WILEY InterScience® DISCOVER SOMETHING GREAT

AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 133:931–940 (2007)

Muscle Markers Revisited: Activity Pattern Reconstruction With Controls in a Central California Amerind Population

Elizabeth Weiss*

Anthropology Department, San Jose State University, San Jose, CA 95192-0113

KEY WORDS musculoskeletal stress markers; body size; activity patterns

ABSTRACT Anthropologists frequently use musculoskeletal stress markers to reconstruct past activity patterns. Yet, researchers have called into question the reliability of muscle marker measurements in part because body size and age affect muscle marker scores. In this study, the author examined an aggregate upper limb muscle marker to determine if after controlling for the effects of body size and age, one could reconstruct activity patterns of a prehistoric Amerind population. Analyses were made of a sample of 102 (43 males, 59 females) prehistoric central California Amerinds. Muscle markers were measured using two-point observer rating scales; body size was measured by humeral articular surfaces; age and sex were determined previously through standard procedures. Using sex separated rankings and partial correlations, disaggregated muscle markers were examined for correlations with age and size to determine if specific muscle markers may be useful in pinpointing to activity patterns. Aggregate upper limb muscle marker correlated with: age, $r = 0.44$; humeral size, $r = 0.44$; and sex, $r = 0.43$; Ps < 0.001. Older individuals had greater muscle markers, as did larger individuals, and males. Rankings seemed to be confounded by the effect size had on the muscle markers. However, based on partial correlations controlling for size and age, the differences that remained between males and females could be used to reconstruct male activities of throwing in hunting and interpersonal aggression acts. Am J Phys Anthropol 133:931–940, 2007. ©2007 Wiley-Liss, Inc.

Muscles leave distinct markers on bones where the muscle, tendon, or ligament inserts into the blood-supplying periosteum and the underlying bony cortex. These markings are known as muscle markers or musculoskeletal stress markers. According to bone remodeling theory 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; Woo et al., 1981; Weiss, 2003, 2004; Ruff et al., 2006). Bones experience forces from muscle use throughout an individual's life to which the bone must respond to prevent breakage. Theoretically, muscle use is important in remodeling bones and maintaining strength because muscle usage places the stress on bones necessary to activate osteoblasts (Hamill and Knutzen, 1995). Where muscles attach, activity increases bones robusticity. Consequently, anthropologists typically view more pronounced muscle markers as being the direct result of muscle use.

Anthropologists have concluded using bone remodeling theory that large muscle markers are due to of continued muscle use in daily and repetitive tasks (especially when started at a young age and continued through adulthood), which has made muscle markers ideal for reconstructing past lifestyles. In the last two decades, anthropologists using muscle markers have addressed issues regarding sexual division of labor, group differences in specific activities related to culture, effects of agriculture on past populations, plus others (e.g., Cohen, 1989; Lai and Lovell, 1992; Hawkey and Merbs, 1995; Chapman, 1997; Hawkey, 1998; Peterson, 1998; Nagy, 1999; Cook and Dougherty, 2001; Toyne, 2003; al-Oumaoui et al., 2004; Eshed et al., 2004; Hayden et al., 2004; Papathanasiou, 2005; Salles et al., 2005; Drapeau, 2006; Jones et al., 2006; Molnar, 2006; Zabecki, 2006).

Some clear patterns in muscle marker research have emerged regardless of the population examined. Researchers, for instance, consistently find that 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; e.g., Molnar, 2006). Anthropologists using muscle markers to reconstruct past lifestyles frequently consider age differences to enable accurate reconstructions (e.g., Hawkey and Merbs, 1995; Nagy and Hawkey, 1995).

Sex differences have also emerged in skeletal studies of muscle markers; males have higher muscle marker scores than females in most skeletal samples (e.g., Cohen, 1989; Hawkey and Street, 1992; Steen and Lane, 1998; Nagy, 1999; Cook and Dougherty, 2001; Molnar, 2006). Higher muscle marker scores in females than in males have been noted in several specific populations (Nagy and Hawkey, 1995; Chapman, 1997; al-Oumaoui et al., 2004); when reverse sex patterns are present, these differences are more likely due to activity patterns since they are the exception to the rule (see Weiss,

*Correspondence to: Elizabeth Weiss, Anthropology Department, San Jose State University, One Washington Square, San Jose, CA 95192-0113, USA. E-mail: eweiss@email.sjsu.edu

Received 30 April 2006; accepted 29 January 2007

DOI 10.1002/ajpa.20607
Published online 9 May 2007 in Wiley InterScience (www.interscience.wiley.com).

2004). Yet, these differences may disappear, if one employs aggregate variables in the studies. Anthropologists most often attribute sex differences to differences in activity patterns (e.g., Chapman, 1997; Peterson, 1998; Wilczak, 1998; Cook and Dougherty, 2001; Molnar, 2006). Weiss (2003, 2004), however, examined sex differences in muscle markers in two populations and found that males had higher muscle marker scores than females, but this sex difference disappeared when controlling for size. It is, therefore, possible that sex differences in muscle markers are often due to differences in body size, rather than activity patterns. If the sex differences do not disappear when controlling for body size, then attribution of sex differences to activity patterns strengthens. 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.

Zumwalt et al. (2000) and Zumwalt (2006) have highlighted further difficulties in using muscle markers to reconstruct activity patterns. In the 2000 study, they 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. Furthermore, in her 2006 article, Zumwalt tested whether muscle markers increase in exercised sheep; she found no evidence of a correlation between muscle markers and the exercise. Zumwalt (2006), nonetheless, pointed out that perhaps the sheep were too mature or that the exercise was not strenuous enough for changes to be significant.

As mentioned in earlier works (Weiss, 2003, 2004), anthropologists have concerns over the lack of objectivity when collecting data on muscle markers and using these data to reconstruct activity patterns (Jurmain, 1990, 1999; Stirland, 1998; Zumwalt, 2005). Work by Hawkey and Merbs (1995) and Robb (1998) have standardized less subjective ways of collecting muscle marker data, some of which the author uses in the present study. Plus, Weiss (2003) advised the use of aggregated muscle marker variables to 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). Zumwalt (2005) has suggested using three-dimensional laser computer technologies, as anthropologists have used in dental studies, to quantify muscle markers more objectively, but this is an expensive and time-consuming alternative. One of the benefits of muscle marker studies has always been the relative low cost and ease of data collection.

Since the above-mentioned studies (especially, Weiss, 2003, 2004, Zumwalt et al., 2000) drew attention to complications of using muscle markers to reconstruct activity patterns, there has been little change to the way muscle markers are studied. As mentioned previously, Zumwalt (2005) has been exploring the use of some computerized laser methods. Ranking is another method that anthropologists are beginning to use to settle questions about sex differences. Eshed et al. (2004), for example, employed ranking methods in their study of muscle markers in Levant Natufian hunter-gatherers compared to muscle markers of Neolithic farmers in the Levant. Using rankings, the authors noticed the farmers had higher upper limb muscle marker scores than did the hunter-gatherers. Furthermore, males and females had differences in muscle markers in both groups, which the authors attributed to sex differences in labor. Size differences, however, may explain some of these differences between males and females or even between the groups. Ranking helps to resolve some size issues, but only if the ranks do not correlate with size. Unfortunately, the skeletal preservation did not allow for aging; thus, age controls were also absent. It is also possible that the differences observed relate to age and size differences in the two populations.

Another recent study looked at muscle markers of 342 individuals from five populations to determine activity patterns in the Iberian Peninsula (al-Oumaoui et al., 2004). The authors found that after controlling for age females had lower muscle marker scores than males (with a few notable exceptions). They coupled the lower female scores to less walking and more domestic labor in females compared to males who engaged in agricultural activities. In addition, it appears that sexual dimorphism increased in Iberia throughout time, which the authors linked to a change in activity patterns. They failed to control for size differences, which may explain the difference in muscle markers in some populations where males are significantly larger than females. Perhaps, the earliest population was the least sexually dimorphic in body size as well as muscle markers.

Molnar (2006) examined muscle markers of 39 Stone-Age individuals on a Baltic Sea island. She scored muscle markers in various age groups to determine if archery, harpooning, and kayaking had a significant effect on upper limb morphology in the population. She found when examining muscle markers related to these activities, males had higher muscle marker scores than did females. Without body size controls, it is not possible to determine whether these differences between males and females are related to activity or simply due to larger male body sizes compared to females.

It has been several years since Zumwalt et al. (2000) and Weiss (2003, 2004) have demonstrated that muscle markers correlate with body size. Still, muscle marker studies continue without controlling for body size (al-Oumaoui et al., 2004; Eshed et al., 2004; Drapeau, 2006; Jones et al., 2006; Molnar, 2006; Zabecki, 2006). The present study uses both aggregated muscle markers and separate muscle markers with size and age controls to attempt an activity reconstruction using the remaining significant sex differences. First, I will determine whether size and age correlate with muscle markers in this California population. Then, I will control for the effects of size and age on muscle markers to determine any remaining sex differences, which one may use to reconstruct activity patterns.

MATERIALS AND METHODS

Sample

The skeletal sample consists of 102 adult individuals (43 males; 59 females) ranging from 16 to 50 years of age from a California site (CA-Ala-329) located on the southeastern side of the San Francisco Bay dating from 2180 to 250 years BP (which is pre-European contact) housed at San José State University Anthropological Collection (Tables 1 and 2).

Jurmain (1990) aged and sexed individuals according to standard osteological procedures. Individuals were excluded if they were not sexed or aged, if they lacked upper limb bones, or if they were immature. Jurmain (1990) reported ages in ranges of 5–10 years. As an aside, the preservation of this collection is excellent;

TABLE I. Sample size displaying age and sex distribution

Age group	Males	Females	Total
Young adult (16–25)	4	6	10
Adult (26–34)	15	16	31
Old adult (35 and older)	24	37	61
	43	59	102

TABLE II. Sample demographics

Dates (in years BP)	Age range (in years)	Median age (in years)	Number of males	Number of females
2,180–250	16–50	36–40	43	59

nearly all individuals examined had a complete set of upper limbs.

The Ryan Mound Site (CA-Ala-329) contained numerous indicators of rich environmental resources (Leventhal, 1993). The site contained large quantities shellfish, waterfowl, and mammal bones (Leventhal, 1993). Additionally, Amerinds utilized acorns, berries, and seeds as indicated by the numbers of mortars, pestles, and refuse found around the site (Leventhal, 1993). Obsidian points, along with shafts and other types of hooks and harpoons, were in abundance at CA-Ala-329; most of these artifacts (especially the obsidian points) were associated with male burials (Leventhal, 1993). This possibly indicates the emphasis on hunting as a male activity; whereas, females were more likely to be buried with pestles and cobblestone (Leventhal, 1993).

The Amerinds from CA-Ala-329 were hunter-gatherers with a heavy reliance on acorns and supplemented by hunted foods (Jurmain, 19901993; Leventhal, 1993). Although the time span is great, there seems to have been cultural continuity as indicated by similarities in mortuary practices and artifacts (Leventhal, 1993).

The remains at CA-Ala-329 represent high lineage or wealthy individuals from various villages. Villagers were not isolated from other villagers as indicated by lack of artifactual and mortuary differences (Leventhal, 1993). A downside to the population density was the high levels of interpersonal aggression (Jurmain, 1988; Jurmain and Bellefemine, 1997). From the skeletal remains and archaeological material, it is known that these Amerinds used shafted obsidian points in hunting and aggressive acts (Jurmain, 1988, 1990, 1993; Leventhal, 1993; Jurmain and Bellefemine, 1997).

METHODS

This study created two aggregate variables—upper limb muscle marker and humeral size. Aggregate upper limb muscle marker was created by adding ordinal scores of muscle markers (which are explained below) and then transforming these additive scores for each individual into a rank. Individuals with the most well-defined or largest muscle markers had the highest rankings. This is a nonparametric procedure that one can use for Spearman correlations (Aron et al., 2005). The upper limb muscle marker variable was calculated by adding ordinal scores from seven muscle markers for left and right arms. The muscle marker scores for were made up of 28 component variables (a total of seven muscle markers from four humeral insertion sites, two radial insertion sites; and one ulnar insertion site, with each marker scored in the two categories of robusticity and stress lesions with right and left upper limb bone scores added together) (Hawkey and Merbs, 1995). *Deltoid*, *latissimus dorsi*, *pectoralis major*, and *teres major* muscle markers were scored on the humerus (Fig. 1, left). *Biceps brachii* and *supinator* muscle markers were scored on the radius (Fig. 1, center). *Triceps brachii* muscle marker was scored on the ulna (Fig. 1, right). All of the scores consisted of insertion sites. The tendinous muscle sites are *deltoid*, *latissimus dorsi, teres major, biceps brachii, supinator,* and *triceps major.* The muscle to bone insertion site is the *pectoralis major.* These sites were chosen because: 1) they are easily distinguishable; 2) they have been associated with specific activities in the literature (e.g., Nagy, 1999; Molnar, 2006); and 3) they have been used frequently and recently in lifestyle reconstruction (e.g., Kenney, 1983, 1989; Peterson, 1998; Robb, 1998; Capasso et al., 1999; al-Oumaoui et al., 2004; Eshed et al., 2004; Papathanasiou, 2005; Salles et al., 2005; Molnar, 2006).

Hawkey and Merbs (1995) methods for characterizing muscle markers were used on the seven muscle sites. These methods were ideal because: 1) the inter-observer and intra-observer 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; and, 4) most of the previously mentioned muscle marker studies employ these methods (Hawkey and Merbs, 1995). The author scored each of the muscle insertion sites on two dimensions: 1) robusticity and 2) stress lesion. Within these categories, there are four specific grades with the absence of the expression being Grade 0. However, the categories are actually on a continuum. Thus, after the scores were taken separately, they were converted from 0 to 3 in each category to 0 to 6 in one category, with 0 being the lowest robusticity and 6 being the greatest stress lesion. Muscle marker scores are, therefore, on an ordinal scale of 0 to 6. For more information on this method, see Hawkey and Merbs (1995).

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 mm and 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.

By adding the z-scores for humeral length, humeral vertical head diameter, and humeral epicondylar breadth, the author created an aggregate variable of humeral size (Fig. 2; Buikstra and Ubelaker, 1994). All humeral measurements were taken according to the *Standards: For data collection from human skeletal remains* procedures (Buikstra and Ubelaker, 1994). These component traits are good proxies for body size, because they do not remodel as readily as shaft dimensions (Ruff et al., 1991). Humeral size was calculated

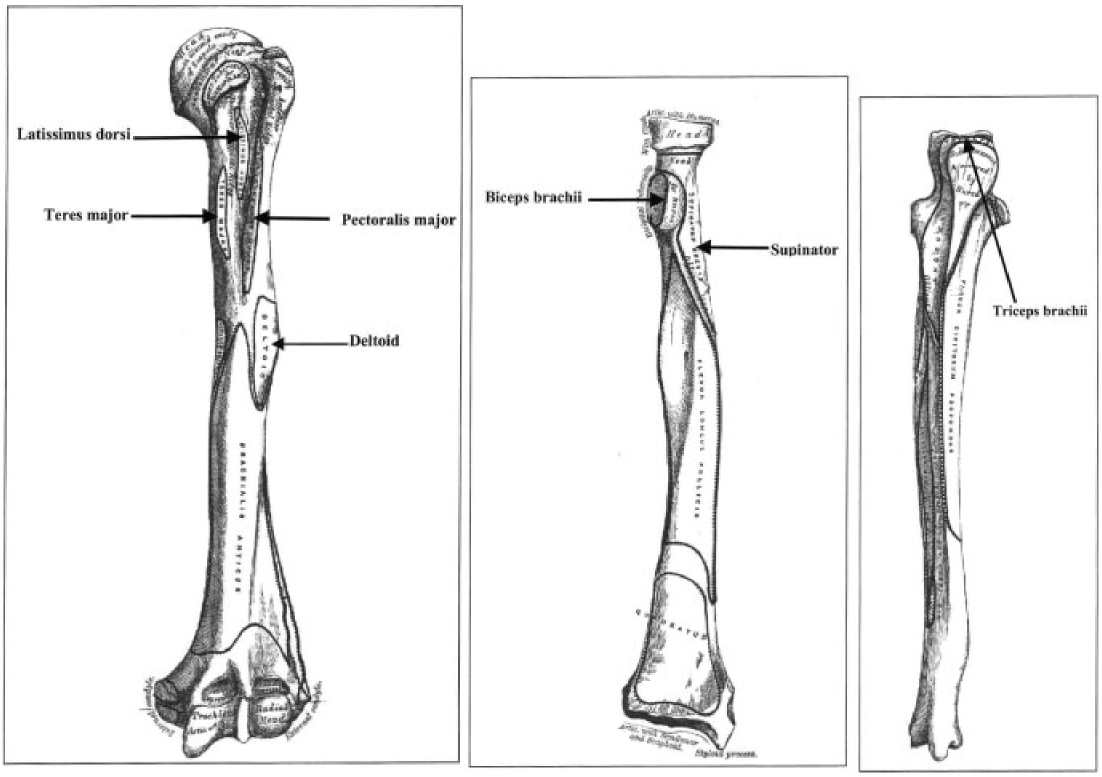

Fig. 1. Muscle markers on the left humerus anterior view, left radius anterior view, and left ulna, posterior view (reproduced from Gray, 1977).

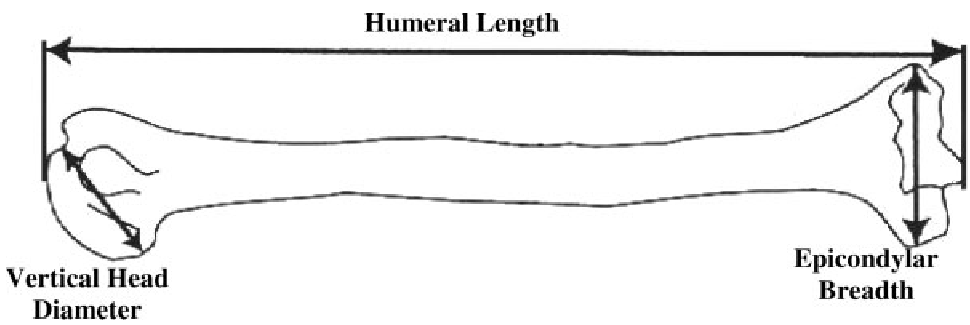

Fig. 2. Measurements of the left humerus, anterior view (modified from Buikstra and Ubelaker, 1994).

with data that was side-averaged following Ruff and Larson (1990). When one side was not present, the author utilized data from the available side.

To allay concern over averaging left and right arm bones (since bilateral asymmetry is common in arm bones), correlations for the right and left arm bones were carried out. Pearson correlations between the various size properties for the left and right arm bones range from 0.96 to 0.99 (mean $r = 0.98$, $P < 0.001$). Pearson correlations between the left and right muscle markers ranged from 0.67 to 0.84 (mean $r = 0.73$, $P < 0.01$). With these high correlations, the author felt justified in combining left and right arm bones for the purpose of this study.

Because of the nature of skeletal material, missing data are inevitable. For missing data on any of the elements that went into the aggregate variables, an average score based on all remaining data substituted that variable (less than 1% of the data was replicated by means). This procedure tends to homogenize scores and, thereby, reducing differences and lessening the chance of getting a significant effect.

Statistical analysis

The data were analyzed using the statistical software program SPSS (Version 14.0). For aggregate humeral size, means and standard deviations were calculated. Two-tailed nonparametric Spearman tests determined upper limb muscle marker correlations with aggregate variable humeral size, age (defined in three groups, 1 = 16–25 years old; 2 = 26–34 years old; 3 = 35–50 years old) and sex. Separate sex rank orders based on average rankings per muscle marker tested for different patterns between males and females. Then, the author compared these ranks with the effect of humeral size on each muscle marker to assess whether humeral size (i.e., the Spearman correlation coefficient) influenced the rankings. Partial Spearman correlations controlling for age and humeral size, between sex and the aggregate upper

TABLE III. Means, SDs, and sample sizes for aggregate humeral size (z-scores), separately for males and females

Property	Mean	SD
Humeral size		
Males (n = 43)	0.7386	0.3
Females (n = 59)	−0.0503	0.2

TABLE IV. Spearman correlation coefficient table of upper limb muscle marker (ULMM), humeral size (HS), age, and sex

		ULMM	Age	HS	Sex
ULMM	Correlation	1.000	0.439***	0.441***	0.425***
Age	Correlation		1.000	0.023	0.058
HS	Correlation			1.000	0.826***
Sex	Correlation				1.000

***P < 0.001.

limb muscle marker as well as separate muscle markers determined whether any sex differences remained that one could use to reconstruct activities. A multivariate factorial optimal scaling test was run as well to test for sex differences with age and humeral size controls. Critical alpha levels were set at 0.05.

RESULTS

Table 3 presents the means, standard deviations, and sample sizes for the aggregate variables used in this study i.e., upper limb muscle marker and humeral size. Upper limb muscle marker correlates significantly with age, humeral size, and sex (Table 4). Older individuals, larger individuals, and males have higher upper limb muscle marker scores than do younger individuals, smaller individuals, and females. Sex and humeral size correlates significantly as well (Table 4).

Since upper limb muscle marker is correlated with age, sex, and humeral size, partial correlations are carried out to re-examine correlations after controlling for age and humeral size. When controlling for age and humeral size, upper limb muscle marker correlates marginally with sex (r = 0.178, P < 0.08). These results suggest that one should disaggregate the upper limb muscle marker variable to determine patterns useful in activity reconstructions.

Table 5 presents each muscle marker correlation with humeral size, sex, and age. Humeral size correlates with muscle markers in all but the left supinators, left latissimus dorsi, left pectoralis major, and left teres major. Age correlates with all muscle markers, except for in the right triceps brachii. In all muscle markers, males have significantly higher muscle marker scores, but the results are not significant in the left latissimus dorsi, left pectoralis major, left teres major, left and right supinator.

Figures 3 and 4 present the rank orders of left and right muscle markers in males and females. Figure 5 presents the rank order of left and right muscle markers and their correlation with humeral size separated by side. These rank orders are compared to determine if the patterns are in part a result of humeral size. Results show that for left muscle markers the highest correlations with humeral size are also the highest ranked muscle markers, which reflects the high influence of humeral size on muscle markers. On the right side, however, the results are mixed. Some muscle markers that are highly correlated with size are ranked high in males and low in females, such as the deltoid. Other muscle markers with lower size correlations rank higher in females than in males, such as the pectoralis major. However, some muscle markers with high size correlations have low ranks in males and females, such as the latissimus dorsi. The mixed results for the right side along with the solid pattern on the left side suggests that humeral size confounds muscle marker rankings.

TABLE V. Spearman correlation coefficient table of disaggregated muscle markers, humeral size, age, and sex

		Humeral size	Age	Sex
Humeral Size	Correlation	1.000	0.023	0.826***
Age	Correlation		1.000	0.058
Sex	Correlation			1.000
Left Side				
Deltoid	Correlation	0.380***	0.261**	0.312***
Latissimus dorsi	Correlation	0.148	0.326***	0.165
Pectoralis major	Correlation	0.161	0.279**	0.222
Teres major	Correlation	0.224*	0.294**	0.240
Biceps brachii	Correlation	0.453***	0.405***	0.445***
Supinator	Correlation	0.220*	0.322***	0.205
Triceps brachii	Correlation	0.319***	0.231*	0.260**
Right Side				
Deltoid	Correlation	0.344**	0.314***	0.335***
Latissimus dorsi	Correlation	0.370***	0.283**	0.393***
Pectoralis major	Correlation	0.298**	0.272**	0.299**
Teres major	Correlation	0.357**	0.427***	0.358***
Biceps brachii	Correlation	0.357**	0.334***	0.307**
Supinator	Correlation	0.236*	0.326***	0.173
Triceps brachii	Correlation	0.399***	0.163	0.436***

***P < 0.001.
**P < 0.01.
*P < 0.05.

Finally, using a partial correlation controlling for humeral size and age, few muscle markers continue to correlate with sex (Table 6). Males have significantly higher muscle marker scores for the left pectoralis major, the right teres major, and the right latissimus dorsi (average r = 0.208, P < 0.05). The multivariate test results corroborate the partial correlation results (Table 7).

DISCUSSION

This study found aggregate upper limb muscle marker correlated with: age, r = 0.44; humeral size, r = 0.44; and, sex, r = 0.43; Ps < 0.001. Older individuals had higher muscle marker scores than did younger individuals. The correlation with age and muscle markers corroborates many other studies (e.g., Kennedy, 1983, 1989; Chapman, 1997; Nagy, 1998; Robb, 1998; Wilczak, 1998; Weiss, 2003, 2004; Molnar, 2006). Anthropologists have theorized that older individuals have greater muscle markers than younger individuals because they have experienced more muscle use over a lifetime of activities. Age differences also could be related to changes in bone structure due to reduction in osteoblast activity resulting in a thinner cortical bone with a greater diameter and a rougher external bone (Dewey et al., 1968; Mays, 2000). Anthropologists need to examine the causes of higher muscle marker scores in older individuals more thoroughly.

Results from this sample also showed that in using the aggregate measure of humeral size as a predictor

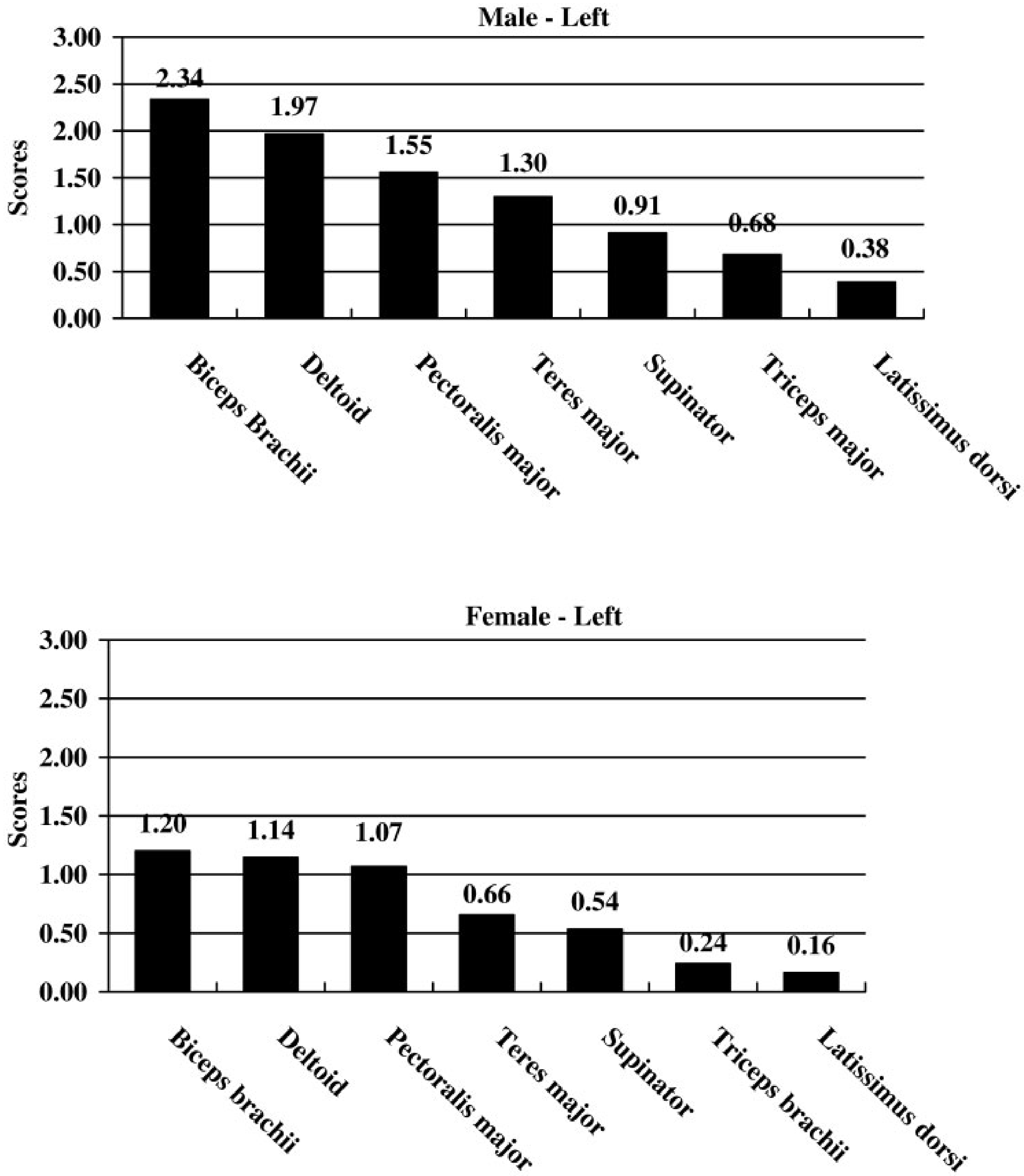

Fig. 3. Ranking of male (top) and female (bottom) left average muscle markers from highest score to lowest score.

variable that individuals with larger humeri had higher muscle marker scores than did individuals with smaller humeri. This humeral size and upper limb muscle marker correlation extends earlier work by Weiss (2003, 2004) and Zumwalt et al. (2000) that found muscle markers correlate with body size. Thus, the body size effect has been replicated in three human populations and in nonhuman primate samples. These results clearly imply that anthropologists need to employ body size controls when using muscle markers to reconstruct activity patterns. Without controlling for body size, one may draw faulty conclusions on activity patterns, especially when comparing sexes or different populations, or populations over time.

Males had higher upper limb muscle marker scores than did females, which is related in part to body size. Higher muscle marker scores in males is a finding well established in the literature (although some studies have found females with higher muscle marker scores than males, e.g., Nagy and Hawkey, 1995; Chapman, 1997). Many researchers interpret sex differences in muscle markers as due to sex differences in activity patterns (e.g., Cohen, 1989; Hawkey and Street, 1992; Steen and Lane, 1998; Nagy, 1999; Cook and Dougherty, 2001;

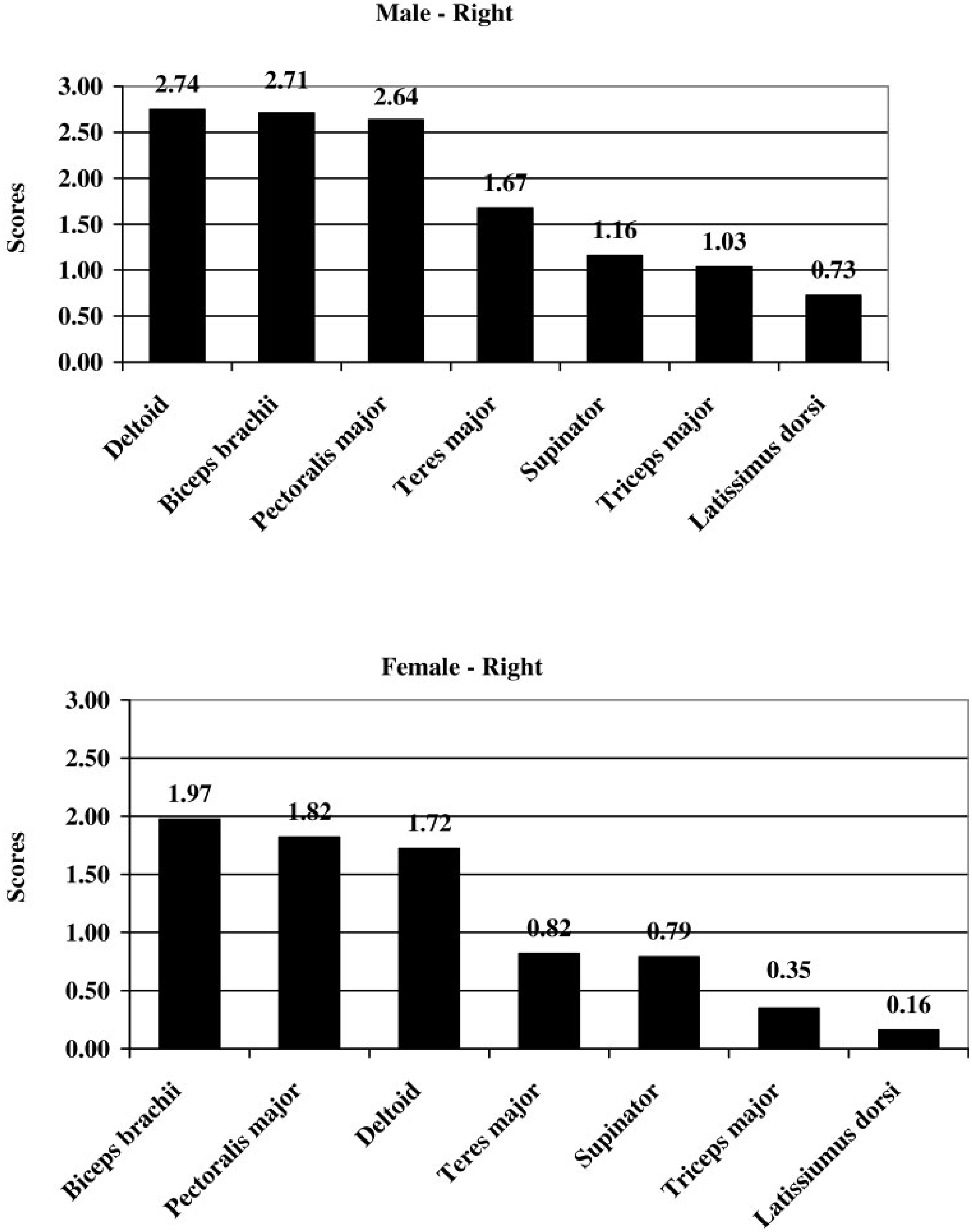

Fig. 4. Ranking of male (top) and female (bottom) right average muscle markers from highest score to lowest score.

al-Oumaoui et al., 2004; Molnar, 2006). Some anthropologists have taken care to make sure that age is not confounded with sex differences (e.g., al-Oumaoui et al., 2004; Molnar, 2006). 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, heavier, and have greater muscle mass than females, and size and sex were highly correlated in the sample studied here. Using a partial correlation controlling for humeral size and

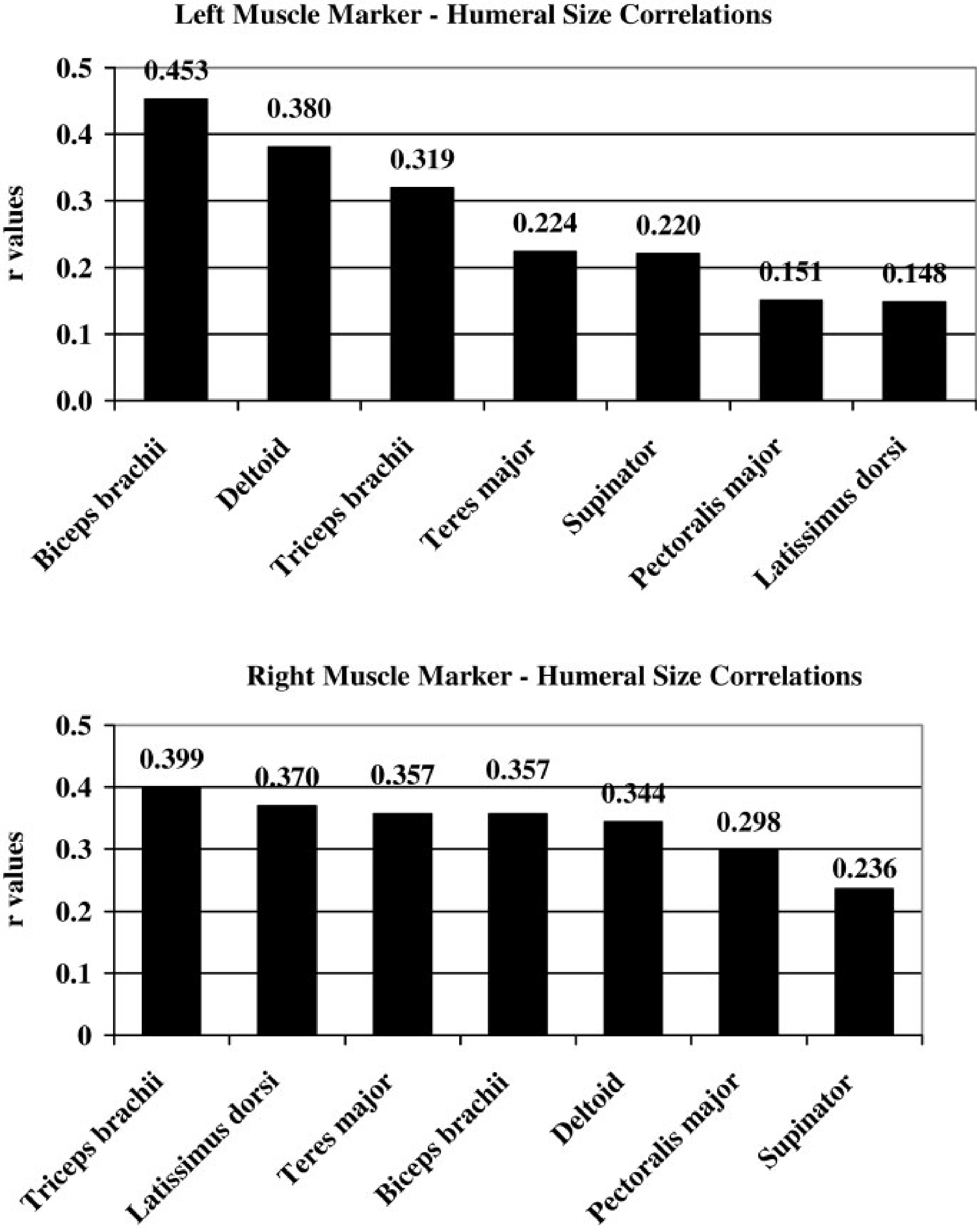

Fig. 5. Ranking of left (top) and right (bottom) muscle markers from highest correlation to lowest correlation with humeral size.

age, some of the muscle markers of males and females still differed. In other words, in this study, the sex difference in muscle markers seemed to be the partly result of sex differences in body size and perhaps partly because of activity patterns.

Since the aggregate upper limb muscle marker correlated with humeral size, but some of the sex differences were not be explained with size, the author ran additional tests on disaggregated muscle markers. When looking at muscle markers separately, the various muscle markers continued to correlate with age and size to differing degrees. Consequently, when muscle markers were ranked in males and females and compared to the effect of size on muscle markers, results showed that on the right side some high ranking muscle markers in females than in males were also the muscle markers that had low correlations with humeral size. On the left side, rankings and correlations with size were identical, which is a result of the high effect of size on rankings. These results suggest studies employing ranks (Eshed et al., 2004; Molnar, 2006) may still be catching a size rather than activity difference sometimes and a more

TABLE VI. Partial correlation coefficient table of muscle markers with sex while controlling for humeral size and age

		Sex
Left Side		
Deltoid	Correlation	0.034
Latissimus dorsi	Correlation	0.154
Pectoralis major	Correlation	0.219*
Teres major	Correlation	0.134
Biceps brachii	Correlation	0.191
Supinator	Correlation	0.078
Triceps brachii	Correlation	0.020
Right Side		
Deltoid	Correlation	0.128
Latissimus dorsi	Correlation	0.209*
Pectoralis major	Correlation	0.148
Teres major	Correlation	0.196*
Biceps brachii	Correlation	0.009
Supinator	Correlation	0.003
Triceps brachii	Correlation	0.194

*$P < 0.05$.

TABLE VII. Multivariate results of muscle markers for significant sex differences while controlling for humeral size and age

	Sum of squares	df	Mean square	F-ratio
Upper limb muscle marker	223.123	1	223.123	3.170†
Left Side				
Deltoid	0.237	1	0.237	0.112
Latissimus dorsi	1.715	1	1.715	2.393
Pectoralis major	9.769	1	9.769	4.928*
Teres major	3.345	1	3.345	1.783
Biceps brachii	16.939	1	16.939	3.724
Supinator	0.769	1	0.769	0.438
Triceps brachii	0.037	1	0.037	0.038
Right Side				
Deltoid	4.146	1	4.146	1.633
Latissimus dorsi	3.841	1	3.841	4.494*
Pectoralis major	5.491	1	5.491	2.280
Teres major	6.848	1	6.848	3.935*
Biceps brachii	0.021	1	0.021	0.008
Supinator	0.001	1	0.001	0.001
Triceps brachii	3.862	1	3.862	3.816

*$P < 0.05$.
†Marginal significant = 0.08.

stringent way of examining muscle markers is required, especially when comparing sexes.

As a result of these findings, partial correlations were run to control for the effects of size and age. A few muscle markers remained higher in males than in females, which included the left pectoralis major, right latissimus dorsi, and right teres major. The pectoralis and the latissimus dorsi muscles are usually associated with throwing or pitching motions, as in baseball (Hamill and Knutzen, 1995). The teres major is associated with internal rotation only when there is resistance in the action involved, such as pulling ones arm through water (Hamill and Knutzen, 1995). Therefore, it is possible that the three humeral muscle markers (two on the right side and one on the left side) is associated with the male California Amerinds throwing spears with a resistant phase of pushing or pulling the spear through something either during hunting or interpersonal aggression. Obsidian points embedded in the skeletons indicate males were victims of interpersonal aggression (Jurmain, 1988; Jurmain and Bellefemine, 1997). Additionally, many male burials included obsidian points, whereas female burials lacked these artifacts (Leventhal, 1993). Bones of various animals and shafts for points were abundant at CA-Ala-329, which support the hunting or throwing argument. Of course, other activities could cause the sex difference in muscle markers.

CONCLUSIONS

Upper limb muscle markers in this California Amerind population correlate with humeral size and age. These results corroborate previously published works. Rankings of muscle markers also demonstrate that patterns between males and females follow in part humeral size correlations; in other words, the rankings are partially a by-product of humeral size effect. Thus, disaggregated muscle markers still need body size controls in order to use muscle markers to reconstruct activity patterns. In this California sample, after controlling for humeral size and age, some muscle marker differences between males and females remained. One can examine these remaining muscle marker differences and compare them to sports information to reconstruct activity patterns. The muscle markers that differed between males and females could be attributed to male activities of throwing involved in hunting and interpersonal aggression, along with pushing in or pulling out a spear lodged in individual or animal. However, one should view this reconstruction with caution, as the controls may not have removed all the body size confounds and Zumwalt (2006) has shown a lack of muscle marker differences related to exercise patterns.

ACKNOWLEDGMENTS

I thank the reviewers and editor Clark Larsen for their thorough reading and thoughtful comments. I would also like to thank Gisela Weiss for helping to record and collect data. Finally, I would like to thank Anne Zumwalt for her fine published works.

LITERATURE CITED

al-Oumaoui I, Jiménez-Brobeil S, du Souich R. 2004. Markers of activity patterns in some populations of the Iberian Peninsula. Int J Osteoarchaeol 14:343–359.
Aron A, Aron EN, Coups E. 2005. Statistics for the behavioral and social sciences: a brief course. New York: Prentice Hall.
Buikstra JE, Ubelaker DH. 1994. Standards for data collection from human skeletal remains. Fayetteville: Archaeology Survey.
Capasso L, Kennedy KAR, Wilczak CA. 1999. Atlas of occupations markers of human remains. Journal of Paleopathology Monograph Publication 3. Teramo: Edigrafital SpA.
Chamay A, Tschantz P. 1972. Mechanical influences in bone remodeling. Experimental research on Wolff's Law. J Biomech 5:173–180.
Chapman NE. 1997. Evidence for Spanish influence on activity induced musculoskeletal stress markers at Pecos Pueblo. Int J Osteoarchaeol 7:497–506.
Cohen MN. 1989. Health and the rise of civilization. New Haven: Yale University Press.
Cook DC, Dougherty SP. 2001. Row, row, row your boat: activity patterns and skeletal robusticity in a series from Chirikof island, Alaska. Am J Phys Anthropol 32:53 (abstract).
Dewey JR, Armelagos GJ, Bartley MH. 1968. Femoral cortical involution in Nubian archaeological populations. Hum Biol 41: 13–28.
Drapeau MSM. 2006. Upper- and lower-limb skeletal muscle site variability in modern humans. Am J Phys Anthropol 42:84 (abstract).

Eshed V, Gopher A, Gage TB, Hershkovitz I. 2004. Has the transition to agriculture reshaped the demographic structure of prehistoric populations? New evidence from the Levant. Am J Phys Anthropol 123:303–315.
Gray H. 1977. Gray's Anatomy. London: Bounty Books.
Hamill J, Knutzen KM. 1995. Biomechanical basis of human movement. Baltimore: Williams & Wilkins.
Hawkey DE. 1998. Disability, compassion and the skeletal record: using musculoskeletal stress markers (MSM) to construct an osteobiography from early New Mexico. Int J Osteoarchaeol 8:326–340.
Hawkey DE, Merbs CF. 1995. Activity-induces musculoskeletal stress markers (MSM) and subsistence strategy changes among ancient Hudson Bay eskimos. Int J Osteoarchaeol 5: 324–338.
Hawkey DE, Street S. 1992. Activity-induced stress markers in prehistoric human remains from the eastern Aleutian islands. Am J Phys Anthropol 14:89 (abstract).
Hayden B, Hatch A, Ullinger J, Van Gerven DP, Sheridan SG. 2004. Musculoskeletal stress markers (MSM) as indicators of kneeling behavior in a Byzantine Jerusalem monastery. Am J Phys Anthropol 38:110–111 (abstract).
Jones WM, Trask WR, Adame M. 2006. Biomechanical stress markers in a historic population from the Central Coast of California: an analysis of Dove cemetery, Atascadero, California. Am J Phys Anthropol 42:110 (abstract).
Jurmain R. 1988. Paleoepidemiology of trauma in a prehistoric central California population. Zagreb Paleopathology Symposium. p 241–248.
Jurmain R. 1990. Paleoepidemiology of a central California prehistoric population from CA-ALA-329: II degenerative disease. Am J Phys Anthropol 83:83–94.
Jurmain R. 1993. Paleodemography and paleopathology. In: Cartier R, Bass J, Ortman S, Jurmain R, editors. The archaeology of the Guadalupe corridor. Santa Clara: Santa Clara County Archaeological Society. p 79–88.
Jurmain R. 1999. Stories from the skeleton: behavioral reconstruction in human osteology. London: Taylor and Francis.
Jurmain R, Bellefemine VI. 1997. Patterns of cranial trauma in a prehistoric population from Central California. Int J Osteoarchaeol 7:43–50.
Kennedy KAR. 1983. Morphological variations in ulnar supinator crests and fossae as identifying markers of occupational stress. J Forensic Sci 28:871–876.
Kennedy KAR. 1989. Skeletal markers of occupational stress. In: Iscan MY, Kennedy KAR, editors. Reconstruction of life from the skeleton. New York: Alan R Liss. p 129–160.
Lai P, Lovell NC. 1992. Skeletal markers of occupational stress in the fur trade: a case study from a Hudson's Bay company fur trade post. Int J Osteoarchaeol 2:221–234.
Leventhal A. 1993. A reinterpretation of some Bay area shellmound sites: a view from the mortuary complex from CA-Ala-329, The Ryan Mound (MA thesis). San Jose State University, San Jose, CA.
Mays S. 2000. Age-dependent cortical bone loss in women from 18th and early 19th century London. Am J Phys Anthropol 112:349–361.
Molnar P. 2006. Tracing prehistoric activities: musculoskeletal stress marker analysis of a stone-age population on the island of Gotland in the Baltic sea. Am J Phys Anthropol 129:12–23.
Nagy BLB. 1998. Age, activity, and musculoskeletal stress markers. Am J Phys Anthropol 26:168–169 (abstract).
Nagy BLB. 1999. Bioarchaeological evidence for atl-atl use in prehistory. Am J Phys Anthropol 28:208 (abstract).
Nagy BLB, Hawkey DE. 1995. Musculoskeletal stress markers as indicators of sexual division of labor: multivariate analyses. Am J Phys Anthropol 20:158 (abstract).
Papathanasiou A. 2005. Health status of the Neolithic population of Alepotrypa cave, Greece. Am J Phys Anthropol 126:377–390.
Peterson J. 1998. The Natufian hunting conundrum: spears, atlatls, or bows? Musculoskeletal and armature evidence. Int J Osteoarchaeol 8:378–389.
Robb JE. 1998. The interpretation of skeletal muscle sites: a statistical approach. Int J Osteoarchaeol 8:363–377.
Ruff C, Holt B, Trinkaus E. 2006. Who's afraid of the big bad Wolff? "Wolff is law" and bone functional adaptation. Am J Phys Anthropol 129:484–498.
Ruff CB, Larsen CS. 1990. Postcranial biomechanical adaptations to subsistence changes on the Georgia coast. In: Larsen CS, editor. The archaeology of Mission Santa Catalina de Guale: 2. Biocultural interpretations of a population in transition (Anthropological Paper of the American Museum of Natural History, Vol. 68). New York: The American Museum of Natural History. p 94–120.
Ruff CB, Scott W, Liu A. 1991. Articular and diaphyseal remodeling of the proximal femur with changes in body mass in adults. Am J Phys Anthropol 86:397–413.
Salles AD, Teiseira ASM, Araujo RA, Alexandre DJA. 2005. Musculoskeletal stress markers on skeletal remains of Cabecuda shellmound population, Laguna, Santa Catarina, Brazil: a biocultural approach. In: Proceedings of the Paleopathology Meetings in South America. Lexington, KY: Paleopathology Association. p 17.
Steen SL, Lane RW. 1998. Evaluation of habitual activities among two Alaskan eskimo populations based on musculoskeletal stress markers. Int J Osteoarchaeol 8:341–353.
Stirland AJ. 1998. Musculoskeletal evidence for activity: problems of evaluation. Int J Osteoarchaeol 8:354–362.
Toyne JM. 2003. Musculoskeletal stress markers (MSM) and weaving activities at a prehistoric coastal site in Peru. Am J Phys Anthropol 36:211 (abstract).
Weiss E. 2003. Understanding muscle markers: aggregation and construct validity. Am J Phys Anthropol 121:230–240.
Weiss E. 2004. Understanding muscle markers: lower limbs. Am J Phys Anthropol 125:232–238.
Wilczak CA. 1998. Consideration of sexual dimorphism, age, and asymmetry in quantitative measurements of muscle insertion sites. Int J Osteoarchaeol 8:311–325.
Woo SL, Kuei SC, Amiel D, Gomez MA, Hayes WC, White FC, Akeson WH. 1981. The effect of prolonged physical training on the properties of long bone: a study of Wolff's Law. J Bone Joint Surg Am 63:780–786.
Zabecki M. 2006. Workloads and activity patterns of three ancient Egyptian populations. Am J Phys Anthropol 42:192 (abstract).
Zumwalt AC. 2005. A new method for quantifying the complexity of muscle attachment sites. Anat Rec B 286:21–28.
Zumwalt AC. 2006. The effect of endurance exercise on the morphology of muscle attachment sites. J Exp Biol 209:444–454.
Zumwalt AC, Ruff CB, Wilczak CA. 2000. Primate muscle insertions: what does size tell you? Am J Phys Anthropol 30:331 (abstract).