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To the Graduate Council:

I am submitting herewith a thesis written by Jeffrey Reed Huber entitled "A Comparison of Knee Joint Size, Obesity, and Osteoarthritis Involving Two Recent Skeletal Samples." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Richard L. Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Lee Meadows Jantz, Michael Logan, William Seaver

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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We have read this thesis
and recommend its acceptance:

Wm. L. Leaver

Accepted for the Council:

Vice Chancellor and Dean of Graduate Studies

Thesis
2004
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A Comparison of Knee Joint Size, Obesity, and Osteoarthritis Involving Two Recent Skeletal Samples

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Jeffrey Huber
August 2004

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Abstract

The purpose of this study was two-fold: to examine secular change in the size of the knee joint during the last century in White males and females, and to compare the prevalence of knee osteoarthritis over the same time frame. In addition, a specific effort was made to determine a relationship between the modern rise in obesity and knee osteoarthritis. The sample included 291 males and 140 females from both the Robert J. Terry Collection and the William M. Bass Donated Skeletal Collection.

The results indicate no consistent secular change in direction or location between White males and females. Although significant secular change was present in some of the size variables, it was generally not indicative of an increase in the area of the weight-bearing surface. The findings suggest that although there is a complex relationship between joint loading and joint area, the modern secular increase in weight, coupled with a more sedentary lifestyle, has not had a sizeable effect on knee joint size.

Clinical studies have noted an increase in the presence of knee osteoarthritis over the last century. Obesity and osteoarthritis have been shown to be associated in several studies utilizing radiological data. However, often the criteria relies heavily on joint space narrowing and not the osteological/dry bone impact. The William M. Bass Donated Skeletal Collection allowed for the possible detection of a relationship between obesity and osteoarthritis of the knee because it provides a modern skeletal sample where weight is known and

obese subjects are present. Including the Terry collection, housing a skeletal sample that pre-dates those found in the Bass collection, allowed for a comparison of general prevalence rates over a longer period of time.

Results are fairly consistent with clinical and radiological research, with the exception that dry bone scoring of osteoarthritis tends to produce prevalence rates much higher than possible from radiological detection. Significant associations were found between the presence of osteoarthritis and the more recent Bass collection, as expected. Age and sex also provided some significant associations with knee osteoarthritis as well.

Based on individuals with known weight, a significant association was observed between the incidence and progression of OA. Obese individuals, in particular, appear to be at a higher risk of developing knee osteoarthritis, as well as having problems with severity. There did not, however, appear to be an association between obesity and osteoarthritis of the medial tibiofemoral compartment, as some reports have posited.

Finally, the nonrandom nature of the available data allows for a comparison between randomization methods and the more traditional standard statistical algorithms that must conform to assumptions of a normal random distribution. This study found only minimal differences between the two approaches illustrating the relevance of randomization methods, while suggesting reliability in the standard tests with regard to the two skeletal samples used for this research.

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Chapter I

Introduction

Secular Change

The constant exchange between an organism or population and its environment results in a change in both: the activities of an individual or population can heavily impact the environment, and the environment also influences the characteristics of an individual or population. Secular change in a human biological context, regarded as the non-genetic change over time in a single element or collection of features, is attributed largely to environmental and cultural influences. New technologies have greatly impacted nutrition, sanitation, control of infectious diseases through immunization, activity levels, and behavior. Given the rapid alteration of the environment in which we live and work and in conjunction with these developments, secular change has been documented in stature, weight, childhood growth and development, and age at menarche for many modern industrialized populations (see for example Cheng-Yi et al., 1995; Damon, 1968; Eveleth and Tanner, 1990; Malina et al., 1987; Marshall, 1978;

Meadows Jantz, 1996; Trotter and Gleser, 1951).

Stature and weight are two of the most documented examples of secular change in the literature. Between 1883 and 1982, the average height of Swedish females at age 14 increased by 12 cm. The increase in the height of Swedish males at age 14 during the same time, 19 cm, was even greater (Lindgren and Hauspie, 1989; Ljung et al., 1974). The positive change in stature documented in Sweden is similar to that in other industrialized countries. Summarizing the secular trend of increased stature in several countries from the late 1800s to the 1970s, Meredith (1976) found that height in late childhood had increased at a rate of ~1.3 cm per decade, height in adolescence had increased at a rate of ~1.9 cm per decade, and adult stature had increased at a rate of ~0.6 cm per decade.

Secular changes have also been attributed to social history, socioeconomic status (SES), or rural/urban status. Definitive differences in growth patterns have been found between high and low SES children, with children of low socioeconomic status often lagging in growth (Malina et al., 1987). Although there is the ability for 'catch-up' if environmental conditions are remedied, if negative status conditions continue into middle childhood, growth differences can become permanent (Bogin, 1988). Similarly, in populations that have not experienced improved environmental conditions, there is little evidence for positive secular trends. A comparison in Southern Mexico of adult heights measured in the 1970s with heights measures in the previous 80 years indicated little evidence of stature variation (Malina et al., 1983).

Migration studies offer as evidence rapid secular change in response to rapid environmental changes. Bogin and Loucky (1997) found that recent Mayan refugees from Guatemala to the United States were, on average, taller and heavier than their counterparts in Guatemala. These differences in body size between migrants and non-migrants were attributed to relief from the chronic malnutrition and disease experienced by Mayan children reared in the United States.

While slowly developing areas and economically disadvantaged populations may still experience secular increases in height, other studies propose that the end is in sight in the United States, particularly among economically-favored Americans (Bakwin and McLaughin, 1964; Damon, 1968). Damon (1968) reported body size measurements on 85 members of twelve four-generation families of Old American descent measured at Harvard between 1870 and 1965. No change in stature was found after the third generation.

The secular trend in weight, however, appears to be continually increasing with no sign of discriminating against specific socioeconomic levels. Tanner (1977) suggests that there has been a secular increase in weight by decade for Europe and North America between 1880 and 1950. In his study of wealthy Old American Harvard families, Damon (1968) found that unlike stature, weight did not level off. Weight has also increased over time in economically disadvantaged Mexican American children (Malina et al., 1987). Thus, while stature increase has exhibited some limitation, the secular increase in weight appears to be growing.

In a comparison between Union Soldiers and white American men in 1959-1962 in the National Health Examination Survey, both Body Mass Index (BMI) and percentage of body fat were found to increase over time for every age category (Costa and Steckel, 1997). BMI is defined as weight/height^2. A study of males attending West Point between during 1874-1894 found an average BMI of 20.22 kg/m^2 (Cuff, 1993: 174). In a similar study involving males attending Amherst College between 1860 and 1900, the mean BMI was found to be 21.25 kg/m^2 (Murray, 1997: 591). Both these averages are several units below those of a comparably aged modern population, with an average BMI of 24.3 kg/m^2 (Flegal and Troiano, 2000: 812).

This trend is also found globally. Comparing Swedish children in 1883 with those in 1938, Tanner (1955) also found an increase in weight at all age levels. The difference in weight is well established by 7 years of age, with the children in 1938 measuring a size corresponding to about 1.5 years advancement over the 1883 children. Even at maturity, the difference in weight remained. Again, this increase is attributed mostly to changing nutrition and improved environmental circumstances and is not restricted to any socioeconomic class or age range. Health researchers predict that about half of European adults will be obese by 2030 (Khan and Boman, 1999). Obesity has also become a growing public health problem for several Asian countries, and even developing countries have noted the number of obese individuals increasing at alarming rates (Khan and Bowman, 1999; Mudur, 2003).

The trend towards obesity continues, and despite increasing public

awareness of the health risks associated with being overweight, the United States is in the midst of an epidemic of obesity involving all ages and nearly all racial and ethnic groups. The annual medical spending due to overweight and obesity is estimated to be as much as $92.6 billion in 2002 dollars, or 9.1% of all U.S. health expenditures (Finkelstein et al., 2003). Between 1960 and 1988, the proportion of men aged 20-29 years with a BMI greater than 30 kg/m^2 increased 1.4 fold. This statistic is even greater for women (Nevitt and Lane, 1999). A BMI greater than 30 is associated with increased risk of mortality in populations (Davis et al., 1988: 1021). Adding to these statistics, in the U.S. the prevalence of obesity has increased from 12.0% in 1991, 17.9% in 1998, to 19.8% in 2000. Again, a steady increase was observed in all states, in both sexes, and across all age groups, races, and education levels (Mokdad et al., 1998, 2001).

Nor is the Body Mass Index the only telling statistic of America's weight epidemic. The Behavioral Risk Factor Surveillance System (BRFSS) is the largest continuously conducted telephone health survey in the world and the primary source of information for states and the nation on the health-related behaviors of adults. According to statistics gathered from the BRFSS, the average weight of American males and females in the year 1990 was 179 lbs and 143 lbs, respectively (CDC, 1990). In 1996, the average weight of American males had grown to 185 lbs (CDC, 1996). The average weight of females had also increased, to 148 lbs. Six years later, by 2002, the average weight of American males and females had expanded to 191 lbs. and 154 lbs (CDC, 2002).

The possible reasons underlying the rise in obesity are just as noteworthy. In the last century, food consumption habits have changed dramatically. In 1970, food consumed outside the home accounted for 34% of the food budget, but was 47% by the late 1990s (Clausen, 1999: 21). During this time, restaurants have "turned to using larger dinner plates, bakers are selling larger muffin tins, pizzerias are using larger pans, and fast-food companies are using larger drinks and french fry containers" (Young and Nestle, 2000: 247). A serving of McDonald's french fries has ballooned from 200 calories in 1960 to 610 calories at present, with the average meal inflating from 590 calories to a supersized 1550 calories (Critser, 2003: 28).

Technological advances in the food industry, such as the introduction of High Fructose Corn Syrup (HFCS), have also impacted our nutrition. Six times sweeter than sugar, HFCS is cheaper to produce and can be used in long-life shelf products. However, unlike sucrose, HFCS does not go through a complex metabolic breakdown process. This, along with increased usage of palm oil, a product extremely high in saturated fat, due to lowered free trade restrictions have greatly increased caloric intake (Vuilleumer, 1993). Coinciding with this increased caloric intake is increased waist size. It is estimated that about 30% of young women in the United States wear a size 14 or larger (Critser, 2003: 60). Recognizing that overweight individuals comprise an increasing segment of the fashion market, some manufacturers have catered to the obese, rushing to add larger sizes, special departments, or even resize their apparel so as not to remind their customers of their largeness (Canedy, 1997; Critser, 2003).

This secular increase in body weight is likely due to more than just changes in food consumption habits. Heini and Weinsier (1997) report that while the US Public Health Service's recent efforts to promote the use of low-calorie and low-fat food products have been highly successful, the reduction in fat and calorie intake does not appear to have prevented the progression of obesity in the population. Rather, lower rates of physical activity facilitated by couch or chair-based entertainment (i.e. video games, online activities, etc.) are also believed to contribute to rising rates of obesity. Berkely et al. (2003: 839) posits a relationship between physical activity/inactivity and obesity. A study by the CDC found that between 1990 and 1998, only one-quarter of U.S. adults aged 18 and over met the physical activity recommendations of moderate intensity activity. In other words, three out of four adults were not physically active enough to obtain health benefits.

Several population studies show a low, but unchanging, level of recreational physical activity among Americans (Piani and Schoenborn, 1993; McGinnis and Lee, 1995). In addition, increasing an individual's exercise does not necessarily increase total physical activity. Goran and Poehlman (1992) found no increase in total daily energy expenditure after 8 weeks of exercise training in adults. The increase in physical activity due to training was offset by a 60% reduction in non-exercise-related physical activities. Since recreational exercise appears not to have changed in recent years, a decline in non-exercise-related physical activity, such as occupational or household activities, may be one factor in explaining the observed trends in body weight and obesity in the

United States.

Project Aims

Osteoarthritis (OA) may be one of the oldest diseases for which there is skeletal evidence and can be found in all past and modern-day populations. However, the joint areas that are commonly impacted today have not always been similarly affected in the past. Specific behaviors or patterned activities have long influenced the manifestation and progression of the disease. Therefore, any large variation in the prevalence of OA at different joints might imply that there has been a large change in risk factor exposure. Overeating and/or poor dietary habits, as well as an increasingly sedentary lifestyle, have led to growing rates of overweight and obese individuals (Crooks, 1999). This increased trend towards obesity has been offered as one explanation for a rise in the manifestation of knee osteoarthritis in modern populations.

The frequency with which osteoarthritis is reported in archaeological material and current figures for the prevalence of the disease are often compared. One area of concern should focus on whether these comparisons are accurate. Most modern studies examining rates of OA and any association with obesity utilize radiological data and rely heavily on joint space narrowing (Figure 1), not the osteological/dry bone impact. Rogers et al. (1990) found that some arthritis changes in the knee joint were invisible in the radiograph, but evident in dry bone specimens. As a result, 11 out of 24 (46%) knee joints were diagnosed

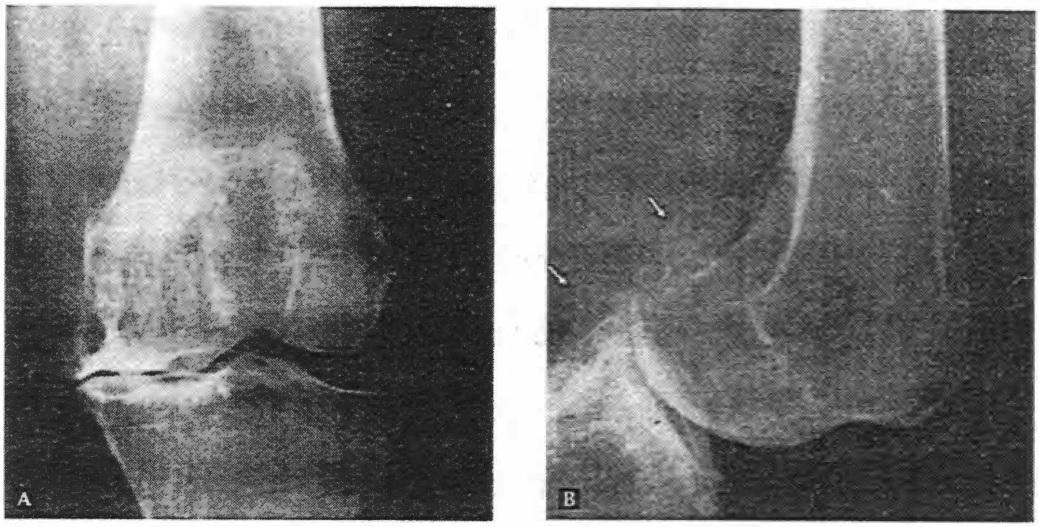


Figure 1: Radiographs of (A), The anteroposterior and (B), The lateral views of an osteoarthritic knee demonstrate joint space narrowing, osteophyte formation (*arrows*), and bony sclerosis. Reproduced from McCarty, 1989.

with osteoarthritis in dry bone specimens. However, only two of the 24 (8%) knee joints were abnormal on radiographs.

Osteological studies may be most beneficial in determining the frequency patterns of osteoarthritis over time as they are likely to produce different prevalence patterns than those found in contemporary studies involving radiographs. In addition, modern skeletal collections may also serve to further illuminate the relationship between obesity and osteoarthritis. The true weight of an individual is difficult to determine from skeletal remains (Trotter, 1954), prohibiting any conclusions to be made about the obesity of most ancient skeletal collections. A modern sample, where the stature and weight of individuals are known, may be able to bridge the gap between historical and contemporary data concerning the accurate prevalence rates of OA and their relationship with

obesity.

Coupled with the idea that obesity is creating additional stress on the knee joint and contributing to the frequency of knee OA is the notion that the knee joint, itself, may be changing in size in response to alterations in load patterning. However, to date, the impact of increased load due to obesity, or decreased load due to sedentary lifestyles, remains undetermined.

A continued secular increase in weight has led to a high percentage of individuals being classified as overweight and obese. Obesity is associated with numerous health risks including an increased risk for cardiovascular disease, insulin resistance, and most relevant to the aims of this research, knee osteoarthritis.

The goal of this research is to examine the possible relationship of obesity and the resulting increased joint load on both the size of the knee joint and the presence of osteoarthritis in two modern skeletal samples. Although there is no reason to imply that the samples utilized in this study were in any way predisposed for or against any of the variables measured at a magnitude greater than the entire population from which they came, these are still, admittedly, non-random samples. Another goal, then, is to offer analogous standard and randomization test statistics in order to facilitate a comparison between two statistical approaches.

Chapter II

The Knee Joint and Biomechanics

Bones of the Human Knee Joint

Two bones meet and make up the main structural elements of the human knee joint: the femur and the tibia, though the proximal end of the fibula is not far away. A third bone, the patella, is also an important component of the knee joint but bears no weight (Shipman et al., 1985: 66). When the knee is in full extension, it is very stable as the femur and tibia are effectively locked in position. However, once in flexion, the knee joint is capable of a second degree of freedom, and the tibia can be rotated about its own long axis relative to the femur (Currey, 1984). The articular surfaces of the opposing bones are not highly congruent, and the distal femur, patella, and proximal tibia do not fit together tightly.

The proximal end of the tibia has two facets, lying adjacent to one another. The lateral facet is convexo-concave, or concave from side to side and convex

from front to back, while the medial facet is biconcave (saucer-shaped). The distal end of the femur consists of two femoral condyles that are both biconvex. Neither condyle is congruent with its articulating tibial facet. The lateral condyle is biconvex and must articulate with a convexo-concave surface. Similarly, while the medial biconvex condyle of the femur has an approximate shape that could be congruent with the biconcave medial facet of the tibia, a size difference tends to limit the area of contact (Currey, 1984: 166). Rather, two semilunar cartilages, or menisci, function to fill the space left by the lack of congruity between the femur and tibia. One of bone's crucial requirements is to transmit load so that the irreplaceable articular cartilage of synovial joints can function within the physiologic range. In addition, the menisci play an important role in the distribution of load, making it much more even, and relieving the stress on the knee joint.

The patella is a sesamoid bone (a bone that develops within a tendon) lying at the distal end of the quadriceps tendon shortly before its insertion onto the anterior crest of the tibia. The patella articulates with the anterior portion of the distal femur. The non-weight bearing bone functions to keep the line of action of the quadriceps tendon away from the axis of rotation of the knee joint, allowing the quadriceps to exert a large turning moment about the knee joint at all degrees of flexion (Currey, 1984).

Knee Joint Loading

Although the structure of the knee joint is well understood, the mechanics and forces acting on the knee allow for continuing examination. An understanding of the mechanics of knee joint loading in relation to normal walking is limited by the difficulty of measuring accurately internal movement of the joint due to the presence of surrounding musculature and other tissue. However, a study by Morrison (1970) calculated the external force system acting at the knee joint by summing ground force and acceleration forces acting on the limb. Under this design, Morrison estimated the maximum joint force at the knee during walking to be in the range of 2 to 4 times one's body weight, with no significant differences in the ratio of load to body weight apparent between male and female subjects. This statistic continues to be reported in literature supporting the hypothesis that an increase in weight also increases the load placed upon the knee joint (Poss, 1984; Adler, 2001).

In the knee, alignment (i.e. the hip-knee-ankle angle) is also a key determinant of load distribution. The load-bearing axis is represented by a line drawn from mid femoral head to mid ankle. Malalignment shifts the load-bearing axis either medially (varus knees) or laterally (valgus knees). In a normal ambulating knee, load is disproportionately transmitted to the medial compartment. Sixty to eighty percent of the total compressive load transmitted across the knee is on the medial compartment (Cerejo et al., 2002; Hsu et al., 1990). From a mechanical point of view, a greater portion of the force transmitted by the medial condyles as opposed to the lateral condyles would

appear to be structurally more favorable. As the medial condyle tends to have a larger bearing surface, the compressive stress at the articular surface is lower. Similarly, as the medial condyle overhangs the shaft of the tibia less than the lateral condyle, the stresses acting in the shaft of the tibia would be less (Morrison, 1970: 60). Varus knees, then, intensify the medial compartment load, while valgus knees increase load in the lateral compartment (Sharma et al., 2001).

The quantification of knee joint loading relative to body weight logically supports a widely published hypothesis that obesity directly increases knee loads (Felson, 1988; Hochberg et al., 1995; Korner and Eberle, 2001). However, others have challenged this concept and studies of dynamic movements provide mixed results. Devita and Hortobagyi (2003) propose that some obese individuals are capable of reorganizing neuromuscular function during gait, altering stride characteristics leading to reduced loads at the knee joint. Foti et al. (2000) reported identical knee torques in women in late pregnancy carrying 13 kg more mass and one year after pregnancy, suggesting that humans compensate for additional body weight to reduce knee loads. However, knee joint loads were found to be higher in a comparison of normal and obese subjects engaged in sit to stand movement (Galli et al., 2000). In sit to stand movement, normal subjects used a strategy characterized by a fully forward flexion of the trunk, producing high momentum at the hip joint and lower back, and a small net momentum at the knee. Obese subjects, in an effort to avoid back pain, tend to use a strategy characterized by limited trunk flexion, producing high momentum

on the knee joint, but limited torque on the hip joint and lower back. While different dynamic movements of obese individuals may allow for an increase or decrease on knee joint loads relative to normal individuals, a change in weight (mass) constitutes a direct change in the mechanical loading of the lower limb. It follows, then, that the static load found in the knee joint of an obese individual is greater than the static load in the knees of a non-obese individual.

Anthropology, Biomechanical Studies, and Joint Size

Numerous studies show a relationship between the observed secular increase in stature and long bone lengths (Trotter and Gleser, 1951; Meadows and Jantz, 1995; Meadows Jantz, 1996; Meadows Jantz and Jantz, 1999). Long bone lengths, particularly those of the lower limb, reflect the observed changes in stature in American individuals during the last 160 years. As stature has increased, so too has the length of long bones. The direct study of bone length in relation to the secular trend of increased height has also evidenced changes in the proportions of the lower limb. The femur, tibia, and fibula are positively allometric with stature, while the humerus, radius, and ulna are isometric. As height increases, the lower limbs become proportionally longer. Meanwhile, the upper limb bones do not change in their proportions as stature changes. In addition, the finding that secular increase in lower limb bone length is accompanied by relatively longer tibiae is important in a forensic context, questioning the use of possibly outdated stature formulae on modern individuals (Meadows and Jantz, 1995).

In examining secular trends, long bones possess an advantage over historical records in that they allow the exploration of changes in shape as well as size. The historical increase in stature and length of the femur may also be associated with an increase in linearity as well as a longer, thinner femoral neck (Bruns et al., 2002; Duthie et al., 1998). While there is seemingly a direct and obvious correlation between increases in lower long bone lengths or proportions and the secular increase in stature, a general association between the noted trend of increased weight in modern individuals and the size and shape of long bones is not immediately evident.

The continued adaptation of bone to its mechanical environment is seen throughout history and has been researched extensively in the field of anthropology. These studies focus primarily on the midshaft, given that the diaphysis of a long bone is responsive to the mechanical loads to which the whole bone is subjected. Rockhold (1998: 2-7, 10-36) provides a thorough summary of research in this area. In short, studies utilizing both cross-sectional and external measurements show that the shafts of long bones respond to the strain of increased load through the remodeling of cortical bone, resulting in increased robusticity. Changes in diaphyseal size are interpreted as representative of the magnitude of loading, while specific diaphyseal shapes are believed to indicate direction of loading, and consequently, specific activities. Differences in midshaft dimensions have been used to assess contrasting loading patterns between prehistoric and modern man (Ruff et al., 1993, 1994), humans engaged in different subsistence strategies (Cole, 1994; Ruff, 1994; Ruff

et al., 1984; Stock and Pfeiffer, 2001), and modern activities (Jones et al., 1977; Lieberman et al, nd; Rockhold, 1998; Ruff et al., 1991). There is a general consensus among researchers that long bone robusticity has decreased as humans have become increasingly sedentary in nature and/or reliant on technology. However, Leiberman et al. (n.d.) urges against using differences in midshaft shape to explain or predict loading patterns and specific activities, arguing that the many complex influences that contribute to bone shape pose serious challenges for efforts to interpret variations in cross-sectional geometric properties.

With specific regard to the effect of increased weight on mechanical load, Ruff et al. (1991) examined the possible relationship of body weight to bone cross-sectional size in the proximal femur. Ruff collected current radiographs of the proximal femur, current body weight, and recalled body weight at 18 years of age from 80 females and males of Black and White ancestry. Results indicated that cross-sectional size is more highly correlated to current body weight than recalled weight at 18. Ruff attributed these results to the ability of the diaphyses to alter size in response to mechanical loads throughout the lifecycle.

However, less is known with regard to the joint areas these increased loads must traverse. Although the metaphyses of long bones are adapted to provide a large weight-bearing surface, Poss (1984) states their primary shape is maintained throughout life despite the notable remodeling changes seen in the diaphyses associated with alterations in load. Fractures of the diaphysis, with resultant angulation, will remodel to a far greater degree than similar angular

deformities at the articular ends of the bone (Poss, 1984: S155). Indeed, little is known about the degree of phenotypic plasticity that characterizes the articular surface areas in response to mechanical load.

Articular stress is largely a function of the force applied to a joint relative to its surface area. One would therefore predict a close relationship between loading and joint size in order to avoid the generation of stress high enough to damage both articular cartilage and osseous components. Alexander (1980) rationalized that maximum joint stresses should be constant regardless of body mass, suggesting that articular surface areas should scale with geometric similarity to body mass. Comparative analyses have largely supported this prediction. In a study of limb joint surface areas in anthropoid primates, Swartz (1989) found that among species of differing size, and among different sized individuals of a given species, joints show a pattern of surface area increase which is positively allometric with body size. These results were attributed to the idea that body size and locomotor mode are the primary determinants of skeletal loading and bone geometry, thus dictating the nature of skeletal stresses and strongly influencing the design of skeletons. In addition, Ruff (1990) also found that articular dimensions are highly correlated with body mass ($r > .95$ for most comparisons) in anthropoid primates, with a notable exception. Human femoral head dimensions are extremely positively allometric with body mass relative to other primate species, possibly related to a bipedal mode of locomotion. As larger joint surfaces are likely an adaptation for resisting larger loads, it follows that, within a single species, such adaptations may occur in vivo to some extent.

Phenotypic plasticity in the area of articular surfaces has been suggested in a number of studies. The mandibular condyle, loaded under compression in mammals, has been shown to grow significantly wider and longer in growing rats fed hard diets compared to controls fed on soft foots (Bouvier and Zimny, 1987). In a reevaluation of the Jones et al. study (1977) to include articular dimensions, Ruff et al. (1994) found significant radial head breadth size differences ($P < .001$) between the playing and non-playing arms of tennis players. There was also bilateral asymmetry in humeral epicondylar breadth, but to a lesser extent than in the articular dimension of the distal radius. In addition, clinical studies have shown that other aspects of subchondral epiphysis morphology, including subchondral bone thickness, Haversian remodeling, trabecular thickness, and trabecular orientation, are responsive to exercise (Radin et al., 1982; Hou et al., 1990).

Despite these findings and the importance of mechanical loading in joints, most researchers assume that the articular areas of long bones remain fairly conservative, constrained by the need to fit precisely with one another (Lieberman et al., 2001; Poss 1984; Rockhold, 1998; Ruff et al., 1991; Ruff et al, 1994; Swartz, 1989). Although Ruff and coworkers did find temporal change in the robusticity of the femoral diaphyses between recent and 'pre-recent' *Homo,* the femoral head did not show the same trend, suggesting that articulations and diaphyses are not closely coupled to each other or related to body mass in the same manner (Ruff et al. 1993).

According to Lieberman et al. (2001), the effects of mechanical loading

are not only complex but also differ substantially in diaphyses and the articular surfaces of epiphyses. Examining the effect of moderate exercise on the articular surface areas of sheep, Lieberman and coworkers found no significant changes in epiphyseal size. Although the articular areas in runners tended to be slightly larger than those of control, the size differences were not significant. However, the researchers posit that the stress magnitude, number of loading events, and possible duration of loading events measured by the study, as well as by most experimental and comparative studies, were insufficient to elicit an appreciable growth response.

Similarly, there was no observed correlation between articular surface area and increased mechanical load stemming from increased weight. Although Ruff et al. (1991) found that femoral cross-sectional areas correlate with current body weight, femoral head size in adult Americans correlated most strongly with recalled body mass at age 18 (the approximate age of skeletal maturity). Thus, although articular surfaces are known to be critical areas in the transmission of load, they do not appear to be highly responsive to alterations in load patterning after reaching skeletal maturity.

Poss (1984) notes that the metaphyses of long bones are adapted to provide the largest weight-bearing surface, and in doing so, decrease the unit load. Indeed, Jungers' (1988) allometric study of linear dimensions of joint in hominoids demonstrates that some human hind limb joints are significantly larger than predicted by body size alone. One possible explanation is that selection may act more effectively to increase the capacity of the joints to bear weight than

to conserve joint material when overall loading is reduced (Swartz 1989). In turn, large joint surface areas will be retained even when there is no mechanical demand for large surfaces. Thus one perception is that larger historical load patterns have created larger than physiologically needed joint surface sizes that effectively transmit modern load patterns and, in addition, can manage the loading effects of increased weight and obesity without changes in size or morphology.

Chapter III

Knee Osteoarthritis

Introduction to Osteoarthritis

Osteoarthritis is a disease of great antiquity, and may be one of the oldest for which there is skeletal evidence (Waldon 1995). Osteoarthritis (OA) can be easily recognized in skeletal material, and it is one of the few diseases for which there are criteria for its paleopathological diagnosis. Not only found in past populations, the condition is also present in all modern-day people as well. OA is one of the most common forms of arthritis today, and visible bone changes can often be found after the age of 50 in modern populations. Thus, the disease is typically one of adults past middle age (Steinbock 1976). In Western countries, radiographic evidence of OA is present in the majority of persons 65 years of age and in about 80% of persons more than 75 years of age (Lane and Manek 2000).

Perhaps a more accurate word for osteoarthritis would be degenerative joint disease. OA is a process of progressive loss of articular cartilage, which is associated with reparative reactions of the cartilage, remodeling processes and

sclerosis of the subchondral bone, together with the formation of subchondral bone cysts, and marginal osteophytes (Klug and Weseloh 2000). The hyaline cartilage is generally regarded as the main target tissue of the disease, but major changes occur concurrently in the bone, synovium and capsule, and at the joint margins. Cartilage degradation is accompanied by a variable degree of repair and inflammation.

For example, mechanical overuse may create fatigue damage in cartilage. This damage may incite an inflammatory process that activates bone and cartilage cells to not only repair the damage, but also attempt to reshape the tissues so as to improve the mechanical situation (Martin et al., 1998: 277). While the size and shape of a joint can be altered rather easily in young people by bone and cartilage remodeling, after growth stops these processes become sluggish and inaccurate. New cartilage and bone production intended to reduce stress instead result in misshapen spurs or osteophytes which often get in the way and cause pain.

Several main risk factors have been described as predispositions to OA. Among them are age, genetic factors, obesity, abnormalities of joint shape, and trauma (Dieppe 1990). Osteoarthritis may develop in one or several joints without any clear identifiable cause (Muehleman and Arsenis 1995). OA is rarely confined to a single joint. On the other hand, generalized involvement is not as frequent as rheumatoid arthritis (Steinbock 1976). The most vulnerable sites are the hand, the knee, the hip, and the apophyseal joints of the cervical and lumbar spine (Dieppe 1990). The wrists, elbows, and shoulders are less commonly

affected (Lane and Manek 2000).

Evidence for Historical Trends

Although osteoarthritis can be found in all past and present populations, the joint areas which are commonly impacted today have not always been similarly affected in the past. Specific behaviors or patterned activities have long influenced the manifestation and progression of the disease. Among the Saldermiut, a Canadian Inuit population, two of the most distinctive activities engaged in by males were harpoon-throwing and kayak paddling. Both appear to have left distinctive arthritic patterns (Merbs 1983). The patterned movement associated with both harpoon throwing and kayak paddling involves primarily the shoulder and elbow. In accordance with these activities, and contrasting with modern samples, the order of osteoarthritis involvement found in a skeletal sample of Saldermiut males is as follows: elbow, shoulder, wrist, hip, knee, and ankle. The Inuit females also follow roughly the same order, with temporomandibular joint OA also being very common. Most important among the female activities were those associated with the making of clothing. The preparation and cutting of skins involved both heavy use of the shoulder and elbow as well as the teeth to grip and soften the skin (Merbs 1983). This serves to illustrate how even normal movements of the limbs, if carried on for long periods of time, can result in the deterioration of joints in significantly different patterns than those found today. In addition, modem day activities placing high amounts of stress on specific joints are also known to produce osteoarthritis.

Even common nicknames, such as tennis elbow or jackhammer joints, have been coined to refer to those affected areas (Merbs 1983).

That osteoarthritis of the knee is more common in modern times than OA of the hip is an almost universal finding (Anderson and Felson 1988; Davis et al. 1988; Dieppe 1990; Waldron 1997; Lane and Manek 2000). Contemporary radiographic data suggests that knee OA is more frequent than hip OA in European adults, and that tibiofemoral joint (TFJ) disease is about twice as prevalent as patello-femoral (PFJ) disease (Dieppe 2000). However, the relative frequency of OA at different joints in ancient skeletons has been shown to vary from these modern samples. Rogers and Dieppe (1994) examined 785 individuals from two different time periods: Saxon/Medieval (n=690), and Post-Medieval (n=90), and OA was diagnosed as either present or absent. From this visual inspection, results indicated that the relative frequency of hip (3.7%) and patello-femoral (1.4%) OA is similar to modem proportions. TFJ osteoarthritis, however, was found to be rare (.04%) in the older samples, with hip OA being over six times as common (Rogers and Dieppe 1994).

Waldron (1995) and Baetson et al. (1997) conducted similar studies. Examining a total of 2,635 skeletons, Waldron (1995) examined the prevalence of OA at various joints over three different historical periods: pre-medieval (n=206), medieval (n=1,453), and post-medieval (n=976). Among the 206 pre-medieval individuals, 47 joints were found to be affected by OA; 561 joints were found to be affected in 1,453 medieval skeletons, and 836 joints were affected among the 976 post-medieval individuals. Results indicated that OA of the knee

is more common (4.4%) than OA of the hip (2.9%) in the post-medieval period, whereas the opposite is true in the earlier periods. Rogers and Dieppe (1994) contend that this change is a result of an increase in knee OA over time whereas that of the hip has remained more or less constant. Contradictory to this, Waldron (1995) uses his data to suggest that the change is due to a fall in the prevalence of OA of the hip with osteoarthritis of the knee remaining constant. However, in a more in-depth study concerning OA of the hip in past populations, Waldron (1997) found the crude prevalence of hip OA to be similar to contemporary data (approximately 3%).

Baetson et al. (1997) compared data from Saxon/medieval and post-medieval England to a new sample of skeletons: 250 individuals buried between 1750 and 1830 in Lawrence, Alkmaar (Netherlands). In the Alkmaar sample, OA of the hip joint is more prevalent than OA of the knee joint. However, the prevalence rates of knee and hip OA in contemporary, radiologically diagnosed individuals from The Netherlands clearly differ from the rates of eighteenth century Alkmaar (Baetson et al. 1997), indicating that knee OA (particularly tibiofemoral OA) was uncommon until the beginning of the nineteenth century.

Any large variation in the relative prevalence of OA at different joints might imply that there has been a large change in risk-factor exposure. Regarding the changes that have taken place with respect to the pattern of OA, the time period under consideration is far too short for genetic factors to have had an influence and is more reasonably attributed to alterations in behavior or activity (Waldron 1997). The increased trend towards obesity has been offered as one

explanation.

Relationship between Obesity and Osteoarthritis

No matter what the cause, less activity, increased caloric intake, or both, obesity is on the rise. However, with specific regard to osteoarthritis of the knee, this trend towards obesity may be irrelevant if no association is found between obesity and modern patterns in the expression of OA. As a result, many studies have examined this relationship.

One of the early studies establishing a relationship between obesity and the expression of OA was conducted using the National Health and Nutrition Examination Survey (NHANES). NHANES provides the only national data that include radiographs of the knee as well as clinical and self-reported measures of osteoarthritis and other associated outcomes (Davis et al. 1988). NHANES also provides data on obesity as measured by BMI, body weight, triceps skinfold, and subscapular skinfold. In examining the association between knee OA and obesity, Anderson and Felson (1988) found that obese adults (BMI >30 and <35 kg/m^2) and very obese adults (>35 kg/m^2) had a much higher rate of knee OA than did modestly overweight persons. The risk associated with osteoarthritis of the knee was 3 times greater for obese adults than normal individuals (Anderson and Felson 1988). In addition, Wendelboe et al. (2003) have found a strong association between increasing BMI and total knee replacement procedures. As osteoarthritis is the most common reason for joint replacement surgery, these findings support their contention that overweight and obese individuals are more

likely to develop osteoarthritis that leads to knee joint replacement.

OA, especially knee OA, has also been observed to be more prevalent in women than in men. Davis et al. (1988) used the NHANES data to conclude that the relative risk of obesity as a factor in OA of the knee is similar for men and women, and that the effect of obesity on the sex difference is due to the higher prevalence of obesity among women than men. Indeed, women have been shown to have a higher proportion of body fat to total body weight and are more obese than men (Abraham et al. 1983). Racial differences also failed to discourage the relationship between obesity and knee OA. Although the prevalence of knee OA is lower in Chinese populations than in Caucasians, epidemiological study has demonstrated that obesity is much less common and severe in the Chinese population. Thus, the finding that subjects with greater body weight, regardless of population, were at a significantly higher risk of osteoarthritis of the knee corroborates the link between obesity and OA (Lau et al. 2000). Similarly, just as the difference in prevalence rates of knee osteoarthritis between sex and race are shown to be largely an indirect result of obesity frequency, higher rates of OA in the knee among persons with lower household income and less education, and among persons not married, disappear once an adjustment is made for body mass index (Anderson and Felson 1988).

Regardless of whether obesity predisposes the knee to osteoarthritis because of increased biomechanical stress or through a metabolic abnormality, it would be expected that both knees would be affected. Again, using the

NHANES data set, Davis et al. (1989) established that obesity was a strong predictor of bilateral OA, whereas knee injury was a stronger predictor of unilateral OA in the knee joint. Bilateral osteoarthritis was found to be more prevalent than unilateral OA, and bilateral OA was twice as prevalent in women as in men. However, there was no sex difference in the prevalence of unilateral osteoarthritis (Davis et al. 1989). The increased frequency of bilateral knee OA, especially among women, may presumably be accounted for by obesity. Obesity is more common in women; thus, bilateral knee OA should also be expected to manifest itself more commonly in women. In contrast, unilateral osteoarthritis appears to be a result of a localized phenomenon such as trauma, and both sexes are equally at risk.

While the above studies helped to demonstrate a relationship between obesity and osteoarthritis in the knee, two main hypotheses have been advanced to explain this association. The most widely accepted theory contends that obesity leads to increased mechanical stress across the joint, thus accelerating deterioration (Davis et al. 1988). Another proposed hypothesis, however, is that the symptomatic effects of OA lead to a sedentary, inactive lifestyle, of which, obesity is a consequence. In response, several longitudinal studies attempted to draw a causal inference. Using a subset (n=1420) of the Framingham Heart Study cohort, Felson et al. (1988) attempted to determine whether obesity preceded knee osteoarthritis by comparing the weight of individuals measured in 1948 through 1951 and the prevalence of knee osteoarthritis in the same individuals approximately 37 years later. Results found a strong and consistent

association between being overweight or obese in 1948-1951 and having knee osteoarthritis years later. Of the heaviest 20% of men and women in 1948-1951, approximately half of these individuals developed radiographic knee osteoarthritis. Out of the remaining 80% of individuals, only a quarter developed radiographic knee OA.

Gelber et al. (1999) investigated osteoarthritis in a cohort of male former medical students who were examined in their 20s. Those who were overweight or obese (BMI >25kg/m^2) as young men had a greater than threefold increased risk of developing knee osteoarthritis by the time they reached the age of 60 than their thinner counterparts. Davis et al. (1988) hypothesized that if obesity were a consequence of activity limitation due to painful symptoms, more symptomatic persons with osteoarthritis of the knee would be obese than nonsymptomatic persons with OA of the knee. Results show that of symptomatic men with osteoarthritis of the knee, 35% would be considered obese. On the other hand, of nonsymptomatic men with OA of the knee, approximately 41% would be considered obese. Similarly, no significant difference is found between symptomatic and nonsymptomatic women. It seems that obesity is more likely a risk factor than a consequence of osteoarthritis of the knee (Davis et al. 1988).

Obesity is known to be strongly associated with the risk of knee OA. However, epidemiological studies have been far less conclusive with regard to hip OA. Tepper and Hochberg (1993) were unable to show an overall association between obesity and hip OA in their examination of the NHANES data set. This study's failure to find a correlation between being overweight and

hip osteoarthritis is consistent with some, but not all, related studies (Gelber et al. 1999). Other than age, sociodemographic factors, obesity, and fat distribution were not associated with hip osteoarthritis (Tepper and Hochberg 1993).

The link between obesity and osteoarthritis of the knee, coupled with the increasing trend towards obesity in modern, developed countries, is in accordance with findings that the prevalence of knee osteoarthritis is on the rise. A recent World Health Organization report on the global burden of disease indicates that knee OA is perched to become the fourth most important cause of disability in women and the eighth most important cause in men (Cooper et al. 2000). The effects of obesity on OA are also witnessed in historical patterns as well. Although the prevalence of knee osteoarthritis wavered among medieval and post-medieval populations, knee OA has consistently been on the rise since the nineteenth century. This parallels the rise in obesity during this time. Further, the inability to conclusively associate obesity with hip OA relates well with the relative stability in the prevalence rate of hip OA over time (Tepper and Hochberg 1993; Waldron 1997).

Varus-Valgus Malalignment

Contemporary epidemiological studies prove that knee osteoarthritis is approximately twice as common as hip osteoarthritis and that tibiofemoral disease is more common than patello-femoral disease. However, Rogers and Dieppe (1994) found that most of the knee OA in older times was due to PFJ rather than TFJ. Another question, then, is whether obesity has increased the

prevalence of knee OA by increasing the prevalence of TFJ.

Again, in the knee, alignment (i.e. the hip-knee-ankle angle) is a key determinant of load distribution. The load-bearing axis is represented by a line drawn from mid femoral head to mid ankle. In a varus knee, this line passes medial to the knee, which increases force in the medial compartment. In a valgus knee, the load-bearing axis passes lateral to the knee, increasing force across the lateral compartment (Sharma et al. 2001). OA development or progression in the PF compartment may be influenced by a number of factors different from those in TF disease. The designs of the PF and TF compartments each reflect unique functions and mechanics, and the same local factors do not have the same effect on the PF and TF articular cartilage (Elahi et al. 2000). Thus, malalignment may tend to impact osteoarthritis more commonly in the TF compartment than the PF compartment, or vice-versa. According to Elahi et al. (2000), 68 out of 92 individuals with moderate-to-severe tibiofemoral OA had varus malalignment (74%), indicating that knees with TFJ were more often varus in nature. A link should then be sought between varus malalignment and obesity.

In the normal ambulating knee, load is disproportionately transmitted to the medial compartment. Sixty to eighty percent of the total compressive load transmitted across the knee is on the medial compartment (Cerejo et al. 2002). Varus malalignment increases medial compartment load; valgus malalignment increases lateral compartment load. As load is more equitably distributed in valgus knees, obesity should have a smaller impact on valgus knees. However, varus malalignment intensifies the effect of excess body weight on the medial

tibiofemoral compartment. Sharma et al. (2000) conducted a study of 292 community-recruited patients with knee osteoarthritis. Of these individuals, 154 patients (53%) were identified as having varus knees, and 115 individuals (39%) were identified as having valgus knees, with the remaining 23 patients presenting neutral alignment. Analysis found that BMI and malalignment were correlated in patients with varus knees, but not in those with valgus knees (Sharma et al. 2000). Also found was that much of the variance in tibiofemoral disease severity explained by BMI can also be attributed to the severity of varus malalignment. Not known, however, is whether obesity contributes to varus malalignment, which in turn contributes to OA, or whether obesity leads to OA and varus malalignment develops subsequently. Even as a consequence, varus malalignment may increase the risk of knee OA progression over time, and these effects have been shown to occur in as little as 18 months (Sharma et al. 2001).

Chapter IV

Materials and Methods

Secular Change in Knee Joint Size

Study Samples

The sample utilized for this facet of the study is derived from a subset (n=199) of the Robert J. Terry collection, housed at the Smithsonian Institution, and the William M. Bass Donated Skeletal Collection curated at the University of Tennessee, Knoxville (n=232). Individuals born prior to 1900 hail primarily from the Terry Collection. Two subgroups were identified to analyze secular change: White females and White Males. Black individuals were excluded from this study based on a small available sample size, and reported findings that environmental and socioeconomic circumstances have a direct impact on rates of secular change (eg. Greiner and Gordon, 1992). Historically, Black and other minority populations have not enjoyed the same advantageous conditions as White individuals (i.e. income, education, and other environmental variables). As a

result, the rates of secular change found for White populations cannot automatically be extended to minority populations. Although the inclusion of Black males and females would undoubtedly be resourceful and informative in regards to secular change, there was not an adequate sample immediately available.

Furthermore, the distinction and labeling between White and Black subgroups is conscious and important as they are socially constructed classifications which may be suggestive of different environmental and socioeconomic conditions useful for the identification of secular change. Not only are these labels predominant in related research literature, they are more socially inclusive than labels emphasizing ancestry.

Robert J. Terry Collection

The Terry collection is one of the premier anatomical research collections, consisting of over 1,700 complete human skeletons of White and Black ancestry from known individuals assembled by Robert J. Terry and Mildred Trotter at Washington University Medical School in St. Louis, Missouri, between 1921 and 1967. Upon Trotter's retirement in 1967, 1,728 specimens were transferred to the Smithsonian Institution's Natural Museum of Natural History Anthropology Department for permanent curation.

The demographic distribution of the Terry collection is as follows: 461 White Males, 323 White Females, 546 Black Males, 392 Black Females, 5 Asian Males, and 1 Unknown Origin. Age at death ranges from 16 years to 102 years;

date of birth ranges between 1822 and 1943. The majority of individuals in the Terry collection are 45 years or older, an expected artifact of any anatomical series.

William M. Bass Donated Skeletal Collection

The William M. Bass Donated Skeletal Collection is comprised of primarily self and familial donated individuals as well as individuals received through the State of Tennessee Medical Examiner system dating from 1981 to present. Subjects were exposed to the natural environment at the Forensic Anthropology Research Facility for various studies and observations on human decomposition. Skeletal elements were then processed to remove residual soft tissue and to facilitate long term curation. Individual skeletons are housed at the Forensic Anthropology Center in the Department of Anthropology at the University of Tennessee. Age, sex, and racial affinity are documented for most specimens. To date, there are 314 individuals available for anthropometric data collection.

The demographic distribution of the William M. Bass Donated Skeletal Collection consists of 207 White Males, 66 White Females, 29 Black Males, 5 Black Females, and 8 other individuals of Hispanic, Mixed, or Unknown Origin. The absence of an adequate number of Black individuals, particularly Black females, was the underlying factor for limiting this study to White individuals. Age at death ranges from 20 years to 101 years; date of birth ranges between 1892 and 1980. The majority of individuals in the Bass collection are 58 years or

older. In addition, the Bass collection also houses a small number of newborn and infant specimens.

Methodology

Inclusion in this study was determined by the availability of birth year statistics, sex and race, and the required measurements of the distal femur and proximal tibia. Only individuals identified as "adult" or over 18 years of age were included in the analysis. Preference was given to measurements from the left side. When left side measurements were unavailable, similar measurements from the right side were substituted. In all, 431 individuals were included in the study. These consisted of 291 males and 140 females. Table 1 presents the number of observations by date of birth broken down into 25-year cohorts.

Articular surface areas of the femoral condyles and tibial plateaus were calculated from anterior-posterior and mediolateral breadth measurements of each surface, assuming an approximately rectangular shape. All measurements were taken to the nearest millimeter. For the femoral condyles, the region of articulation with the patella, discernable as a faintly marked ridge or relatively abrupt change in contour, was excluded from the articular surface area calculations.

Femora were placed on an osteometric board in a standardized position with the posterior borders of the condyles on the board surface. The A-P height of each condyle surface was then measured from the board to the edge of the patellar articular surface, and M-L breadth measured parallel to the board just

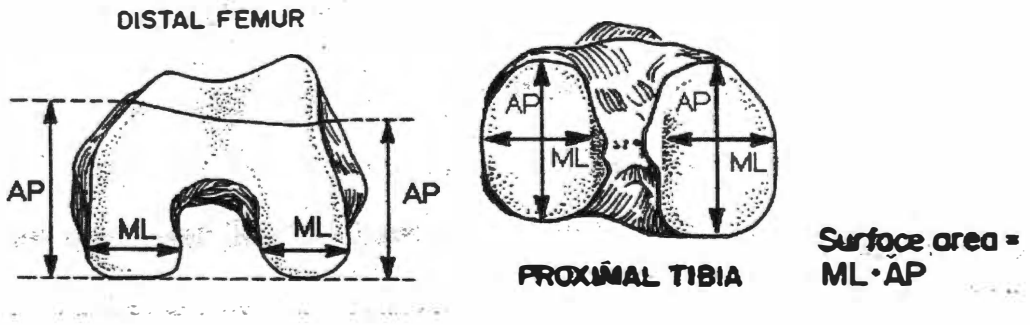
Table 1: Sample size and mean age by 25-year cohorts

Year of Birth	*Males*				*Females*			
	N	Mean Age	Min	Max	N	Mean Age	Min	Max
1850-1875	52	66.15	50	82	30	68.10	41	87
1875-1900	44	49.66	32	101	34	58.41	30	76
1900-1925	57	65.58	20	97	37	59.38	27	89
1925-1950	100	57.32	32	76	31	61.90	33	75
1950-1975	38	38.67	25	52	8	40.75	25	52
TOTAL	291	56.92	20	101	140	60.51	25	89

above the board surface (Figure 2). Tibial plateau measurements included only the relatively flat portions of the surfaces, excluding the projections of the tibial intercondylar eminences. The two femoral condyles and tibial plateaus were analyzed both separately and as sums over medial and lateral articular surfaces.

The femoral condyle measurements do not directly take into account the effects of curvature on area of this articular surface (Tardieu, 1981). However, the measurement techniques for this study were extracted from similar studies by Ruff (1988, 1990) involving articular surface area of the lower limbs. These studies found the A-P and M-L breadths measured to represent the major dimensions of the articular surfaces, providing reasonable estimates of relative surface area (Ruff, 1988: 690).

In addition, other measurements not directly reflecting articular surface area size were also noted. These measurements include the epicondylar breadth of the distal femur as well as the width of the proximal tibia. Also, the



(A) (B)

Figure 2: The distal end of the femur (A), with corresponding measurements of the lateral and medial condyle. The proximal end of the tibia (B), with corresponding measurements of the lateral and medial tibial plateau. Reproduced from Ruff, 1990.

anterior-posterior lengths, including the area of articulation with the patella, of both the medial and lateral femoral condyles were measured. These four measurements are more indicative of the general size of the distal femur and proximal tibia, rather than merely the weight-bearing articular surface area. All measurements, and accompanying abbreviations, are listed in Table 2.

Statistical Analysis

Data were entered in to a Microsoft Excel spreadsheet, and then imported into both Number Cruncher Statistical System (NCSS) software and Blossom Statistical Software. Blossom is an interactive program for making statistical comparisons with distance function-based randomization tests, and for testing parameters estimated in linear models with permutation procedures (Cade and Richards, 2001: 1).

Calculation of general secular trends was assessed through least squares regression analysis. Least squares regression was chosen because of the clear assignment of date of birth (DOB) as the independent variable. The null hypothesis was that there was no relationship between DOB and knee joint size. Two sample t-tests were also run on these data to examine sex differences. T-tests were conducted between males and females. The null hypothesis was that the means were not significantly different between the two groups (two-tailed test). Polynomial regressions were also used to assess change over time; however, these methods did not increase the significance of the least squares regression.

Table 2: Abbreviations and brief description of the femur and tibia measurements utilized in this study

Element	Abbreviation	Measurement Information
Femur:		
	FLCW	M-L width of the lateral femoral condyle
	FLCL	A-P length of the lateral femoral condyle (excluding patellar surface)
	FLCL2	A-P length of the lateral femoral condyle (including patellar surface)
	FMCW	M-L width of the medial femoral condyle
	FMCL	A-P length of the medial femoral condyle (excluding patellar surface)
	FMCL2	A-P length of the medial femoral condyle (including patellar surface)
	FBL	Epicondylar breadth of the distal femur
	FLCA	Surface area of the lateral femoral condyle (FLCW * FLCL)
	FMCA	Surface area of the medial femoral condyle (FMCW * FMCL)
	TFCA	Total surface area of both femoral condyles (FLCA + FMCA)
Tibia:		
	TLW	M-L width of the lateral tibial plateau
	TLL	A-P length of the lateral tibial plateau
	TMW	M-L width of the medial tibial plateau
	TML	A-P length of the medial tibial plateau
	TPW	Width of the proximal tibia
	TLCA	Surface area of the lateral tibial plateau (TLW * TLL)
	TMCA	Surface area of the medial tibial plateau (TMW * TML)
	TTCA	Total surface area of both tibial plateaus (TLCA + TMCA)

In an effort to examine possible changes in knee joint size due to normal bone growth and remodeling due to advancing age and not secular change, partial correlation coefficients were derived for age and knee joint variables controlling for date of birth. First order correlations and partial correlations between age and knee joint variables were computed and T statistics for the partial correlation coefficients were derived by:

$$T = \frac{r_{12*3}}{\sqrt{(1-r_{12*3})}} * \sqrt{(n-3)}$$

Where r_{12*3} is the partial correlation coefficient and *n* equals the number of observations. Corresponding two-tailed p-values were generated to test the null hypothesis that there was no correlation between age and the knee joint variables.

In addition to all the standard statistical analyses, randomization methods were also applied when appropriate algorithms were available and comparable to the standard methods. Anthropological research often deals with small or non-randomly sampled datasets. For example, the Bass Collection can be considered primarily a self-selected dataset that hardly meets the standard of a random sample, requiring each and every element in the entire "relevant population" to have an equal and independent opportunity of being selected for participation (Edgington, 1995). Randomization tests do not entail most of the underlying assumptions regarding random and independent samples, or normal distribution of the parent population (Niness et al., 2002). Randomization tests (Edgington, 1995) are a series of precise computation procedures generating

probabilities based on all possible permutations that could occur with a given dataset. Using these conservative but accurate algorithms eliminates concern that the assumptions underlying the normal curve have somehow been violated (Ninness et al., 2002: 66). The randomization test computes all possible permutations for any number of data points and calculates the probability that the obtained results could have occurred simply as a matter of chance.

Osteoarthritis and Weight

Study Sample

This facet of the study borrows the sample used in the preceding section, with one notable addition. Weight, along with stature, is known in a subset (n=72) of the individuals gathered from the Bass Collection. This allows for the specific comparison and analysis between weight and osteoarthritic conditions. Although anthropometric data, including weight, were collected for more than 60% of the Terry collection, the weight values are relatively unreliable for the purposes of this study. Thus, while all broad comparisons of osteoarthritis involve specimens from both the Terry collection and Bass collection, specific analysis involving weight borrows exclusively from a subset of the latter.

Methodology

Osteoarthritis

The analysis of osteoarthritis in skeletal series has been undertaken previously using ordinal scoring systems (e.g. Merbs 1983, Collins Pierce 1987).

The diagnosis of osteoarthritis in living patients depends primarily on radiological evidence and scored using the *Atlas of Standard Radiographs of Arthritis* (1963). Since the degree of joint space narrowing is impossible to determine on dry bone, visual examination replaces radiographic examination of skeletal material. Collins Pierce (1987) and Waldron (1995) are two sources that briefly discuss the diagnosis of osteoarthritis in dry bone.

This study uses an ordinal scoring system (0-3) identifying osteoarthritis as either absent (0), mild (1), moderate (2), or severe (3). A classification of mild generally only required the presence of slight lipping on any or all compartmental borders. This new bone represents an attempt of the joint to stabilize itself, and may be referred to as an osteophyte (Rogers and Waldron, 1995). Remodelling of the subchondral bone can be observed even in the early stages of osteoarthritis (Muehleman and Arsenis, 1995).

Scoring the presence of OA as either moderate or severe required more definitive evidence of OA, and utilized standards set forth by Waldron (1995). Here, the diagnosis of OA relied predominantly on the presence of eburnation on the joint surface. When ebumation was not present, at least two of the following were found together: marginal osteophytes, new bone on the joint surface, pitting on the joint surface, or alteration in the joint contour (Waldron 1995). Figures 3-7 serve as examples of increasing severity of OA in the knee joint. Differential progression was scored in both the medial and lateral tibiofemoral compartments, as well as the patellofemoral compartment of the knee joint. Severity was scored, taking the condition of all three compartments into

Figure 3: Example of osteoarthritis scored as absent (0)

Figure 4: Example of osteoarthritis scored as mild (1)

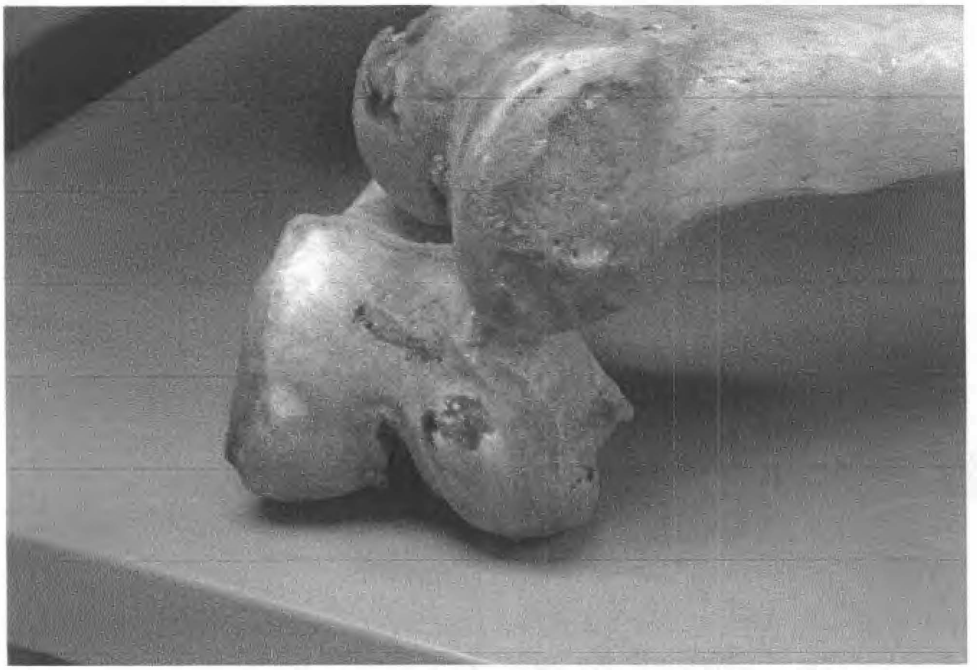


Figure 5: Example of osteoarthritis scored as moderate (2)

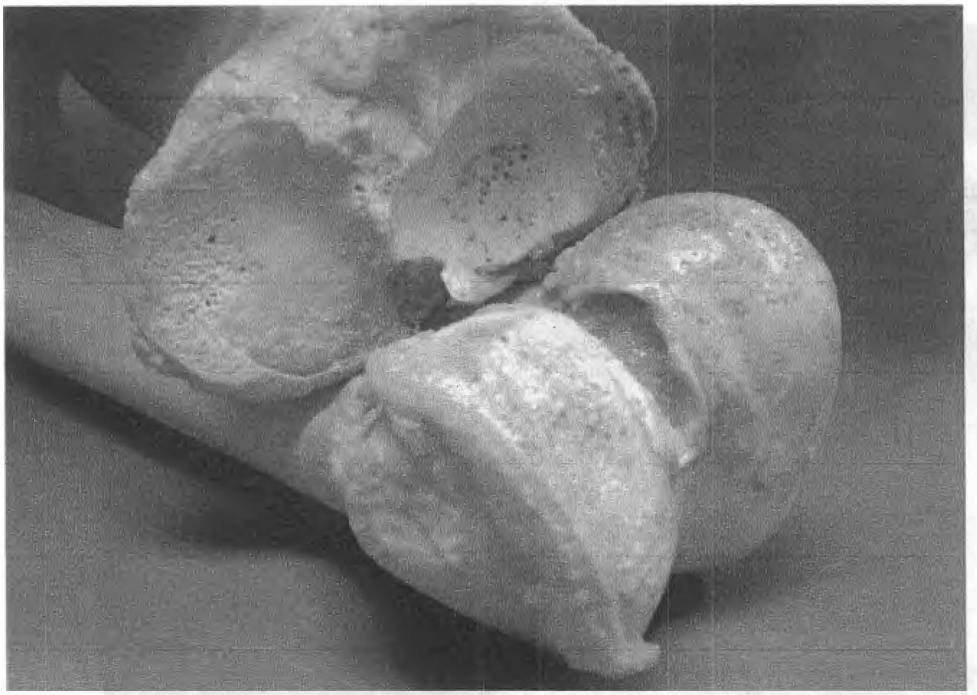


Figure 6: Example of osteoarthritis scored as severe (3)

Figure 7: Example of unilateral knee osteoarthritis

consideration. In addition, the condition of unilateral or bilateral osteoarthritis was noted.

Weight

For the subset of individuals from the Bass Collection with known weight and stature, Body Mass Index was calculated using the following formula:

$$BMI = (\text{Weight in Kilograms} / (\text{Height in Meters})^2$$

This index provides a relative measure of body size controlling for one's height. A BMI of 24.99 kg/m^2 or less is considered normal weight. BMI values between 25.00 and 29.99 kg/m^2 are considered overweight, while values of 30.00 kg/m^2 and above are considered obese. Table 3 presents a brief breakdown of BMI for the known weight subset, while Appendix A provides further detailed individual data from this subset.

Table 3: Breakdown of the known weight subset by Body Mass Index

	BMI (kg/m^2)	# of Individuals
Normal Weight	≥ 24.99	34
Overweight	25.00-29.99	18
Obese	≤ 30.00	20

Statistical Analysis

Chi-square tests were employed to assist the general comparison of prevalence rates of knee osteoarthritis between the Terry and Bass Collections, as well as between the sexes and age. The chi-square test statistic is used to test the hypothesis of no association of columns and rows in tabular data. In this instance, the test will examine association between either the two samples, two sexes, or two age groups and the presence or absence of osteoarthritis as well as the degree of involvement. Chi-square tests are also used to examine the specific relationship between obesity and the presence and/or severity of osteoarthritis in the known weight sample. The null hypothesis was that there was no significant association between increased weight and presence and/or severity of knee osteoarthritis. For these analyses, N starts off relatively large but due to the available samples size reduces to fairly small numbers when comparing the individuals of known weight and the presence of knee OA.

Again, randomization test are also utilized to complement the standard statistical approach as it is impossible to be sure that the chosen samples adequately meet the distribution assumptions required of random samples. However, randomization tests for solely categorical data are dramatically rare compared to those found for ordinal univariate and multivariate methods. One accessible solution was provided by Dr. Seaver and computed in NCSS. In order to perform a randomization test for computing chi square test statistics, 300 random samples with replacement were generated from the dataset. Often, 1,000 or more generated random samples are preferable, but computation

limitations did not permit such a large number for this part of the analysis. Chi square test statistics, and their associated p values, were computed for each of the 300 random samples and then averaged. The average p value was then compared to the p value of the original observed table. Similar p values of significance lend support to the belief that the observed test statistics are stable and reliable indicators of the associations being tested by the null and alternative hypotheses.

Chapter V

Results

Knee Joint Size

Secular Change

Tables 4 (Males) and 5 (Females) present the results of the least squares regression of the knee joint variables regressed on DOB. Males are statistically significant for secular change in FLCW (p=0.0399), FLCL (p=0.0007), TLW (p=0.0499), TLL (p=0.0257), TML (p=0.0026), TPW (p=.0124), and TMCA (p=0.0224). These changes reflect the femoral lateral condyle decreasing in the anterior-posterior dimension, while increasing in the mediolateral dimension. As a result, there is no significant change in the overall surface area of the femoral lateral condyle. The surface area directly opposite of the femoral lateral condyle, the lateral tibial plateau exhibits a different pattern of secular change. In contrast to the femoral lateral condyle, the lateral tibial plateau exhibits a decrease in the mediolateral dimension and in increase in the anterior-posterior length. Again, the result is no significant change in the overall surface area of the lateral

Table 4: Intercept, slope, T statistic, r^2, and p values for knee joint variables regressed on date of birth for males

	White Males (N=291)					
Variable	Intercept	Slope	T stat.	r^2	p value (standard)	p value (randomization)
FLCW	12.3216	.0085	2.0644	.0145	.0399*	.0418*
FLCL	83.8331	-.0255	-3.4461	.0395	.0007*	.0009*
FLCL2	50.9067	.0075	1.0510	.0038	.2941	.2904
FMCW	37.5871	-.0057	-1.3030	.0058	.1936	.1962
FMCL	64.3634	-.0095	-1.4360	.0071	.1521	.1529
FMCL2	52.0524	.0052	.7606	.0020	.4475	.4501
FBL	62.1088	.0077	1.0633	.0039	.2885	.3020
TLW	44.4600	-.0071	-1.9692	.0132	.0499*	.0519*
TLL	19.8723	.0117	2.2416	.0171	.0257*	.0245*
TMW	24.4739	.0035	.8614	.0026	.3898	.3903
TML	13.1755	.0183	3.0331	.0309	.0026*	.0023*
TPW	44.8487	.0173	2.5171	.0215	.0124*	.0129*
FLCA	1805.8559	-.4179	-1.4301	.0070	.1538	.1528
FMCA	2199.2498	-.5040	-1.4301	.0098	.0926	.0875
TFCA	4005.1057	-.9128	-1.7570	.0106	.0800	.0816
TLCA	1174.4344	.0400	.2629	.0002	.7928	.7909
TMCA	66.0988	.7264	2.2954	.0179	.0224*	.0226*
TTCA	1240.5332	.7964	1.5468	.0082	.1230	.1311

Statistically significant at $p<.05$

Table 5: Intercept, slope, T statistic, r^2, and p values for knee joint variables regressed on date of birth for females

	White Female (N=140)					
Variable	Intercept	Slope	T stat.	r^2	p value (standard)	p value (randomization)
FLCW	23.6052	.0006	.1041	.0001	.9173	.9155
FLCL	117.3567	-.0451	-4.2101	.1138	.0000*	.0002*
FLCL2	68.0750	-.0048	-.4637	.0016	.6436	.6446
FMCW	46.1048	-.0122	-1.7464	.0216	.0830	.0794
FMCL	97.0793	-.0294	-2.9828	.0606	.0034*	.0039*
FMCL2	70.3182	-.0077	-.6926	.0035	.4897	.4850
FBL	67.0421	-.0003	-.0303	.0000	.9759	.9765
TLW	43.2662	-.0085	-1.3697	.0134	.1730	.1699
TLL	50.9426	-.0074	-1.0190	.0075	.3100	.3117
TMW	31.1575	-.0025	-.4788	.0017	.6328	.6332
TML	57.5353	-.0078	-.9734	.0068	.3320	.3259
TPW	87.7504	-.0104	-1.0654	.0077	.3023	.2981
FLCA	2888.6937	-1.1076	-3.2252	.0701	.0016*	.0022*
FMCA	3200.5616	-1.1876	-2.9801	.0605	.0034*	.0035*
TFCA	6089.2553	-2.2952	-3.4307	.0786	.0008*	.0008*
TLCA	1991.2274	-.5215	-1.4083	.0142	.1613	.1547
TMCA	1731.3022	-.3187	-.8480	.0052	.3979	.4019
TTCA	3722.5296	-.8402	-1.2614	.0114	.2093	.2113

Statistically significant at $p<.05$

plateau. However, the total surface area of the medial tibial plateau does illustrate a secular increase in size, largely due to a significant increase in anterior-posterior length. Finally, in contrast to the significant decrease in the medio-lateral dimension of the lateral tibial plateau, there is an overall significant increase in the width of the entire proximal tibia.

Females evidence a radically different degree of secular change. Females are statistically significant for secular change in FLCL ($p=0.0000$), FMCL ($p=0.0034$), FLCA ($p=0.0016$), FMCA ($p=0.0034$), TFCA ($p=0.0008$). In females, there is a significant decrease in the anterior-posterior dimension of both the medial and lateral femoral condyles. In addition, these significant decreases also lead to significant decreases in the total surface area of the femoral condyles, both individually and combined.

Permutation tests and statistics did not alter the results in either sex group. Differences in p-values for the standard and permutation methods were minimal. Only once did the difference in p-values reach a value greater than .01 (FBL in males).

Sex Differences

Sex differences between White males and females are presented in Table 6. Results of the t-test show statistically significant sex differences at $p<.0001$ for all knee joint size variables. These results illustrate the well known pattern that males are generally larger than females. Again, statistical results based on permutation tests did not disagree with those based on standard techniques.

Table 6: Independent sample t-tests for sex differences

Variable	Male Mean	Female Mean	T statistic	P value (standard)	P value (randomization)
FLCW	28.64	24.68	18.2260	<.0001	<.0001
FLCL	35.03	31.61	8.4046	<.0001	<.0001
FLCL2	65.35	58.97	17.6125	<.0001	<.0001
FMCW	26.69	22.81	16.0553	<.0001	<.0001
FMCL	46.17	41.17	13.9034	<.0001	<.0001
FMCL2	62.09	55.63	17.0166	<.0001	<.0001
FBL	76.77	66.42	26.6688	<.0001	<.0001
TLW	30.87	27.09	18.5485	<.0001	<.0001
TLL	42.30	36.79	21.1508	<.0001	<.0001
TMW	30.11	26.34	19.5826	<.0001	<.0001
TML	48.26	42.64	17.5702	<.0001	<.0001
TPW	77.94	67.94	28.3454	<.0001	<.0001
FLCA	1006.02	781.43	16.7039	<.0001	<.0001
FMCA	1234.56	941.03	19.9601	<.0001	<.0001
TFCA	2240.59	1722.46	20.4657	<.0001	<.0001
TLCA	1308.46	999.09	21.9647	<.0001	<.0001
TMCA	1456.46	1124.98	22.9768	<.0001	<.0001
TTCA	2764.92	2124.07	26.1095	<.0001	<.0001

Statistically significant at $p<.05$

Effect of Age at Death

Partial correlations were computed between age and the knee joint variables, controlling for DOB and the potential effects of secular change. Although joint size is reported to be relatively stable throughout one's lifetime, there has been documented diaphyseal expansion caused by periosteal bone apposition past the third decade (Martin and Burr, 1989; Ruff and Hayes: 1988). These reports, coupled with a few significant first order Pearson correlations between age and the knee joint dimensions found in this study, warrant this approach. The results are presented in Tables 7 (males) and 8 (females). No accompanying permutation tests were utilized in this analysis.

On average, the partial correlation coefficients are higher than their first order counterparts. Significant partial correlations for males include most of the mediolateral dimension or width variables (FLCW, FMCW, FBL, TMW, and TPW). In addition, the measurements FLCL2 and FMCL2, reflecting the anterior-posterior length of both the medial and lateral femoral condyles (including the area of articulation with the patella) also had significant correlations. Also found to be significant were a few total surface area variables: FMCA, TMCA, and TTCA. These correlations support some expansion of lower long bone metaphyses with aging, but do not necessarily signify the absence of reportedly stable weight-bearing joint surface areas.

Females demonstrate significant correlations with age and the anterior-posterior dimension of the lateral femoral condyle (FLCL), epicondylar breadth of the femur (FBL), and width of the proximal tibia (TPW). With the exception of

Table 7: Pearson correlation coefficient, partial correlation, and T statistic of partial correlation coefficient for knee joint variables and age controlling for date of birth in males

	White Males (N=291)		
Variable	r	T statistic	Partial Correlation
FLCW	.115*	2.927	.170*
FLCL	-.021	-1.698	-.100
FLCL2	.168*	3.530	.204*
FMCW	.258*	4.340	.248*
FMCL	-.010	-0.735	-.043
FMCL2	.121*	2.512	.146*
FBL	.191*	3.971	. 228*
TLW	.112	1.297	.076
TLL	.011	1.044	.061
TMW	.150*	3.103	.180*
TML	.008	1.301	.076
TPW	.178*	4.362	.249*
FLCA	.039	0.164	.010
FMCA	.160*	2.310	.135*
TFCA	.113	1.399	.082
TLCA	.067	1.315	.077
TMCA	.091	2.557	.149*
TTCA	.090	2.252	.132*

Statistically significant at $p<.05$

Table 8: Pearson correlation coefficient, partial correlation, and T statistic of partial correlation coefficient for knee joint variables and age controlling for date of birth in females

	White Females (N=140)		
Variable	r	T statistic	Partial Correlation
FLCW	.105	1.321	0.112
FLCL	.067	-2.087	-0.176*
FLCL2	.032	0.264	0.023
FMCW	.114	0.911	0.078
FMCL	-.006	-0.919	-0.078
FMCL2	.050	0.414	0.035
FBL	.167*	2.050	0.173*
TLW	.001	-0.381	-0.033
TLL	.037	0.158	0.013
TMW	.115	1.266	0.108
TML	.092	0.851	0.073
TPW	.209*	2.302	0.193*
FLCA	-.003	-0.950	-0.081
FMCA	.079	0.143	0.012
TFCA	.045	-0.401	-0.034
TLCA	.018	-0.180	-0.015
TMCA	.118	1.202	0.102
TTCA	.076	0.575	0.049

Statistically significant at $p<.05$

FLCL, these correlations also support some expansion of the lower long bone metaphyses with aging, but not the actual weight bearing articular surfaces. Males, in general, demonstrate higher correlations with age and significant correlations with age for more of the knee joint variables, suggesting that sex specific patterns do exist.

General Trends for Knee Osteoarthritis

Comparisons between Two Skeletal Samples

Knee osteoarthritis was found in 91 out of 199 (45.7%) cases for the Terry collection. Out of the 91 individuals with OA of the knee, 87 (95.6%) had some evidence of tibiofemoral OA in the medial compartment. Tibiofemoral OA was evident in the lateral compartment of the knee in 67 (73.6%) individuals. Patellofemoral OA was found in 44 (48.4%) cases. Bilateral OA was more common than unilateral OA, occurring in a total of 66 (72.5%) specimens. Knee OA was coded as mild in the majority of instances, representing 73 of the 91 (80.2%) cases of osteoarthritis. Moderate or severe was coded in the remaining 18 (19.8%) individuals.

The Bass collection also exhibited high rates of knee OA in all compartments. Knee osteoarthritis was found in 144 out of 232 (62.0%) individuals. Of the 144 instances of osteoarthritis, 131 (91.0%) cases exhibited tibiofemoral OA in the medial compartment, 100 (69.4%) cases had some evidence of lateral tibiofemoral OA, and 82 (56.9%) cases presented some degree of patellofemoral OA. Bilateral knee OA was present in 98 (68.1%)

instances, with unilateral knee OA present in the remaining 46 (31.9%) individuals. As in the Terry collection, the majority of the 144 cases of knee OA were classified as mild. Of 144 specimens, 112 (77.8%) were coded as mild and 32 (22.2%) individuals exhibited either moderate of severe OA in the knees.

Table 9 presents the results of the chi-square tests for the presence and severity of osteoarthritis between the Terry and Bass collections. Appendix B provides the individual frequency tables that correspond to the chi square test statistics found in Table 9. The Bass collection has significantly more frequent involvement of OA in the knee (p=.0000). Regarding all individuals scored for the presence of osteoarthritis of the knee, the Terry collection had higher frequencies of tibiofemoral OA in both the medial and lateral compartments. On the other hand, the Bass collection had a higher frequency of patellofemoral OA. In none of these instances, however, were the results found to be statistically significant (MTFJ p=.2075, LTFJ p=.5557, PFJ p=.2275).

The condition of unilateral or bilateral osteoarthritis was also noted for each individual scored for knee OA. Bilateral OA was more common in both collections, while the Terry collection had a higher frequency of bilateral knee OA. Again, however, there was no significant association between bilateral OA and the Bass collection (p=.5599).

Not surprisingly, mild OA was most common in both collections. There was no difference in the presence of moderate OA, and severity was more common in the Bass collection. Nonetheless, there was not a significant association between the Bass collection and increased severity of OA (p=.8321).

Table 9: Chi square test and significance statistics for the association between skeletal collection and knee OA variables

Variable	X^2	P value (standard)	P value (randomization)
Presence of Knee OA	11.535	.0000*	.0170*
Medial TFJ	1.783	.2075	.2900
Lateral TFJ	.474	.5557	.5164
PFJ	1.656	.2275	.2917
Bilateral Knee OA	.529	.5599	.4416
Severity of Knee OA	.451	.8321	.3799

Statistically significant at $p<.05$

Significance results did not change when moderate and severe scores were grouped together in each collection.

Randomization tests, also found in Table 9, provided results similar to the standard tests. In no instance did the randomization tests alter the significance below (or above) the chosen alpha. There remained a significant association between the Bass collection and the presence of OA (p =.0170), while all other statistics failed to reject the null hypotheses.

Sex Differences

Table 10 presents the chi-square test results for the presence and severity of osteoarthritis between the males and females, both skeletal samples combined. Appendix C provides the individual frequency tables that correspond to the chi square test statistics found in Table 10. No significant association was found between sex and the presence of osteoarthritis as a whole (p=.5358), or in each compartment individually (MTFJ p=1.000; LTFJ p=.3554; LTFJ p=.3229).

The condition of unilateral or bilateral osteoarthritis was also noted for each individual scored for knee OA. Bilateral OA was more common in both sexes, while females (79.5%) had a higher frequency of bilateral knee OA than males (65.4%). Regarding severity, both males and females had high frequencies of mild OA; however, women were more likely to develop moderate and severe OA. Women were found to have moderate knee OA in 23.3% of the cases, and severe knee OA in 11.0% of the cases. Males, on the other hand, only presented moderate knee OA in 8.6% of the individuals, and severe knee

Table 10: Chi square test and significance statistics for the association between sex and knee OA variables

Variable	X^2	P value (standard)	P value (randomization)
Presence of Knee OA	.474	.5358	.4850
Medial TFJ	.023	1.000	.6278
Lateral TFJ	.943	.3554	.3492
PFJ	1.190	.3229	.3969
Bilateral Knee OA	4.691	.0324*	.0469*
Severity of Knee OA	11.527	.0028*	.0297*

Statistically significant at $p<.05$

OA in 6.8% of all individuals. Interestingly, although women were not more likely to be diagnosed with knee OA, there was a significant association between women and bilateral knee OA (p=.0321), as well as increased severity (p=.0032).

Randomization tests provided end results similar to the standard tests. In no instance did the randomization tests alter the significance below (or above) the chosen alpha. There remained a significant association between the females and the condition of bilateral knee OA (p=.0469) and severity (p=.0297), while all other statistics failed to reject the null hypotheses.

Age Differences

Table 11 presents the chi-square test results for the presence and severity of osteoarthritis between two age groups, both samples combined. Appendix D provides the individual frequency tables that correspond to the chi square test statistics found in Table 11. The age groups were chosen by finding the median age of all observations and making this the cut-off point. Standard statistical techniques found a significant association between age and the presence of osteoarthritis (p=.0000). Individuals 58 years of age and under were found to have knee OA in 42.5% of the cases, while 67.1% of individuals older than 58 years of age were classified as having knee OA. Standard statistical techniques also found an association between age and the presence of knee OA in each compartment of the knee. However, no significant association was found between increased age and the presence of bilateral knee OA (p=.1127).

Table 11: Chi square test and significance statistics for the association between age and knee OA variables

Variable	X^2	P value (standard)	P value (randomization)
Presence of Knee OA	26.230	.0000*	.0002*
Medial TFJ	4.661	.0397*	.0695
Lateral TFJ	10.057	.0020*	.0375*
PFJ	14.784	.0002*	.0012*
Bilateral Knee OA	2.637	.1127	.1782
Severity of Knee OA	16.626	.0003*	.0014*

Statistically significant at $p<.05$

As with the presence of OA, age was also found significant for the progression of OA, or the increased severity of OA with increased age (p=.0003).

The randomization test gave similar results, with one exception. Whereas standard statistical approaches lead to a rejection of the null hypothesis that there is no association between age and the presence of MTFJ (p=.0397), the randomization test fails to reject the null hypothesis (p=.0695). The remaining randomization tests all agree with the conclusions of the standard statistical tests.

Specific Comparisons between Weight and Knee Osteoarthritis

Out of the 72 individuals of known weight and stature, the average BMI was 26.85 kg/m^2. An individual with a BMI value of 25.00 kg/m^2 or above is considered overweight. Knee osteoarthritis was diagnosed as present in 40 individuals (55.6%). Of the 40 instances of osteoarthritis, 36 cases (90.0%) exhibited tibiofemoral OA in the medial compartment, 29 cases (72.5%) had some evidence of lateral tibiofemoral OA, and 20 cases (50.0%) presented some degree of patellofemoral OA. Bilateral knee OA was present in 28 instances (70.0%), with unilateral knee OA present in the remaining 12 individuals (30.0%). As in the general comparison, the majority of the 40 cases of knee OA were classified as mild. Mild OA was scored in 32 out of 40 individuals (80.0%), and 8 individuals (20.0%) exhibited either moderate of severe OA in the knees.

Table 12 displays the chi-square test results for a linear association between increasing weight and the presence/absence and severity of knee

Table 12: Chi square test and significance statistics for the association between increasing BMI and knee OA variables

Variable	X2	P value (standard)	P value (randomization)
Presence of Knee OA	6.734	.0380*	.0754
Medial TFJ	.4167	.8119	.5331
Lateral TFJ	3.010	.2714	.1854
PFJ	3.750	.1928	.2015
Bilateral Knee OA	2.500	.3673	.3126
Severity of Knee OA	11.406	.0146*	.0305*

Statistically significant at $p<.05$

osteoarthritis. Appendix E provides the individual frequency tables that correspond to the chi square test statistics found in Tables 12, 13, and 14. The chi-square statistic is 6.734 (p=.0380) for the overall presence of knee OA indicating an association between BMI and the presence of osteoarthritis. While individuals classified as normal weight and overweight had a similar percentage of osteoarthritis (47.1% and 44.4%, respectively), obese individuals were diagnosed with knee OA in 80% of the cases. Table 13 illustrates that the association between BMI and the presence of OA is found specifically in individuals who are obese (BMI>30.00 kg/m^2), and not simply among all overweight individuals (BMI> 25.00 kg/m^2).

Table 12 also contains data on the association between increasing weight and the presence OA in the three different compartments of the knee. Regarding all individuals scored for the presence of osteoarthritis of the knee, the overweight and obese individuals had frequencies of osteoarthritis in all three knee compartments that were equal to or higher than the frequencies found in non-overweight individuals. In none of these instances, however, were the results found to be statistically significant (MTFJ p=.1000, LTFJ p=.2714, PFJ p=.1928).

The condition of unilateral/bilateral knee OA was noted for all individuals. As expected, overweight and obese individuals had a higher frequency of bilateral knee osteoarthritis than normal weight individuals. However, as shown in Table 12, the results were not found to be statistically significant (p=.3673).

Table 13: Chi square test and significance statistics for the association between overweight/obesity and presence of knee OA

Variable	X2	P value (standard)	P value (randomization)
BMI≥25.00(overweight)/ BMI<25.00	1.884	.2354	.2056
BMI≥30.00(obese)/ BMI<30.00	6.702	.0160*	.0299*

Statistically significant at p<.05

Table 14: Chi square test and significance statistics for the association between overweight/obesity and severity of knee OA

Variable	X2	P value (standard)	P value (randomization)
BMI≥25.00(overweight)/ BMI<25.00	4.714	.0799	.0978
BMI≥30.00(obese)/ BMI<30.00	10.964	.0021*	.0091*

Statistically significant at p<.05

Finally, the severity of OA was examined across all three BMI groups. Both normal weight and overweight individuals presented extremely high frequencies of mild OA (93.75% and 100.00%, respectively). However, mild OA was less common in obese subjects (56.25%), with moderate and severe knee OA scored in no less than 7 out of 15 individuals (43.75%). The increased severity in obese subjects was found significant with a p-value of .0146. Noteworthy, however, is that Table 14 illustrates that the association between BMI and the severity of OA is found specifically in individuals who are obese (BMI>30.00 kg/m^2), and not simply among all overweight individuals (BMI> 25.00 kg/m^2)

Again, the randomization test performed similarly to the standard techniques assuming a random sample, with one exception. The significant association between increasing weight and the presence of OA became non-significant (p=.0754), failing to reject the null hypothesis. However, a significant association returned (p=.0299) when looking specifically at the relationship between obese people (BMI greater than 30.00 kg/m^2) and the presence of knee OA.

Chapter VI

Discussion

Knee Joint Size

Secular Trend

These results are comparable with those reported by others. Despite the importance of mechanical loading in joints, most researchers assume that the articular areas of long bones remain fairly conservative, constrained by the need to fit precisely with one another, and this study finds no overwhelming evidence to the contrary. However, although articular surfaces are resistant to change, and adapted to create the largest weight-bearing surface (Poss 1984), they do not appear to be entirely free from the effects of the environment and associated secular change.

In males, some evidence of change was detected, most notably in the lateral condyle of both the femur and tibia. In the later condyle of the distal femur, males exhibited evidence of a decrease in the anterior-posterior

dimension, but an increase in the mediolateral dimension. However, the surface area that articulates with the lateral condyle exhibits the complete reverse. The lateral tibial plateau appears to be lengthening in the anterior-posterior direction, with an accompanying decrease in the mediolateral dimension. Due to the biconvex shape of the lateral condyle of the femur and convexo-concave surface of the lateral tibial plateau, these changes may actually create a more highly congruent surface for the two areas by increasing the area available for articulation without significantly altering the overall size of the joint.

Similarly, the secular increase in the medial tibial plateau in both the anterior-posterior and mediolateral dimension may also be a reflection of an increase in the congruency of the articular surfaces. The medial condyle of the femur, by design, tends to overhang the medial facet of the tibia. A larger tibial plateau may provide a more stable weight-bearing surface.

Compared to males, the secular change displayed in females is moderately different in both direction and location. Females exhibited significant secular change in the anterior-posterior dimension (excluding the area of articular with the patella) of the medial and lateral femoral condyles. These changes also resulted in significant secular decreases in the total surface area of both condyles, individually and combined. However, like males, the decrease in the anterior-posterior dimensions may also serve to create more congruent weight bearing surfaces. A shortened medial femoral condyle may lessen the overhang of the medial tibial plateau, while a shortened concave lateral femoral condyle may have increased articulation with the convex surface of the lateral tibial facet.

Swartz (1989) found that compressive loading of the hind limbs of humans is large relative to other primates and that human hind limb joints are significantly larger than predicted solely by body size. One proposed explanation is that selection may act more effectively to increase the capacity of the joints to bear weight than to conserve joint material when overall loading is reduced, implying that joint surface areas will be retained even when there is no mechanical demand for larger surfaces. The secular change found in this study, then, may simply be a reflection of the body's effort to effectively increase the capacity and stability of the joint to bear weight, if not necessarily the size of the joint surface.

Although acceptable joint loads are highly influenced by joint size, and despite the known interspecific relationship between body mass and limb joint surface area, most reports maintain that articular surface areas remain fairly conservative. Ruff et al. (1991) found no significant association between body mass and joint size, nor did this study (Appendix F). Rockhold (1998) also found little evidence of secular change for articular dimensions, including epicondylar and femoral head breadth. Although the present study does present some degree of secular change in various knee joint measurements, the relationship between joint loading and the shifting knee joint dimensions remains speculative. Still, due to the well-documented phenomenon that members of the U.S. population are becoming not only systematically heavier for their stature, but also systematically more sedentary than that seen in earlier or preindustrial populations, changes in knee joint dimensions responsive to altered loads remains probable.

Sex Differences

Predictably, results of this analysis demonstrated statistically significant sex differences in all size variables, with males consistently larger than females. Sexual dimorphism in human populations is a near universal finding in all anthropometric studies (i.e Dibennardo and Taylor, 1983; Gray and Wolfe, 1980; Keen, 1950; Iscan et al., 1999; Relethford and Hodges, 1985; Steyn and Iscan, 1998; Van Vark et al., 1989). However, another noteworthy pattern is suggested by a greater degree of secular change among males than females concerning knee morphology.

Some studies report differences between the sexes in sensitivity to environmental changes. However, there is no uniform opinion regarding which sex enjoys greater sensitivity to environmental stimuli. Wolankski and Kasprzak (1976) claim that the difference in stature between men and women in a given population is a measure of each sex's reaction to environmental influences. The female body, they argue, is thus more resistant to change. Meadows Jantz and Jantz (1999) also offer evidence that male secular change is stronger than that recorded for females, particularly for whites. However, Malina et al. (1987) noted differences between the sexes regarding secular change. Males were found to have higher rates of change with regard to stature, while females tended to have increased rates of secular change regarding weight and BMI.

In this study, females did appear more resistant to change. Not only did females have fewer variables exhibiting significant rates of secular change, but the direction of change was more consistent across all variables. In nearly all

knee joint variables, regardless of significance, the directional change was toward a decrease in size. In males, there was no consistent pattern, with some variables exhibiting an increase in size, while others evidenced a decrease in size.

Effect of Aging

Due to concern about normal bone remodeling and expansion past the third decade, the interaction between aging and the knee joint variables was explored.

The overall conclusion of the correlation between age and the knee joint variables is that the weight bearing articular surfaces of the knee joint are no more directly responsive to aging than increases in body mass. Those partial correlation coefficients that were found to be significant represent measurements that often included an area larger than the actual articular surfaces. For instance, several measurements were designed to examine the dimensions of the entire distal femur or proximal tibia, not just the weight bearing surfaces. These measurements were typically, although not exclusively, those found to be significantly associated with age related expansion. The decrease in the anterior-posterior dimension of lateral femoral condyle (FLCL) with age for females remains unexplained.

Overall, males and female appear to exhibit different patterns of age related expansion. These results are in agreement with Ruff and Hayes (1988)

and Rockhold (1998), who reported sex specific remodeling responses with aging, with males exhibiting more expansion than females.

General Comparisons of Osteoarthritis

Historical Comparison

Current radiological studies estimate that approximately 10% of modern-day populations are affected by osteoarthritis of the knee. This prevalence increases with age, finding radiological abnormalities present in more than 30% of persons more than 65 years old. The mean age for the Terry collection was 55.64. The mean age for the Bass collection was 60.18. Thus, if dry bone diagnosis is comparative to radiological studies, the two study samples should present prevalence rates of knee OA slightly below 30%. In both osteological study samples the presence of knee OA was found to be far greater. The Terry collection exhibited a 45.73% frequency of OA in the knee, while the Bass collection sample exhibited 62.07% frequency. These results compare favorably to another study which reported higher rates of knee OA based on visual detection than radiological detection (Rogers et al. 1990). Radiological studies, then, may be underreporting the actual prevalence of knee OA in modern day populations.

Even when restricting prevalence rates exclusively to moderate and severe scores, the rate of knee osteoarthritis was 19.8% in the Terry collection and 22.2% in the Bass collection. Thus, the prevalence of osteoarthritis could have been reported in the Bass collection as either 22.2% or 62.1%, depending

on the diagnostic criterion used. This also agrees with Rogers et al. (1990), who reported the prevalence of osteoarthritis based on visual detection as 21.0% or 67.0%, depending on the adopted diagnostic criterion.

Even using the conservative estimates of knee OA, modem frequencies are drastically higher than those reported in historical samples. In a Saxon/medieval sample, 1.8% of the individuals were affected with knee OA. In a post-medieval sample, 5.5% of the individuals were affected with knee OA. In an Eighteenth century urban population, 6.4% of the individuals were affected with knee OA. In addition, osteoarthritis is more common in both the tibiofemoral and patellofemoral compartments in the modem osteological samples than in the historical skeletal samples. These results indicate that risk factors, linked to a modern lifestyle that predispose to knee OA, may have become more prominent from the nineteenth century onwards.

Comparison between Two Modern Skeletal Samples

Despite the lack of accurate weight information available for the entire Robert J. Terry Collection, it still seems reasonable to conclude that obesity was not as common in this collection than what is seen in more recent collections based on contemporary health statistics and reported data. According to radiological studies which have reported significant relationships between increased weight and the presence of knee OA, one would expect a higher degree of OA in the Bass collection than the Terry sample.

Osteoarthritis of the knee was prevalent in both samples, though the Bass collection displayed a higher degree of involvement than the Terry collection (p=.0000). The Terry collection exhibited a 45.7% frequency of OA in the knee, while the Bass collection sample exhibited 62.1% frequency. Interestingly, and in direct contrast to studies suggesting an association between increased weight and an increased prevalence of OA in the tibiofemoral joint (Rogers and Dieppe, 1994), the Bass collection had consistently higher frequencies of involvement in all three knee compartments. However, the differences between these two samples were not significant. Thus, while the Bass collection did have a significantly higher frequency of knee OA, the result cannot be attributed to more frequent involvement in any one specific knee compartment.

The Bass collection, with an expected higher proportion of overweight individuals, would also be expected to have elevated frequencies of bilateral knee OA. This is not the case, however. Although both collections presented bilateral knee OA more common than unilateral knee OA, the Terry collection actually has a higher frequency of bilateral OA than the Bass collection. A likely explanation for this occurrence is that bilateral OA in any joint can be attributable to a number of risk factors, including but not limited to weight. Similarly, increased severity failed to be associated with either collection. Again, the severity of OA is likely dependent upon a number of risk factors, and the failure of the Bass collection to hold a significant relationship with increased severity does not negate the possibility of an association between weight and severity of OA.

Sex and Age Differences

Clinical studies are mixed regarding sex differences and presence of knee osteoarthritis. Mannimen et al. (1996) and Tsau and Lui (1992) found that women were more likely to develop knee OA than men. Meanwhile Davis et al. (1989) found that sex differences in the presence of OA disappear when controlling for weight. This study found no significant association between sex and the presence of OA.

On the other hand, sex differences were found regarding the presence of bilateral OA and increased severity. In both instances, females demonstrated positive significant associations. Females were more likely to possess bilateral knee OA, as well as increased severity. Due to the absence of sex differences with respect to the presence of OA, these associations remain unexplained. Perhaps they are linked to various risk factors not recorded in this study.

The significant association found between age and the presence and severity of OA is not surprising. Osteoarthritis, or degenerative joint disease, implies the eventual breakdown of the joint with increasing age. For this analysis, the median age at death of all individuals was 58 years of age. All cases were then classified into 2 groups, above or below the median age. This sectioning point was favorable, as clinical studies demonstrate that visible bone changes are usually present after the age of 50 in modem populations (Steinbock, 1976). In clear comparison, there did appear to be a significant association between increased age and the presence of OA collectively, and in each compartment of the knee. Only the bilateral knee OA failed to be

significantly associated with increased age. Again, this finding may also be attributable to other risk factors of OA that were not considered in this study.

Specific Comparisons between Body Weight and Osteoarthritis

A significant association was apparent between increased weight and the presence of knee osteoarthritis in osteological remains. Skeletal samples where weight is known and reliable are uncommon, preventing any direct comparison with other skeletal series. However, these results compare with the reported findings of several radiological reports (Anderson and Felson, 1988; Davis et al., 1988; Gelber et al., 1999; Lau et al., 2000) that observe a positive relationship between obesity and the onset of osteoarthritis.

BMI was not found to be positively correlated with an increased presence of OA in any of the three knee compartments. This finding questions the relationship posited by Sharma et al. (2000) that obesity leads to increased varus malalignment and, consequently, medial TFJ. Rather, while obese people appear more likely to be afflicted with some degree of osteoarthritis, the onset of OA does not appear site specific.

Similarly, there was no significant association between BMI and bilateral knee osteoarthritis. Although Davis et al. (1989) report a significant association between obesity and bilateral osteoarthritis of the knee, the same study also reports that unilateral injury, given time to progress, also significantly correlates with bilateral knee OA. The known weight sample used in this study did present a higher frequency of bilateral knee OA for obese individuals, and the failure for

this association to be significant may be attributable to unilateral knee OA's tendency to progress into bilateral knee OA.

Finally, BMI also had a significant association with increased severity (p=.0146). Clinical studies also compare favorably with this finding. Cooper et al. (2000) found that obesity was the only risk factor that served as a significant predictor of both the presence and progression of radiographic knee osteoarthritis. The other risk factors examined (baseline knee pain, Heberden's nodes, previous knee injury, or regular sports participation) were only associated with prevalence. In the present study, BMI had a significant association with both the presence of knee OA, as well as the severity (progression).

Statistical Design

The randomization methods that accompanied the standard statistical techniques employed in this study were in near complete unison. In general, the difference in significance levels between the standard and randomization approaches used for comparisons of knee joint size and secular change were minimal and never resulted in contrasting conclusions regarding the null hypotheses. While the samples used in this study are admittedly and unavoidably non-random, fairly large sample sizes (when present) tend to create nearly equivalent results, as the randomization distribution converges to the tabulated distribution (Good, 2001: 113). To some extent, the similar results between the two approaches may be attributable to the relatively uniform distributions created by the resampling methods. Had exponentially distributed

data or log-normal data been employed in the analysis, the relationship between the standard and randomization techniques may not have been so strongly correlated (Ninness et al., 2002: 71).

The randomization method used in the chi-square analyses, on the other hand, did provide an occasional discrepancy with the conclusions of the standard statistics. In both instances, the standard approach, which led to a conclusion that rejected the null hypothesis of no association, was reversed. This can be attributed to any number of factors, including a relatively small N for portions of analysis (N reduced to 40 cases for some tests involving known weight and the presence of knee osteoarthritis), as well as a small number of randomized samples. Although there is ample theoretical and empirical evidence that standard tests provide good large-sample approximations to the corresponding randomization test, it is also clear that this is not the case when group sizes are small (Ludbrook and Dudley, 1998). An increased number of randomized samples greater than simply 300 samples may have also made the standard tests and randomization approaches even more comparable than at present. Nonetheless, both study samples' tendency to provide analogous results would lend credibility to the use of standard statistical models in the absence of any comparable randomization approach.

Chapter VII

Conclusion

The sample on which the present study is based is admittedly non-random. Like many anthropological datasets, the two skeletal series reported on here do not meet the standard of a truly random sample, where each and every element in the entire "relevant population" has an equal and independent opportunity of being selected for participation (Edgington, 1995). Nonetheless, the comparability of randomization tests with standard statistical results, coupled with findings similar to published results, provides confidence that the results of this study have not been diluted or weakened by the non-random nature of the samples employed.

Results from this study suggest that there has been some degree of secular change in knee joint size during the time period represented (from 1850 to 1975). However, this change is not consistent in direction or location between males and females. Males appear to have exhibited a higher degree of change

in a greater number of directions, while females have been more resistant to change. In neither sex did the degree of secular change appear to suggest an attempt to modify the actual size of the weight-bearing surfaces. Although speculative, the minor changes may be an attempt to increase the area of articulation and stability of the joint, rather than an actual increase or decrease in the overall size dimension.

Also, as noted earlier, modern populations are not only becoming heavier than earlier populations, but are also becoming increasingly sedentary. Presumably, then, increased weight is also increasing the joint loading, but decreased physical activity is also decreasing the frequency in which the joint must bear an individual's weight. These counteracting forces may be one reason for the observed stability of the knee joint size over the time period represented in this study.

Sex differences in the current sample yielded similar results to other published accounts of the amount of dimorphism in twentieth century populations. Also similar to other published accounts was the finding of sex-specific patterns of age related expansion and that, when present, males appear to have a higher degree of involvement.

Osteoarthritis of the knee was present in higher frequencies than that reported for historical samples. This is not surprising. Risk factors linked to modern lifestyles have reportedly increased the likelihood of developing OA. However, the frequency of knee OA was also higher than those reported in clinical and radiological studies, suggesting that the increase in OA, even since

the beginning of the nineteenth century is greater than previously expected. Not only has the prevalence of knee osteoarthritis increased over time, but severity has increased as well.

Many clinical studies report that females are more likely to develop knee OA. However, this study did not find an association between gender and the presence of osteoarthritis. There was a significant association, however, between being female and bilateral knee osteoarthritis, as well as increased severity. Obviously, a number of risk factors play a role in the presence and progression of OA, and any number of these could have affected the findings of this study.

The outcome of the specific comparison between increased BMI and osteoarthritis was expected. As BMI increased, the presence and severity of OA increased. Moreover, obese individuals are much more likely to develop OA than normal and even overweight individuals. Unexpectedly, there was no significant correlation between obesity and bilateral knee OA. Again, clinical studies suggest that unilateral knee injury-induced OA is associated with the eventual development of bilateral knee OA. Given that the samples utilized here are skeletal series, with a relatively high average age, bilateral knee OA should not be unexpected, even among normal weight subjects.

Historical records suggest that tibiofemoral joint disease was relatively uncommon until recent times. Modem-day risk factors are believed to be the primary cause for this development. While both collections exhibited a high frequency of medial and lateral tibiofemoral joint disease, no association was

found between obesity and TFJ in either compartment. If tibiofemoral joint disease is truly a modern phenomenon, results from this study do not indicate that it is attributable to increased weight in modern populations.

Stini (1995) suggests that modern lifestyles are exposing the biological cost of certain human adaptations. As a specific example, Stini argues that due to increased life expectancies a once beneficial adaptation, one to avoid a build up of high concentrations of calcium in the body, now eventually leads to osteoporosis. Assuming that the weight-bearing articular surfaces of the knee joint are highly adapted to support even modern body mass values, these increased weight values, when coupled with increased life expectancies, may be generating the widespread breakdown of the knee joint and high incidence of knee OA.

Implications for Future Research

The statistical methods used in this study were often limited by the absence of appropriate permutation techniques required for non-random samples. At one point, randomization tests were not popularly employed because their extensive computations required more processing speed than the existing technology could provide, but this has changed dramatically in the last few years. Now, technology is available, but appropriate algorithms are lacking.

However, due to wide-spread use of non random samples in all fields of research and the availability of computer resources, this is likely to change rapidly. When available, permutation and/or randomization methods are

beneficial for achieving reliable statistical results without violating the assumptions required of random samples.

A major limitation of this thesis may be its own timing. As articular dimensions remain fairly conservative after skeletal maturation, the effect of increased weight may only be noticeable in the articular dimensions of individuals considered overweight and obese during childhood and adolescence. Although the average weight of modern-day populations has increased over the last 150 years, it is the last few decades which have seen the most substantial weight gains. Only during this time has childhood obesity become prevalent and a dominant medical concern as the risk of becoming obese is greatest among children who have obese parents (Dietz, 1983). Unfortunately, few individuals in the Bass collection, or any other modern skeletal series, are representative of the last three decades. Thus, it may be some time, as much as one generation, before the effect of increased weight prior to skeletal maturity and its potential impact on the secular change of knee joint size can be determined.

The direct impact of physical activity on joint surface area was not considered in this study. Appropriate information regarding the activity levels of individuals housed in the Terry and Bass collections is not available. A study involving two populations of comparable weight and stature but contrasting physical activity levels might serve to illuminate the impact our increasingly sedentary lifestyle has had on articular dimensions.

In addition, the presence and severity of osteoarthritis in other weight bearing joints, specifically the hip and ankle, may also be an important area of

future research. Increased weight should predictably also lead to the increased presence of OA at these weight-bearing joints, but clinical reports do not consistently report such a relationship. An osteological examination of these articular surfaces, as well as increased understanding of the biomechanics of joint loading, would be beneficial in determining a correlation between increased weight in modern populations and the increase in the prevalence of osteoarthritis.

One thing is certain. Although forensic and anthropometric studies have often focused, albeit unsuccessfully, on weight in an effort to provide an accurate method for calculating human body weight based on skeletal elements (Pierce, Jr., 1999; Ruff et al., 1991; Trotter, 1954), the known secular increase in weight still represents a vitally important area of research. This data serves to illuminate just one way in which obesity, now reaching epidemic status in numerous populations, is impacting the human skeleton and increasing stress on joints in relatively new and novel ways.

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Appendices

Appendix A

Weight Information from Known Weight Subset of the Bass Collection

ID Number	Sex	Stature(cm)	Weight (lbs)	Weight(Kg)	BMI
17_01	1	195	369	167.73	44.11
39_01	2	158	200	90.91	36.42
34_93	1	182.88	225	102.27	30.58
37_03	1	165	180	81.82	30.05
9_01	1	185.4	225	102.27	29.75
1_95	1	180	210	95.45	29.46
24_00	2	124.5	100	45.45	29.33
30_93	1	182.88	210	95.45	28.54
19_92	1	180.34	197.2	89.64	27.56
31_99	1	183	196.5	89.32	26.67
39_93	1	173	173	78.64	26.27
4_90	1	171.45	166.2	75.55	25.7
31_02	1	185	192	87.27	25.5
21_99	1	174	167	75.91	25.07
7_97	2	172.72	161	73.18	24.53
4_93	1	180.34	175	79.55	24.46
8_98	1	171.5	151	68.64	23.34
3_93	1	160.02	131	59.55	23.25
9_00	2	169.5	145.5	66.14	23.02
14_90	1	175.26	153.2	69.64	22.67
1_00	1	182.9	160	72.73	21.74
7_87	1	170.18	138.2	62.82	21.69
23_00	2	160	120	54.55	21.31
14_91	1	172.72	139	63.18	21.18
16_00	1	175.3	140	63.64	20.71
14_87	1	180.34	144.6	65.73	20.21
6_95	2	165.1	115	52.27	19.18
11_89	1	185.42	139	63.18	18.38
21_00	1	172.7	117	53.18	17.83
8_87	1	190.5	141.6	64.36	17.74
1_93	2	157.48	96	43.64	17.6
26_99	2	165	98	44.55	16.36
7_01	2	160	252	114.55	44.74
22_01	1	182.9	318	144.55	43.21
14_93	1	175.26	284	129.09	42.03
6_91	1	180.34	300	136.36	41.93
5_87	2	168.91	260.8	118.55	41.55
3_90	1	182.88	294.8	134	40.07
13_01	1	182.9	280	127.27	38.05

ID Number	Sex	Stature(cm)	Weight (lbs)	Weight(Kg)	BMI
19_00	2	167.6	220	100	35.6
2_92	2	157.48	200	90.91	36.66
16_91	1	165.1	201	91.36	33.52
29_93	1	177.8	227	103.18	32.64
18_01	1	175.2	220	100	32.58
10_92	1	182.88	226	102.73	30.72
22_91	1	182.88	225	102.27	30.58
5_83	1	184	225	102.27	30.21
01_01	1	177.8	210	95.45	30.19
2_89	1	182.88	220	100	29.9
10_87	1	162.56	163	74.09	28.04
5_93	1	174	181.8	82.64	27.29
22_90	1	175.26	183.4	83.36	27.14
42_02	1	176	182	82.73	26.71
16_92	1	182.88	190	86.36	25.82
38_01	1	174.5	169	76.82	25.23
24_99	1	177.8	175	79.55	25.16
1_83	2	167.6	150	68.18	24.27
10_95	1	179.1	171	77.73	24.23
3_87	1	182.88	176.6	80.27	24
3_92	1	170.18	152	69.09	23.86
28_03	1	175	160	72.73	23.75
17_99	1	162.56	138	62.73	23.74
21_01	1	177.8	163	74.09	23.44
13_91	1	185.42	174.2	79.18	23.03
27_93	1	185.5	166.2	75.55	21.95
8_94	1	177.8	148.6	67.55	21.37
7_94	1	175.26	137.2	62.36	20.3
38_93	1	179	135	61.36	19.15
22_00	1	165.1	114	51.82	19.01
03_02	1	164	110	50	18.59
12_91	1	175.26	112	50.91	16.57
32_93	1	176.53	110	50	16.04

Sex: Male= 1 ; Female = 2

Appendix B

Frequency Tables and Chi-Square Test Results for Comparing Knee Osteoarthritis Between The Terry and Bass Collections

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
OA	Absent	108 (54.27)	88 (37.93)	11.535	.0000
	Present	91 (45.73)	144 (62.07)		

Statistically significant at p<.05

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
Medial TFJ	Absent	4 (4.40)	13 (9.03)	1.783	.2075
	Present	87 (95.60)	131 (90.97)		

Statistically significant at p<.05

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
Lateral TFJ	Absent	24 (26.37)	44 (30.56)	.474	.5557
	Present	67 (73.63)	100 (69.44)		

Statistically significant at p<.05

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
PFJ	Absent	47 (51.65)	62 (43.06)	1.656	.2275
	Present	44 (48.35)	82 (56.94)		

Statistically significant at p<.05

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
Unilateral/ Bilateral	Unilateral	25 (27.47)	46 (31.94)	.529	.5599
	Bilateral	66 (72.53)	98 (68.06)		

Statistically significant at p<.05

		Collection		X^2	p-value (standard)
		Terry (%)	Bass (%)		
Severity	Mild	73 (80.22)	112 (77.78)	.451	.8321
	Mod.	12 (13.19)	19 (13.19)		
	Severe	6 (6.59)	13 (9.03)		

Statistically significant at p<.05

Appendix C

Frequency Tables and Chi-Square Test Results for Comparing Knee Osteoarthritis Between Males and Females

		Sex		X^2	p-value (standard)
		Males (%)	Females(%)		
OA	Absent	129 (44.33)	67 (47.86)	0.474	.5358
	Present	162 (55.67)	73 (52.14)		

Statistically significant at p<.05

		Sex		X^2	p-value (standard)
		Males (%)	Females (%)		
MTFJ	Absent	12 (7.41)	88 (6.85)	0.023	1.000
	Present	150 (92.59)	68 (93.15)		

Statistically significant at p<.05

		Sex		X^2	p-value (standard)
		Males(%)	Females(%)		
LTFJ	Absent	50 (30.86)	18 (24.66)	0.943	.3554
	Present	112 (69.14)	55 (75.34)		

Statistically significant at p<.05

		Sex		X^2	p-value (standard)
		Males (%)	Females(%)		
PFJ	Absent	79 (48.77)	30 (41.10)	1.190	.3229
	Present	83 (51.23)	43 (58.90)		

Statistically significant at p<.05

		Sex		X^2	p-value (standard)
		Males(%)	Females(%)		
Unilateral/ Bilateral	Unilateral	56 (34.57)	15 (20.55)	4.691	.0324
	Bilateral	106 (65.43)	58 (79.45)		

Statistically significant at p<.05

		Sex		X^2	p-value (standard)
		Males (%)	Females (%)		
Severity	Mild	137 (84.57)	48 (65.75)	11.527	.0028
	Mod.	14 (8.64)	17 (23.29)		
	Severe	11 (6.79)	8 (10.96)		

Statistically significant at p<.05

Appendix D

Frequency Tables and Chi-Square Test Results for Comparing Knee Osteoarthritis Between Individuals 58 Years Old or Younger and Individuals Over 58 Years of Age

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
OA	Absent	127 (57.47)	69 (32.86)	26.230	.0000
	Present	94 (42.53)	141 (67.14)		

Statistically significant at p<.05

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
Medial TFJ	Absent	11 (64.71)	83 (38.07)	4.661	.0397
	Present	6 (35.29)	135 (61.93)		

Statistically significant at p<.05

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
Lateral TFJ	Absent	38 (40.43)	30 (21.28)	10.057	.0020
	Present	56 (59.57)	111 (78.72)		

Statistically significant at p<.05

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
PFJ	Absent	58 (61.70)	51 (36.17)	14.784	.0002
	Present	36 (38.30)	90 (63.83)		

Statistically significant at p<.05

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
Unilateral/ Bilateral	Unilat.	34 (36.17)	37 (26.24)	2.637	.1127
	Bilat.	60 (63.83)	104 (73.76)		

Statistically significant at p<.05

		Age		X^2	p-value (standard)
		≥ 58 (%)	< 58 (%)		
Severity	Mild	86 (91.49)	99 (70.21)	16.626	.0003
	Mod.	6 (6.38)	25 (17.73)		
	Severe	2 (2.13)	17 (12.06)		

Statistically significant at p<.05

Appendix E

Frequency Tables and Chi-Square Test Results for Comparing Knee Osteoarthritis and Body Mass Index (BMI)

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
OA	Present	16 (47.06)	8 (44.44)	16 (80.00)	6.734	.0380
	Absent	18 (52.94)	10 (55.56)	4 (20.00)		

Statistically significant at p<.05

		BMI		X^2	p-value (standard)
		Less than 25.00	25.00 and above		
OA	Present	16 (47.06	24 (63.16)	1.884	.2354
	Absent	18 (52.94)	14 (36.84)		

Statistically significant at p<.05

		BMI		X^2	p-value (standard)
		Less than 30.00	30.00 and above		
OA	Present	24 (46.15)	16 (80.00)	6.702	.0160
	Absent	28 (53.85)	4 (20.00)		

Statistically significant at p<.05

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
MTFJ	Present	14 (87.50)	7 (87.50)	15 (93.75)	.4167	.8119
	Absent	2 (12.50)	1 (12.50)	1 (6.25)		

Statistically significant at p<.05

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
LTFJ	Present	10 (62.50)	5 (62.50)	14 (87.50)	3.010	.2714
	Absent	6 (37.50)	3 (37.50)	2 (12.50)		

Statistically significant at p<.05

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
PFJ	Present	5 (31.25)	5 (62.50)	10 (62.50)	3.750	.1928
	Absent	11 (68.75)	3 (37.50)	6 (37.50)		

Statistically significant at p<.05

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
Uni/ Bi.	Uni.	7 (43.75)	2 (25.00)	3 (18.75)	2.500	.3673
	Bi.	9 (56.25)	6 (75.00)	13 (81.25)		

Statistically significant at p<.05

		BMI			X^2	p-value (standard)
		Normal (%)	Overweight(%)	Obese(%)		
Sev.	Mild	15 (93.75)	8 (100.00)	9 (56.25)	11.406	.0146
	Mod.	0 (0.00)	0 (0.00)	6 (37.50)		
	Severe	1 (6.25)	0 (0.00)	1 (6.25)		

Statistically significant at p<.05

		BMI		X^2	p-value (standard)
		Less than 25.00	25.00 and above		
Severity	Mild	15 (93.75)	17 (70.83)	4.714	.0799
	Mod.	0 (0.00)	6 (25.00)		
	Severe	1 (6.25)	1 (4.17)		

Statistically significant at p<.05

		BMI		X^2	p-value (standard)
		Less than 30.00	30.00 and above		
Severe	Mild	23 (95.83)	9 (56.25)	10.964	.0021
	Mod.	0 (0)	6 (37.50)		
	Severe	1 (4.17)	1 (6.25)		

Statistically significant at p<.05

Appendix F

Correlations between BMI and Knee Joint Size Variables

Variable	Male N=59	Female N=13
FLCW	0.236	-0.209
FLCL	0.257	-0.289
FLCL2	0.023	-0.068
FMCW	0.122	0.114
FMCL	0.112	-0.358
FMCL2	0.159	-0.179
FBL	0.157	0.495
TLW	0.184	-0.144
TLL	0.11	-0.462
TMW	-0.017	0.191
TML	0.012	-0.114
TPW	0.158	-0.159
FLCA	0.311	-0.354
FMCA	0.141	-0.154
TFCA	0.256	-0.262
TLCA	0.173	-0.405
TMCA	-0.008	0.034
TTCA	0.095	-0.129
BMI	1	1

*statistically significant at $p<.05$

Vita

Jeffrey Reed Huber was born in Sarasota, Fl on July 29, 1979 and graduated from Pine View High School in 1997. Mr. Huber graduated from the University of Florida in 2001 with a Bachelor of Arts in Anthropology and Criminology. The following fall he left his home state for the University of Tennessee to pursue graduate studies. Three years later, Mr. Huber will have completed his Master's degree in Anthropology as well as attained a minor in the field of Statistics. After a short break, he will figure out how to pay off his growing debt.

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