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UNDERSTANDING OSTEOARTHRITIS PATTERNS: AN EXAMINATION OF AGGREGATE OSTEOARTHRITIS

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Abstract.

In order to understand some of the sex differences in osteoarthritis, it is pertinent to examine the influence body size may have on arthritis. As mentioned earlier, the medical literature has reported a positive correlation between osteoarthritis and body weight, especially obesity (Tepper & al., 1993). Anthropologists, however, have not fully examined whether there may be a correlation between body size and osteoarthritis scores. This author conducted two studies that found a positive correlation with body size and muscle marker scores (Weiss, 2003; 2004) and, for this reason and others, thinks that there may be a confound with body size and osteoarthritis scores as well. Anthropologists Zumwalt & colleagues (2000) examined lower and upper limb bones from non-human primates and found that muscle markers correlated with body weight and did not vary with locomotor type, raising the question of whether research on human remains should also take body size into account when using muscle markers and other bone characteristics, such as osteoarthritis, to reconstruct activity patterns. Human upper limbs are unique because they are free of locomotor responsibilities and, as a result, are not weight bearing. This lack of weight bearing by human upper limbs may decrease the influence of body weight and size on upper limb osteoarthritis scores, as it did for muscle markers (Weiss, 2004). Weiss (2003) examined human upper limbs and found they correlated with upper limb size; though, these correlations became insignificant when controlling for age and sex. Weiss (2003) hypothesized that future studies may show that human lower limb muscle markers have a greater correlation with size than do human upper limb muscle markers. Then, in her next study, Weiss (2004) showed that there is a greater correlation with body size in the human lower limb than in the upper limb. Most anthropologists now agree that osteoarthritis cannot be effectively used to reconstruct specific activities. Osteoarthritis may or may not be more useful in understanding broader cultural differences, such as hunter-gatherer versus agriculturalists (Bridges, 1990; Jurmain, 1990, 1999; Larsen, 1982). Ju-

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rmain (1999) reviews many of the inconsistencies in the anthropological literature, such as the failure to find specific patterns from hunter-gatherer to agricultural populations. He also points out that many anthropologists have become more careful in their interpretations through time. However, Jurmain (1999) reports that there is still much work in anthropology that uses osteoarthritis scores as a tool to reconstruct specific activity patterns with little controls. Some anthropologists use specific activities as determined by ethnographic or artifactual data as a means to understand patterns of osteoarthritis in populations or between populations (especially when presenting data on specific populations) without considering non-activity related issues, such as genetic differences, sex, differences, or body size differences (e.g., Cope & al., 2004; Derevenski, 2000; Lovell & Dublenko, 1999). This author suggests that it may be more appropriate to consider all possible causes of osteoarthritis when examining skeletal samples and trying to control some of the non-activity related influences even when activity patterns are known. The present study attempts to examine and understand non-activity pattern related osteoarthritis by examining effects of size, age, sex, and cross-sectional robusticity in two populations using aggregated osteoarthritis scores. Using aggregate osteoarthritis scores the author makes an effort to determine whether there are body size confounds in osteoarthritis scores, whether there are sex differences in osteoarthritis and whether these sex differences are caused by activity patterns or biological sex differences, and whether age is the best predictor of osteoarthritis, like other anthropologists have found. If there is a body size correlation with osteoarthritis scores, then this calls into question the accuracy of reconstructing past lifestyles through osteoarthritis without controlling for body size. In addition, it was tested whether other skeletal features, such as age and sex, correlate with osteoarthritis as other anthropologists have found. Greater osteoarthritis scores among older individuals may signal that these markers have accumulated over life due to activity patterns. Also, this study sought to determine whether any sex differences here are related to body size or other differences between the sexes. If the sex difference is due to the size difference between the sexes, then it raises the uncertainty of the accuracy of using osteoarthritis to reconstruct sexual differences in activity patterns without controlling for body size differences. Finally, the relationship between cross-sectional robusticity, which is also used to reconstruct activity patterns, and osteoarthritis scores is examined.

Material and methods.

Sample.

A skeletal sample of 77 adult individuals (57 males; 20 females) ranging from 18 to 69 years of age from two populations (Euroamericans and British Columbian Amerinds) housed at the Canadian Museum of Civilization at Hull, Quebec were examined (Table 1). Cybulski (1988; 1990; 1992) sexed the individuals using pelvic and cranial indicators. He also aged them

Table 1. Sample size, where L refers to number of individuals with only left bones, R refers to number of individuals with only right bones, B refers to number of individuals with both right and left bones available, and 77 individuals had vertebrae (not listed in table), total refers to the number of bones in each category.

	Shoulder			Elbow			Wrist			Hip			Knee			Ankle			Total
	L	R	B	L	R	B	L	R	B	L	R	B	L	R	B	L	R	B	
Male	19	22	13	13	21	19	7	11	26	6	9	42	2	6	48	3	11	32	310
Fe-male	4	5	7	5	6	8	3	4	6	1	1	16	0	3	16	5	2	11	103
Total	23	27	20	18	27	27	10	15	32	7	10	58	2	9	64	8	13	43	413

by means of the pubic symphysis, the ilium auricular surface, cranial suture closure, dental development, and the epiphyseal union of long bones, clavicles, vertebrae, and innominates (Cybulski, 1988, 1990, 1992). For the present study, individuals were excluded if they were not sexed or aged, if they lacked any joint surfaces, or if they were immature.

The British Columbian skeletal remains come from seven Prince Rupert Harbor sites located in the traditional territories of the Amerind tribes belonging to the Tsimshian language family and the Northwest Pacific Coast cultural area. The Tsimshin were fishers and gatherers during the short summers and whale hunters in winter (Table 2) (Cybulski, 1990; Weiss, 2001). These remains date from 3500 to 1300 yrs BP. The Euroamerican skeletal remains come from English prisoners of war who died after being captured by French Canadians about 200 years ago (Table 2) (Cybulski, 1988; Piedalue & Cybulski, 1997; Weiss, 2001).

Methods.

This study used *z*-scores to create three composite (or aggregate) variables – osteoarthritis, size, and robusticity. The osteoarthritis composite was created by averaging the *z*-scores for osteoarthritis scores taken according the Standards method (Buikstra & Ubelaker, 1994). The joints measured were the shoulder (on the proximal humerus), the elbow (on the distal humerus and proximal ulna and radius), the wrist (on the distal ulna and radius), the hip (on the proximal femur), the knee (on the proximal tibia), the ankle (on the distal tibia), and the back (on the available vertebrae). These scores were taken on both left

Table 2. Sample demographics

	Dates (in years BP)	Age Range (in years)	Average Age (in years)	Number of Males	Number of Females
BC Amerinds	3,500 - 1,500	18 - 69	30.6	36	18
Euroamericans	200	18 - 69	29.4	21	2

and right limb bones, when available. The scores of all the joints (from both left and right sides) were converted in *z*-scores and then the upper limb and lower limb scores were added and averaged separately (to form two arthritis variables – upper limb and lower limb composites). The scores from the upper limb and lower limb composites were then added to the back arthritis scores and averaged for an overall arthritis score that weighs each portion of the body equally. This also allowed for upper limb and lower limb arthritis scores to be analyzed separately. Due to the nature of skeletal material, missing data are inevitable. When data were missing, the composite variables upper limb arthritis and lower limb arthritis were calculated by adding the *z*-scores of all the available joint scores and then dividing the sum by the number of joint scores added.

A composite variable of size was created by averaging the *z*-scores for both composite humeral size and lower limb size (again this method weighs each limb equally and allows for additional analyses). Humeral size was created by averaging the three z-scores for humeral length, humeral vertical head diameter, and humeral epicondylar breadth (Buikstra & Ubelaker, 1994). These component traits are good proxies for body size, because they do not remodel (Ruff & al., 1991). Then, humeral size was calculated with data that was side-averaged following Ruff & Larsen (1990).

The composite variable of lower limb size was created by averaging the *z*-scores for three femoral size variables (maximum length, epicondylar breadth, and maximum head diameter) and three tibial size variables (length, maximum proximal epiphyseal breadth, and maximum distal epiphyseal breadth) (Buikstra & Ubelaker, 1994). The composite variable of lower limb size was calculated with data that was side-averaged by adding the right and left values and dividing the value by two.

The composite variable of size was created by averaging the *z*-scores for both composite humeral size and lower limb size. Again, this method weighs each limb equally and allows for additional analyses. When both sides were not available for the size variable, then the available data was used. When other data were missing, the composite variables humeral size and lower limb size were calculated by adding the *z*-scores of all the available measures and then dividing the sum by the number of measures added.

A composite robusticity variable was created by averaging the z-scores for five humeral cross-section variables: total area, cortical area, moment of inertia about the anteroposterior axis, moment of inertia about the mediolateral axis, and polar moment of inertia (all of which were taken at 35% of bone length, side-average, standardized-by-body-size, and log-transformed).

In order to calculate cross-section variables, several steps were performed. Following Ruff & Larsen (1990), humeral lengths were used to mark the specific location on the humeri where cross-sectional geometry is calculated, i.e., 35%, of bone length, in which 100% is the proximal end. Humeri were first x-rayed in the anteroposterior (AP) orientation (i.e., the anterior side of the bone faces upward) and, then, in the mediolateral (ML) orientation (i.e., the medial side of the bone faces upward). Before removing the bones from the x-ray machines, the magnification factor was calculated to remove any magnification errors. This was done using the formula:

Source-to-film distance/(Source-to-film distance – Object-center-to-film distance)

where, source-to-film is the distance from the x-ray bulb to the film, and object-center-to-film is the distance from the middle of the bone to the film, which varied depending on the bone and position of the bone being x-rayed.

Next, each radiographed humerus was measured for inner and outer diameters at both orientations. These values allowed calculation of the derived values. The derived values for compressive strength are the total cross-sectional area (TA) and cortical cross-sectional area (CA). Total area is calculated with the formula:

TA = II X
(MLouter diameter X AP outer diameter/4)

Medullary area (MA) is calculated with the formula:

MA = II X
(MLinner diameter X AP inner diameter/4)

Then, the cortical area is calculated by subtracting the medullary area from the total area (CA= TA-MA) (Biknevicius & Ruff, 1992).

For bending strength in particular planes, resultant values are anatomically oriented moments of inertia calculated about the mediolateral and anteroposterior axes (*I*ml and *I*ap). The formulas for *I*ml and *I*ap require several steps sketched out in Biknevicius & Ruff (1992), and Fresia & al. (1990), and detailed in Timoshenko & Gere (1972). In short, the formulas for *I*ml and *I*ap are:

$$I\text{ml} = \Pi /64 \text{ x } (\text{Tml x Tap}^3 - \text{Mml x Map}^3)$$
$$I\text{ap} = \Pi /64 \text{ x } (\text{Tap x Tml}^3 - \text{Map x Mml}^3)$$

where, Tml = total mediolateral breadth; Tap = total anteroposterior breadth; Mml = medullary mediolateral breadth; and, Map = medullary anteroposterior breadth.

Polar moment of inertia, which allows a determination of strength against overall bending and torsional strains and stresses (Runestad & al., 1993), is calculated using the formula:

$$J = I\text{ml} + I\text{ap}$$

For all of these humeral geometric properties, percentage differences between the right and the left sides had to be calculated using the formula [right - left/right] on data not standardized by body size. Then, the geometric properties were adjusted by this factor depending on the direction of asymmetry, and whether the bone was from the left or the right side. For individuals with missing data for either the right or the left humerus, mean bilateral asymmetry values for that sex and population were used. The averaged data were then standardized by body size using the formulas described below.

Following Ruff & (1993), the resultant

values are presented standardized for body size. Ruff & al. (1993) provided effective formulas for standardizing humeral areal (cortical area, CA and total area, TA) and inertial (moments of inertia, *I* and J) values. Areal measures (CA and TA) were standardized by dividing the result by humeral length cubed (HL^3) and then multiplying it by 10^8. Moments of inertia and polar moments of inertia (*I* and J) were standardized by dividing the result by $HL^{5.33}$ and then multiplying it by 10^{12}. Finally, the data were log-transformed and converted to z-scores.

To allay concern over averaging left and right bones (especially in arm bones since bilateral asymmetry is common in arm bones), correlations for the right and left bones were carried out. For upper limb size, Pearson correlations between the various size properties for the left and right arm bones range from 0.88 to 0.94 (mean $r = 0.90$, $P < 0.01$). For lower limb size, Pearson correlations between the various size properties for the left and right lower limb bones ranged from 0.71 to 0.99 (mean $r = 0.97$, $P < 0.01$). For robusticity, Pearson correlations between the various cross-sectional properties for the left and the right arm bones range from 0.88 to 0.97 (mean $r = 0.93$, $P < 0.01$). With these high correlations, the author felt justified in combining left and right sides for the purpose of this study.

Statistical analysis.

The data were analyzed using the statistical software program SPSS (Version 11.5).

The data used here violated the assumptions of parametric tests; thus, nonparametric tests were used (Weiss & Hassett, 1982).

For each composite variable, means and standard deviations were calculated. Composite variable osteoarthritis was correlated using two-tailed Spearman tests with composite variable size, composite variable robusticity, along with age (defined in six groups, 1 = 18-24 years old; 2 = 25-31 years old; 3 = 32-38 years old; 4 = 39-45 years old; 5 = 46-52 years old; and 6 = 53+ years old) and sex (Weiss & Hassett, 1982). Spearman tests were run separately for males and females on correlations between osteoarthritis, robusticity, size, and age. Partial Pearson correlations controlling for age and sex were also run to determine causes of osteoarthritis. Additionally, Spearman tests were run separately for the lower limb and upper limb in order to test whether there are any differences as a result of bipedality. Critical alpha levels were set at 0.05, with marginally significant findings being 0.10 to 0.06; non-significant findings are marked with *n.s.*

Results.

Table 3 presents the means, standard deviations, and sample sizes for the composite variables used in this study i.e., osteoarthritis, size, and robusticity in *z*-scores, separately for males and females. Osteoarthritis correlates significantly with age, $r = 0.61$ and robusticity, $r = 0.25$, P*s* < 0.05, but not with size, $r = -0.08$; nor sex, $r = -0.07$, *n.s.*

In males, osteoarthritis correlates significantly with age ($r = 0.69$, $P < 0.001$)

Table 3. Means, SDs, and sample sizes for the composite osteoarthritis, size, and robusticity (z-scores), separately for males and females

Property		Mean	SE
Osteoarthritis	Males (n = 57)	-0.0457	0.3
	Females (n = 20)	0.1036	0.4
Size	Males (n = 57)	0.4050	0.1
	Females (n = 20)	-1.1310	0.1
Robusticity	Males (n = 57)	0.3694	0.1
	Females (n = 20)	0.1229	0.2

and robusticity ($r = 0.27$, $P = 0.05$), but not with size ($r = -0.06$, *n.s.*). In females, osteoarthritis correlates marginally with age ($r = 0.39$, $P < 0.10$), but not with robusticity ($r = 0.34$, *n.s.*) or size ($r = 0.12$, *n.s.*).

When age is controlled for, osteoarthritis correlates with size ($r = -0.26$, $P < 0.05$), but not with robusticity ($r = 0.15$, *n.s.*) or sex ($r = -0.17$, *n.s.*). When sex is controlled for, osteoarthritis correlates significantly with age ($r = 0.67$, $P < 0.001$) and robusticity ($r = 0. 25$, $P < 0.05$), but osteoarthritis does not correlate with size ($r = -0.02$, *n.s.*). When both age and sex are controlled for, osteoarthritis correlates marginally significantly with size ($r = -0.20$, $P < 0.09$), but not with robusticity ($r = 0.17$, *n.s.*).

Since previous studies often examined relations within either the upper or lower limb, the correlations here were also run on the upper and lower limb separately. Table 4 presents the means, standard deviations, and sample sizes for the composite variables of upper limb arthritis and lower limb arthritis in *z*-scores, separately for males and females. Upper limb osteoarthritis correlates significantly with age, $r = 0.37$ and robusticity, $r = 0.30$, P*s* < 0.01, but not with upper limb size, $r = -0.08$, *n.s.* nor sex, $r = 0.08$, *n.s.* Lower limb osteoarthritis correlates significantly with age, $r = 0.45$; sex, $r = -0.25$; and size, $r = -0.27$; P*s* < 0.05, but not with robusticity, $r = 0.06$, *n.s.*

Discussion.

Osteoarthritis does correlate with age and robusticity. The single best predictor for osteoarthritis severity is age; older indi-

Table 4. Means, SEs, and sample sizes for the composite upper limb and lower limb (z-scores), separately for males and females

Property		Mean	SE
Upper Limb Osteoarthritis	Males (n = 57)	0.0280	0.1
	Females (n = 20)	- 0.1326	0.2
Lower Limb Osteoarthritis	Males (n = 57)	0.0122	0.1
	Females (n = 20)	0.3096	0.2

viduals have more severe osteoarthritis than do younger individuals. When controlling for age, osteoarthritis also correlates with body size; yet, this correlation comes from lower limb osteoarthritis scores and within the lower limb osteoarthritis scores there is also a correlation with sex. Thus, the size correlation, in which smaller individuals have greater osteoarthritis scores, may actually be a sex difference.

In review, aggregate osteoarthritis was constructed from the *z*-scores of seven joint sites (three upper limb sites, three lower limb sites, and vertebrae). Aggregate size was constructed from three humeral measurements, three femoral measurements, and three tibial measurements (all of which were taken according to *Standards* procedures, side-averaged, and converted to *z*-scores). Robusticity was measured from humeral areal and inertial cross-sectional properties (which were side-averaged, standardized-by-body-size, and converted into *z*-scores). Age and sex were previously determined by Cybulski (1988; 1990; 1992).

This study found that the highest correlations with osteoarthritis were found with age. Older individuals had more severe osteoarthritis than did younger individuals. This finding held for both sexes separately although only marginally so in females. The correlation with age and osteoarthritis corroborates many other studies (Jurmain, 1990; Kahl & Smith, 2000; Larsen & al., 1995; Merbs, 2001; Waldron, 1997). Older individuals could have higher osteoarthritis scores than younger individuals because they have experienced more stress over a lifetime of activities, but age differences also could be related to changes in cartilage and bone structure. In other words, greater severity in osteoarthritis among older individuals may be a result of the normal aging process. The causes of greater osteoarthritis scores in older individuals need to be examined more thoroughly. In nearly all studies, including the present one, older individuals have greater osteoarthritis scores than younger individuals, and, thus, it is important to control for age when using osteoarthritis scores to reconstruct activity patterns, as do many anthropologists.

Results from this sample also showed that osteoarthritis scores correlate with robusticity. Greater osteoarthritis scores were found in individuals with greater humeral robusticity. This finding held in males, but not in females. The lack of correlation is most likely a result of a small female sample size (N = 20) since the correlation was still fairly high (r = 0.34). The correlation did not hold up when age was controlled for or when looking at lower limb osteoarthritis scores. The lack of findings when age was controlled for suggests that the correlation is an affect of age rather than osteoarthritis severity; that is, individuals of similar ages have similar bone morphologies. The lack of correlation with lower limb osteoarthritis is not surprising considering that the robusticity variable was measured on humeral cross-sections. Had femoral cross-sections been used there probably would have been a correlation as seen in the upper limb osteoarthritis results. In this author's opinion, the correlation between osteoarthritis and robusticity is a result of age similarities in bone morphology, which implies that when using robusticity to reconstruct activity patterns age needs to be taken into consideration.-

Osteoarthritis, in this study, also correlated with body size when controlling for age. This finding did not hold up in either sex separately and was found only in the lower limb osteoarthritis score. Individuals with smaller lower limbs had greater osteoarthritis scores than did individuals with larger lower limbs, a pattern that remained when controlling for age, but not when controlling for sex. The lower limb size and lower limb osteoarthritis correlation extends earlier work by Weiss (2004) that showed that lower limb traits are more affected by body size than are upper limb traits. Interestingly, the size outcome was in the opposite direction as expected. Smaller individuals had greater osteoarthritis scores than did larger individuals, which seems to go against the clinical literature on weight as well (Heliovaara & al., 1993; Tepper & al., 1993). Body size as measured by on skeletal remains, however, is not body weight and it is unlikely that the individuals in this sample were overweight. One could hypothesize that the smaller the individual the smaller their joints and that if they add extra pounds to their frame this would affect a smaller individual greater than a larger individual.

When sex was controlled for through a partial correlation, osteoarthritis and body size did not correlate significantly. It is important to note that sex and size were highly correlated ($r = 0.79$; $P < 0.001$). The sex and size confound suggests that the body size correlation with lower limb osteoarthritis scores may actually be a sex differences rather than a pure size difference. This makes it difficult to determine whether one should control for body size when using osteoarthritis scores to reconstruct activity patterns, but it does suggest that the relationship between osteoarthritis and body size needs to be further investigated.

The sex differences in osteoarthritis scores were not consistent. Basically, there was no correlation with sex and osteoarthritis in the upper limb, but in the lower limb there was a sex correlation with osteoarthritis. Females had greater lower limb osteoarthritis scores than did males. Sex differences in osteoarthritis scores have been reported many times, but there has never been a clear consistency. The lack of consistency has often been argued as due to the difference relying on the particular activities within the population studied (Šlaus, 2000; Wedel & al., 2004; Derevenski, 2000). Although, sex differences in osteoarthritis scores are often interpreted as due to sex differences in activity patterns (as mentioned above) and most anthropologists take care to make sure that age is not confounded with sex differences (Jurmain, 1990; Kahl & Smith, 2000; Merbs, 2001), there are other factors that can cause differences between males and females, such as body size and hormones. The data here suggest that some of the clinical literature that have found more severe osteoarthritis in females, especially around the hip joint, could be a factor when looking at skeletal remains (Spector, 1996; Waldron, 1997; Wilson & al., 1990). It is possible that differences in the lower limb in this study are related to biology rather than to activity patterns. More studies to help determine the causes of sex differences are needed before we can access how much is due to biology and how much is due to activity.

Conclusions.

In conclusion, osteoarthritis scores in this sample from British Columbia and Quebec correlate with age and robusticity. Older individuals had more severe osteoarthritis than did younger individuals; individuals with more robust humeri had more severe osteoarthritis than individuals with less robust humeri. When age is controlled for, osteoarthritis also correlates with body size. Smaller individuals had more severe osteoarthritis than larger individuals. However, this body size correlation is mainly in the lower limb, where there is also a correlation with osteoarthritis and sex. Since sex and body size correlate, the size correlation may be due to sex differences caused by hormones or activity differences. This study extends previous research that suggests age, sex, and size need to be considered more closely when examining osteoarthritis. Finally, confounds of body size and sex should be noted and one should be careful when assigning osteoarthritis differences to sexual division of labor.

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