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Humeral Cross-Sectional Morphology From 18th Century Quebec Prisoners of War: Limits to Activity Reconstruction

Elizabeth Weiss*

Canadian Museum of Civilization, Hull, Quebec J8X 4H2, Canada

KEY WORDS cross-sectional morphology; humeri; robusticity; asymmetry

ABSTRACT This study uses measures of cross-sectional robusticity and asymmetry (based on humeral areal and inertial cross-sectional components) to test a prediction from bone remodeling theory that a physically active 18th century Quebec prisoner of war sample (N = 25) should have more robust and asymmetrical humeri than a nonphysically active 20th century New Mexico suburbanite sample (N = 27). Narrative accounts document that prisoners of war engaged in labor-intensive activities, and these activities were confirmed by observations of osteoarthritis and other pathologies. The suburbanite sample, for the most part, did not engage in such activities. The prisoners had higher levels of pathology than the suburbanites (e.g., 80% vs. 22% osteoarthritis; F = 17.95, $P < 0.01$). For robusticity, the populations did not differ significantly in total area, cortical area, moment areas of inertia about the mediolateral plane, or polar moment area of inertia. The Quebec prison sample did have significantly higher values for moment areas of inertia about the anteroposterior plane. For asymmetry, the populations did not differ in any values (total area, cortical area, moment areas of inertia about the mediolateral plane, moment areas of inertia about the anteroposterior plane, or polar moment of inertia). Thus, examinations of cross-sectional robusticity and asymmetry failed to conclusively confirm the hypothesis that intensive labor leads to changes in humeral morphology. Possible explanations for the lack of differences are discussed, such as poor diet impeding bone remodeling. Nevertheless, the one significant finding suggests that cross-sectional shape is more useful in reconstructing activity patterns than amount of bone in a cross section. Results from this study join those from other recent investigations to suggest that additional controls are required before cross-sectional differences may be confidently attributed to activity patterns. Am J Phys Anthropol 126:311–317, 2005. © 2004 Wiley-Liss, Inc.

This study tests whether cross-sectional morphology is discernibly affected by activity patterns in two populations that are similar in age, ethnicity, and sex. It examines whether humeral cross sections from 18th century Quebec prisoners of war who engaged in hard labor, such as carrying heavy loads, farming, and training for battle, differed from humeral cross sections of 20th century New Mexico suburbanites who did not engage in hard labor. If activity patterns cause significant changes in cross-sectional morphology, then the prison population should have cross sections that are stronger (more robust) and more asymmetrical (most individuals favor the use of one upper limb over the other) than the suburbanite population.

According to Wolff's law (Wolff, 1892), bone interacts dynamically with specific environmental forces, such as muscle use. When such a force is applied to a bone, it causes the bone to deform, which induces local bone formation. In theory, bone remodeling leads to stronger bones with a reduced chance of breaking from excessive force. Anthropologists have used bone remodeling theory to examine limb-bone cross sections (which are measures of strength against forces) and to assess the effects of such phenomena as division of labor, subsistence pattern changes, and aging on past populations (Bridges, 1989; Ledger et al., 2000; Ruff, 1987; Stock and Pfeiffer, 2001). For more information on this complex issue, please refer to the vast body of literature, such as Betram and Swartz (1991), Lieberman (1996), and references listed in these and other works.

Bridges (1989) studied changes associated with the transition from a preagricultural to an agricultural subsistence in Tennessee Valley Amerindian populations, and found that male femoral cross sections underwent few changes across this transition from hunting-and-gathering to agriculturalism, but female cross sections increased substantially in cortical bone. Bridges (1989) deduced that these

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*Correspondence to: Dr. Elizabeth Weiss, 425 W. Paseo Redondo, Apt. 4K, Tucson, AZ 85701. E-mail: eweiss@anthrosciences.com

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changes occurred because females increased the use of their lower limb muscles through agricultural work, whereas males kept similar behavioral intensities from hunting and gathering practices. Bridges (1989) also found that female upper limb strength increased with the introduction of agriculture, which she attributed to the grinding of corn. Thus, Bridges (1989) concluded that females, but not males, increased their bone strength with the introduction of agriculture due to their intensified labor, which placed more stress on the bones.

Another example of bone remodeling comes from Ledger et al. (2000), who found that 18th century South African slaves had stronger upper-limb cross sections but weaker lower-limb cross sections compared to Later Stone Age African hunter-gatherers. Ledger et al. (2000) attributed these differences to the manual labor required of slaves as opposed to the high mobility experienced by hunter-gatherers. In a similar study, Stock and Pfeiffer (2001) compared Later Stone Age South African hunter-gatherers to 19th century fishers from the Andaman Islands (between Sumatra and Borneo). Stock and Pfeiffer (2001) found that, whereas the hunter-gatherer population had more robust (stronger) lower-limb cross sections, the fishing population had more robust upper-limb cross sections. Stock and Pfeiffer (2001) attributed these population differences to the use of particular muscles in relation to specific activity patterns, such as lower limb muscles being used for long-distance travel in the hunting group and upper limb muscles being used for rowing watercrafts, swimming, and fishing.

There is a vast body of literature reporting positive relationships between bone loading and diaphyseal robusticity (e.g., Jones et al., 1977; Trinkaus et al., 1994; Woo et al., 1981). However, not all anthropologists agree that the use of muscles leads to alterations in bone that can, in turn, be used to understand activity patterns. Betram and Swartz (1991), for example, reported that previous experiments using force-causing devices surgically inserted into the bone do not show evidence of bone remodeling, but result in a damage response similar to when bone has been broken or after other surgical interventions. They further suggested that evidence of atrophy (or bone loss due to lack of force) is more complex than a mere absence of bone remodeling due to decreased muscle use, for even those bones not normally affected by activity patterns suffer atrophy where there is an absence of force, such as in antigravity experiments or restraining movements in rats.

Stirland (1998) took another approach in trying to understand bone remodeling. She examined 100 adult males from the crew of the *Mary Rose*, which was a flagship of Henry VIII that sank in AD 1545, and 100 modern male divers. Stirland (1998) found in both samples that a greater amount of cortical bone did not correlate with greater muscle marker scores, which are often used as indicators of muscle use. In light of these findings, Stirland (1998) concluded that muscle markers were simply too subjective to be used reliably for reconstruction of activity patterns. Stirland (1998), however, did not consider the possibility that this discordance might be the consequence of problems with measurements of cross-sectional morphology for reconstructing activities. Interestingly, in an earlier study with the same skeletal remains from the *Mary Rose* compared to a Norwich sample from AD 1254–1468, Stirland (1993) found that the crew of the *Mary Rose* was less asymmetrical than the Norwich population, and related this to activities the crew engaged in that required the used of both arms.

In another study, Weiss (2003a) looked at the potential effects of rowing on humeral strength in a skeletal sample of 358 individuals from seven populations. Weiss (2003a) predicted that ocean-rowers would have stronger humeral cross sections than river-rowers or nonrowers. Since rowing on oceans is mainly a male activity pattern (Suttles, 1990), analyzing the sex differences in humeral robusticity provided a control. Although ocean-rowing males had more robust humeri than did nonocean-rowing males, the same differences showed up in females. Thus, Weiss (2003a) concluded that such population differences were perhaps more correctly attributable to overall activity levels or some preexisting biological factors rather than to rowing. Weiss (2003a) also found very clear sex differences, with greater male robusticity in all studied populations. Sex differences in robusticity have often been interpreted as due to sexual division of labor (e.g., Bridges, 1989; Ruff, 1987). However, many physical sex differences are known to be in large part due to biology, such as genetics or hormonal effects. Hence, both population and sex differences in cross-sectional morphology need to be considered when testing hypotheses about the effects of cultural activities.

The present study tests whether limb-bone morphology is discernibly affected by activity patterns in two populations that are similar in age, ethnicity, and sex. It examines whether humeral cross sections from 18th century Quebec prisoners of war who engaged in hard labor, such as carrying heavy loads, farming, and training for battle, differed from humeral cross sections of 20th century New Mexico suburbanites who did not engage in hard labor. If activity patterns cause significant changes in cross-sectional morphology, then the prison population should have cross sections that are more robust and more asymmetrical than the suburbanite population.

MATERIALS AND METHODS

Sample

Samples drawn from two populations are compared in this study. Both samples have similar age distributions and consist of European males born in the New World. The first consists of 25 adult male

TABLE 1. Sample size

Populations	Number of individuals with left humeri	Number of individuals with right humeri	Number of individuals with both humeri	Total number of individuals
Quebec prisoners of war	7	10	8	25
New Mexico suburbanites	0	1	26	27
Total	7	11	34	52

18th century prisoners of war from Quebec, Canada, previously sexed and aged using cranial, pelvic, and dental characteristics (Table 1; Cybulski, 1988). The second consists of 27 adult male 20th century suburbanites from New Mexico of known age and sex (morgue sample) (Table 1; Churchill, 1994).

The 18th century prisoners came to light in 1986 when the Canadian Park Services were restoring part of the historic Quebec Wall. Construction workers discovered 50 skeletons that archaeologists dated between AD 1745–1748 (Cybulski, 1988; Piedalue and Cybulski, 1997). These individuals were White Canadians and Americans from the English region of Canada who had been captured by French Canadians in the French-English war of 1744. The prisoners examined in this study died while under French control.

The majority of prisoners had relatively long and high brain cases, long and flat facial features, and narrow noses, consistent with their North European origin (Cybulski, 1988). Dental crowding, rotation, and displacement, the result of small jaw size, also support this conclusion. The diaries of a few prisoners narrowed the biological affinities even further; the prisoners were mainly of English, Scottish, Irish, and Dutch descent (Piedalue and Cybulski, 1997). The prisoners averaged 173.3 cm (5′ 8″) in height (Cybulski, 1988).

The health of the prisoners was also determined through skeletal examinations (Cybulski, 1988; Piedalue and Cybulski, 1997; Weiss, 2003a,b). Most individuals had severe osteoarthritis, disc ruptures, and fractures of their skull, limbs, and back. Eighty percent of prisoners had osteoarthritis, and 73% had Schmorl's nodes. Given the young age at death of many of the prisoners, such prevalence is unusually high and is most likely due to the hard labor experienced in the prison camp, especially the carrying of heavy loads (Piedalue and Cybulski, 1997). In addition, prior to their imprisonment, many of the individuals were farmers in the region and engaged in hard manual labor while farming. Farming at this time was very labor-intensive and required long hours of working fields with few technical advances, which should translate to robust upper limbs. At least some of these individuals were trained to fight in war, and hence were likely required to participate in long marches, extensive physical training, and carrying loads. Table 2 displays various traumatic lesions and pathologies in individuals used in this study; 19 of 25 individuals (76%) had noticeable pathologies or traumatic lesions. Ages ranged from 18–69 years (median age, 28.5 years; mean age, 33 years, which was calculated using the median age estimate of each individual). Diaries found at the site showed that many prisoners died of fever, consumption, dysentery, and scurvy (Piedalue and Cybulski, 1997).

The 20th century "suburban" sample from the Maxwell Museum in Albuquerque was collected from morgues in the Central Rio Grande region of New Mexico. These individuals lived in urban to semiurban environments and represent individuals born in the early- to mid-1900s (Churchill, 1994). These individuals were of European ancestry and represent an industrialized (i.e., modern) population, most of whose members led fairly sedentary and inactive lives. Individuals who died following protracted illnesses were excluded (Churchill, 1994). These individuals were from donated bodies, some of whom came from lower income groups, and a few may have been transients. However, there were also professionals, such as astrologers, graduate students, and teachers, among this population. About 22% of individuals from the Maxwell Collection had osteoarthritis and other trauma-related conditions (Table 3). Such a low prevalence of osteoarthritis is typical of populations that do not engage in much hard physical labor; only two members of the sample had occupations that would have required much physical labor (one rancher and one laborer). For this study, 27 males between 20–60 years of age were examined (median age, 37.5; mean age, 37 years).

Methods

For the prisoners of war, humeri were radiographed to obtain cross-sectional data at the Canadian Museum of Civilization in Hull, Quebec. Following Ruff and Larsen (1990), humeral lengths were used to mark the 35% of bone length location (in which 100% is the proximal end), and cross-sectional geometries were calculated at this point. Humeri were arranged on the film in anteroposterior orientation (i.e., the anterior side of the bone faces upward) and X-rayed; then they were arranged on it in mediolateral orientation (i.e., the medial side of the bone faces upward) and X-rayed. When available, both left and right humeri were radiographed.

Each radiographed humerus was measured for inner (the diameter of the medullary canal) and outer (the diameter of the entire cross section) diameters, and the values were used to calculate the derived cross-sectional values: total area, cortical

TABLE 2. Quebec prisoners of war with pathologies or traumatic lesions (from self-observations and Cybulski, 1988)

Burial	Age	Pathology/traumatic lesions
G35C3	35–44	Two fractured right foot bones; incomplete fracture of left tibia; fracture in left hand bone and proximal phalanx; three arthritic left carpal bones.
G35D1	18–22	Depressed fracture in posterior skull vault; injury to left hand and associated spurlike growth on left third metacarpal; scorbutic signs on tibiae and fibulae; arthritic right elbow.
G35H1	20–24	Fatigue fractures in feet; left femur enlarged and inflamed due to trauma or scurvy; unusual prominences on right humerus and clavicle, suggesting anomalous development of upper chest and shoulder muscles.
G35H2	30–39	Lumbar spondylolysis.
G35H3	24–34	Unusually curved and short ulnae: left ulna 7 mm shorter than right ulna; severe arthritic left elbow and shoulder.
G35K1	25–34	Compression fracture of eight thoracic vertebral body; traumatic ossification of tissue in distal right femur; left ulna bowed: left ulna 15 mm shorter than right ulna.
G35K8	25–29	Arthritic right elbow.
G35K9	20–24	Arthritic right elbow.
G35K12	65–74	Five fractured right ribs; right sternoclavicular joint enlarged and irregular surface suggesting trauma; lumbar spondylolysis; osteophyte on right distal humerus.
G37E5	40–49	Arthritic right elbow and wrist; femora show scorbutic signs; osteophyte on right distal radius.
G37E6	35–44	Compression fractures in bodies of sixth thoracic and third lumbar vertebrae; third lumbar spinous process fractured; femur and tibia enlarged and inflamed due to trauma or scurvy; osteophyte on left distal radius.
G37F2	55–64	Right ulna severely broken and unhealed, possibly due to trauma; arthritic left elbow.
G37F3	60–69	Osteophyte on left distal humerus; arthritic elbows and wrists; sternoclavicular joint enlarged and arthritic.
G37M1	25–29	Arthritic right elbow.
G37M2	18–21	Lumbar spondylolysis; arthritic right elbow.
G37M3	18–22	Left sternoclavicular joint enlarged and arthritic; arthritic elbows and wrists.
G37N1	18–21	Compression fracture on first lumbar vertebral body; lumbar spondylolysis.
G41D1	45–54	Broken left clavicle with healed overlap of the two parts; right foot fraction; arthritic elbows and wrists; osteophyte on left distal humerus.
G41D2	18–21	Distal articular surface of left fifth metatarsal was distorted and arthritic; osteophyte on left proximal humerus.

TABLE 3. New Mexico suburbanites with pathologies or traumatic lesions (from self-observations)

Burial	Age	Pathology/traumatic lesions
OMI00006	41	Slight arthritis in vertebrae.
OMI00017	41	Slight arthritis in vertebrae.
OMI00027		Many broken bones as a result of death by suicide: jumped in front of a moving train.
OMI00044	50	Slight bone loss in femora and arthritic sacrum.
OMI00050		Lipping arthritis in vertebrae and femora.
OMI00058	20–25	Fresh unhealed break in femur (possibly occurred at time of death).
OMI00063	59	Fractured rib and arthritic vertebrae.
OMI00191	39	Bony protrusion on humerus, Schmorl's nodes, and slight arthritis on various bones.

area, moment area of inertia about the mediolateral plane, moment area of inertia about the anteroposterior plane, and polar moment area of inertia.

Derived values were calculated using formulas published by Biknevicius and Ruff (1992). Total area (TA) was calculated with the formula:

$$\mathrm{TA} = \Pi \times \mathrm{ML\ outer\ diameter} \times \mathrm{AP\ outer\ diameter}/4.$$

Medullary area (MA) was calculated with the formula:

$$\mathrm{MA} = \Pi \times \mathrm{ML\ inner\ diameter} \times \mathrm{AP\ inner\ diameter}/4.$$

Cortical area (CA) was calculated with the formula:

$$\mathrm{CA} = \mathrm{TA} - \mathrm{MA}.$$

The formulas used for calculating moment area of inertia about the mediolateral plane (*I*ml) and moment area of inertia about the anteroposterior plane (*I*ap) were:

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

where Tml = total mediolateral breadth, Tap = total anteroposterior breadth, Mml = medullary mediolateral breadth, and Map = medullary anteroposterior breadth (Biknevicius and Ruff, 1992). Finally, polar moment area of inertia (J) was calculated using the formula:

$$\mathrm{J} = I\mathrm{ml} + I\mathrm{ap}.$$

Areal values (TA, CA) reflect compressive strength, while inertial values (*I*ml, *I*ap, J) reflect bending and torsional strength.

Churchill (1994) provided raw data for the New Mexico suburbanite sample. The data consisted of humeral lengths, total and cortical areas, moment areas of inertia about the mediolateral and anteroposterior planes, and polar moments of inertia. Whenever possible, both the right and left humeri were used (Churchill, 1994).

Although X-rayed data and CT-scanned data may vary slightly (by about 5%; Churchill, 1994), Biknevicius and Ruff (1992) showed that this difference was statistically insignificant. Furthermore, this author took care to remove any magnification errors associated with radiographs, which are often forgotten. This was done using the formula:

TABLE 4. Means and SDs for age; side-averaged femoral head breadth, body mass, and humeral length of Quebec prisoners of war and New Mexico suburbanites

	Prisoners of war		New Mexico suburbanites		
Property	Mean	SE	Mean	SE	P (one-way ANOVA)
Age (years)	32.40	2.99	36.37	2.79	0.35 (n.s.)
Femoral head breadth (mm)	48.77	0.41	47.54	0.71	0.14 (n.s.)
Body mass (kg)	78.79	1.13	75.41	1.95	0.14 (n.s.)
Length (mm)	333.06	3.31	324.30	4.67	0.13 (n.s.)

$$\text{Source to film distance}/(\text{Source to film distance} - \text{Object center to film distance}).$$

Source to film is the distance from the X-ray bulb to the film, which is printed on the X-ray machine. Object center to film distance is the distance from the middle of the bone to the film.

For both samples, the dependent variables (total area, cortical area, moment areas of inertia about the mediolateral and anteroposterior planes, and polar moment area of inertia) were side-averaged, following the procedure of Ruff and Larsen (1990): 1) percentage differences between right and the left sides were calculated using the formula [right − left/right]; 2) humeral properties were adjusted by this factor, depending on direction of asymmetry, and whether the bone was from the left or the right side; and 3) for missing data, the available side was used.

Then, following Ruff et al. (1993), the side-averaged data were standardized by body mass. Body mass was calculated using femoral head breadth (in mm), which was collected following Buikstra and Ubelaker (1994). Femoral head breadth data for the Quebec population were taken at the Canadian Museum of Civilization in Hull, Quebec, and data for the suburbanite population were taken at the Maxwell Museum of Anthropology in Albuquerque, New Mexico. Then body mass was calculated, using the formula of Ruff et al. (1997):

$$\text{Body mass} = 2.741 \times (\text{femoral head breadth}) - 54.9.$$

Body mass and humeral length, which were also collected following Buikstra and Ubelaker (1994), were then used to standardize the dependent variables. Areal measures (TA, CA) were divided by body mass (TA/BM, CA/BM); inertial measures (I and J) were raised to the power of 0.73 and divided by humeral length times body mass ($I\text{ap}^{0.73}/(\text{HL} \times \text{BM})$; $I\text{ml}^{0.73}/(\text{HL} \times \text{BM})$; $\text{J}^{0.73}/(\text{HL} \times \text{BM})$) (Ruff, 2000).

In addition to data standardized by body mass, bilateral asymmetries were calculated for humeral length, total area, cortical area, moment area of inertia about the mediolateral plane, moment area of inertia about the anteroposterior plane, and polar moment area of inertia, using the formula for any specific strength of:

$$(\text{Large value} - \text{Small value}/\text{Small value}) * 100.$$

Only individuals with both humeri available were used in the calculation of bilateral asymmetry. Bilateral asymmetry values do not need to be standardized for body mass, since within-individual ratios make up the asymmetry comparisons.

In summary, total area, cortical area, moment area of inertia about the mediolateral plane, moment area of inertia about the anteroposterior plane, and polar moment area of inertia were analyzed, all of which were standardized by body mass. Additionally, bilateral asymmetries of the above-mentioned cross-sectional properties were analyzed.

Statistical analysis

Data were analyzed using the statistical software program KYPLOT. The variables met all the assumptions required to run parametric tests, and the relationships between variables were linear. Means and standard deviations were calculated for all variables. An analysis of variance (ANOVA) was used to analyze the data. The independent factor was group, and the dependent variables were body-mass-standardized total area (TA), cortical area (CA), moment area of inertia about the mediolateral plane (Iml), moment area of inertia about the anteroposterior plane (Iap), polar moment area of inertia (J), and the corresponding asymmetry measures (TA asymmetry, CA asymmetry, Iml asymmetry, Iap asymmetry, and J asymmetry). The critical alpha level was set at 0.05.

RESULTS

In order to put the results in context, data (arithmetic means, standard errors, and statistical significance of group differences) on age, femoral head breadth, body mass, and humeral length are presented in Table 4.

Table 5 presents the arithmetic means and standard errors of dependent variables by group (the independent variable) multiplied by 100 for areal measures and 10,000 for inertial values, and in percentiles for asymmetry variables. Tables 6 and 7 present the statistical test results.

The Quebec prisoners of war did not differ significantly from the New Mexico suburbanites in standardized-by-body-mass total area, cortical area, moment area of inertia about the mediolateral plane, or polar moment area of inertia (Tables 5 and 6). They did differ in moment area of inertia about the an-

TABLE 5. Means and SDs for TA, CA, I*ml,* I*ap, J, TA asymmetry, CA asymmetry,* I*ml asymmetry,* I*ap asymmetry, and J asymmetry of Quebec prisoners of war and new Mexico suburbanites*

	Prisoners of war		New Mexico suburbanites	
Property	Mean	SE	Mean	SE
Standardized-by-body mass (areal measures * 100; inertial measures * 10,000)				
TA	409.6	10.4	425.2	13.9
CA	313.6	80.6	276.6	17.8
*I*ml	230.7	13.2	267.0	18.7
*I*ap	292.6	11.6	255.9	13.7
J	423.7	24.4	444.9	22.4
Asymmetry (in percentiles)				
TA	2.83	1.49	2.13	1.74
CA	2.76	4.01	0.18	2.69
*I*ml	5.85	4.87	4.55	2.67
*I*ap	8.02	3.10	2.27	5.32
J	6.59	2.45	3.54	3.72

TABLE 6. ANOVA results for TA, CA, I*ml,* I*ap, and J on group differences*

Property	Source	Sum of squares	*df*	*F*	*P*
TA	Between groups	0.255663	1	0.82	0.37
	Within groups	12.39804	40		
	Total	12.65370	41		
CA	Between groups	1.470644	1	3.7	0.06
	Within groups	16.279560	40		
	Total	17.750204	41		
*I*ml	Between groups	0.000145	1	2.58	0.12
	Within groups	0.002353	42		
	Total	0.002498	43		
*I*ap	Between groups	0.000141	1	4.22	0.05*
	Within groups	0.001339	40		
	Total	0.001480	41		
J	Between groups	4.80E-005	1	0.40	0.53
	Within groups	0.004928	41		
	Total	0.004976	42		

* Statistically significant.

TABLE 7. ANOVA results for asymmetries of TA, CA, I*ml,* I*ap, and J on group differences*

Property	Source	Sum of squares	*df*	*F*	*P*
TA	Between groups	2.094985	1	0.05	0.82
	Within groups	796.178701	20		
	Total	798.273686	21		
CA	Between groups	29.658921	1	0.25	0.62
	Within groups	2,452.924470	21		
	Total	2,482.583391	22		
*I*ml	Between groups	8.228114	1	0.06	0.80
	Within groups	2,712.608160	21		
	Total	2,720.836274	22		
*I*ap	Between groups	144.088227	1	0.41	0.53
	Within groups	7,079.004496	20		
	Total	7,223.092723	21		
J	Between groups	40.856364	1	0.23	0.63
	Within groups	3,502.601519	20		
	Total	3,543.457883	21		

teroposterior plane, with the Quebec prisoners having greater values (Table 6).

The Quebec prisoners of war did not differ significantly from the New Mexico suburbanites in asymmetries of total area, cortical area, moment area of inertia about the mediolateral plane, moment area of inertia about the anteroposterior plane, or polar moment area of inertia (Tables 5 and 7).

DISCUSSION

The present study found that the Quebec prisoners of war for the most part did not differ from the New Mexico suburbanites in bone robusticity or asymmetry, despite major differences in activity patterns between members of these two groups. Both samples had similar age distributions, same sex, and same ethnicity. Yet they differed greatly in number of injuries, osteoarthritis, and other pathologies (e.g., 80% of Quebec prisoners had osteoarthritis; 22% of Euroamericans had osteoarthritis). The results showed that the populations did not differ significantly in 4 out of 5 robusticity measures (side-average and standardized by body mass) or any of the asymmetry measures. As such, these results do not conclusively confirm that intensive labor discernibly affected upper limb bone cross sections. It may be that the cross-sectional morphology of these individuals was similar due to factors of age, sex, and/or ethnicity. Of course, there can be other explanations, such as the poor diet of prisoners being detrimental to muscle and bone development, which may have impeded the growth of robust bones despite heavy activity. The causes of robusticity and asymmetry are difficult to disentangle from this sample, especially due to the small sample sizes. Nevertheless, these findings suggest that when using cross-sectional morphology to test hypotheses, many factors need to be considered. Age is a common factor that anthropologists consider when examining bone health. Ruff and Jones (1981), for example, pointed out changes that occur to bone over a person's lifetime. However, similarities related to ethnicity and sex are often overlooked. More specific to the sample studied here, the Quebec prison population had many pathologies and traumas that would suggest heavy labor, but the humeral cross sections for the most part did not seem to reflect the same amount of heavy labor. It could be that these injuries had an effect on upper-limb function that would impede normal bone remodeling. Another possibility is that the external characteristics and the cross-sectional characteristics represent remodeling in response to different behavioral stimuli.

Nevertheless, it is interesting to note that the Quebec prison population had a higher value for the moment area of inertia about the anteroposterior plane variable than the suburbanite population. This result is most likely a factor of the heavy labor engaged in by the prison population. Furthermore, this result adds credibility to the argument that the distribution of bone may be more important in reconstructing activity patterns than overall bone mass in a cross section, especially when age or nutrition may affect bone mass. Lieberman et al. (2004) reported similar findings using a more experimental method. Their findings suggest that polar moment of inertia is the best single measure to use in understanding loading, especially when experimental data are not available. Furthermore, Lieberman et al. (2004) found that while absolute values are likely to be inaccurate, the patterns of results are more likely correct, especially within species or individual comparisons. Similar to the study of Lieberman et al. (2004), the significant result found in the present study suggests that even with the unknowns and difficulties of reconstruction activity patterns using cross-sectional morphology, the method should not be dismissed, but rather refined with more knowledge about age, population, sex, and diet effects.

In conclusion, both populations had similar robusticity and asymmetry, which may have been due to similarities in age or sex or ethnicity, or a combination of these factors, or other unknown factors mentioned above. Future research is needed to help disentangle the causes of humeral morphology.

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