

Understanding Muscle Markers: Lower Limbs

Elizabeth Weiss*

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

KEY WORDS muscle markers; size; sex; age

ABSTRACT Musculoskeletal markers are frequently used to reconstruct past lifestyles and activity patterns. Yet the reliability of muscle marker measurements has been called into question because they may be confounded by body size. In this study, an aggregate muscle marker variable was calculated using 20 insertion sites (14 femoral, 6 tibial), and I examined their effects on lower limb size (as a proxy for body size), age, and sex. Analyses were made of a sample of 77 (57 males, 20 females) Native British Columbians (3,500–1,500 years BP) and 18th century Quebec prisoners. Muscle markers were measured

using two-point observer rating scales; size was measured by standard methods; and age and sex were determined through pelvic, cranial, and dental morphology. Lower limb muscle markers correlated with: age, $r = 0.61$; lower limb size, $r = 0.52$; and sex, $r = 0.49$; $P < 0.001$. Older individuals had higher muscle marker scores, as did larger individuals and males. Based on partial correlations and regression analyses, age was the best overall predictor of lower limb muscle markers. *Am J Phys Anthropol* 125:232–238, 2004. © 2004 Wiley-Liss, Inc.

Muscle markers (i.e., musculoskeletal stress markers) are distinct skeletal markings and bony projections that occur where a muscle, tendon, or ligament inserts into the blood-supplying periosteum and underlying bony cortex. Bone remodeling theory states that when muscle insertion sites are subjected to stress, blood flow is increased, which stimulates bone-forming cells that result in bone hypertrophy and increased size of musculoskeletal stress markers (Chamay and Tschantz, 1972; Wolff, 1892; Woo et al., 1981).

The use of bone remodeling theory in anthropology has led to the conclusion that large muscle markers are the result of continued muscle use in daily and repetitive tasks, which has made them ideal for reconstructing past lifestyles. Questions regarding whether males and females differ in activity patterns, whether groups differed in specific activities related to hunting and fishing, what effects shifts in subsistence patterns have on past populations, plus many more, have been tentatively answered using muscle marker examinations (e.g., Chapman, 1997; Cook and Dougherty, 2001; Hawkey, 1998; Hawkey and Merbs, 1995; Lai and Lovell, 1992; Nagy, 1999; Peterson, 1998).

Older individuals have more pronounced muscle markers than do younger individuals, which many anthropologists relate to the stress of activity patterns that accumulate over time (Nagy, 1998; Robb, 1998; Wilczak, 1998). Using muscle markers to reconstruct past lifestyles frequently takes age differences into account, to enable more accurate reconstructions (e.g., Hawkey and Merbs, 1995; Nagy and Hawkey, 1995).

In many skeletal samples, males have higher muscle marker scores than females (e.g., Cohen,

1989; Cook and Dougherty, 2001; Hawkey and Street, 1992; Nagy, 1999; Steen and Lane, 1998). A few studies found certain muscle markers to be higher in females than in males (e.g., Chapman, 1997; Nagy and Hawkey, 1995). These reverse sex differences may disappear if aggregate variables are used, but they may also be truly due to activity pattern differences. Sex differences are most often attributed to differences in activity patterns (Chapman, 1997; Cook and Dougherty, 2001; Peterson, 1998; Wilczak, 1998). However, Weiss (2003) examined sex differences in muscle markers in two populations and found that males had higher upper limb muscle marker scores than females, but this correlation disappeared when controlling for size. Thus, it seems possible that sex differences in muscle markers are sometimes due to differences in body size, rather than activity patterns. If the sex differences do not disappear when controlling for body size, then the sex-differences-in-activity-patterns explanation is strengthened within specific studies. Finally, it is important to note that it is complicated to determine whether sex differences are a result of size differences, which can lead to differences in activity patterns, or whether the reverse is true.

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

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TABLE 1. Sample size, where *L* refers to number of individuals with complete left lower limb bones, *R* refers to number of individuals with complete right lower limb bones. *B* refers to number of individuals with complete right and left lower limb bones available, and total refers to total number of complete bones examined

	Males						Females						Total
	Femur			Tibia			Femur			Tibia			
	L	R	B	L	R	B	L	R	B	L	R	B	
BC Amerinds	1	4	30		8	26		2	15	5		12	103
Euroamericans		1	20			14			2			1	38
Total	1	5	50		8	40		2	17	5		13	141

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

In this same vein, Zumwalt et al. (2000) examined upper and lower limb bones from nonhuman primates and found that muscle markers correlated with body weight and did not vary with locomotor type, raising the question of whether human research should take body size into account. Additionally, Weiss (2003) examined human upper limbs and found that they correlated with upper limb size; however, these correlations became insignificant when controlling for age and sex. Since human upper limbs are free of locomotor responsibilities and, as a result, are not weight-bearing, 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.

Other anthropologists voiced concerns over the lack of objectivity when collecting muscle marker data and using these data to infer activity patterns (Jurmain, 1990, 1999; Stirland, 1998). Work by Hawkey and Merbs (1995) and Robb (1998) responded to some of the criticism by Jurmain (1990) and Stirland (1998) by formulating less subjective ways of collecting muscle marker data. Weiss (2003) advised that the use of aggregated muscle marker variables can improve muscle marker studies by enhancing construct validity and reducing error variance in the data. For more in-depth discussions of muscle marker issues, see Jurmain (1999), Robb (1998), Stirland (1998), and Weiss (2003).

This study uses aggregate muscle markers to attempt to determine whether lower limb muscle markers are affected by body size (like upper limb muscle markers, or more so), whether the sex difference in muscle markers is related to size, and whether age differences are the best predictor of lower limb muscle markers (as they were for upper limb muscle markers; Weiss, 2003).

MATERIALS AND METHODS

Sample

A skeletal sample of 77 adult individuals (57 males; 20 females), ranging from 18–69 years of

age, from two populations (Euroamericans and British Columbian Amerinds) housed at the Canadian Museum of Civilization (Hull, Quebec), was examined (Table 1). This is a subset of the individuals used in Weiss (2003). Cybulski (1988, 1990, 1992) sexed the individuals using pelvic and cranial indicators. He also aged them by means of the pubic symphysis, ilium auricular surface, cranial suture closure, dental development, and epiphyseal union of long bones, clavicles, vertebrae, and innominates (Cybulski, 1988, 1990, 1992). Individuals were excluded if they were not sexed or aged, if they lacked any lower limb bones, 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 3,500–1,300 years 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 and Cybulski, 1997; Weiss, 2001).

Methods

This study used z-scores to create two composite (or aggregate) variables: lower limb muscle marker, and lower limb size. The lower limb muscle marker composite was created by averaging the z-scores for 80 component variables (a total of 20 muscle markers from 14 femoral insertion sites and 6 tibial insertion sites, with each marker scored in the two categories of robusticity and stress lesions, and with right and left lower limb bone scores added together). Gluteus maximus, gluteus medius, adductor magnus, vastus intermedius, vastus medialis, piriformis, gluteus minimus, obturator externus, quadratus femoris, popliteus, vastus lateralis, gastrocnemius, iliopsoas, and pectineus muscle markers were scored on the femur (Table 3). Soleus, popli-

TABLE 3. Muscle marker insertion sites used in lower limb muscle marker variable

Femoral sites	Tibial sites
Gluteus maximus	Soleus
Gluteus medius	Popliteus
Adductor magnus	Semimembranosus
Vastus intermedius	Tibialis posterior
Vastus medialis	Flexor digitorum
Piriformis	Tibialis anterior
Gluteus minimus	
Obturator externus	
Quadratus femoris	
Popliteus	
Vastus lateralis	
Gastrocnemius	
Iliacus	
Pectineus	

teus, semimembranosus, tibialis posterior, flexor digitorum, and tibialis anterior muscle markers were scored on the tibia (Table 3). These sites were chosen because: 1) they are easily distinguishable; 2) they are all tendinous muscle sites; and 3) they were used in the literature in lifestyle reconstruction (e.g., Hawkey, 1998; Lai and Lowell, 1992; Steen and Lane, 1998).

The methods employed by Hawkey and Merbs (1995) for characterizing muscle markers were used on the 20 muscle sites. These methods were chosen because: 1) the interobserver and intraobserver error rates are low; 2) the scoring establishes identifiable thresholds for each score; and 3) the guidelines for scoring muscle markers are straightforward, with photographs illustrating various scores. Each muscle insertion site was scored on two dimensions: 1) robusticity and 2) stress lesion. Within these categories are four specific grades, with absence of expression being grade 0. However, the categories are more accurately treated as a continuum. Thus, after scores were taken separately, they were converted from 0–3 in each category to 0–6 in one category, with 0 being the lowest robusticity, and 6 being the greatest stress lesion.

The robusticity category describes the normal variation in areas where muscles attach. In robusticity grade 1 (R1), the outer portion of the bone is only slightly rounded with elevation apparent when touched, although no distinct crests or ridges are present. In robusticity grade 2 (R2), the outer portion of the bone is uneven, with a mound-shaped elevation clearly visible. In robusticity grade 3 (R3), distinct sharp crests or ridges are present, and there may be a small depression between crests, although this depression does not extend into the cortex or the outer portion of bone.

The stress lesion category is defined as pitting into the cortex. Stress lesion grade 1 (S1) is shallow pitting into the cortex, less than 1 mm in depth. In stress lesion grade 2 (S2), the pitting is between 1–3 mm in depth and covers a greater surface area, although not longer than 5 mm. In stress lesion grade 3 (S3), pitting is greater than 3 mm in depth and more than 5 mm in length.

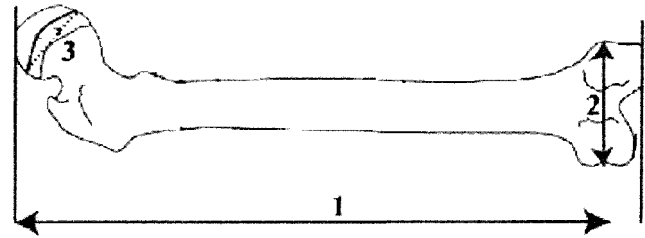


Fig. 1. Measurements of left femur, anterior view. 1, maximum length; 2, epicondylar breadth; 3, maximum head diameter (modified from Buikstra and Ubelaker, 1994).

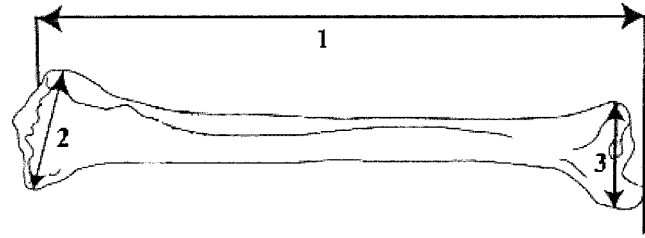


Fig. 2. Measurements of left tibia, anterior view. 1, length; 2, maximum proximal epiphyseal breadth; 3, maximum distal epiphyseal breadth (modified from Buikstra and Ubelaker, 1994).

A 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; Fig. 1) and three tibial size variables (length, maximum proximal epiphyseal breadth, and maximum distal epiphyseal breadth; Fig. 2) (Buikstra and Ubelaker, 1994). The composite variable of lower limb size was calculated with data that were side-averaged by adding the right and left values and dividing the value by two; when both sides were not available, the available data were used. To allay concerns over averaging left and right lower limb bones, correlations for the right and left bones were carried out. Pearson correlations between the various size properties for the left and right lower limb bones ranged from 0.71–0.99 (mean $r = 0.97$, $P < 0.01$). With these high correlations, the author felt justified in combining left and right lower limb bones for the purpose of this study.

Table 4 lists the six size variables that entered into the composite lower limb size, along with the sample size for each, the range for the variables, and the means and standard deviations.

Due to the nature of skeletal material, missing data are inevitable. When data were missing, the composite variables of lower limb muscle marker and lower limb size were calculated by adding the z-scores of all available measures and then dividing the sum by the number of measures added. Fourteen percent of the data was missing in the lower limb muscle marker variable. Ten percent of the data was missing in the lower limb size variable.

TABLE 4. Sample sizes, minimum values (mm), maximum values (mm), means (mm), and SDs for size variables that went into composite lower limb size

	N	Minimum	Maximum	Mean	SD
Femoral length	66	355.00	510.00	426.12	34.38
Femoral epicondylar breadth	70	66.00	89.50	79.20	5.90
Femoral head diameter	71	38.06	51.92	46.00	3.60
Tibial length	57	290.50	426.00	345.84	30.13
Tibial maximum proximal epiphyseal	61	60.75	83.99	73.11	5.44
Tibial maximum distal epiphyseal	63	35.97	60.42	50.34	5.49

Statistical analysis

The data were analyzed using the statistical software program SPSS (version 11.5; SPSS, Inc., 1988).

The data used here were tested for violations of assumptions of parametric tests. Independence of the variants will be handled through the use of adjusted error rates with critical alpha levels varying, depending on the number of correlations per matrix; the formula used was (0.10/number of tests) (Weiss and Hassett, 1982). Homogeneities of variances were tested through the Levene statistic test. A significance level greater than 0.05 signifies homogeneous variance. The variables were homogeneous (significances were 0.08 and 1.01). To test whether the data were normally distributed, the Kolmogorov-Smirnov test was run, which is an appropriate test for skeletal samples because it “focuses on the greatest observed differences between two cumulative frequency distributions, loss of information from tied data is minimized” (Lovejoy, 1971, p. 105). Additionally, the Kolmogorov-Smirnov test combines high-power efficiency (about 0.96) with a central expression of skewness, central tendency, and dispersion (Lovejoy, 1971). A significance value less than 0.05 indicates that the distribution of the data differs significantly from a normal distribution. The variables were normally distributed (significances were 0.14 and 0.86). Thus, the aggregate measures met all the assumptions required to run parametric tests, and the relationships between the variables were linear.

For each composite variable, means and standard deviations were calculated. The composite variable lower limb muscle marker was correlated using two-tailed Pearson tests with composite variable lower limb size, 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 and Hassett, 1982). Pearson tests were run separately for males and females on correlations between lower limb muscle marker and lower limb size, and age. Partial Pearson correlations controlling for age, sex, and lower limb size were also run to determine causes of muscle markers. Critical alpha levels varied, depending on the number of correlations per matrix, nonsignificant findings are indicated as “n.s.” Additionally, a stepwise regression analysis (with an ANOVA to show significant variances) was run to test which

TABLE 5. Means, SDs, and sample sizes for composite lower limb muscle marker and lower limb size (z-scores), separately for males and females

Property	Mean	SD
Lower limb muscle marker		
Males (n = 57)	0.4223	0.9
Females (n = 20)	-1.0829	0.4
Lower limb size		
Males (n = 57)	0.1394	0.4
Females (n = 20)	-0.3514	0.4

TABLE 6. Pearson correlation coefficient table of lower limb muscle marker (LLMM), lower limb size (LLS), age, and sex

	LLMM	Age	LLS	Sex
LLMM correlation	1.000	0.609**	0.522**	0.492**
Age correlation	0.609**	1.000	0.276*	0.108
LLS correlation	0.522**	0.276*	1.000	0.658**
Sex correlation	0.492**	0.108	0.658**	1.000

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

factor best predicts the lower limb muscle marker scores (McCall, 1990).

RESULTS

Table 5 presents the means, standard deviations, and sample sizes for the composite variables used in this study, i.e., lower limb muscle marker and lower limb size, in z-scores. Lower limb muscle marker correlates significantly with age, $r = 0.609$; lower limb size, $r = 0.522$; and sex, $r = 0.492$; $P < 0.001$ (Table 6).

In males, lower limb muscle marker correlates significantly with lower limb size ($r = 0.305$, $P < 0.05$) and age ($r = 0.651$, $P < 0.001$). In females, lower limb muscle marker correlates significantly with age ($r = 0.626$, $P < 0.01$), but no longer with lower limb size ($r = 0.360$, n.s.).

Since lower limb muscle marker is correlated with age and sex, partial correlations were carried out to reexamine correlations after controlling for age, sex, and both. When age is controlled for, lower limb muscle marker continues to correlate significantly with sex ($r = 0.541$, $P < 0.001$) and lower limb size ($r = 0.464$, $P < 0.001$). When sex is controlled for, lower limb muscle marker still correlates significantly with age ($r = 0.642$, $P < 0.001$) and lower limb size ($r = 0.302$, $P < 0.01$). When age and sex are controlled for, lower limb muscle marker no longer correlates significantly with lower limb size ($r = 0.172$, n.s.).

TABLE 7. Regression analysis of lower limb muscle marker, lower limb size, age, and sex ($N = 77$)

Model	R	R ²	Adjusted R ²
1) Age	0.609	0.370	0.362
2) Age and sex	0.745	0.555	0.297

TABLE 8. ANOVA of predictor models from regression analysis ($N = 77$)

Model	Sum of squares	df	F
1) Age			
Regression	5.454	1	44.12***
Residual	9.272	75	
Total	14.727	76	
2) Age and sex			
Regression	8.166	2	46.05***
Residual	6.561	74	
Total	14.727	76	

* $P < 0.001$.

Since lower limb size and sex correlate significantly ($r = 0.658$, $P < 0.001$), a partial correlation controlling for size was run to determine whether the sex differences are related to size, rather than activity patterns. When controlling for lower limb size, sex still correlates significantly with lower limb muscle marker ($r = 0.231$, $P < 0.05$).

A regression analysis was carried out to determine what the best predictor of lower limb muscle marker is from the variables in this study, i.e., lower limb size, age, and sex. Table 7 presents the results and shows that age is the overall best predictor. The predictions become higher when sex is entered into the equation. Table 8 presents the ANOVA analysis of these models, which shows the F-ratios and significance levels for the various models.

Since previous studies examined relations within specific populations, the correlations here were also run on each population separately. The correlations remained significant (i.e., in the British Columbian sample, lower limb muscle marker correlated with age, $r = 0.65$; sex, $r = 0.46$; and lower limb size, $r = 0.54$, $P < 0.001$; in the Euroamerican sample, lower limb muscle marker correlated with age, $r = 0.58$, and lower limb size, $r = 0.35$, $P < 0.05$). Due to the small female sample size in the Euroamerican sample ($n = 2$), lower limb muscle marker was not correlated with sex.

To summarize the findings using graphs, see Figures 3–5. Figure 3 shows the rise in muscle marker scores with age; Figure 4 shows the regression line of muscle marker scores and size; and Figure 5 shows the difference in muscle marker scores between males and females.

DISCUSSION

This study found aggregate lower limb muscle marker correlated with: age, $r = 0.62$; size, $r = 0.59$; and sex, $r = 0.46$; $P < 0.001$. As predicted by Weiss (2003), lower limb muscle markers correlate with

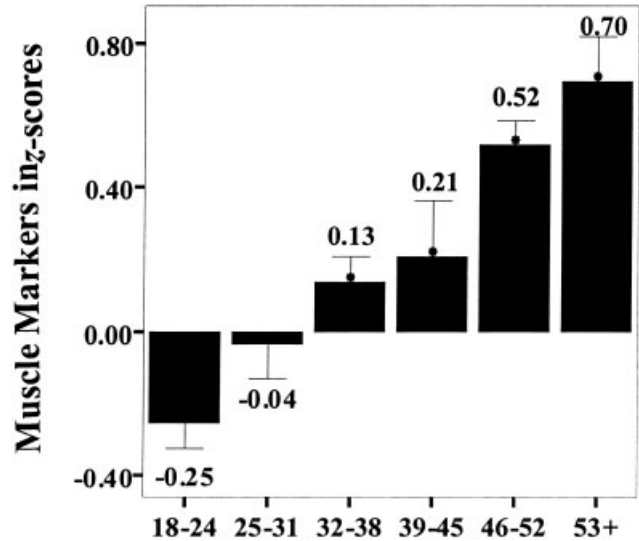


Fig. 3. Age differences in lower limb muscle markers (in z-scores). Bars show means ± 1.0 SE. Sample sizes: 18–24, 20 males and 9 females; 25–31, 12 males and 3 females; 32–38, 13 males and 4 females; 39–45, 4 males and 0 females; 46–52, 4 males and 0 females; 53+, 4 males and 0 females.

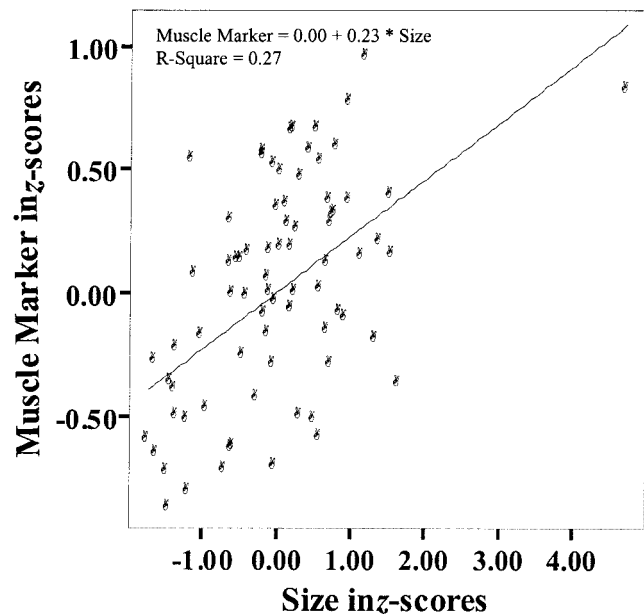


Fig. 4. Regression line for lower limb muscle marker and lower limb size (both in z-scores).

size to a greater extent than upper limb muscle markers. Furthermore, when controlling for sex, the muscle marker and size correlations are still significant, but to a lesser degree, most likely because sex and size are so highly correlated. Muscle markers also correlate again with age, which is the best predictor of muscle markers.

This study found that age was the single best predictor of lower limb muscle markers; age was also the best predictor of upper limb muscle markers (Weiss, 2003). Older individuals had higher muscle marker scores than did younger individuals. This

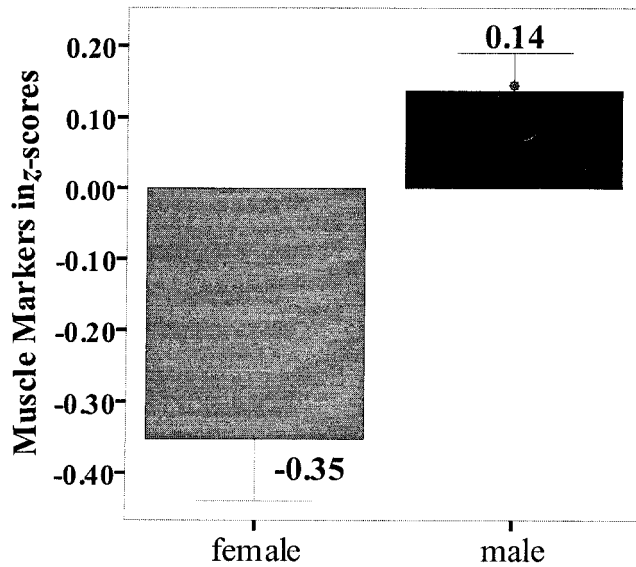


Fig. 5. Sex differences in lower limb muscle markers (in z-scores). Bars show means \pm 1.0 SE.

finding held for both sexes separately. The correlation with age and muscle markers corroborates many other studies (e.g., Chapman, 1997; Kennedy, 1983, 1989; Nagy, 1998; Robb, 1998; Weiss, 2003; Wilczak, 1998). Many anthropologists hypothesize that older individuals have more muscle markers than younger individuals because they have experienced more stress over a lifetime of activities. Age differences also could be related to changes in bone structure due to the slowing down of bone remodeling, resulting in a thinner cortical bone with a greater diameter and rougher external bone (Dewey et al., 1968; Mays, 2000). The causes of higher muscle marker scores in older individuals need to be examined more thoroughly.

Results from this sample also showed that, in using the composite measure of lower limb size as a predictor variable, individuals with larger lower limbs had higher muscle marker scores than did individuals with smaller lower limbs, a pattern that remained when controlling for age and sex, but not when controlling for both age and sex together. The lower limb size and lower limb muscle marker correlation extends earlier work by Weiss (2003) that showed that upper limb muscle markers are correlated with humeral size. Furthermore, the correlation in this study was sufficiently strong to hold within males, but it did not hold within females. This lack of a significant correlation between lower limb size and lower limb muscle marker within females is most likely due to the small sample size ($N = 20$), because the correlation coefficient was still fairly high ($r = 0.36$). When sex was controlled for through a partial correlation, lower limb muscle markers and size continued to correlate significantly, but the correlation coefficient was reduced by nearly half, suggesting that some of the sex differences in muscle markers are related to size differ-

ences. It is important to note that sex and size were highly correlated ($r = 0.66$; $P < 0.001$). In summary, a stronger effect was found with size in lower limb muscle markers than in upper limb muscle markers.

Males had higher muscle marker scores than did females, a finding that is well-established in the literature (although some studies found females with higher muscle marker scores than males, e.g., Chapman, 1997; Nagy and Hawkey, 1995). Sex differences in muscle markers are often interpreted as due to sex differences in activity patterns (e.g., Chapman, 1997; Cook and Dougherty, 2001; Steen and Lane, 1998; Wilczak, 1998). Some anthropologists take care to make sure that age is not confounded with sex differences (e.g., Weiss, 2003). When age was controlled, males still had higher muscle marker scores than females. The data here support the hypothesis that males have higher muscle marker scores at least in part because of their size rather than activity patterns. Males are, on average, larger and heavier, and with more muscle mass than females, and size and sex were highly correlated in the sample studied here. When a partial correlation was carried out controlling for lower limb size, males and females still differed in muscle markers, but the correlation coefficient was reduced by half. In other words, in this study, the sex difference in muscle markers seems to be partly a result of sex differences in body size, and partly a result of activity patterns. However, small sample sizes make this study less than definitive, and more research is needed to disentangle the causes of muscle markers. Furthermore, some may argue that this is a substantial "chicken and egg issue" that needs to be examined. That is, it may be that the sex differences in muscle markers are related to activity patterns, and that the size difference is related to these activity patterns. This author thinks this is less likely: the size variable in this study was created using variables that do not remodel much as an effect of activity patterns. Nevertheless, this view needs to be considered, and more research is needed along these lines.

CONCLUSIONS

Lower limb muscle markers, like upper limb muscle markers, correlate with age, size, and sex in this sample from British Columbia and Quebec. Older individuals had higher muscle marker scores than did younger individuals; individuals with larger lower limbs had higher muscle marker scores than did individuals with smaller lower limbs; and males had higher muscle marker scores than did females. This study extends previous research suggesting that age and size should be taken into consideration when examining muscle markers. Finally, the confound of body size and sex should be noted, and one should be careful when assigning muscle marker differences to sexual division of labor.

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