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Osteoarthritis and body mass

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Abstract

Osteoarthritis is the second most common pathology found in anthropological collections. Although a great deal is known about osteoarthritis, it is not yet known whether in skeletal populations there is a correlation between osteoarthritis and body mass. In this study, lower limb and spinal osteoarthritis scores were taken to determine whether body mass and femoral length correlate with osteoarthritis on weight bearing joints. Osteoarthritis was measured using a four-point ordinal scale on a sample of 114 adult prehistoric Californian Amerinds. Body mass was calculated from femoral head breadth; femoral length was measured using standard procedures; and age and sex were determined through standard osteological procedures. Using Spearman correlations, body mass and femoral length did not correlate significantly with any of the osteoarthritis variables. Age correlated significantly with nearly all of the osteoarthritis variables (hip, $r = 0.507$; knee, $r = 0.528$; cervical, $r = 0.513$; thoracic, $r = 0.647$; lumbar, $r = 0.507$, P-values < 0.001); and body mass and femoral length correlated with sex (r-values $= 0.835$ and 0.654, P-values < 0.001). With age and sex controls, body mass negatively correlated with the hip osteoarthritis variable ($r = -0.202$, $P < 0.05$), but not with any of the other osteoarthritis variables. Results concur with previous findings in the anthropological literature and highlight complexities of osteoarthritis etiology.
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Researchers define osteoarthritis in many ways and any simple definition is deceptive of the complexity of osteoarthritis pathogenesis and etiology. One definition anthropologists commonly use defines osteoarthritis as "a degenerative disease of the cartilage of joints" [18, p. 1132]. Osteologists detect osteoarthritis on joint surfaces by its characteristic polishing, bony spicules, and erosion [4]. These skeletal changes may reflect more severe osteoarthritis involvement than in clinical diagnosis [12]. Although osteoarthritis is difficult to define, a great deal is known about osteoarthritis, such as osteoarthritis frequency and severity increases with age, genes play a role in osteoarthritis severity, and strenuous activity started at an early age seems to increase osteoarthritis [7,9,10,12,29, and references within these work]. Yet, we do not know whether in skeletal populations there is a correlation between osteoarthritis and body mass and femoral length. Anthropologists recently have shown concern over the use of musculoskeletal stress marker and cross-sectional geometry data not standardized for body mass [33,34,37]. The same standardization issue may be warranted for osteoarthritis studies, which this study addresses.

Many anthropologists working with osteoarthritis use it to reconstruct past activity patterns [6,19,26,27,32,36]. These researchers emphasize the role of repetitive mechanical loading caused by activities as the second main factor leading to osteoarthritis; anthropologists readily acknowledge that age seems to be the main factor in the etiology of osteoarthritis. If the cause of osteoarthritis is repetitive mechanical loading, then the logical conclusion is that severe osteoarthritis on specific joints results from continued use of specific muscles and joints in daily and repetitive tasks. This approach has led some researchers to consider osteoarthritis as a good activity pattern indicator. Questions regarding whether males and females differed in activity patterns, whether groups differed in specific activities related to food production and trade, what effects shifts in subsistence patterns had on past populations, and numerous others have been tentatively answered using osteoarthritis

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[6,15,17,19,26,27,32,36]. On the other hand, many anthropologists suggest caution when trying to reconstruct specific activities; that is, they recognize the complexity of osteoarthritis formation and mechanical loading causes [2,3,10–12].

The best-established findings in the anthropological osteoarthritis literature relate to its association with age. Anthropologists using osteoarthritis to reconstruct past lifestyles frequently consider age differences to enable more accurate reconstructions [12,13,15,20,31], but controls beyond age, such as for body mass, may be necessary as well. The lack of body size controls could lead to reconstruction errors, such as when looking at sex differences. Researchers often attribute sex differences in osteoarthritis to activity pattern differences due to division of labor [13,14,20,26,30–32]. Sex differences in osteoarthritis alternatively may be due to body size differences, especially considering the frequency of sex differences in body size [11]. If there is a correlation between osteoarthritis and body mass, then anthropologists who control for body mass will create more accurate lifestyle reconstructions than those who fail to control for body mass.

Anthropologists have no precise way of determining an individual's weight; rather they use proxies for body mass that are dependent on skeletal element size and most likely reflect a "normal" weight [1]. Ruff [23] discusses the difficulties in reconstructing body mass in skeletal populations, particularly addressing issues of variability between different populations. Thus, while it may be impossible to calculate an accurate body mass from skeletal elements, it is essential to get a measure of how body mass affects osteoarthritis before reconstructing past lifestyles.

In this study, I explore whether body mass and size, as measured on skeletal elements, affect osteoarthritis as it affects musculoskeletal stress markers and cross-sectional geometries [22–25,33–35,37]. The prediction is that osteoarthritis will be more severe in individuals with greater body sizes, particularly since this study looks at weight bearing joints. Results will reveal effects on osteoarthritis anthropologists previously overlooked. The results reported here will shed light on the etiology of osteoarthritis to improve the use of osteoarthritis in anthropological research, especially with regard to reconstructing past lifestyles.

1. Materials and methods

1.1. Sample

I examined a skeletal sample of 114 adult individuals (58 males; 56 females) ranging from 19 to 50 years of age. The skeletal remains come from a California site (CA-Ala-329) located on the southeastern side of the San Francisco Bay dating from 500 AD to 1500 AD (which is pre-European contact) housed at San José State University Anthropological Collection [10]. The sample contains remains from several hunting–gathering villages, but the cultural group was most likely cohesive and probably shared genetic relatedness [10]. Due to rich environmental resources, it is unlikely that sex or age determined differences in nutritional resources. Interpersonal aggression was common. I excluded individuals with observable injuries to the bones to avoid the possibility of secondary arthritis development.

Jurmain [10] previously aged and sexed individuals according to standard osteological procedures. None of the procedures used to sex or age individuals were based on the size of skeletal elements [10]. Jurmain [10] initially recorded the ages in 5–10 year ranges. For the purposes of this study, I used the middle of the range for each individual's age. I excluded individuals if they were not sexed or aged, lacked lower limb bones, or lacked vertebral bones. The preservation of this collection is excellent; nearly all individuals have a complete set of lower limbs and most of their vertebral column.

1.2. Methods

The terminology of degenerative changes on skeletal remains has led to confusion in anthropology. Researchers often describe osteoarthritis as degenerative changes in synovial joints only while they term vertebral degenerative changes as vertebral osteophytosis. To simplify matters and because most osteologists agree the etiology of the two conditions are similar, I refer to both vertebral and synovial joint degenerative changes as osteoarthritis.

Anthropologists measure osteoarthritis in various ways and there is no consensus on which method is best [12]. There are precautions one can take to improve the utility of any chosen method. As previously mentioned, I minimized the possibility of including individuals with secondary osteoarthritis by excluding individuals with visual signs of trauma or disease. I also looked for patterns of involvement; for example, rheumatoid arthritis greatly affects finger and toe joints. I, therefore, examined individuals' hands and feet to determine whether they had rheumatoid arthritis. I excluded any problematic individuals. Furthermore, Jurmain [12] pointed out that replicating osteoarthritis measures is often difficult and, consequently, suggested using simple methodologies.

Individual joint surfaces were rated using a modified version of Jurmain's [10] ordinal scale. Scoring was based on evidence of lipping, pitting, and eburnation on the evaluated surfaces. I measured osteoarthritis on the lower limb joints, which included femoral heads and acetabulums for hips; femoral condyles, tibial plateaus, and patellas for knees; and distal tibias for ankles. Each element was scored separately, but each joint (hip, knee, ankle) and each vertebral section (cervical, thoracic, lumbar) were given a composite score by adding the separate scores together and dividing by the number of elements available (e.g., hip osteoarthritis variable = (left femoral head + right femoral head + left acetabulum + right acetabulum)/4). Table 1 summarizes the exact scoring system utilized on the sample along with information on the amount of aggregation utilized and the surfaces examined.

Body mass was based on a femoral head breadth calculation. In a recent article, Auerbach and Ruff [1] analyzed body mass formulae for inaccuracies and biases. Formulae

Table 1
Ordinal scaling system of osteoarthritis modified from Jurmain [10]

Vertebral osteoarthritis (taken on both upper and lower sides of the vertebral bodies)
0 None/Slight
1 Moderate (raised edge)
2 Severe (osteophyte remodeled and made concave with original surface)
3 Ankylosis

Lower limb osteoarthritis
0 None/Slight
1 Moderate (small osteophyte and/or pitting <10% of articular surface)
2 Severe (very large osteophyte, remodeled and concave with original surface), and/or pitting >10% of articular surface or any eburnation
3 Ankylosis

Additional information
*Half scores (e.g., 0.5, 1.5, 2.5) were used when in between scores seemed most appropriate.
*Lower limb joints measured included: hip = femoral head, acetabulum; knee = femoral condyles, tibial plateau, patella; ankle = distal tibia.
*Each element was scored separately, but each joint (hip, knee, ankle) and each vertebral section (cervical, thoracic, lumbar) were given a composite score by adding the separate scores together and dividing by the number of elements available (e.g., hip osteoarthritis variable = (left femoral head + right femoral head + left acetabulum + right acetabulum)/4).

using femoral head breadths had high correlations with other formulae that employed stature and bi-iliac breadth [1]. Since bi-iliac breadth is not easy to obtain in archaeological samples, I researched femoral head breadth formulae and chose an appropriate formula. Femoral head breadths were easy to take, available in the sample, and reproducible. Moreover, mechanical methods employing articular surface dimensions have the advantage of providing a body mass independent of activity levels or muscular loadings [1].

Grine and colleagues' [8] femoral head breadth formula for body mass is useful in samples of large body sizes [1]. The sample explored in this present study (Ca-Ala-329) consists of large bodied males and females [21]. Additionally, Grine et al. [8] based their formula on a diverse sample set, including Native American remains, whereas other formulae employing femoral head breadth did not use Native American samples when initially created [1]. There is a chance of overestimating body mass in small individuals using Grine and coworkers' [8] formula, but for the other formulae published there is a chance of underestimating body mass for large individuals [1]. While Grine et al.'s [8] formula is most appropriate for this study, the sex difference is quite large (16%) compared to other studies that use this formula [1,8]. The large sex difference may be due to the large sample size or due to the sample itself.

Body mass was calculated in kilograms by measuring femoral head anteroposterior breadth in millimeters using a digital sliding caliper. I measured both left and right femoral head breadths whenever possible. Then, I took the average of left and right femoral head breadths and put that average into Grine and colleagues' [8] non-sex specific formula: body mass (kg) $= 2.268 \times$ femoral head breadth $- 36.5$.

The second body size variable was maximum femoral length [4]. Femoral length correlates highly with stature. Activity patterns and musculature, moreover, do not affect femoral length. In the current sample, osteoarthritis traits, such as lipping, did not affect femoral length, whereas tibial length was highly affected if the tibial plateau experienced osteoarthritis lipping. Femoral lengths were easily taken and available in all individuals.

To allay concerns over averaging left and right measurements, I carried out Pearson correlations for the left and right bones. Left and right femoral lengths correlated at 0.978 ($P < 0.001$). Femoral head breadths correlated at 0.961 ($P < 0.001$). With such a high correlations, I felt justified in combining left and right sides for the purpose of this study.

Due to the nature of skeletal material, missing data are inevitable. When data were missing, I used the available side for body mass and femoral length calculations. For the osteoarthritis variables, missing surfaces resulted in a lower number of surfaces in the overall joint variable. As mentioned earlier, the skeletal preservation is excellent; less than 4% of data were missing.

1.3. Statistical analysis

The data were analyzed using the statistical software program SPSS (Version 11.5). I tested the data for violations of assumptions of parametric tests following Lovejoy [16]. The aggregate measures met all the assumptions required to run parametric tests, but some of the relationships (before age and sex controls) between the variables deviated slightly from a linear relationship. For each variable, I calculated means and standard deviations. Body mass, femoral length, age, and sex were correlated using two-tailed Spearman tests (which are ideal for ordinal data) with hip osteoarthritis, knee osteoarthritis, ankle osteoarthritis, cervical osteoarthritis, thoracic osteoarthritis, and lumbar osteoarthritis. Then, partial Pearson correlations controlling for age and sex were run between body mass and femoral length and the various osteoarthritis variables. Critical alpha levels were set at 0.05 and non-significant findings were marked with n.s.

2. Results

Table 2 presents the means, standard deviations, and sample sizes for the body mass, femoral length, age, and the various osteoarthritis variables analyzed in this study. Table 3 presents the Spearman correlations for the variables. Body mass correlates significantly with sex ($r = 0.835$, $P < 0.001$) and femoral length ($r = 0.720$, $P < 0.001$), but not with any of the other variables. Femoral length correlates with sex ($r = 0.654$, $P < 0.001$), but not with any osteoarthritis variables. Age, in contrast, correlates with all osteoarthritis variables (hip, $r = 0.507$; knee, $r = 0.528$; cervical, $r = 0.513$; thoracic, $r = 0.647$; lumbar, $r = 0.835$ P-values < 0.001), except for the ankle ($r = 0.166$, n.s.). Age does not correlate significantly with body mass, femoral length, or sex (r-values $= 0.037$, 0.033, 0.016, respectively, n.s.). The osteoarthritis variables correlate significantly with each other.

Since age correlates with the osteoarthritis variables and sex correlates with body mass and femoral length, I carried out partial Pearson correlations to re-examine correlations

Table 2
Means, SDs, and sample sizes for the body mass, femoral length, age, hip, knee, ankle, cervical, thoracic, and lumbar osteoarthritis for males ($n = 58$) and females ($n = 56$)

Property	Sex	Mean	SD
Body mass (kg)	Males	66.71	4.58
	Females	55.49	3.18
Femoral length (mm)	Males	440.25	19.30
	Females	410.77	20.16
Age (years)	Males	35.12	6.66
	Females	34.85	7.49
Osteoarthritis scores (presented in the ordinal scale averages)			
Hip (minimum = 0; maximum = 1.74)	Males	0.3421	0.45
	Females	0.3505	0.41
Knee (minimum = 0; maximum = 2.70)	Males	0.4293	0.61
	Females	0.6432	0.64
Ankle (minimum = 0; maximum = 1.00)	Males	0.0833	0.26
	Females	0.0000	0.00
Cervical (minimum = 0; maximum = 1.79)	Males	0.3358	0.44
	Females	0.2657	0.35
Thoracic (minimum = 0; maximum = 1.58)	Males	0.2073	0.28
	Females	0.1770	0.18
Lumbar (minimum = 0; maximum = 2.00)	Males	0.5209	0.44
	Females	0.4493	0.40

after controlling for age and sex (Table 4). When age and sex are controlled for, body mass correlates significantly with hip osteoarthritis ($r = -0.202$, $P < 0.05$) and femoral length ($r = 0.430$, $P < 0.001$), but not with any of the other variables. Femoral length, conversely, does not correlate with any osteoarthritis variables (r-values range from -0.132 to -0.028, n.s.). The osteoarthritis variables continue to correlate significantly with each other.

3. Discussion

This study concurs with other studies that show a strong correlation between age and osteoarthritis [10,11,13,15,20,31]. Older individuals had more severe osteoarthritis than did younger individuals. Some anthropologists hypothesize that older individuals have more severe osteoarthritis than do younger individuals because they have experienced more stress on their joints over a lifetime of activities. Age differences also could relate to changes in bone structure due to the slowing down of bone remodeling, hormonal changes, or a variety of other biological reasons. Anthropologists need to investigate the causes of greater osteoarthritis in older individuals more thoroughly.

Sex highly correlated with body mass and femoral length; therefore, one must control for sex when determining whether body mass affects osteoarthritis. When controlling for age and sex, body mass significantly correlated with hip osteoarthritis and the direction was negative. In this study, individuals with lower body masses had greater hip osteoarthritis than did individuals with higher body masses. One could hypothesize that smaller joints have less surface area to distribute the stresses of activity and weight (either external loads or body weight loads). Thus, repetitive stresses on smaller joints may be more taxing than they are on larger joints, which could result in smaller individuals developing more osteoarthritis. With this said the effect of body mass seems minor. The effect of body mass on osteoarthritis in the present sample seems to be small, apparently only contributing 4% of the phenotypic variation on one joint. One calculates percentage of phenotypic variation by turning correlations into percentage of effect by squaring the correlation [5].

Although no size variables were used to sex individuals, high correlations between body mass, femoral length, and sex existed. Even with partial Pearson correlations controlling for sex and age, researchers still need to address issues regarding sex and body size confounds in regard to osteoarthritis and lifestyle reconstructions. Body size and mass may be too interrelated with sex to tease apart the subtleties that would allow anthropologists to determine the true etiologies of osteoarthritis using skeletal samples. If anthropologists cannot resolve the sex and size confound, then researchers may be drawing conclusions based on sex that are truly size issues or visa versa. Osteologists must be cautious when relating sex differences in osteoarthritis to activity. They ought to examine body mass and sex to determine whether there are any confounds with body mass, sex, and osteoarthritis in their samples. Osteologists should consider clinical literature discussing sex differences in osteoarthritis. For example, in clinical studies females have more hip osteoarthritis, which may be due to

Table 3
Spearman correlation coefficient table of body mass (BM), femoral length (Length), age, sex, and osteoarthritis variables (Hip, Knee, Ankle, Cervical, Thoracic, and Lumbar)

	BM	Length	Age	Sex	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
BM	1.000	0.720**	0.037	0.835**	−0.111	0.014	0.173	0.105	−0.004	0.098
Length	0.720**	1.000	0.033	0.654**	−0.058	−0.015	0.134	0.037	−0.046	0.019
Age	0.037	0.033	1.000	0.016	0.507**	0.528**	0.166	0.513**	0.647**	0.646**
Sex	0.835**	0.654**	0.016	1.000	0.036	0.025	−0.235*	−0.109	0.002	−0.073
Hip	−0.111	−0.058	0.507**	0.036	1.000	0.633**	0.125	0.557**	0.671**	0.550**
Knee	0.014	−0.015	0.528**	0.025	0.633**	1.000	0.278**	0.552**	0.667**	0.623**
Ankle	0.173	0.134	0.166	−0.235*	0.125	0.278**	1.000	0.262**	0.252**	0.222*
Cervical	0.105	0.037	0.513**	−0.109	0.557**	0.552**	0.262**	1.000	0.641**	0.616**
Thoracic	−0.004	−0.046	0.647**	0.002	0.671**	0.667**	0.252**	0.641**	1.000	0.816**
Lumbar	0.098	0.019	0.646**	−0.073	0.550**	0.623**	0.222*	0.616**	0.816**	1.000

* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

Table 4
Partial Pearson correlation coefficient table controlling for age and sex of body mass (BM), femoral length (Length) and osteoarthritis variables (Hip, Knee, Ankle, Cervical, Thoracic, and Lumbar)

	BM	Length	Hip	Knee	Ankle	Cervical	Thoracic	Lumbar
BM	1.000	0.430**	−0.202*	−0.013	−0.043	−0.049	−0.068	−0.044
Length	0.430**	1.000	−0.028	−0.067	−0.057	−0.132	−0.096	−0.109
Hip	−0.202*	−0.028	1.000	0.387**	0.052	0.372**	0.378**	0.232**
Knee	−0.013	−0.067	0.387**	1.000	0.267**	0.531**	0.501**	0.468**
Ankle	−0.043	−0.057	0.052	0.267**	1.000	0.261**	0.202**	0.146
Cervical	−0.049	−0.132	0.372**	0.531**	0.261**	1.000	0.609**	0.520**
Thoracic	−0.068	−0.096	0.378**	0.501**	0.202**	0.609**	1.000	0.673**
Lumbar	−0.044	−0.109	0.232*	0.468**	0.146	0.520**	0.673**	1.000

* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

genes, hormones, or body size [7,9,28]. Countless sex differences, including some size differences and osteoarthritis patterns, are biological in nature and can make deciphering activity patterns difficult [7,9,11,12,28,29].

Individuals who had osteoarthritis seemed to have it on most of the joints measured. There were high correlations between joints. One can explain the between joint correlations in several ways that are not mutually exclusive. First, very active individuals likely perform many activities that would affect all the weight bearing joints, such as carrying heavy loads over long distances. Second, it could be an age factor and, thereby, osteoarthritis would affect many of the joints in older individuals. Third, an individual may have a genetic propensity toward osteoarthritis involving genes directly, hormones, or a combination of both [7,9,28].

4. Conclusions

Osteoarthritis correlated with age in this prehistoric Californian Amerind sample, which is to be expected. Older individuals had more osteoarthritis than did younger individuals. Furthermore, sex correlated with body mass and femoral length. Males were heavier and taller than females. When controlling for age and sex, the correlation between body mass and osteoarthritis was absent, except in the hip joint where it was significant but weak. Individuals with lower body masses had greater hip osteoarthritis scores than did individuals with higher body masses. Anthropologists should take note of the body mass correlation, but it does not seem to be a large factor in osteoarthritis etiology in archaeological skeletal samples. This correlation with size was only in body mass and not in femoral length. Individuals had high inter-joint osteoarthritis correlations.

Future studies using osteoarthritis to reconstruct past lifestyles should continue to control for age. Anthropologists do not need to control for body mass in osteoarthritis studies, except for those containing hip data. Researchers, nonetheless, may want to consider body mass and sex confounds to determine how they relate to osteoarthritis before reconstructing activity patterns. Finally, anthropologists need to examine more extensively the causes of multi-joint osteoarthritis in individuals.

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