Age- and Occupation-Based Public Health Considerations Related to Osteoarthritis of the Knee Joint: A Cadaveric Study

Jessica Immonen¹ and Chris Sieftring¹

Abstract

Objective. Osteoarthritis (OA) literature makes minimal suggestion regarding age of disease onset or preventative strategies to reduce risk for onset in various populations. In 2005, the Centers for Disease Control and Prevention estimated that 33.6% of Americans 65+ years old were affected by OA; this cadaveric analysis suggests this is largely underestimated. The objective of this assessment is to identify at-risk populations for OA in the knee joint and make recommendations to prevent or delay disease onset. **Design.** Morphometric analyses of the articular cartilage of the tibial plateau were performed on cadaver specimens using Image Pro software on 3 age populations and surface area measurements for articular cartilage degradation were compared with donors' reported ages, clinical histories, and occupations. **Results.** Data showed that by the seventh decade of life, when patients are in their 60s, articular cartilage degeneration on the tibial plateau had commenced in 100% of specimen. All "homemakers" displayed above-average medial tibial plateau degeneration ($32.33\% \pm 24.85\%$) for their age group while simultaneously reporting pathologies in their clinical history that encourage a sedentary lifestyle. **Conclusions.** This assessment identifies an occupational class with a propensity to develop disease and also identifies a more realistic time frame than previous advisory committees have produced regarding age of disease onset and initiation of preventative measures. It is recommended that strengthening of the hip abductors and the musculature supporting the knee commence early in adult life to avoid valgus collapse and shearing at the knee joint.

Keywords

osteoarthritis, public health, knee joint, articular cartilage

Introduction

The knee joint is the most common site for degenerative joint diseases such as osteoarthritis (OA). The Centers for Disease Control and Prevention reported that in 2005, 13.9% of Americans 25 years old and older and 33.6% of Americans 65 years old and older are affected by OA. Prevalence of OA increased by approximately 22% from 1990 to 2005. By 2020, estimates indicate there will potentially be as many as 32.8 million Americans with OA.¹ Given the prevalence of OA in the knee joint, patients with this pathology greatly contributes to OA-related hospitalizations and deaths.^{2,3} In the United States, females have clinically been shown to display signs and symptoms of OA more regularly than males.^{3,4} In the United Kingdom, a 14-year longitudinal study conducted on a population of 561 women determined that 47.8% of women aged 60 years or older had radiographic signs and symptoms of OA.⁵

OA greatly affects the anatomical integrity of the knee joint, especially affecting the articular cartilage, synovium, menisci, and the cruciate ligaments of the joint. It is an organ-based degenerative disease based on dysregulated inflammation and remodeling.⁶ The dysregulated inflammation and

remodeling associated with OA that is localized to the knee joint may be due to variation in developed biomechanics. The variations may be derived from valgus or varus deformities, muscle weakness, unequal lower extremity length, scoliosis, hyper- and hypomobility syndromes, and obesity.⁷ It has been estimated that two-thirds of the American population is overweight or obese with 1 in 20 Americans having severe obesity with body mass index (BMI) $>40 \text{ kg/m}^2$.⁸ In this study, data demonstrated increases in degeneration on the *medial* aspect of the tibial plateau. Based on the altered biomechanics developed with obesity, patients are more likely to degrade the articular cartilage and cortical bone mass on the *lateral* aspect of the tibial plateau. These facts directly identify a public health misnomer; the knee joint is not

¹Department of Physical Therapy, Rocky Mountain University of Health Professions, Provo, UT, USA

Corresponding Author:

Jessica Immonen, Department of Physical Therapy, Rocky Mountain University of Health Professions, 122 East 1700 South, Provo, UT 84606, USA.

Email: jimmonen@rmuohp.edu

necessarily free of disease or OA because the BMI is within acceptable ranges.

On the whole, sex, age, clinical history, recreational choices and occupation can affect a patient's biomechanics and joint health.⁹⁻¹⁵ Current literature states that age and physical inactivity are the most influential public health risk factors in the development of OA.¹⁶⁻²⁰ Comorbidities commonly accompanying OA include diabetes, hypertension, obesity, dyslipidemia, metabolic syndrome, and depression, most of which greatly increase a patient's propensity to develop a sedentary lifestyle.²¹ This assessment follows a study which analyzed morphometric anatomy and degenerative changes in cadaveric knee specimens. All signs of damage in the knee specimens were attributed to OA without it stated in each donor's clinical history therefore, presenting a limitation of the methodology. This article documents specific age-based degenerative changes in the articular cartilage of the knee joint and correlates these changes to occupation and clinical history provided by donors prior to death and body donation. This analysis aimed to identify specific biomechanical reasons, whether they are occupational or clinical, for above average cartilage degeneration in donors by comparing medial tibial plateau degeneration to patient history provided to the Body Donation Program.

It is hypothesized that donors with clinical history or occupations that may lead to a sedentary lifestyle or higher levels of physical inactivity will display greater articular cartilage degeneration on the tibial plateau. Height, weight, and BMI were not collected from the donor population therefore, presenting an additional limitation of the study. Cross-sectional photography at the transfemoral and trans-tibial cuts which produced a disarticulated specimen will be analyzed in future studies for subcutaneous adipose thickness. These measurements will allow for a correlation to obesity and BMI. It is recommended that strength training of the hip abductors and the musculature supporting the knee joint commence early in adult life to avoid valgus collapse and shearing at the knee joint.²²⁻²⁶ Several strengthening techniques have been suggested in the clinical literature such as clinic-based physical therapy programs, home-based physical therapy programs, yoga, and pilates.²²⁻²⁶ The purpose of this manuscript is not to determine the best mode of strengthening exercise for at-risk populations but rather to highlight the importance of initiating strength training in early adulthood for individuals that may be predisposed to OA based on occupational and clinical backgrounds.

Methods

Cadaver Sample and Dissection

A population of 21 cadavers, 12 males and 9 females, were analyzed for signs of OA in the knee joint, unilaterally. The

population was divided into 3 age cohorts: <70 years old ($n = 6$), 70 to 79 years old ($n = 9$) and ≥ 80 years old ($n = 6$). Knees were 57% right knees and 43% left knees. Cadavers that were 4% above or below the average medial tibial plateau degeneration were selected as a sample of the population for occupation and clinical history comparisons. The Body Donation Program at the University of Utah provides researchers the clinical history, age of death, and occupation with each specimen. Knee joints were removed from the cadavers with trans-femoral and trans-tibiofibular cuts. Once knee joints were removed, the quadriceps tendon was transected and the vastus lateralis muscles and the vastus medialis muscle were bluntly dissected off of the distal femur. The quadriceps tendon and the patellar ligament were reflected inferiorly and the anterior fibrous capsule was cut away from the periosteal attachment superior to the articular surface. Posteriorly, the capsule was dissected away from the posterior aspects of the femoral condyles, menisci, posterior cruciate ligament (PCL), and posterior meniscofemoral ligament.

Morphometric Analysis of the Tibial Articular Cartilage and Its Degeneration in the Knee Joint

Once the joint space was opened anteriorly, all components of the joint capsule and collateral ligaments were dissected away leaving the femur and tibia attached by only the anterior cruciate ligament (ACL) and PCL. At this time, the cruciate ligaments were bisected to disarticulate the knee joint. For each knee specimen, a photograph was taken of the tibial plateau with a standardized drafting ruler once the menisci were dissected from the intercondylar eminence and the capsule was reflected inferiorly. A 12.1-megapixel Sony digital camera was used for photography of each specimen. These photographs were imported into Image Pro software and each image was calibrated. Photography of each tibial plateau gave rise to the total surface area of the medial tibial plateau and the lateral tibial plateau independent of one another by using the trace tool in Image Pro. Tracing was completed at the most peripheral margins of the lateral, medial, and posterior plateau. Tibial plateau traces did not include the intercondylar eminence or the superior aspects of the tibial tuberosity that can be visualized from the plateau (**Fig. 1**).

Once the total tibial plateau surface area was measured, the sites of degenerative changes on the medial and lateral tibial plateau were traced within their respective total surface area traces. Visible erosions, substantial articular cartilage loss exposing cortical bone, large stellate cracks, and fibrillated areas were included as visible and traceable signs of OA. Each area of degeneration was traced independently and total surface areas of all of the sites of degeneration

Figure 1. Photograph of the tibial plateau of a right cadaveric knee specimen. Photograph displays the degenerative changes to the articular cartilage on the medial and lateral aspects of the plateau that represent signs of osteoarthritis and the preliminary external trace of the medial and lateral aspects of the tibial plateau.

Figure 2. Photograph of the tibial plateau of a right cadaveric knee specimen. Photograph displays the traces for degenerative changes to the articular cartilage on the medial and lateral aspects of the plateau. Degenerative surface area traces were summed on the medial and lateral aspects of the tibial plateau independent of one another.

were summed (**Fig. 2**). This summed area of degeneration was calculated as a percentage of degeneration for each side of the tibial plateau. Summed degenerative surface areas were divided by the total surface area of each side of the plateau. Surface areas of cartilage degeneration on the tibial plateau for the three age populations were compared using an analysis of variance statistical test with a Newman-Keuls posttest for multiple comparisons; these complete population findings have been published.²⁷

Occupational and Clinical History Correlation with State of Disease

Comparing the state of degeneration of the articular cartilage on the tibial plateau to a specific cadaver's occupation and clinical history utilized age group averages for tibial plateau degeneration. There were no parametric statistical analyses performed on this data but potential trends were observed. Cadavers that were 4% above or below the average medial tibial plateau degeneration were specifically analyzed for trends related to occupation or clinical history. This is how the population of analysis was refined from 21 cadaveric specimens to 6 specimens undergoing occupation and clinical history correlations.

Comparison of Average Degenerative Changes for Age Groups with a 26-Year-Old Cadaver Knee

The average state of degeneration of the knee joint in the three age groups was compared with the 26-year-old cadaver's intracapsular anatomy. Although, no statistical significance can be achieved with this comparison it provides a theoretical example of intracapsular anatomy of the knee in its more pristine state. The morphometric analysis of the 26-year-old cadaver's medial and lateral tibial plateau articular cartilage degeneration was compared with the average of the 3 age populations. This cadaver had no orthopedic injuries or surgical interventions documented in the provided clinical history or noted in dissection. This cadaver's measurements were removed from the <70 years old population averages before comparisons were made.

Results

Occupational Correlation with State of Disease

All 3 female cadavers that sited occupation as "Homemaker" exhibited degeneration of the medial tibial plateau's articular cartilage that was above average for their assigned age group by at least 4% (**Table 1**). In the 70- to 79-year-old age population, *Cadaver C Homemaker* had the greatest degeneration of the medial tibial plateau. *Cadaver C Homemaker* exhibited 61% degeneration to the medial tibial plateau whereas the average degeneration for the age population was 25%. This was 17% more degeneration than the next most degenerated specimen in this age population, which was a 77-year-old Principal exhibiting 44% degeneration of the articular cartilage of the medial tibial plateau. Two of the 3 homemakers in the study had an age of death in the <70-year-old age population and the third homemaker had an age of death between 70 and 79 years old. There were no homemakers that had an age of death at or above the age of 80 years old.

Table 1. Medial Tibial Plateau Degeneration of Homemakers Compared with Age Group Averages for Medial Tibial Plateau Degeneration.

Cadaver	Age Group, years	Average Degeneration of Medial Tibial Plateau for Age Group, %	Degeneration of Medial Tibial Plateau of Cadavers A, B, and C, %
Cadaver A homemaker	<70	13	19
Cadaver B homemaker	<70	13	17
Cadaver C homemaker	70-79	25	61

Table 2. Medial Tibial Plateau Degeneration of Physically Active Professions Compared with Age Group Averages for Medial Tibial Plateau Degeneration.

Cadaver	Age Group, years	Average Degeneration of Medial Tibial Plateau for Age Group, %	Degeneration of Medial Tibial Plateau of Cadavers D, E, and F, %
Cadaver D wildlife biologist	70-79	25	15
Cadaver E delivery driver	70-79	25	13
Cadaver F rancher	≥80	43	26

Professions that required substantial physical activity as part of the job description exhibited below-average degeneration of the medial tibial plateau's articular cartilage compared with other specimens in their respective age groups (**Table 2**). *Cadaver D* listed their occupation with the Body Donation Program as "Wildlife Biologist," *Cadaver E* listed their occupation as "Delivery Driver," and *Cadaver F* listed their occupation as "Rancher." All 3 of these cadavers had at least 10% less degeneration of the medial tibial plateau compared with the averages for their respective age groups. Physical activity is a necessary component of all three of the donors' occupations. Physical activity in the form of outdoor hiking to collect field data, door-to-door walking and carrying of parcels and horse-back riding, lifting, or herd management are potential ways that the biologist, delivery driver, and rancher, respectively, increased lower extremity muscle mass to stabilize the knee joint and decrease the potential for the development of obesity.

Clinical History Correlation with State of Disease

Nine out of 10 specimens that had above-average degeneration of the articular cartilage on the medial tibial plateau had documented clinical history that may have accounted for the increased pathology of the cartilage. The single specimen that did not fit this trend was from a donor that chose not to provide the Body Donation Program with details on their clinical history. All 10 of the specimens with above-average degeneration for their age populations had degeneration of the medial plateau that was at least 3% greater than that of the average. The 9 specimens

that documented their clinical history and displayed above-average degeneration of the medial plateau included lower extremity musculoskeletal injuries and surgeries, obesity, arthritis, and cardiovascular or respiratory diseases that may lead to or be due to a sedentary lifestyle. These cardiovascular and respiratory diseases include chronic obstructive pulmonary disease (COPD), atherosclerotic cardiovascular disease (ASCVD), and high blood pressure.

Comparison of Average Degenerative Changes in Tibial Plateau Articular Cartilage for Age Groups with a 26-Year-Old Cadaver Knee

The 26-year-old specimen displayed no visible articular cartilage damage on the medial or lateral tibial plateau. This contrasts to the 16% and 18% of articular cartilage degeneration on the medial and lateral tibial plateaus, respectively, in the <70-year-old population; these complete population findings are published.²⁷ All cadaveric specimens analyzed in the <70 years old age group, 70 to 79 years old age group, and the ≥80 years old age group had some degree of articular cartilage damages related to OA.

Discussion

In review, the purpose of this study was to identify potentially at-risk populations of patients for development of OA based on occupation and clinical history. By 2020, it has been estimated that there will be 32.8 million Americans with OA so identifying at-risk populations and delivering health education on OA may greatly reduce nation-wide morbidity associated with the disease. Within

the cadaver population at hand, all 3 female donors that were “homemakers” exhibited degeneration of the medial tibial plateau’s articular cartilage that was above average for their assigned age group. There may be several potential hypotheses related to occupation that explain these findings. These degenerative findings in homemakers may be due to above average joint use and potential shearing based on child care, home cleaning, and/or the ability to spend more time pursuing recreational activities that put strain on the knee joint. Tibiofemoral compression force equals 1.6 times the patient’s body weight during isometric contraction of the quadriceps, hamstrings and posterior compartment of the leg.²⁸ During 60° of flexion of the knee joint the tibiofemoral compression force equals 3 times the patient’s body weight.²⁸ For example, regularly playing with children on the floor or scrubbing a bathroom may predispose homemakers to medial articular cartilage degradation. Atrophy or degeneration of crucial ligaments supporting the joint may give rise to above-average shear in the knee.^{27,28} Morphometric analyses of the ACL were completed on this population and findings were documented.²⁷ Cadaver knee specimens in the 70- to 79-year-old age group displayed a 10.5% decrease in average ACL circumference (mm) compared with the group of <70 years old specimens ($P < 0.001$). Specimens included in the ≥80 years old age group had a 19% decrease in ACL circumference compared with the <70-year-old age group ($P < 0.001$). These findings show that the ACL does significantly thin with aging but there was no trend in ACL circumference measurements in the “homemaker” population. There was no significant change in circumference and the PCL in this assessment and the collateral ligaments of the knee were not assessed. The medial collateral ligament (MCL) and lateral collateral ligament (LCL) will be measured in future knee cohorts.

Another perspective may indicate that these degenerative findings may be due to sedentary lifestyle, especially if homemakers had school-age children. A study shows that homemakers have reported they less regularly participate in “vigorous leisure-time physical activity” sufficient to promote cardiovascular and respiratory fitness.¹⁵ Arthroscopic and radiographic analyses of OA symptoms in occupational populations have yet to determine specific surface area losses of the articular cartilage on the tibial plateau. A current study does identify the “homemaker” occupation as an at-risk population for the development of a sedentary lifestyle and increased inactivity can increase one’s propensity to develop OA.¹⁵ Identifying the at-risk population is a start but researchers make little to no suggestions to the population regarding age of disease onset or preventative strategies to reduce risk for disease onset.

After investigating the clinical history of the 3 cadavers that cited “homemaker” as an occupation, sedentary lifestyle appears to be the more likely cause of above-average

degeneration of the medial tibial plateau articular cartilage. *Cadaver A Homemaker* exhibited above average degeneration (19%) on the medial tibial plateau compared to the group’s average (13%). This above-average degeneration appears to correlate with the clinical history of the cadaver; this history included high blood pressure and COPD. These are pathologies that may lead to sedentary lifestyle based on decreased physical functionality. Sedentary lifestyle may lead to muscular atrophy, weakness, and obesity.^{15,29,30} Obesity and muscle weakness can directly lead to biomechanical medial tibial plateau degeneration.²⁸ During ordinary gait, 60% of the tibiofemoral compression force bears down on the medial aspect of the tibial plateau. With greater weight or obesity, the compression force can greatly increase on the medial side of the joint.²⁸ *Cadaver B Homemaker* had a clinical history that included debility and COPD that may have led to decreases in physical activity. *Cadaver C Homemaker* had a hip replacement prior to death, which may have led to gait alterations and knee degeneration. This cadaver also had a pacemaker implanted prior to death, which may have contributed to a sedentary lifestyle. One should consider that these cadaver specimens did not have a specific BMI or an approximated BMI associated with their analysis; data should be interpreted with this concept in mind.

The data shows that by the seventh decade of life, when patients are in their 60s, articular cartilage breakdown on the medial and lateral tibial plateau has commenced in every specimen. Having a comparison with a 26-year-old specimen highlights that very little to no degeneration is likely to occur in the third decade of life if no lower extremity injuries or posture-related diseases are present in a patient’s history. These comparisons determine that it is between the fourth through sixth decade of life, when patients are in their 30s through 50s, that visible signs of OA are first appearing.²⁷ It is within this age range that patients should view the health of their joints in a less naïve manner, addressing the fact that an acceptable BMI does not guarantee knee joint health. As this appraisal could not produce any statistical significance it is simply a comparison and can be viewed as a limitation of the assessment. In future studies, a cohort of “non-arthritic knees” will be compared to disease in specimens that have documented OA or OA-producing pathologies in their clinical histories.

Several of the donors included in the population specifically stated in their clinical history their likely cause of OA symptoms. Some donors’ symptoms were idiopathic and directly stated as OA whereas others stated secondary causes of OA such as musculoskeletal pathology. The majority of donors do not indicate a cause of OA in their clinical history therefore, presenting a limitation. The study assumes all damages are due to OA given the incidence of the disease although other pathologies or medical regimens may cause similar degenerative alterations. Signs and

symptoms of OA may vary in characteristic and precise location depending on cause of disease (e.g., obesity, postural abnormalities, lower extremity injuries). Therefore, recommended prevention strategies may vary in the population and sub-populations at hand. There was an additional limitation related to the anatomy of the tibial plateau and its photography. A degree of error can be attributed to the fact that the tibial plateau is not perfectly flat. Measurements for the total tibial plateau surface areas and the surface areas of degeneration are most likely underestimated. The sample size in this assessment is small although, future studies will be completed on a population of 55 specimens that all include data on clinical history and occupation. Several of these specimens will have data collected on bilateral knee joints to answer questions regarding the frequency of bilateral and unilateral disease progression in various populations. A final limitation is related to a lack of histological analysis on the knee specimens. In future studies, this will improve the ability to assess the different causes of OA and will allow for the use of standardized and validated scales for degeneration evaluation.

Conclusions

These findings do not suggest that dedicating one's time to developing a home is not a time-worthy task. Rather, these findings have isolated an occupational group that should be aware of their potential to develop OA in the knee joint and should use preventative techniques to combat this propensity. Combining the homemaker occupation with a clinical history that promotes a sedentary lifestyle can result in substantial disease as indicated by the above-average medial degeneration in all of the homemakers in the cadaver sample analyzed. This assessment identified an age range within an occupational class that needs to be aware of their propensity to develop disease while considering the concept that an appropriate BMI does not guarantee health of the intracapsular anatomy of the knee joint.

The primary anatomical structures that reduce shearing forces at the knee joint are the cruciate ligaments and the musculature that acts on the joint. From a physical therapy perspective, patients with the homemaker occupation would be encouraged to regularly exercise muscles that stabilize the knee joint as their atrophy may directly lead to medial tibial plateau damages.²⁸ Females are more prone to developing OA in the knee joint therefore, female homemakers should be especially conscious of the suggestion to maintain, if not increase, muscle mass related to the supporters of the knee.^{3,4} These suggestions are especially important for female homemakers that are in their 30s to 50s as early onset muscle strengthening may be preventative for degenerative diseases such as OA. The critical muscles to strengthen are the quadriceps muscles, the hamstring muscles and the muscles of the posterior compartment of the leg.^{24-26,31}

There are a wide range of strengthening and exercise regimens that would be appropriate for the 30- to 50-year-old homemaker such as clinic-based physical therapy, home-based physical therapy, and yoga. This assessment does not seek to determine best clinical therapy for the population at hand but rather reinforces the recommendation to initiate strength training in early adult life to reduce the likelihood for developing symptoms of OA. Integrating yoga therapy opposed to therapeutic exercise, transcutaneous electrical stimulation, and ultrasound treatment has been shown to improve knee disabilities and quality of life in patients experiencing OA.²² Squat and lunge postures, specifically the wide-legged squat (Goddess Position) and the lunge with upright torso (Warrior Position) have been shown to produce increased quadriceps and hamstring activation.³² Clinic-based and home-based physical therapy regimens have shown functional improvement and OA symptom relief in previously assessed patient populations although, clinic-based physical therapy programs were shown to be more effective in the initial month of program compliance.³³ The practice of yoga or home-based physical therapy may be ideal for patients with at-home occupations and can be performed in short segments throughout the day giving accessibility and schedule flexibility to a homemaker. There is currently no consensus on best at-home strengthening programs but benefits have been clinically shown for all previously mentioned options. Initiating a form of strength training such as clinic-based physical therapy, home-based physical therapy, yoga, or pilates in early adult life is recommended to reduce one's propensity for developing OA.

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Declaration of Conflicting Interests

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Ethical Approval

Ethical approval for this study was obtained from *the Rocky Mountain University of Health Professions Institutional Review Board (745057-2).

Trial Registration

Not applicable.

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