	KPRKN3
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	1	1
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	1	1
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	1	1	1
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	1	1	1
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	0	0	0
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	0	0	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	0	1
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	0	1
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	1	0	1
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	1	0	1
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	2	0	1
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	2	0	1
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	3	0	0
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	3	0	0
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	1
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	1
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	2	2	2
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	2	2	2
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	0	0	0
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	0	0	0
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0

9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	1	0	3
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	1	0	3
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	1	0	1
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	1	0	1
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	1	3	2
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	1	3	2
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	1	2
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	1	2
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	1	1	0
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	1	1	0
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	0	0	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	0	0	0
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	1	1
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	1	1
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	2	1	3
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	2	1	3
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	2	1	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	2	1	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	1	1	1
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	1	1	1
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	2	2	1
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	2	2	1
9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	4	2	2
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	4	2	2
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	1	0	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	1	0	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	0	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	0	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	1	1	2
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	1	1	2
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	1	0	1
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	1	0	1

9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	1	0	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	1	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	2	1	2
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	2	1	2
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	3	0	1
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	3	0	1
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	1	1
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	1	1
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	1	0	0
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	1	0	0
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	3	3	3
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	3	3	3
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	2	2	2
9917307	1	2.01	7.92	3.25	6.54	0.25	0.50	0.38	2	2	2
9996865	1	1.4	7.46	2.69	5.63	0.19	0.48	0.33	0	0	0
9907909	2	2.23	9.84	3.84	7.56	0.23	0.51	0.37	0	0	1
9907909	1	2.04	9.82	3.77	7.62	0.21	0.49	0.35	0	0	1
9905863	2	1.79	9.88	3.43	7.12	0.18	0.48	0.33	0	0	1
9905863	1	1.75	9.59	3.47	7.26	0.18	0.48	0.33	0	0	1
9883715	2	1.86	5.11	2.67	6.27	0.36	0.43	0.39	1	0	0
9883715	1	1.86	8.03	2.63	6.27	0.23	0.42	0.33	1	0	0
9870569	2	1.66	7.54	2.44	5.92	0.22	0.41	0.32	0	0	0
9870569	1	1.59	7.61	2.37	6.07	0.21	0.39	0.30	0	0	0
9857555	2	2.19	8.06	2.66	6.13	0.27	0.43	0.35	1	1	2
9857555	1	2.15	7.99	2.77	6.05	0.27	0.46	0.36	1	1	2

Table 6. Intercondylar notch measures, calculated indices, and OAI outcome information for DIRKN1, DIRKN2, DIRKN3, and DIRKN4.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	DIRKN1	DIRKN2	DIRKN3	DIRKN4
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	0	1	0
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	0	1	0
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	1	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	1	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	1	1	1	0
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	1	1	1	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	1	1	2	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	1	1	2	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	1	1	1	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	1	1	1	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	1	0	1	0
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	1	0	1	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	1	1	2	1
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	1	1	2	1
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	1	2	2	1
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	1	2	2	1
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	0	0	1	1
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	0	0	1	1
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	0	1	1	0
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	0	1	1	0
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	0	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	3	1	2	1
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	3	1	2	1
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	2	2	2	1
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	2	2	2	1
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0	0

9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	0	0	2	0
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	0	0	2	0
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	2	2	2	1
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	2	2	2	1
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	1	0	1
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	1	0	1
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	2	1	3	1
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	2	1	3	1
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	1	1	1
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	1	1	1
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	1	1	2	0
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	1	1	2	0
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	0	1	0	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	0	1	0	0
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	1	1	0	0
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	1	1	0	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	2	2	1	1
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	2	2	1	1
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	1	1	0
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	1	1	0
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	1	1	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	1	1	1	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	1	2	1	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	1	2	1	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	0	1	1	2
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	0	1	1	2
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	2	2	1	1
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	2	2	1	1
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	0	1	1	0
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	0	1	1	0

9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	3	3	1	0
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	3	3	1	0
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	1	1	1	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	1	1	1	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	1	0	1	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	1	0	1	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	0	0	0	0
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	0	0	0	0
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	0	0	1	0
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	0	0	1	0
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	1	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	1	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	1	2	1	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	1	2	1	0
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	0	0	0	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	0	0	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	0	0	0	0
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	0	0	0	0
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	3	1	1	0
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	3	1	1	0
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	2	2	2	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	2	2	2	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	1	1	1	1
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	1	1	1	1
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	0	0	1	0
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	0	0	1	0
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	2	1	1	1

Table 7. Intercondylar notch measures, calculated indices, and OAI outcome information for DIRKN5, DIRKN6, DIRKN7, and DIRKN8.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	DIRKN5	DIRKN6	DIRKN7	DIRKN8
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	0	1	0
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	0	1	0
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	0	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	0	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	2	0	1	0
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	2	0	1	0
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	1	0	1	0
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	1	0	1	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	2	0	2	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	2	0	2	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	1	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	1	0	0	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	2	0	1	0
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	2	0	1	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	0	0	0	0
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	0	0	0	0
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	2	1	1	1
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	2	1	1	1
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	0	0	1	0
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	0	0	1	0
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	1	1	1	1
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	1	1	1	1
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	1	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	1	0	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	2	1	2	1
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	2	1	2	1
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	2	1	1	2
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	2	1	1	2

9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	0	2	3	2
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	0	2	3	2
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	3	0	2	1
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	3	0	2	1
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	1	0	0	1
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	1	0	0	1
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	2	2	2	2
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	2	2	2	2
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	2	1	2	2
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	2	1	2	2
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	2	0	1	2
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	2	0	1	2
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	0	0	1	2
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	0	0	1	2
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	1	0	1	0
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	1	0	1	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	2	2	2	2
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	2	2	2	2
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	1	1	1
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	1	1	1
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	3	1	2	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	3	1	2	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	2	1	2	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	2	1	2	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	1	2	1	1
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	1	2	1	1
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	0	2	2	2
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	0	2	2	2

9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	1	0	1	0
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	1	0	1	0
9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	1	2	3	3
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	1	2	3	3
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	1	0	1	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	1	0	1	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	0	0	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	0	0	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	0	0	0	0
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	0	0	0	0
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	1	0	1	1
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	1	0	1	1
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	2	1	1	1
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	2	1	1	1
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	1	0	1	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	1	0	1	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	0	0	0	0
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	0	0	0	0
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	0	1	2	1
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	0	1	2	1
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	2	0	2	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	2	0	2	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	1	1	1	1
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	1	1	1	1
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	2	0	1	0

Table 8. Intercondylar notch measures, calculated indices, and OAI outcome information for DIRKN9,DIRKN10, and DIRKN11.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	DIRKN9	DIRKN10	DIRKN11
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	1	0
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	1	0
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	1	1	1
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	1	1	1
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	0	0	0
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	0	0	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	1	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	1	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	1	0	1
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	1	0	1
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	1	1	1
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	1	1	1
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	2	2	2
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	2	2	2
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	0	0	0
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	0	0	0
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	0	0	0
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	0	0	0
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	2	0	1
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	2	0	1
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	1	1	1

9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	1	1	1
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	1	3	1
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	1	3	1
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	2	0	2
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	2	0	2
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	1	0
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	1	0
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	2	2	2
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	2	2	2
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	1	1	1
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	1	1	1
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	1	1	1
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	1	1	1
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	0	0	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	0	0	0
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	0	1	0
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	0	1	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	3	0	0
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	3	0	0
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	2	0
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	2	0
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	1	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	1	1	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	1	1	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	1	1	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	0	0	0
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	0	0	0
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	1	1	2

9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	1	1	2
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	0	1	0
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	0	1	0
9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	0	3	0
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	0	3	0
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	0	1	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	0	1	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	0	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	0	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	0	0	0
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	0	0	0
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	0	0	0
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	0	0	0
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	1	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	1	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	0	1	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	0	1	0
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	0	0	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	0	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	0	0	0
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	0	0	0
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	3	1	2
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	3	1	2
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	2	2
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	2	2
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	0	1	0
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	0	1	0
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	0	1	0

Table 9. Intercondylar notch measures, calculated indices, and OAI outcome information for DIRKN12, DIRKN13, and DIRKN14.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	DIRKN12	DIRKN13	DIRKN14
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	0	1	0
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	0	1	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	0	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	0	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	0	0	0
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	0	0	0
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	1	1	1
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	1	1	1
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	1	0	1
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	1	0	1
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	0
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	0	1	1
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	0	1	1
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	3	2	2
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	3	2	2
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	0	0
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	0	0
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	0	1	0

9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	0	1	0
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	2	0	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	2	0	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	0	0	0
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	0	0	0
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	0	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	0	1	1
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	1	1	1
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	1	1	1
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	1	1	0
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	1	1	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	0	0	0
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	0	0	0
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	1	1	1
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	1	1	1
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	0	0	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	0	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	0	0	0
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	0	0	0
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	2	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	2	0
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	0	0	1
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	0	0	1
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	1	1	1
9917307	1	2.01	7.92	3.25	6.54	0.25	0.50	0.38	1	1	1
9996865	1	1.4	7.46	2.69	5.63	0.19	0.48	0.33	0	0	0
9905863	2	1.79	9.88	3.43	7.12	0.18	0.48	0.33	0	0	1
9905863	1	1.75	9.59	3.47	7.26	0.18	0.48	0.33	0	0	1
9870569	2	1.66	7.54	2.44	5.92	0.22	0.41	0.32	0	0	0
9870569	1	1.59	7.61	2.37	6.07	0.21	0.39	0.30	0	0	0
9857555	2	2.19	8.06	2.66	6.13	0.27	0.43	0.35	1	1	1
9857555	1	2.15	7.99	2.77	6.05	0.27	0.46	0.36	1	1	1

9041946	1	1.9	8.45	2.74	6.39	0.22	0.43	0.33	0	0	0
9075815	2	1.6	8.68	2.73	6.75	0.18	0.40	0.29	1	1	0
9075815	1	1.68	8.71	2.48	7.04	0.19	0.35	0.27	1	1	0
9118430	2	1.75	7.98	2.92	6.67	0.22	0.44	0.33	1	2	2
9118430	1	1.82	7.98	2.81	6.7	0.23	0.42	0.32	1	2	2
9157758	2	1.5	8.36	3.14	6.57	0.18	0.48	0.33	1	2	2
9157758	1	1.49	8.14	3.21	6.6	0.18	0.49	0.33	1	2	2
9204055	2	1.75	8.21	3.03	6.45	0.21	0.47	0.34	0	2	2
9204055	1	1.72	8.17	3.03	6.38	0.21	0.47	0.34	0	2	2
9262506	2	1.61	7.8	2.81	5.69	0.21	0.49	0.35	0	0	0
9262506	1	1.68	7.7	2.7	5.47	0.22	0.49	0.36	0	0	0
9273362	2	1.75	7.7	2.59	6.42	0.23	0.40	0.32	1	2	2
9273362	1	1.64	7.84	2.59	6.56	0.21	0.39	0.30	1	2	2
9299944	2	2.19	8.68	2.63	6.86	0.25	0.38	0.32	0	0	0
9299944	1	2.05	8.48	2.67	6.98	0.24	0.38	0.31	0	0	0
9635177	2	2.99	8.84	2.99	6.73	0.34	0.44	0.39	1	0	0
9635177	1	1.68	8.58	3.06	6.93	0.20	0.44	0.32	1	0	0
9439411	2	1.86	9.74	3.43	7.22	0.19	0.48	0.33	0	0	0
9439411	1	1.71	7.99	2.95	6.78	0.21	0.44	0.32	0	0	0
9435421	2	1.86	9.74	3.43	7.22	0.19	0.48	0.33	0	0	0
9435421	1	1.5	8.47	2.48	6.38	0.18	0.39	0.28	0	0	0
9427002	2	1.9	8.78	3.06	6.33	0.22	0.48	0.35	0	0	0
9427002	1	2.09	8.88	2.96	6.29	0.24	0.47	0.35	0	0	0
9422381	2	1.71	7.73	2.81	6.16	0.22	0.46	0.34	2	1	2
9422381	1	1.5	8.47	2.48	6.38	0.18	0.39	0.28	2	1	2
9421281	2	1.71	7.73	2.81	6.16	0.22	0.46	0.34	0	0	0
9421281	1	1.82	7.84	2.77	6.2	0.23	0.45	0.34	0	0	0
9363979	2	2.26	9.45	3.1	6.71	0.24	0.46	0.35	0	0	0
9363979	1	2.26	9.41	3.14	6.64	0.24	0.47	0.36	0	0	0
9356305	2	1.71	8.8	3.03	6.71	0.19	0.45	0.32	1	1	1

Table 10. Intercondylar notch measures, calculated indices, and OAI outcome information for DIRKN15, DIRKN16, and DIRKN17.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	DIRKN15	DIRKN16	DIRKN17
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	0	1	0
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	0	1	0
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	0	0	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	0	0	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	2	2	1
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	2	2	1
9355257	2	1.42	7.8	2.84	6.36	0.18	0.45	0.31	0	1	0
9355257	1	1.89	7.85	2.82	6.35	0.24	0.44	0.34	0	1	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	2	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	2	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	1	1	0
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	1	1	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	1	1	0
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	1	1	0
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	0
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	0
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	2	2	2
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	2	2	2
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	0	0	0
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	0	0	0
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	1	1	1
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	1	1	1
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	0	0	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	0	0	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	1	2	1
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	1	2	1
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	1	2	1

9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	1	2	1
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	0	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	0	0
9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	3	1	1
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	3	1	1
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	0	0	0
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	0	0	0
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	1	2	1
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	1	2	1
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	1	0
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	1	0
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	1	2	1
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	1	2	1
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	0	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	0	0
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	1	3	2
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	1	3	2
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	0	1	0
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	0	1	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	0	0	0
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	0	0	0
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	0	0	0
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	0	0	0
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	1	1
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	1	1
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	1	1	1
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	1	1	1
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	2	1	1
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	2	1	1
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	0	1	1
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	0	1	1
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	2	1	1
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	2	1	1
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	1	1	1
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	1	1	1
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	0	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	0	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	0	0	0

9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	0	0	0
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	1	1	0
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	1	1	0
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	0	0	0
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	0	0	0
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	1	1	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	1	1	0
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	1	1	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	1	1	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	0	0	0
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	0	0	0
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	0	1	0
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	0	1	0
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	2	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	2	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	0	1	1
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	0	1	1
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	1	1	0
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	1	1	0
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	1	1	1
9917307	1	2.01	7.92	3.25	6.54	0.25	0.50	0.38	1	1	1
9907909	2	2.23	9.84	3.84	7.56	0.23	0.51	0.37	0	0	0
9907909	1	2.04	9.82	3.77	7.62	0.21	0.49	0.35	0	0	0
9905863	2	1.79	9.88	3.43	7.12	0.18	0.48	0.33	0	0	0
9905863	1	1.75	9.59	3.47	7.26	0.18	0.48	0.33	0	0	0
9883715	2	1.86	5.11	2.67	6.27	0.36	0.43	0.39	1	1	0
9883715	1	1.86	8.03	2.63	6.27	0.23	0.42	0.33	1	1	0
9870569	2	1.66	7.54	2.44	5.92	0.22	0.41	0.32	0	0	0

Table 11. Intercondylar notch measures, calculated indices, and OAI outcome information for WPLKN1, WPLKN2, and WPLKN3.

Patient ID	Side	Notch Width	Condylar Width	Notch Depth	Condylar Depth	Notch Width Index	Notch Depth Index	Combined Notch Index	WPLKN1	WPLKN2	WPLKN3
9212530	2	1.49	8	2.77	5.72	0.19	0.48	0.34	1	2	0
9212530	1	1.53	8.02	2.77	6.02	0.19	0.46	0.33	1	2	0
9225592	2	2.16	7.39	2.45	5.6	0.29	0.44	0.36	1	2	0
9225592	1	2.15	7.5	2.37	5.77	0.29	0.41	0.35	1	2	0
9309170	2	1.39	7.55	3.1	6.13	0.18	0.51	0.34	1	2	0
9309170	1	1.5	7.41	3	6.13	0.20	0.49	0.35	1	2	0
9355648	2	2.12	8.61	2.85	6.31	0.25	0.45	0.35	0	0	0
9355648	1	2.19	8.6	2.85	6.53	0.25	0.44	0.35	0	0	0
9361974	2	2.04	7.91	2.77	6.64	0.26	0.42	0.34	0	0	0
9361974	1	1.9	7.69	2.77	6.42	0.25	0.43	0.34	0	0	0
9384158	2	1.64	7.85	2.52	5.98	0.21	0.42	0.32	1	1	0
9384158	1	1.68	7.87	2.44	5.94	0.21	0.41	0.31	1	1	0
9396242	2	1.94	8.52	2.95	6.86	0.23	0.43	0.33	0	2	0
9396242	1	1.9	8.66	2.89	6.76	0.22	0.43	0.32	0	2	0
9402960	2	2.08	9.26	2.81	6.89	0.22	0.41	0.32	0	0	2
9402960	1	2.79	9.22	2.88	6.96	0.30	0.41	0.36	0	0	2
9416381	2	1.82	8.06	2.74	6.38	0.23	0.43	0.33	2	2	0
9416381	1	1.79	7.88	2.81	6.27	0.23	0.45	0.34	2	2	0
9423008	2	1.75	9.16	3.14	6.97	0.19	0.45	0.32	0	0	1
9423008	1	1.42	9.15	3.21	6.82	0.16	0.47	0.31	0	0	1
9432102	2	2.66	9.89	2.81	7.16	0.27	0.39	0.33	0	0	0
9432102	1	2.77	9.84	2.81	6.93	0.28	0.41	0.34	0	0	0
9453626	2	1.94	8.82	3.1	6.27	0.22	0.49	0.36	2	2	0
9453626	1	1.94	8.68	3.03	6.24	0.22	0.49	0.35	2	2	0
9456233	2	1.03	7.51	2.34	5.65	0.14	0.41	0.28	0	1	0
9456233	1	1.5	7.74	2.15	5.54	0.19	0.39	0.29	0	1	0
9458868	2	2.01	7.86	3.14	6.35	0.26	0.49	0.38	2	3	2
9458868	1	1.9	7.84	3.03	6.34	0.24	0.48	0.36	2	3	2
9503434	2	1.94	7.95	3	6.6	0.24	0.45	0.35	0	1	0
9503434	1	1.8	8.17	2.82	6.74	0.22	0.42	0.32	0	1	0

9528955	2	1.79	8.93	2.59	6.82	0.20	0.38	0.29	2	0	1
9528955	1	1.87	8.87	2.63	6.64	0.21	0.40	0.30	2	0	1
9532533	2	1.46	7.37	2.7	6.13	0.20	0.44	0.32	0	0	0
9532533	1	1.55	7.55	2.57	6.01	0.21	0.43	0.32	0	0	0
9537090	2	1.68	8.39	3.1	6.46	0.20	0.48	0.34	2	2	2
9537090	1	1.6	8.22	3.05	6.64	0.19	0.46	0.33	2	2	2
9560965	2	1.82	8.06	2.88	6.49	0.23	0.44	0.33	0	1	0
9560965	1	1.71	7.99	2.81	6.46	0.21	0.43	0.32	0	1	0
9562591	2	1.61	8.65	2.96	6.74	0.19	0.44	0.31	0	1	0
9562591	1	1.8	8.7	2.67	6.6	0.21	0.40	0.31	0	1	0
9569715	2	1.72	7.32	2.41	5.94	0.23	0.41	0.32	3	3	0
9569715	1	1.64	7.26	2.37	5.95	0.23	0.40	0.31	3	3	0
9590145	2	1.75	8.31	2.99	6.45	0.21	0.46	0.34	0	1	0
9590145	1	1.68	8.23	3	6.52	0.20	0.46	0.33	0	1	0
9590485	2	1.43	8.06	2.88	6.38	0.18	0.45	0.31	0	1	0
9590485	1	1.29	7.94	2.96	6.52	0.16	0.45	0.31	0	1	0
9637676	2	1.42	8.83	2.44	6.81	0.16	0.36	0.26	0	0	0
9637676	1	1.39	8.93	2.6	7	0.16	0.37	0.26	0	0	0
9640473	2	1.87	9.09	2.99	7.04	0.21	0.42	0.32	0	1	0
9640473	1	1.82	9.11	2.99	6.89	0.20	0.43	0.32	0	1	0
9646958	2	1.79	8.45	2.92	6.6	0.21	0.44	0.33	0	0	0
9646958	1	1.68	8.57	2.92	6.71	0.20	0.44	0.32	0	0	0
9651949	2	1.76	8.26	3	6.4	0.21	0.47	0.34	0	1	1
9651949	1	1.86	8.27	2.88	6.48	0.22	0.44	0.33	0	1	1
9659472	2	1.83	9.17	3.04	7.01	0.20	0.43	0.32	1	1	1
9659472	1	1.93	9.2	3.14	7.19	0.21	0.44	0.32	1	1	1
9659956	2	1.75	9.49	3.43	7.08	0.18	0.48	0.33	1	1	0
9659956	1	1.75	9.42	3.32	7.01	0.19	0.47	0.33	1	1	0
9660607	2	1.87	9.46	3.63	7.14	0.20	0.51	0.35	0	0	0
9660607	1	1.91	9.52	3.41	7.23	0.20	0.47	0.34	0	0	0
9664468	2	1.94	9.01	2.96	6.71	0.22	0.44	0.33	0	0	0
9664468	1	1.86	9.28	2.95	6.82	0.20	0.43	0.32	0	0	0
9669143	2	1.63	8.2	2.7	6.06	0.20	0.45	0.32	1	1	2
9669143	1	1.5	8.24	2.81	6.27	0.18	0.45	0.32	1	1	2
9676235	2	1.35	7.89	3.21	6.64	0.17	0.48	0.33	0	0	0
9676235	1	1.35	7.91	3.24	6.78	0.17	0.48	0.32	0	0	0
9680344	2	1.97	8.68	2.44	6.49	0.23	0.38	0.30	0	1	0
9680344	1	2.01	8.61	2.52	6.43	0.23	0.39	0.31	0	1	0
9682254	2	1.53	7.55	2.44	6.35	0.20	0.38	0.29	0	2	1
9682254	1	1.53	7.66	2.48	6.5	0.20	0.38	0.29	0	2	1

9690658	2	1.82	8.39	2.92	6.38	0.22	0.46	0.34	0	0	0
9690658	1	1.99	8.57	3.12	6.46	0.23	0.48	0.36	0	0	0
9695430	2	2.12	9.15	3.21	7.18	0.23	0.45	0.34	2	2	0
9695430	1	2.3	9.12	3.32	7.04	0.25	0.47	0.36	2	2	0
9699340	2	1.8	9.06	3.12	6.89	0.20	0.45	0.33	0	1	0
9699340	1	1.78	9.09	3.07	7.05	0.20	0.44	0.32	0	1	0
9704858	2	1.97	8.79	2.96	7.37	0.22	0.40	0.31	3	3	2
9704858	1	2.11	8.83	3.03	6.89	0.24	0.44	0.34	3	3	2
9712471	2	1.86	8.86	2.99	7.04	0.21	0.42	0.32	2	2	3
9712471	1	1.71	8.93	3.1	7.15	0.19	0.43	0.31	2	2	3
9714996	2	1.86	8.69	3.03	6.78	0.21	0.45	0.33	2	2	3
9714996	1	1.79	8.75	2.84	6.75	0.20	0.42	0.31	2	2	3
9719999	2	1.82	9.01	3.17	6.89	0.20	0.46	0.33	0	0	0
9719999	1	1.97	9.03	3.03	7.41	0.22	0.41	0.31	0	0	0
9726778	2	1.97	8.93	2.82	6.71	0.22	0.42	0.32	1	1	0
9726778	1	1.9	9.08	2.92	7.04	0.21	0.41	0.31	1	1	0
9993650	2	1.97	7.91	2.63	5.76	0.25	0.46	0.35	0	0	0
9993650	1	1.75	7.81	2.52	6.02	0.22	0.42	0.32	0	0	0
9978026	2	1.86	9.01	3	6.79	0.21	0.44	0.32	2	3	3
9978026	1	1.64	9.04	2.96	6.75	0.18	0.44	0.31	2	3	3
9967728	2	1.57	7.22	2.19	5.76	0.22	0.38	0.30	0	2	0
9967728	1	1.61	7.13	2.05	5.57	0.23	0.37	0.30	0	2	0
9954040	2	1.93	8.6	2.77	6.64	0.22	0.42	0.32	0	0	0
9954040	1	1.73	8.6	2.73	6.56	0.20	0.42	0.31	0	0	0
9937239	2	2.04	8.14	2.48	6.42	0.25	0.39	0.32	2	2	2
9937239	1	1.97	8.1	2.62	6.32	0.24	0.41	0.33	2	2	2
9929102	2	1.9	8.9	2.99	7	0.21	0.43	0.32	0	0	0
9929102	1	1.94	8.86	3.1	6.97	0.22	0.44	0.33	0	0	0
9917307	2	1.9	7.9	3.47	6.43	0.24	0.54	0.39	1	1	1

Appendix E: CAOS grade assessments for each knee and related outcome variable scores used to calculate frequency distributions

Table 1. CAOS grade assessments and related OAI variable outcome scores for SF1, SF2, SF3, SF4, SF5, SF6, and SF7.

Patient ID	Side	Degree	SF1	SF2	SF3	SF4	SF5	SF6	SF7
9212530	2	3	3	3	3	4	5	4	5
9225592	1	1	2	3	2	3	4	5	5
9309170	2	3	3	3	2	5	5	5	4
9309170	1	3	3	3	2	5	5	5	4
9355257	2	0	1	3	3	5	5	5	5
9355257	1	1	1	3	3	5	5	5	5
9355648	2	2	3	3	3	5	5	5	5
9355648	1	2	3	3	3	5	5	5	5
9361974	2	3	3	3	2	3	5	5	5
9361974	1	2	3	3	2	3	5	5	5
9384158	2	1	3	2	2	3	3	4	4
9384158	1	1	3	2	2	3	3	4	4
9396242	2	1	2	3	3	5	5	4	4
9396242	1	1	2	3	3	5	5	4	4
9402960	2	3	2	3	3	5	5	5	5
9402960	1	0	2	3	3	5	5	5	5
9416381	2	1	4	2	1	3	3	4	5
9416381	1	1	4	2	1	3	3	4	5
9423008	2	1	2	1	1	4	5	4	5
9423008	1	1	2	1	1	4	5	4	5
9432102	2	1	3	3	2	4	4	5	5
9432102	1	1	3	3	2	4	4	5	5
9453626	2	2	3	3	3	4	2	3	3
9453626	1	1	3	3	3	4	2	3	3
9456233	2	3	1	2	1	3	3	5	5
9456233	1	3	1	2	1	3	3	5	5
9458868	2	2	3	1	2	2	3	2	4
9458868	1	1	3	1	2	2	3	2	4
9503434	2	2	3	3	3	5	5	5	5

9503434	1	1	3	3	3	5	5	5	5
9528955	2	2	2	3	3	3	3	5	5
9528955	1	2	2	3	3	3	3	5	5
9532533	2	0	2	3	3	5	4	5	5
9532533	1	0	2	3	3	5	4	5	5
9537090	2	1	2	2	2	4	4	4	4
9537090	1	1	2	2	2	4	4	4	4
9560965	2	2	2	3	2	4	2	3	3
9560965	1	2	2	3	2	4	2	3	3
9562591	2	1	3	3	3	5	5	5	5
9562591	1	1	3	3	3	5	5	5	5
9569715	2	1	2	3	3	5	5	5	5
9569715	1	0	2	3	3	5	5	5	5
9590145	2	1	3	3	3	5	5	5	5
9590145	1	1	3	3	3	5	5	5	5
9590485	2	1	2	2	2	1	1	2	1
9590485	1	2	2	2	2	1	1	2	1
9637676	2	1	3	2	1	2	3	3	3
9637676	1	2	3	2	1	2	3	3	3
9640473	2	1	4	2	2	4	4	4	5
9640473	1	1	4	2	2	4	4	4	5
9646958	2	1	2	3	3	5	5	5	5
9646958	1	2	2	3	3	5	5	5	5
9651949	2	1	3	3	1	2	2	5	4
9651949	1	2	3	3	1	2	2	5	4
9659472	2	1	2	3	3	5	5	5	5
9659472	1	1	2	3	3	5	5	5	5
9659956	2	3	3	3	2	4	4	4	4
9659956	1	1	3	3	2	4	4	4	4
9660607	2	1	3	3	3	4	4	5	5
9660607	1	1	3	3	3	4	4	5	5
9664468	2	1	3	3	2	4	4	5	5
9664468	1	2	3	3	2	4	4	5	5
9669143	2	1	2	3	3	4	5	5	4
9669143	1	0	2	3	3	4	5	5	4
9676235	2	2	2	3	3	5	5	5	5
9676235	1	2	2	3	3	5	5	5	5
9680344	2	1	3	1	1	3	2	5	5
9680344	1	1	3	1	1	3	2	5	5
9682254	2	1	2	3	3	5	5	5	5

9682254	1	2	2	3	3	5	5	5	5
9690658	2	3	3	3	2	3	3	5	5
9690658	1	1	3	3	2	3	3	5	5
9695430	2	2	3	2	2	3	3	5	5
9695430	2	2	3	2	2	3	3	5	5
9695430	1	2	3	2	2	3	3	5	5
9695430	1	1	3	2	2	3	3	5	5
9699340	2	1	1	3	3	5	5	5	5
9699340	2	1	1	3	3	5	5	5	5
9699340	1	1	1	3	3	5	5	5	5
9699340	1	0	1	3	3	5	5	5	5
9704858	2	1	3	2	2	4	4	5	5
9704858	2	2	3	2	2	4	4	5	5
9704858	1	1	3	2	2	4	4	5	5
9712471	2	2	2	3	3	5	5	5	5
9712471	1	1	2	3	3	5	5	5	5
9714996	2	2	2	3	2	4	5	5	5
9714996	1	2	2	3	2	4	5	5	5
9719999	2	1	2	2	3	5	5	5	5
9993650	2	2	2	3	3	5	5	5	5
9993650	1	1	2	3	3	5	5	5	5
9978026	2	1	2	2	2	3	3	5	5
9978026	1	1	2	2	2	3	3	5	5
9967728	2	2	3	2	1	3	3	3	3
9967728	1	2	3	2	1	3	3	3	3
9954040	2	1	4	3	2	2	3	5	3
9954040	1	1	4	3	2	2	3	5	3
9937239	2	2	4	3	2	3	4	4	5
9937239	1	2	4	3	2	3	4	4	5
9929102	2	1	2	3	3	5	5	5	5

Table 2. CAOS grade assessments and related OAI variable outcome scores for SF8, SF9, SF10, SF11, SF12, and WPRKN1.

Patient ID	Side	Degree	SF8	SF9	SF10	SF11	SF12	WPRKN1
9212530	2	3	2	4	4	5	5	1
9225592	1	1	2	2	2	5	5	0
9309170	2	3	2	3	3	4	5	0
9309170	1	3	2	3	3	4	5	0
9355257	2	0	1	2	2	5	5	0
9355257	1	1	1	2	2	5	5	0
9355648	2	2	1	2	2	5	5	0
9355648	1	2	1	2	2	5	5	0
9361974	2	3	1	2	4	5	5	0
9361974	1	2	1	2	4	5	5	0
9384158	2	1	3	2	2	4	5	1
9384158	1	1	3	2	2	4	5	1
9396242	2	1	2	1	2	4	4	1
9396242	1	1	2	1	2	4	4	1
9402960	2	3	1	2	3	5	5	0
9402960	1	0	1	2	3	5	5	0
9416381	2	1	3	3	4	3	3	1
9416381	1	1	3	3	4	3	3	1
9423008	2	1	3	2	5	5	5	0
9423008	1	1	3	2	5	5	5	0
9432102	2	1	2	3	2	4	5	1
9432102	1	1	2	3	2	4	5	1
9453626	2	2	2	3	3	3	3	1
9453626	1	1	2	3	3	3	3	1
9456233	2	3	2	2	2	5	5	1
9456233	1	3	2	2	2	5	5	1
9458868	2	2	3	3	5	3	4	1
9458868	1	1	3	3	5	3	4	1
9503434	2	2	1	2	2	4	5	0
9503434	1	1	1	2	2	4	5	0
9528955	2	2	3	1	2	5	5	3
9528955	1	2	3	1	2	5	5	3
9532533	2	0	2	2	2	5	5	0
9532533	1	0	2	2	2	5	5	0
9537090	2	1	2	3	2	4	4	0

9537090	1	1	2	3	2	4	4	0
9560965	2	2	3	2	2	5	5	0
9560965	1	2	3	2	2	5	5	0
9562591	2	1	2	2	3	5	5	0
9562591	1	1	2	2	3	5	5	0
9569715	2	1	1	2	1	4	5	2
9569715	1	0	1	2	1	4	5	2
9590145	2	1	1	4	3	3	5	0
9590145	1	1	1	4	3	3	5	0
9590485	2	1	4	3	4	2	3	2
9590485	1	2	4	3	4	2	3	2
9637676	2	1	4	3	4	3	2	1
9637676	1	2	4	3	4	3	2	1
9640473	2	1	3	2	4	5	5	1
9640473	1	1	3	2	4	5	5	1
9646958	2	1	2	2	2	5	5	1
9646958	1	2	2	2	2	5	5	1
9651949	2	1	3	4	4	4	4	2
9651949	1	2	3	4	4	4	4	2
9659472	2	1	1	1	1	5	5	0
9659472	1	1	1	1	1	5	5	0
9659956	2	3	2	2	4	4	5	1
9659956	1	1	2	2	4	4	5	1
9660607	2	1	2	1	2	5	5	1
9660607	1	1	2	1	2	5	5	1
9664468	2	1	1	2	2	5	5	1
9664468	1	2	1	2	2	5	5	1
9669143	2	1	2	2	3	4	5	2
9669143	1	0	2	2	3	4	5	2
9676235	2	2	1	2	2	4	5	0
9676235	1	2	1	2	2	4	5	0
9680344	2	1	3	2	3	4	4	2
9680344	1	1	3	2	3	4	4	2
9682254	2	1	3	1	3	5	5	0
9682254	1	2	3	1	3	5	5	0
9690658	2	3	3	2	3	5	5	2
9690658	1	1	3	2	3	5	5	2
9695430	2	2	4	4	5	4	5	0
9695430	2	2	4	4	5	4	5	0
9695430	1	2	4	4	5	4	5	0

9695430	1	1	4	4	5	4	5	0
9699340	2	1	2	2	2	5	5	0
9699340	2	1	2	2	2	5	5	0
9699340	1	1	2	2	2	5	5	0
9699340	1	0	2	2	2	5	5	0
9704858	2	1	3	3	4	4	5	1
9704858	2	2	3	3	4	4	5	1
9704858	1	1	3	3	4	4	5	1
9712471	2	2	2	1	2	4	5	1
9712471	1	1	2	1	2	4	5	1
9714996	2	2	2	2	2	4	5	0
9714996	1	2	2	2	2	4	5	0
9719999	2	1	1	2	2	5	5	0
9993650	2	2	2	2	2	5	5	0
9993650	1	1	2	2	2	5	5	0
9978026	2	1	3	2	2	5	5	1
9978026	1	1	3	2	2	5	5	1
9967728	2	2	4	4	4	4	2	4
9967728	1	2	4	4	4	4	2	4
9954040	2	1	3	2	3	4	5	0
9954040	1	1	3	2	3	4	5	0
9937239	2	2	2	2	2	3	4	1
9937239	1	2	2	2	2	3	4	1
9929102	2	1	2	3	3	4	4	1

Table 3. CAOS grade assessments and related OAI variable outcome scores for WPRKN2, WPRKN3, WPRKN4, WPRKN5, and KSXRKN1.

Patient ID	Side	Degree	WPRKN2	WPRKN3	WPRKN4	WPRKN5	KSXRKN1
9212530	2	3	1	0	1	1	0
9225592	1	1	1	0	0	0	0
9309170	2	3	2	0	0	0	1
9309170	1	3	2	0	0	0	1
9355648	2	2	2	0	0	0	1
9355648	1	2	2	0	0	0	1
9361974	2	3	1	0	0	0	0
9361974	1	2	1	0	0	0	0
9384158	2	1	1	0	0	0	0
9384158	1	1	1	0	0	0	0
9396242	2	1	1	0	0	1	0
9396242	1	1	1	0	0	1	0
9402960	2	3	0	0	0	0	0
9402960	1	0	0	0	0	0	0
9416381	2	1	2	0	1	1	0
9416381	1	1	2	0	1	1	0
9423008	2	1	0	2	2	2	0
9423008	1	1	0	2	2	2	0
9453626	2	2	0	0	0	0	0
9453626	1	1	0	0	0	0	0
9456233	2	3	3	0	0	2	1
9456233	1	3	3	0	0	2	1
9458868	2	2	2	1	1	1	0
9458868	1	1	2	1	1	1	0
9503434	2	2	0	0	0	0	0
9503434	1	1	0	0	0	0	0
9528955	2	2	1	3	3	1	0
9528955	1	2	1	3	3	1	0
9532533	2	0	0	0	0	0	0
9532533	1	0	0	0	0	0	0
9537090	2	1	0	0	0	0	0
9537090	1	1	0	0	0	0	0
9560965	2	2	2	0	0	1	0
9560965	1	2	2	0	0	1	0
9562591	2	1	1	0	0	1	0

9562591	1	1	1	0	0	1	0
9569715	2	1	3	0	0	0	2
9569715	1	0	3	0	0	0	2
9590145	2	1	1	0	0	0	0
9590145	1	1	1	0	0	0	0
9590485	2	1	3	1	1	1	2
9590485	1	2	3	1	1	1	2
9637676	2	1	1	0	0	1	1
9637676	1	2	1	0	0	1	1
9640473	2	1	1	3	3	0	0
9640473	1	1	1	3	3	0	0
9646958	2	1	1	1	1	1	1
9646958	1	2	1	1	1	1	1
9651949	2	1	3	0	0	2	0
9651949	1	2	3	0	0	2	0
9659472	2	1	0	0	0	0	0
9659472	1	1	0	0	0	0	0
9659956	2	3	1	0	0	1	0
9659956	1	1	1	0	0	1	0
9660607	2	1	1	0	1	1	3
9660607	1	1	1	0	1	1	3
9664468	2	1	2	1	2	1	0
9664468	1	2	2	1	2	1	0
9669143	2	1	0	2	2	2	0
9669143	1	0	0	2	2	2	0
9676235	2	2	0	0	0	0	0
9676235	1	2	0	0	0	0	0
9680344	2	1	2	1	2	1	3
9680344	1	1	2	1	2	1	3
9682254	2	1	2	2	2	0	0
9682254	1	2	2	2	2	0	0
9690658	2	3	3	0	0	0	2
9690658	1	1	3	0	0	0	2
9695430	2	2	1	0	0	0	0
9695430	2	2	1	0	0	0	0
9695430	1	2	1	0	0	0	0
9695430	1	1	1	0	0	0	0
9699340	2	1	1	0	0	0	0
9699340	2	1	1	0	0	0	0
9699340	1	1	1	0	0	0	0

9699340	1	0	1	0	0	0	0
9704858	2	1	1	1	1	2	0
9704858	2	2	1	1	1	2	0
9704858	1	1	1	1	1	2	0
9712471	2	2	1	1	1	1	0
9712471	1	1	1	1	1	1	0
9714996	2	2	0	0	0	0	0
9714996	1	2	0	0	0	0	0
9719999	2	1	1	0	0	0	0
9993650	2	2	0	0	0	0	0
9993650	1	1	0	0	0	0	0
9978026	2	1	2	1	1	1	0
9978026	1	1	2	1	1	1	0
9967728	2	2	3	0	0	1	2
9967728	1	2	3	0	0	1	2
9954040	2	1	0	0	0	0	0
9954040	1	1	0	0	0	0	0
9937239	2	2	1	1	0	1	0
9937239	1	2	1	1	0	1	0
9929102	2	1	1	0	1	1	0
9929102	1	1	1	0	1	1	0
9996865	1	3	1	2	0	0	0
9907909	2	1	1	0	0	0	0
9907909	1	1	1	0	0	0	0

Table 4. CAOS grade assessments and related OAI variable outcome scores for DIRKN2, DIRKN3, DIRKN4, DIRKN5, DIRKN6, and DIRKN8.

Patient ID	Side	Degree	DIRKN2	DIRKN3	DIRKN4	DIRKN5	DIRKN6	DIRKN8
9212530	2	3	0	1	0	0	0	0
9225592	1	1	0	0	0	0	0	0
9309170	2	3	1	1	0	2	0	0
9309170	1	3	1	1	0	2	0	0
9355648	2	2	1	2	0	2	0	0
9355648	1	2	1	2	0	2	0	0
9361974	2	3	1	1	0	1	0	0
9361974	1	2	1	1	0	1	0	0
9384158	2	1	0	1	0	2	0	0
9384158	1	1	0	1	0	2	0	0
9396242	2	1	1	2	1	0	0	0
9396242	1	1	1	2	1	0	0	0
9402960	2	3	0	0	0	0	0	0
9402960	1	0	0	0	0	0	0	0
9416381	2	1	2	2	1	2	1	1
9416381	1	1	2	2	1	2	1	1
9423008	2	1	0	1	1	0	0	0
9423008	1	1	0	1	1	0	0	0
9432102	2	1	1	1	0	1	1	1
9432102	1	1	1	1	0	1	1	1
9453626	2	2	0	0	0	0	1	0
9453626	1	1	0	0	0	0	1	0
9456233	2	3	1	2	1	2	1	1
9456233	1	3	1	2	1	2	1	1
9458868	2	2	2	2	1	2	1	2
9458868	1	1	2	2	1	2	1	2
9503434	2	2	0	0	0	0	0	0
9503434	1	1	0	0	0	0	0	0
9528955	2	2	0	2	0	0	2	2
9528955	1	2	0	2	0	0	2	2
9532533	2	0	0	0	0	0	0	0
9532533	1	0	0	0	0	0	0	0
9537090	2	1	0	0	0	0	0	0
9537090	1	1	0	0	0	0	0	0
9560965	2	2	2	2	1	3	0	1

9560965	1	2	2	2	1	3	0	1
9562591	2	1	1	0	1	1	0	1
9562591	1	1	1	0	1	1	0	1
9569715	2	1	1	3	1	2	2	2
9569715	1	0	1	3	1	2	2	2
9590145	2	1	0	0	0	0	0	0
9590145	1	1	0	0	0	0	0	0
9590485	2	1	1	1	1	2	1	2
9590485	1	2	1	1	1	2	1	2
9637676	2	1	1	2	0	2	0	2
9637676	1	2	1	2	0	2	0	2
9640473	2	1	1	0	0	0	0	2
9640473	1	1	1	0	0	0	0	2
9646958	2	1	1	0	0	1	0	0
9646958	1	2	1	0	0	1	0	0
9651949	2	1	2	1	1	2	2	2
9651949	1	2	2	1	1	2	2	2
9659472	2	1	0	0	0	0	0	0
9659472	1	1	0	0	0	0	0	0
9659956	2	3	1	1	0	1	1	1
9659956	1	1	1	1	0	1	1	1
9660607	2	1	1	1	1	3	1	1
9660607	1	1	1	1	1	3	1	1
9664468	2	1	2	1	1	2	1	1
9664468	1	2	2	1	1	2	1	1
9669143	2	1	1	1	2	1	2	1
9669143	1	0	1	1	2	1	2	1
9676235	2	2	0	0	0	0	0	0
9676235	1	2	0	0	0	0	0	0
9680344	2	1	2	1	1	0	2	2
9680344	1	1	2	1	1	0	2	2
9682254	2	1	1	1	0	1	0	0
9682254	1	2	1	1	0	1	0	0
9690658	2	3	3	1	0	1	2	3
9690658	1	1	3	1	0	1	2	3
9695430	2	2	1	1	0	1	0	0
9695430	2	2	1	1	0	1	0	0
9695430	1	2	1	1	0	1	0	0
9695430	1	1	1	1	0	1	0	0
9699340	2	1	0	1	0	0	0	0

9699340	2	1	0	1	0	0	0	0
9699340	1	1	0	1	0	0	0	0
9699340	1	0	0	1	0	0	0	0
9704858	2	1	0	0	0	0	0	0
9704858	2	2	0	0	0	0	0	0
9704858	1	1	0	0	0	0	0	0
9712471	2	2	0	1	0	1	0	1
9712471	1	1	0	1	0	1	0	1
9714996	2	2	0	0	0	0	0	0
9714996	1	2	0	0	0	0	0	0
9719999	2	1	0	0	0	0	0	0
9993650	2	2	0	0	0	1	0	0
9993650	1	1	0	0	0	1	0	0
9978026	2	1	0	0	0	0	0	0
9978026	1	1	0	0	0	0	0	0
9967728	2	2	1	1	0	0	1	1
9967728	1	2	1	1	0	0	1	1
9954040	2	1	2	2	0	2	0	0
9954040	1	1	2	2	0	2	0	0
9937239	2	2	1	1	1	1	1	1
9937239	1	2	1	1	1	1	1	1
9929102	2	1	0	1	0	2	0	0
9929102	1	1	0	1	0	2	0	0
9917307	2	2	1	1	1	2	1	1

Table 6. CAOS grade assessments and related OAI variable outcome scores for DIRKN7, DIRKN9, DIRKN10, DIRKN11, DIRKN12, and DIRKN13.

Patient ID	Side	Degree	DIRKN7	DIRKN9	DIRKN10	DIRKN11	DIRKN12	DIRKN13
9309170	2	3	1	1	1	1	0	1
9309170	1	3	1	1	1	1	0	1
9355648	2	2	2	0	1	0	0	0
9355648	1	2	2	0	1	0	0	0
9361974	2	3	0	0	0	0	0	0
9361974	1	2	0	0	0	0	0	0
9396242	2	1	0	1	1	1	0	0
9396242	1	1	0	1	1	1	0	0
9402960	2	3	0	0	0	0	0	0
9402960	1	0	0	0	0	0	0	0
9416381	2	1	1	2	2	2	1	1
9416381	1	1	1	2	2	2	1	1
9423008	2	1	1	0	0	0	1	0
9423008	1	1	1	0	0	0	1	0
9453626	2	2	0	0	0	0	0	0
9453626	1	1	0	0	0	0	0	0
9458868	2	2	1	1	1	1	0	1
9458868	1	1	1	1	1	1	0	1
9503434	2	2	0	0	0	0	0	0
9503434	1	1	0	0	0	0	0	0
9528955	2	2	3	1	3	1	3	2
9528955	1	2	3	1	3	1	3	2
9532533	2	0	0	0	0	0	0	0
9532533	1	0	0	0	0	0	0	0
9537090	2	1	0	0	0	0	0	0
9537090	1	1	0	0	0	0	0	0
9562591	2	1	0	0	1	0	0	0
9562591	1	1	0	0	1	0	0	0
9637676	2	1	1	1	1	1	0	1
9637676	1	2	1	1	1	1	0	1
9640473	2	1	1	0	0	0	2	0
9640473	1	1	1	0	0	0	2	0
9651949	2	1	2	3	0	0	0	0
9651949	1	2	2	3	0	0	0	0
9659472	2	1	0	0	0	0	0	0

9659472	1	1	0	0	0	0	0	0
9660607	2	1	2	1	1	1	0	1
9660607	1	1	2	1	1	1	0	1
9676235	2	2	0	0	0	0	0	0
9676235	1	2	0	0	0	0	0	0
9680344	2	1	2	1	1	2	1	1
9680344	1	1	2	1	1	2	1	1
9682254	2	1	1	0	1	0	1	1
9682254	1	2	1	0	1	0	1	1
9704858	2	1	0	0	0	0	0	0
9704858	2	2	0	0	0	0	0	0
9704858	1	1	0	0	0	0	0	0
9712471	2	2	1	0	0	0	1	1
9712471	1	1	1	0	0	0	1	1
9714996	2	2	0	0	1	0	0	0
9714996	1	2	0	0	1	0	0	0
9719999	2	1	0	0	0	0	0	0
9978026	2	1	0	0	0	0	0	0
9978026	1	1	0	0	0	0	0	0
9954040	2	1	2	0	2	2	0	2
9954040	1	1	2	0	2	2	0	2
9929102	2	1	1	0	1	0	0	0
9929102	1	1	1	0	1	0	0	0
9917307	2	2	2	1	1	1	1	1
9917307	1	2	2	1	1	1	1	1
9996865	1	3	0	0	0	0	0	0
9905863	2	1	1	0	1	0	0	0
9905863	1	1	1	0	1	0	0	0
9870569	2	2	0	0	0	0	0	0
9870569	1	2	0	0	0	0	0	0
9857555	2	1	1	2	0	1	1	1
9857555	1	0	1	2	0	1	1	1
9041946	1	1	0	0	0	0	0	0
9075815	2	3	2	1	1	1	1	1
9075815	1	3	2	1	1	1	1	1
9118430	2	2	2	2	2	2	1	2
9118430	1	2	2	2	2	2	1	2
9157758	2	0	2	2	1	1	1	2
9157758	1	0	2	2	1	1	1	2
9204055	2	1	2	2	2	2	0	2

9204055	1	3	2	2	2	2	0	2
9262506	2	2	1	0	1	0	0	0
9262506	1	2	1	0	1	0	0	0
9273362	2	0	3	1	1	1	1	2
9273362	1	0	3	1	1	1	1	2
9299944	2	1	0	0	0	0	0	0
9299944	1	1	0	0	0	0	0	0
9635177	2	2	0	0	0	1	1	0
9635177	1	1	0	0	0	1	1	0
9439411	2	1	0	0	0	0	0	0
9439411	1	0	0	0	0	0	0	0
9435421	2	1	1	0	1	1	0	0
9435421	1	1	1	0	1	1	0	0
9427002	2	1	0	0	0	0	0	0
9427002	1	1	0	0	0	0	0	0
9422381	2	2	1	1	0	0	2	1
9422381	1	3	1	1	0	0	2	1
9421281	2	0	0	0	0	0	0	0
9421281	1	0	0	0	0	0	0	0
9363979	2	1	1	0	0	0	0	0
9363979	1	1	1	0	0	0	0	0
9356305	2	2	1	1	1	1	1	1
9356305	1	2	1	1	1	1	1	1
9314056	2	0	1	0	1	0	2	2

Table 7. CAOS grade assessments and related OAI variable outcome scores for DIRKN14, DIRKN15, DIRKN16, DIRKN17, and WPLKN1.

Patient ID	Side	Degree	DIRKN14	DIRKN15	DIRKN16	DIRKN17	WPLKN1
9212530	2	3	0	0	1	0	1
9225592	1	1	0	0	0	0	1
9309170	2	3	0	2	2	1	1
9309170	1	3	0	2	2	1	1
9355257	2	0	0	0	1	0	1
9355257	1	1	0	0	1	0	1
9355648	2	2	0	0	2	0	0
9355648	1	2	0	0	2	0	0
9361974	2	3	0	0	0	0	0
9361974	1	2	0	0	0	0	0
9384158	2	1	0	1	1	0	1
9384158	1	1	0	1	1	0	1
9396242	2	1	0	1	1	0	0
9396242	1	1	0	1	1	0	0
9402960	2	3	0	0	0	0	0
9402960	1	0	0	0	0	0	0
9416381	2	1	1	2	2	2	2
9416381	1	1	1	2	2	2	2
9423008	2	1	1	0	0	0	0
9423008	1	1	1	0	0	0	0
9432102	2	1	0	1	1	1	0
9432102	1	1	0	1	1	1	0
9453626	2	2	0	0	0	0	2
9453626	1	1	0	0	0	0	2
9456233	2	3	0	1	2	1	0
9456233	1	3	0	1	2	1	0
9458868	2	2	1	1	2	1	2
9458868	1	1	1	1	2	1	2
9503434	2	2	0	0	0	0	0
9503434	1	1	0	0	0	0	0
9528955	2	2	2	3	1	1	2
9528955	1	2	2	3	1	1	2
9537090	2	1	0	0	0	0	2
9537090	1	1	0	0	0	0	2
9560965	2	2	1	1	2	1	0

9560965	1	2	1	1	2	1	0
9562591	2	1	0	0	1	0	0
9562591	1	1	0	0	1	0	0
9569715	2	1	1	1	2	1	3
9569715	1	0	1	1	2	1	3
9590145	2	1	0	0	0	0	0
9590145	1	1	0	0	0	0	0
9637676	2	1	0	1	3	2	0
9637676	1	2	0	1	3	2	0
9646958	2	1	0	0	1	0	0
9646958	1	2	0	0	1	0	0
9651949	2	1	0	0	0	0	0
9651949	1	2	0	0	0	0	0
9659472	2	1	0	0	0	0	1
9659472	1	1	0	0	0	0	1
9659956	2	3	0	1	1	1	1
9659956	1	1	0	1	1	1	1
9660607	2	1	1	1	1	1	0
9660607	1	1	1	1	1	1	0
9664468	2	1	2	2	1	1	0
9664468	1	2	2	2	1	1	0
9669143	2	1	1	0	1	1	1
9669143	1	0	1	0	1	1	1
9676235	2	2	0	0	0	0	0
9676235	1	2	0	0	0	0	0
9682254	2	1	0	2	1	1	0
9682254	1	2	0	2	1	1	0
9695430	2	2	0	1	1	1	2
9695430	2	2	0	1	1	1	2
9695430	1	2	0	1	1	1	2
9695430	1	1	0	1	1	1	2
9699340	2	1	0	0	0	0	0
9699340	2	1	0	0	0	0	0
9699340	1	1	0	0	0	0	0
9699340	1	0	0	0	0	0	0
9704858	2	1	0	0	0	0	3
9704858	2	2	0	0	0	0	3
9704858	1	1	0	0	0	0	3
9712471	2	2	1	1	1	0	2
9712471	1	1	1	1	1	0	2

9714996	2	2	0	0	0	0	2
9714996	1	2	0	0	0	0	2
9719999	2	1	0	0	0	0	0
9993650	2	2	0	1	1	0	0
9993650	1	1	0	1	1	0	0
9978026	2	1	0	0	0	0	2
9978026	1	1	0	0	0	0	2
9967728	2	2	0	0	1	0	0
9967728	1	2	0	0	1	0	0
9954040	2	1	0	0	2	0	0
9954040	1	1	0	0	2	0	0
9937239	2	2	0	0	1	1	2
9937239	1	2	0	0	1	1	2
9929102	2	1	1	1	1	0	0
9929102	1	1	1	1	1	0	0
9917307	2	2	1	1	1	1	1
9917307	1	2	1	1	1	1	1
9907909	2	1	0	0	0	0	1
9907909	1	1	0	0	0	0	1
9905863	2	1	1	0	0	0	1
9905863	1	1	1	0	0	0	1
9883715	2	2	1	1	1	0	0
9883715	1	1	1	1	1	0	0
9870569	2	2	0	0	0	0	0

Table 8. CAOS grade assessments and related OAI variable outcome scores for KQOL2, KQOL3, KQOL4, WOMTSL, and WOMSTFL.

Patient ID	Side	Degree	KQOL2	KQOL3	KQOL4	WOMTSL	WOMSTFL
9212530	2	3	1	1	1	28.25	3
9225592	1	1	3	0	0	12.4	4
9309170	2	3	0	1	2	26	4
9309170	1	3	0	1	2	26	4
9355257	2	0	2	0	2	6.892857143	2
9355257	1	1	2	0	2	6.892857143	2
9355648	2	2	2	0	2	0	0
9355648	1	2	2	0	2	0	0
9361974	2	3	1	1	1	4	0
9361974	1	2	1	1	1	4	0
9384158	2	1	4	1	1	20.9375	2
9384158	1	1	4	1	1	20.9375	2
9396242	2	1	2	2	1	17	2
9396242	1	1	2	2	1	17	2
9402960	2	3	0	1	1	6	2
9402960	1	0	0	1	1	6	2
9416381	2	1	2	2	2	36	4
9416381	1	1	2	2	2	36	4
9423008	2	1	3	2	1	9	1
9423008	1	1	3	2	1	9	1
9432102	2	1	1	1	1	0	0
9432102	1	1	1	1	1	0	0
9453626	2	2	2	1	2	30	2
9453626	1	1	2	1	2	30	2
9456233	2	3	1	2	2	8.375	1
9456233	1	3	1	2	2	8.375	1
9458868	2	2	4	4	2	49	4
9458868	1	1	4	4	2	49	4
9503434	2	2	1	1	1	5	2
9503434	1	1	1	1	1	5	2
9528955	2	2	0	0	2	16	4
9528955	1	2	0	0	2	16	4
9532533	2	0	1	0	1	0	0
9532533	1	0	1	0	1	0	0
9537090	2	1	2	2	1	13	3

9537090	1	1	2	2	1	13	3
9560965	2	2	4	2	2	26.375	1
9560965	1	2	4	2	2	26.375	1
9562591	2	1	1	1	1	12	2
9562591	1	1	1	1	1	12	2
9569715	2	1	1	1	2	41.625	5
9569715	1	0	1	1	2	41.625	5
9590145	2	1	0	0	1	3	2
9590145	1	1	0	0	1	3	2
9590485	2	1	4	3	3	5.1875	1
9590485	1	2	4	3	3	5.1875	1
9637676	2	1	3	2	2	13	1
9637676	1	2	3	2	2	13	1
9640473	2	1	3	1	1	4.1875	0
9640473	1	1	3	1	1	4.1875	0
9646958	2	1	2	2	1	1	1
9646958	1	2	2	2	1	1	1
9651949	2	1	3	1	2	16.625	2
9651949	1	2	3	1	2	16.625	2
9659472	2	1	0	0	1	8	1
9659472	1	1	0	0	1	8	1
9659956	2	3	0	1	1	16.75	2
9659956	1	1	0	1	1	16.75	2
9660607	2	1	2	0	2	12	2
9660607	1	1	2	0	2	12	2
9664468	2	1	3	3	3	0	0
9664468	1	2	3	3	3	0	0
9669143	2	1	0	1	1	21.75	3
9669143	1	0	0	1	1	21.75	3
9676235	2	2	0	0	0	0	0
9676235	1	2	0	0	0	0	0
9680344	2	1	2	2	2	1	0
9680344	1	1	2	2	2	1	0
9682254	2	1	1	1	0	24	1
9682254	1	2	1	1	0	24	1
9690658	2	3	4	2	2	0	0
9690658	1	1	4	2	2	0	0
9695430	2	2	3	4	3	29.3125	2
9695430	2	2	3	4	3	29.3125	2
9695430	1	2	3	4	3	29.3125	2

9695430	1	1	3	4	3	29.3125	2
9699340	2	1	1	0	1	3	2
9699340	2	1	1	0	1	3	2
9699340	1	1	1	0	1	3	2
9699340	1	0	1	0	1	3	2
9704858	2	1	0	2	2	54	4
9704858	2	2	0	2	2	54	4
9704858	1	1	0	2	2	54	4
9712471	2	2	1	0	2	26	3
9712471	1	1	1	0	2	26	3
9714996	2	2	1	1	2	40	5
9714996	1	2	1	1	2	40	5
9719999	2	1	1	2	1	0	0
9993650	2	2	1	0	1	5.25	1
9993650	1	1	1	0	1	5.25	1
9978026	2	1	3	2	2	51.9375	5
9978026	1	1	3	2	2	51.9375	5
9967728	2	2	4	3	2	10.25	4
9967728	1	2	4	3	2	10.25	4
9954040	2	1	0	2	2	22	4
9954040	1	1	0	2	2	22	4
9937239	2	2	0	1	1	35.25	4
9937239	1	2	0	1	1	35.25	4
9929102	2	1	0	1	1	11	2

Appendix F: Examples of frequency distributions used to compile probabilities

Table 1. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 1, right knee difficulty: down stairs, last 7 days.

	Dirkn 1 - Outcome	
CAOS Grade	0 = best	3 = worst
0	69	35
1	25	27
2	6	12
3	0	27
4	0	0

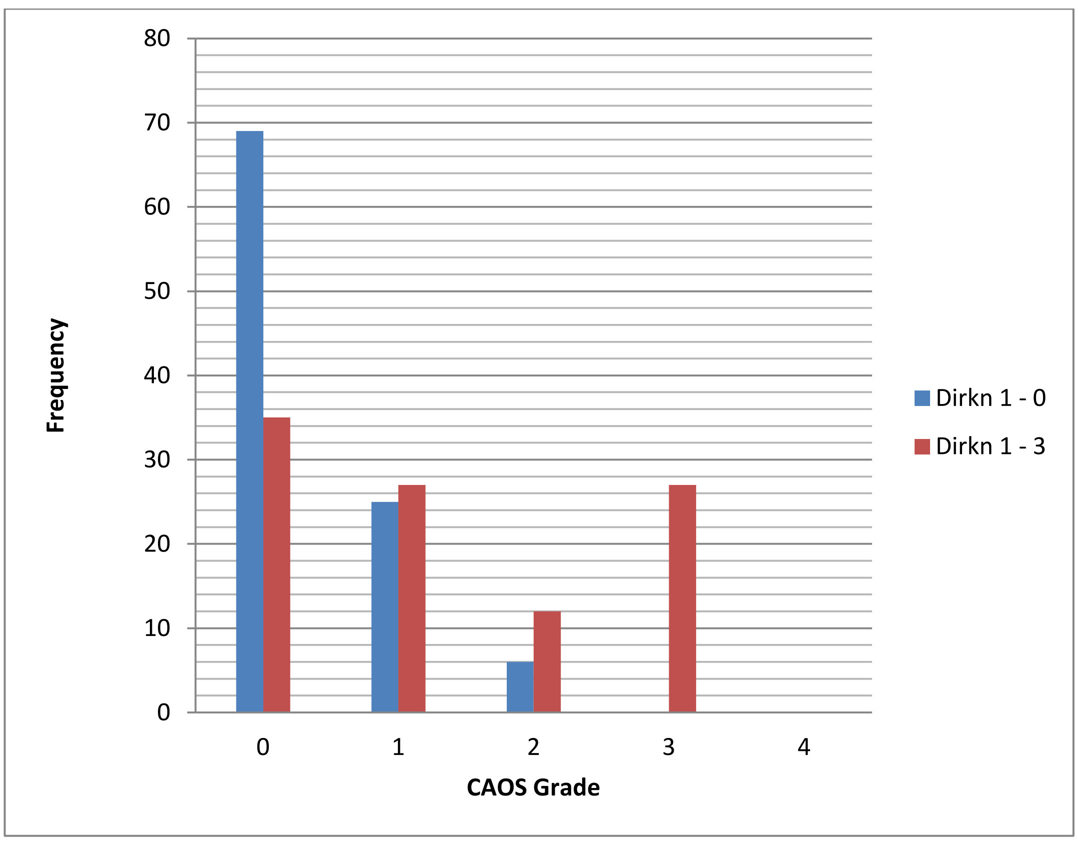


Figure 1. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 1, right knee difficulty: down stairs, last 7 days.

Table 2. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 2, right knee difficulty: up stairs, last 7 days.

	Dirkn 2 - Outcome	
CAOS Grade	0 = best	3 = worst
0	57	27
1	33	42
2	10	15
3	0	15
4	0	0

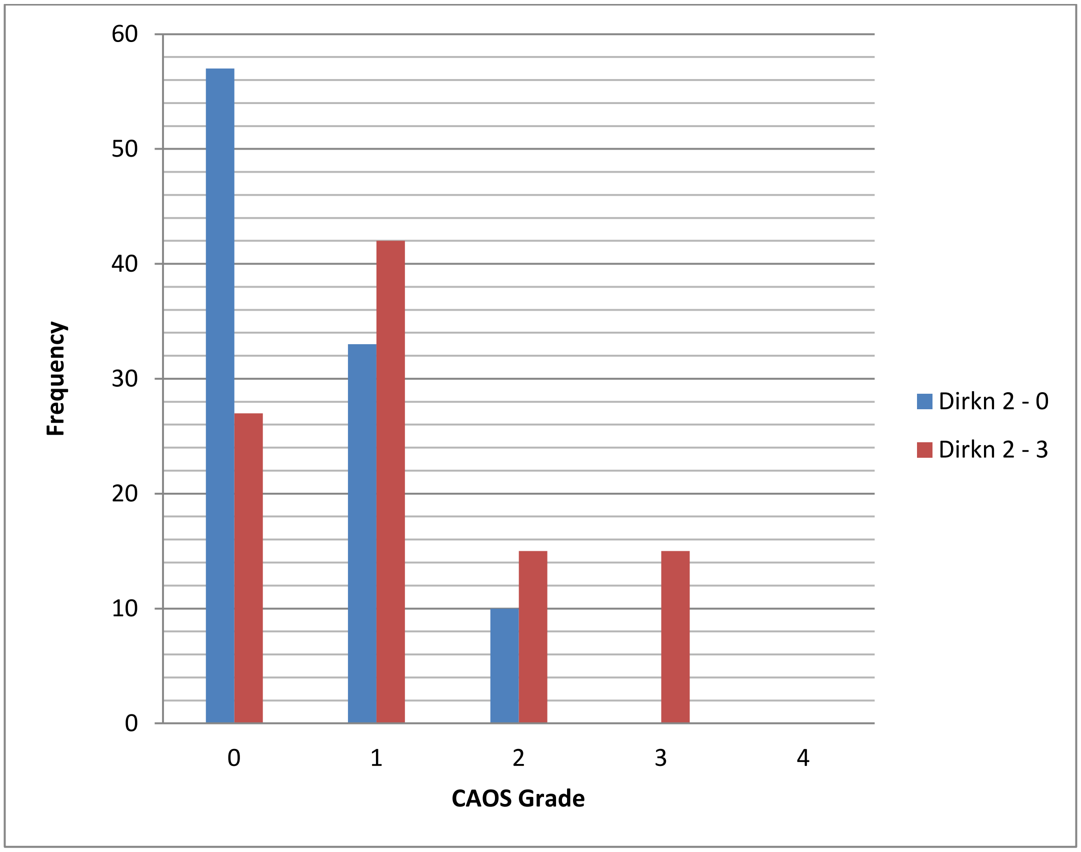


Figure 2. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 2, right knee difficulty: up stairs, last 7 days.

Table 3. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 3, right knee difficulty: stand from sitting, last 7 days.

	Dirkn 3 - Outcome	
CAOS Grade	0 = best	3 = worst
0	54	12
1	36	46
2	8	35
3	1	8
4	0	0

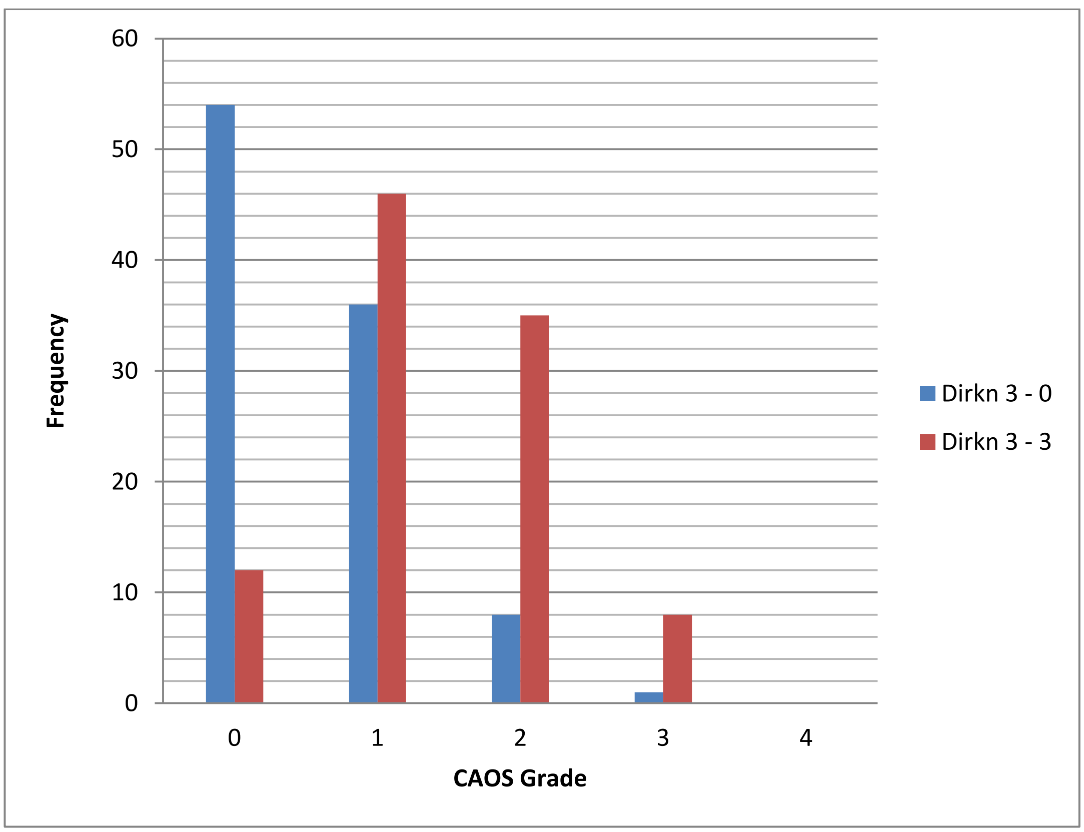


Figure 3. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 3, right knee difficulty: stand from sitting, last 7 days.

Table 4. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 4, right knee difficulty: standing, last 7 days.

	Dirkn 4 - Outcome	
CAOS Grade	0 = best	3 = worst
0	69	46
1	28	31
2	3	15
3	0	4
4	0	4

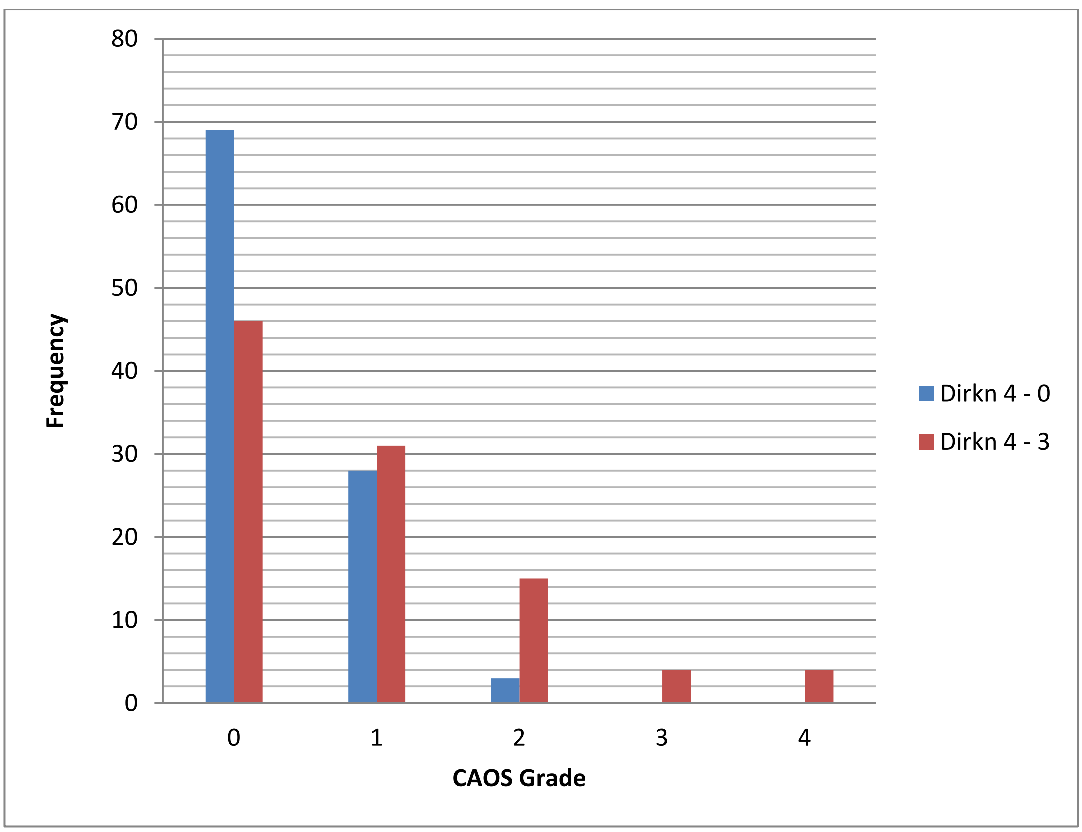


Figure 4. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 4, right knee difficulty: standing, last 7 days.

Table 5. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 5, right knee difficulty: bending, last 7 days.

	Dirkn 5 - Outcome	
CAOS Grade	0 = best	3 = worst
0	69	24
1	19	29
2	12	29
3	0	14
4	0	5

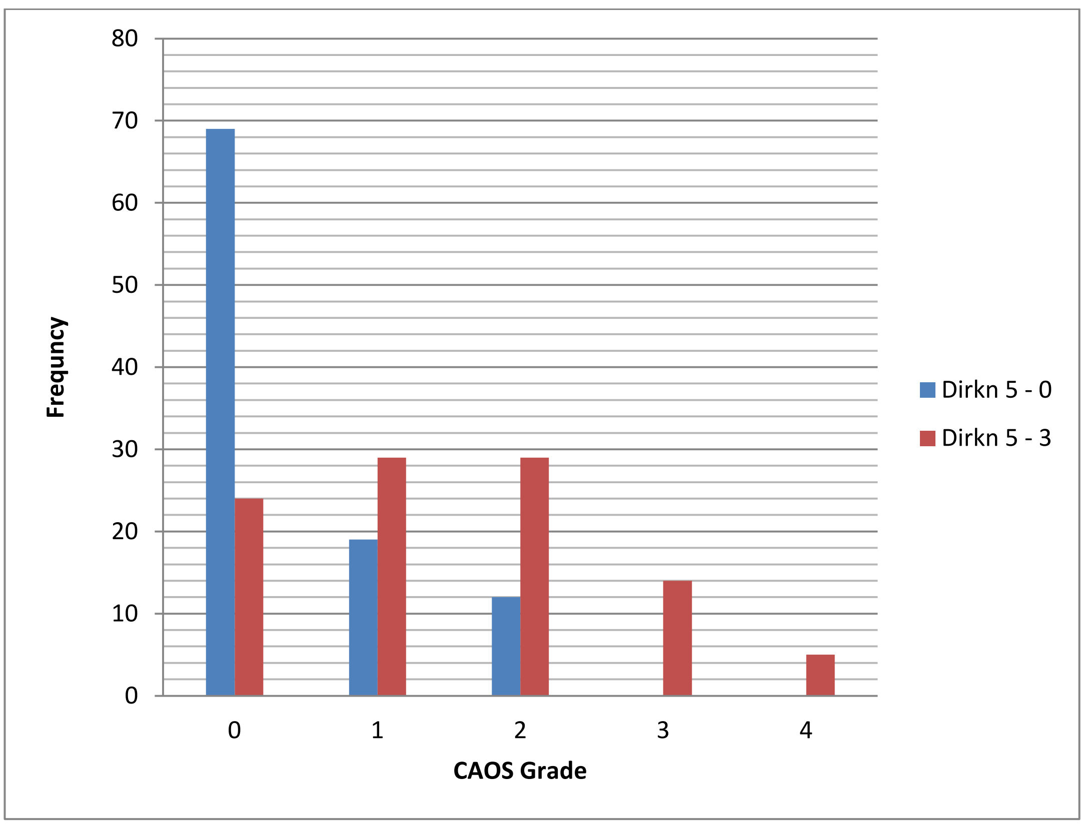


Figure 5. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 5, right knee difficulty: bending, last 7 days.

Table 6. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 6, right knee difficulty: walking, last 7 days.

	Dirkn 6 - Outcome	
CAOS Grade	0 = best	3 = worst
0	79	42
1	18	23
2	3	31
3	0	4
4	0	0

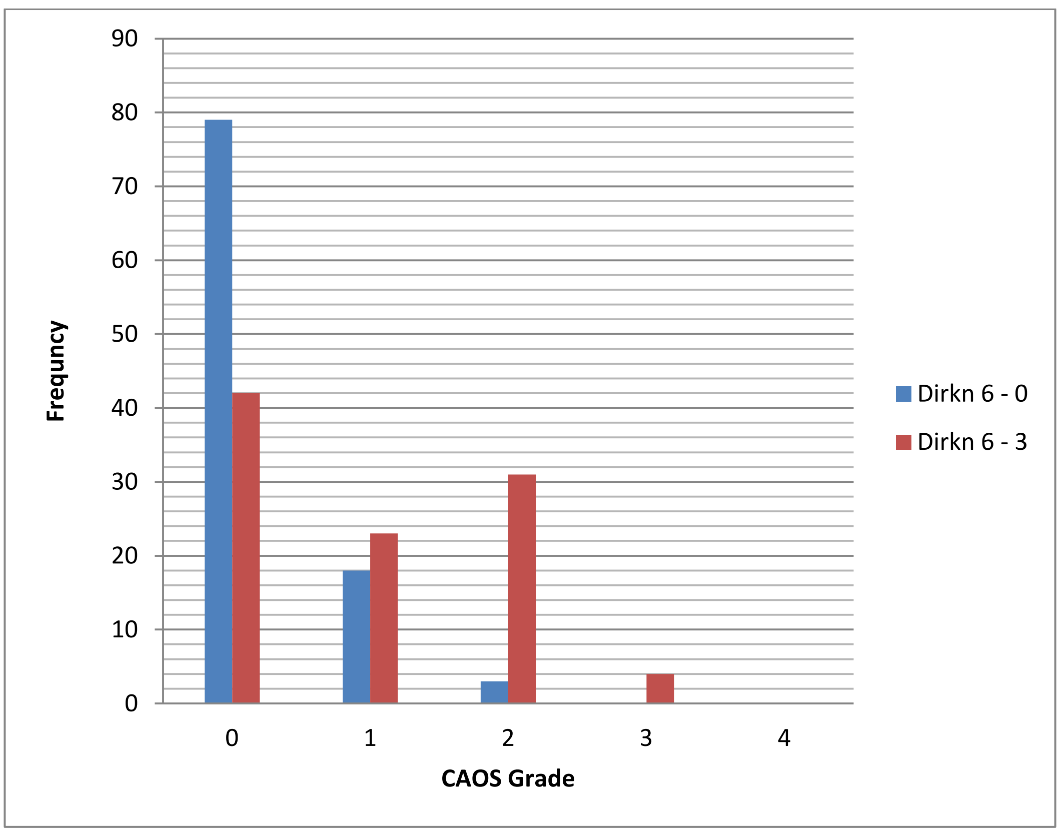


Figure 6. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 6, right knee difficulty: walking, last 7 days.

Table 7. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 7, right knee difficulty: in car/out of car, last 7 days.

	Dirkn 7 - Outcome	
CAOS Grade	0 = best	3 = worst
0	59	27
1	28	27
2	12	31
3	1	15
4	0	0

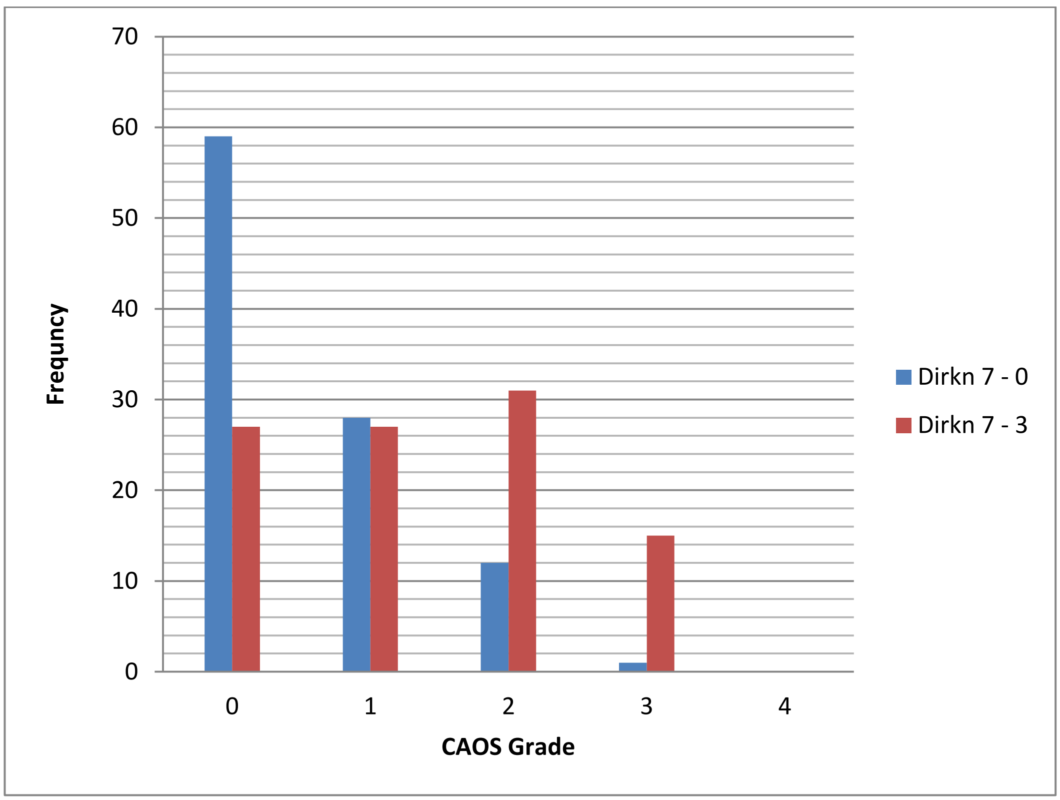


Figure 7. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 7, right knee difficulty: in car/out of car, last 7 days.

Table 8. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 8, right knee difficulty: shopping, last 7 days.

	Dirkn 8 - Outcome	
CAOS Grade	0 = best	3 = worst
0	69	38
1	28	27
2	3	15
3	0	19
4	0	0

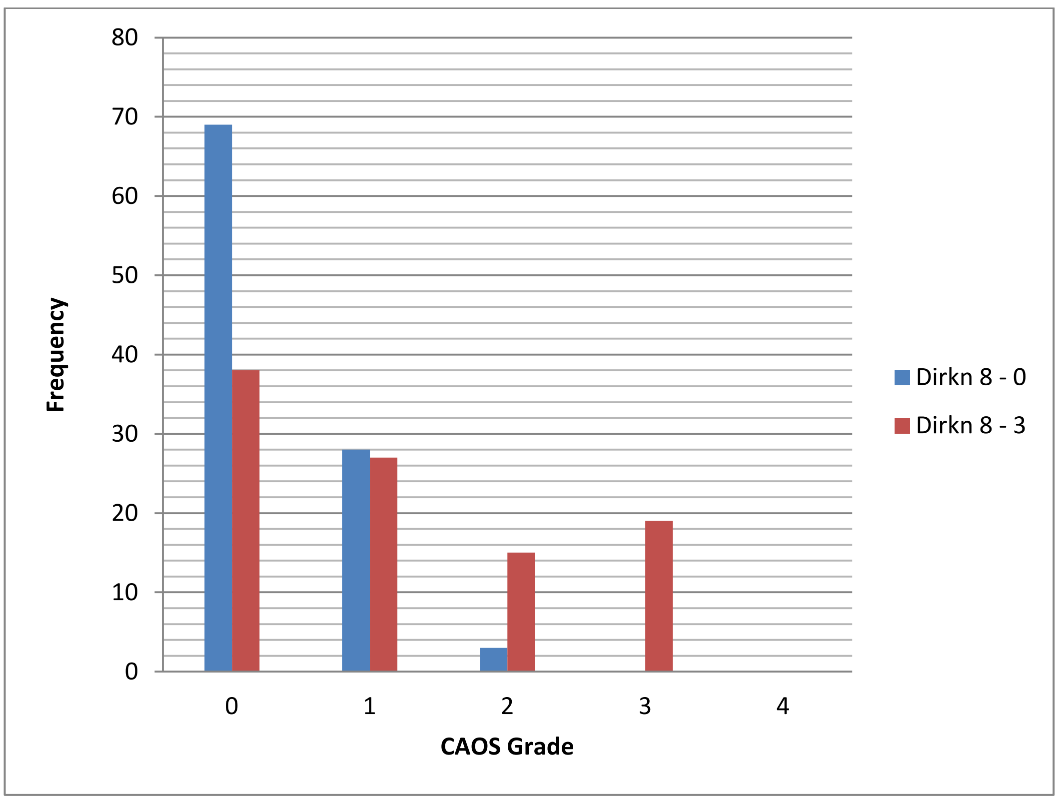


Figure 8. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 8, right knee difficulty: shopping, last 7 days.

Table 9. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 9, right knee difficulty: socks on, last 7 days.

	Dirkn 9 - Outcome	
CAOS Grade	0 = best	3 = worst
0	82	35
1	9	35
2	9	19
3	0	12
4	0	0

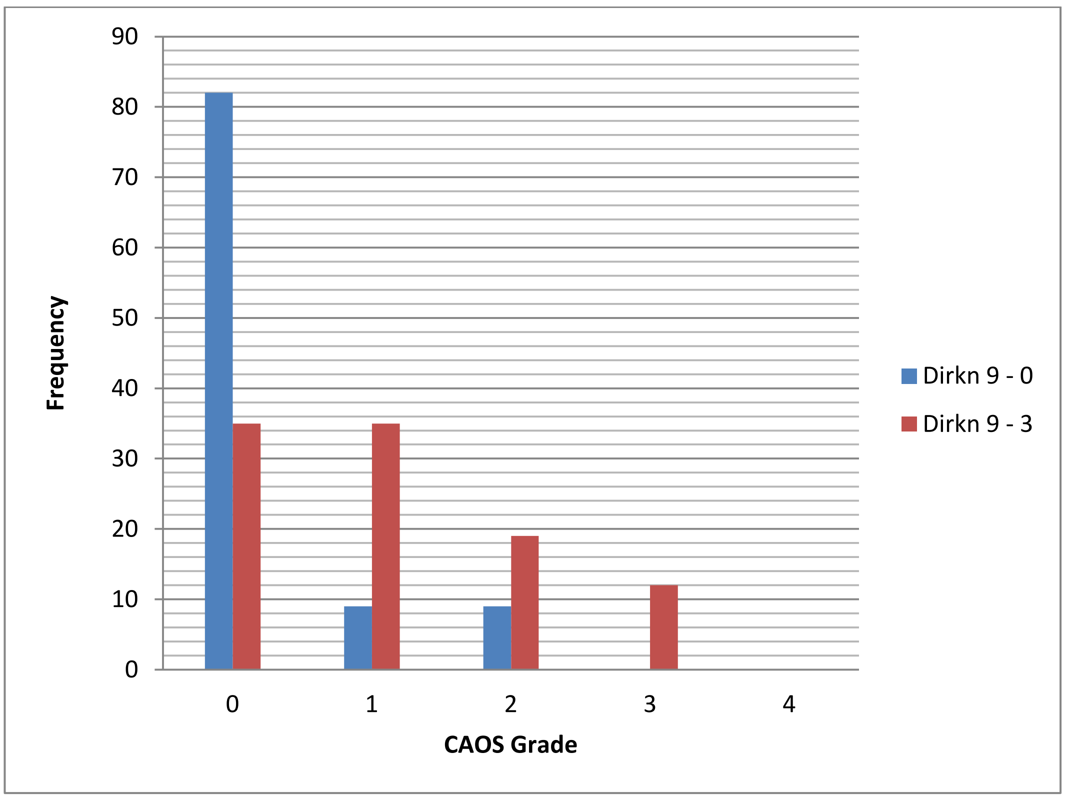


Figure 9. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 9, right knee difficulty: socks on, last 7 days.

Table 10. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 10, right knee difficulty: get out of bed, last 7 days.

	Dirkn 10 - Outcome	
CAOS Grade	0 = best	3 = worst
0	75	46
1	21	23
2	4	15
3	0	15
4	0	0

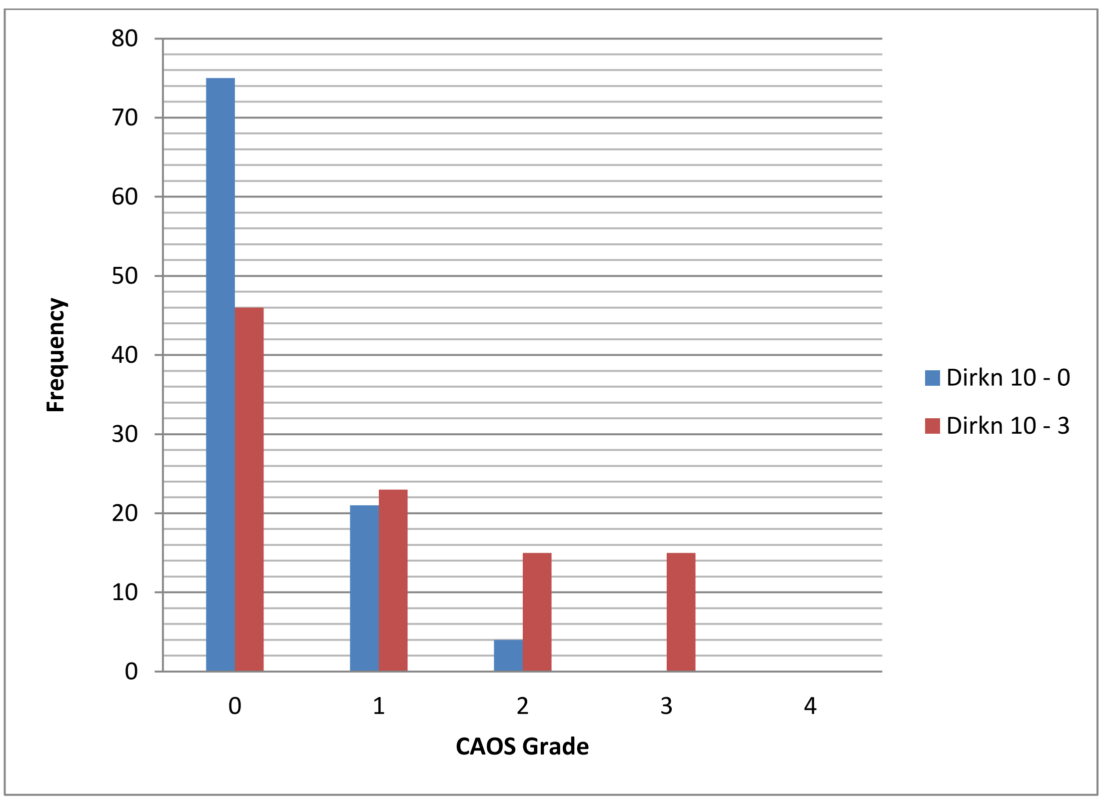


Figure 10. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 10, right knee difficulty: get out of bed, last 7 days.

Table 11. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 11, right knee difficulty: socks off, last 7 days.

	Dirkn 11 - Outcome	
CAOS Grade	0 = best	3 = worst
0	84	46
1	13	31
2	3	12
3	0	12
4	0	0

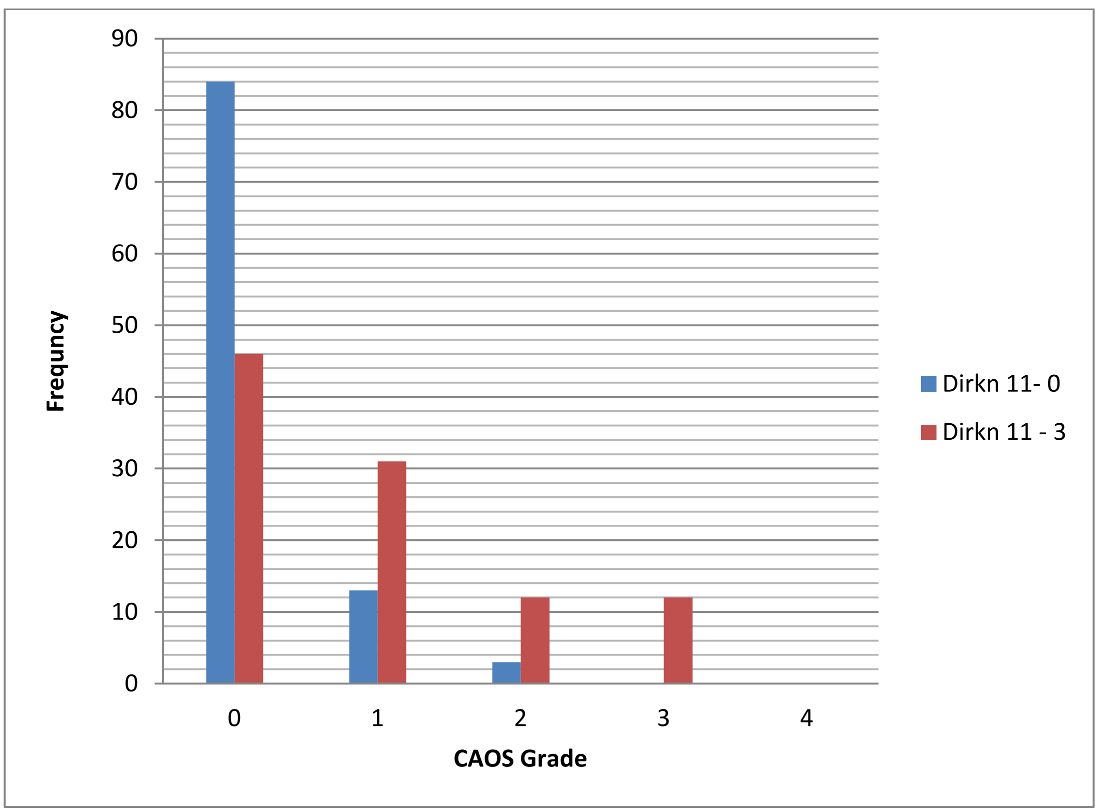


Figure 11. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 11, right knee difficulty: socks off, last 7 days.

Table 12. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 12, right knee difficulty: lying down, last 7 days.

	Dirkn 12 - Outcome	
CAOS Grade	0 = best	3 = worst
0	82	65
1	12	15
2	6	19
3	0	0
4	0	0

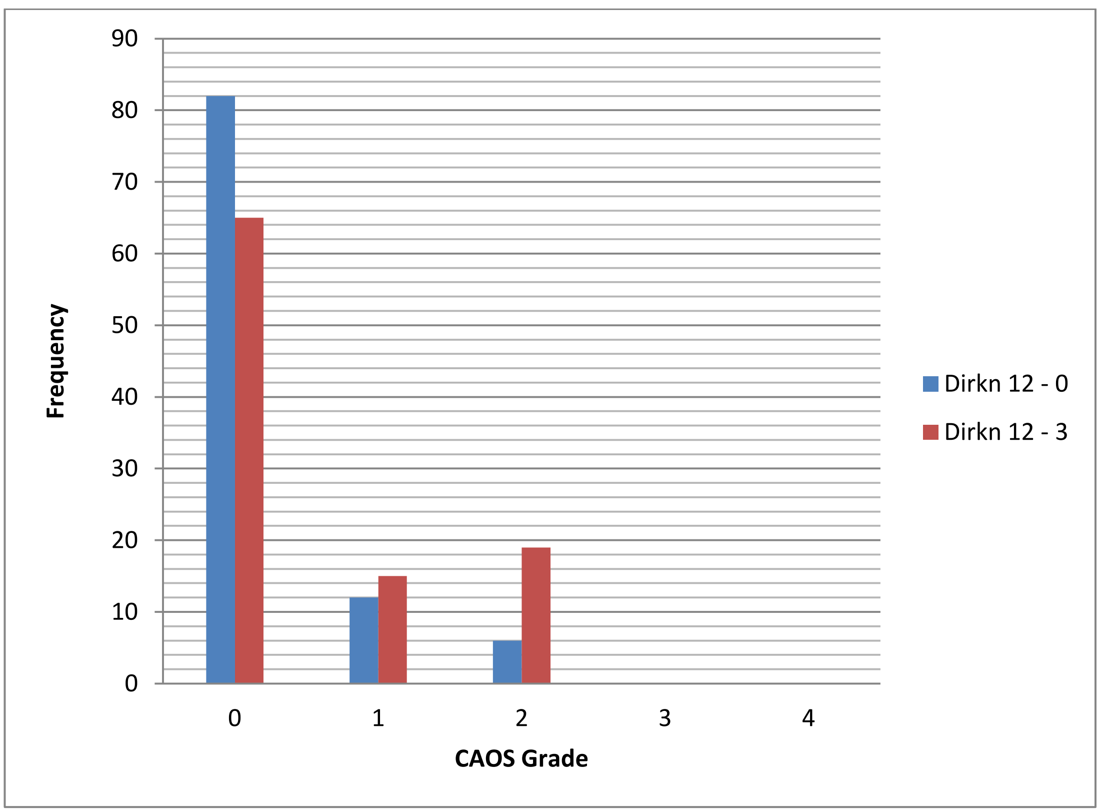


Figure 12. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 12, right knee difficulty: lying down, last 7 days.

Table 13. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 13, right knee difficulty: get in/out of bathtub, last 7 days.

	Dirkn 13 - Outcome	
CAOS Grade	0 = best	3 = worst
0	70	39
1	18	39
2	12	11
3	0	11
4	0	0

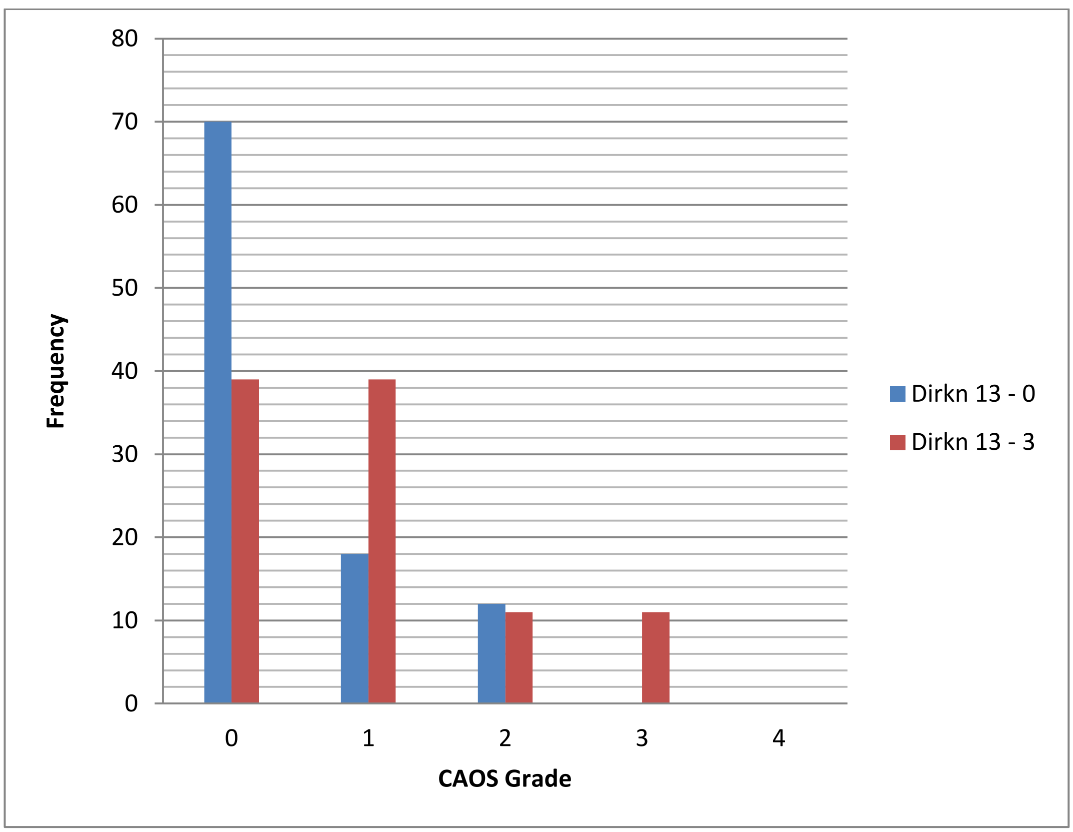


Figure 13. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 13, right knee difficulty: get in/out of bathtub, last 7 days.

Table 14. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 14, right knee difficulty: sitting, last 7 days.

	Dirkn 14 - Outcome	
CAOS Grade	0 = best	3 = worst
0	76	65
1	19	12
2	6	23
3	0	0
4	0	0

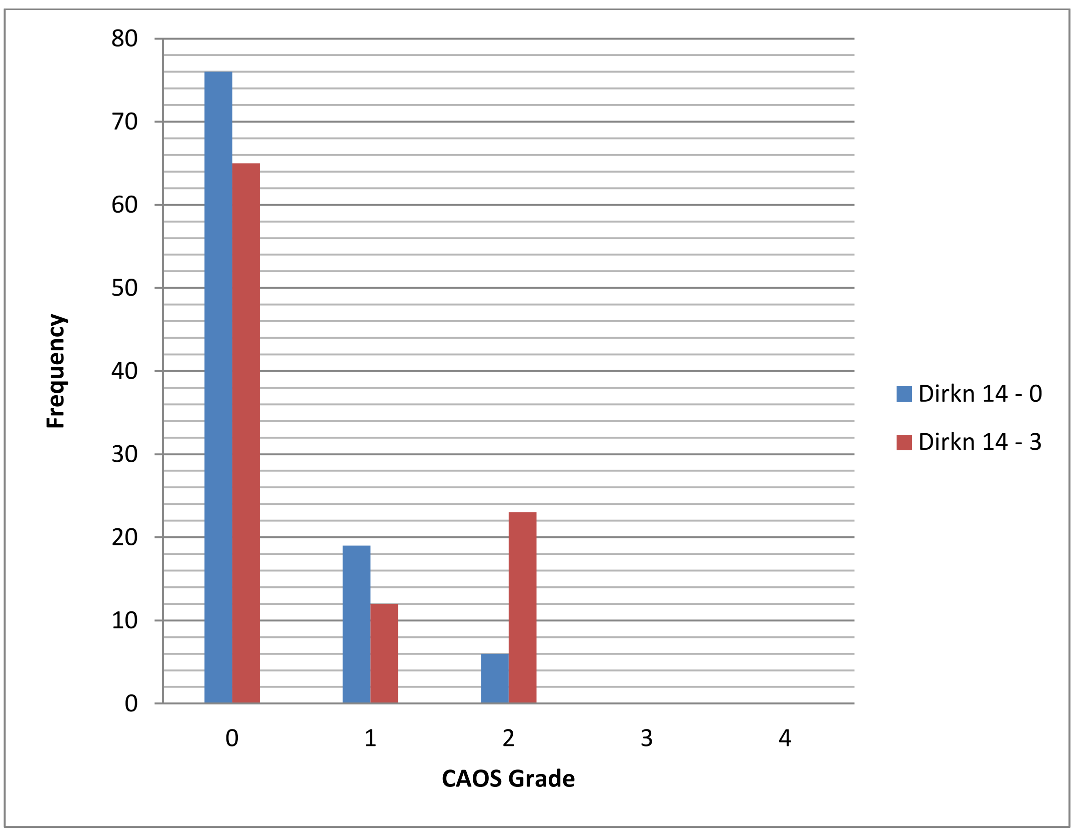


Figure 14. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 14, right knee difficulty: sitting, last 7 days.

Table 15. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 15, right knee difficulty: on/off toilet, last 7 days.

	Dirkn 15 – Outcome	
CAOS Grade	0 = best	3 = worst
0	71	38
1	21	27
2	7	27
3	0	8
4	0	0

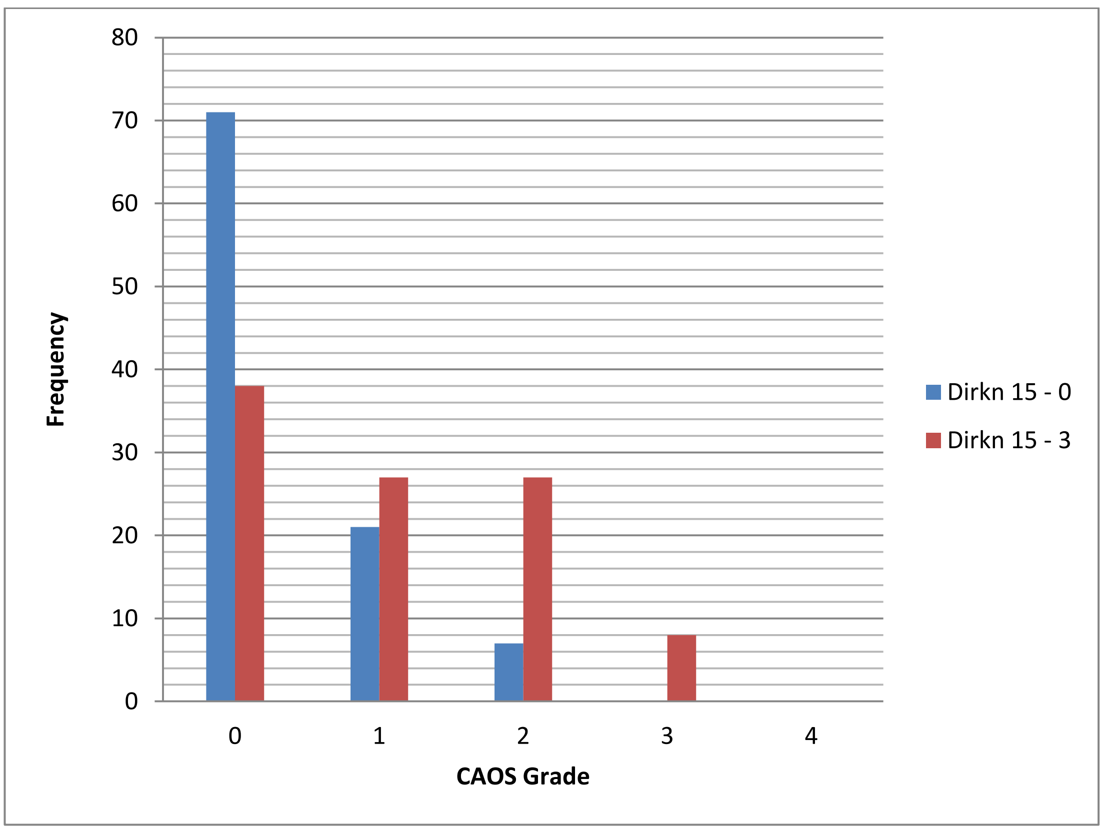


Figure 15. Frequency distributions by CAOS grade for best outcome (0) and worst outcome (3) for OAI variable Dirkn 15, right knee difficulty: on/off toilet, last 7 days.