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Sexual differences in a Californian hunter-gatherer population

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Sexual Differences in Activity Patterns of a Central Californian Hunter-Gatherer Population

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ABSTRACT: *This project examined the skeletal remains of a 3,000-year-old preagricultural population to determine whether a sexual division of labor existed. Cortical bone remodels itself throughout an individual's lifetime in response to the stresses experienced by activity patterns. Cortical bone morphology, therefore, discloses the nature of the stresses caused by different activity patterns. Computer tomography was used to obtain femoral cross-sections for 30 females and 34 males, taken at two levels along the diaphysis of the bone in order to determine the direction from which the major bending stresses are created. Student's t-tests and Analysis of Variance were used to analyze the differences in means and variances of the ratios for the sexes. The statistical tests revealed that two of the four ratios showed a significant difference between males and females. It is suggested that males were doing more traveling than were females. Females were probably participating in food preparation close to a home base.*

Introduction

In recent years, analyses of the cross-sections of limb bones have been a popular way to determine if there were sexual divisions of labor in the activity patterns of ancient populations. Cross-sectional studies enable one to examine the cortical thickness and, ergo, infer which activities were being performed. Bones experience external and muscular stresses throughout an individual's life to which the bone must respond to prevent breakage. The bone responds through bone remodeling, which is a thickening of cortical bone in areas where extra strength is needed in order to avoid breakage from stresses. Cortical bone remodels itself throughout an individual's lifetime in response to the stresses that may be caused by muscle movement used in specific activities. Cortical bone densities and orientation, consequently, reveal the nature of the stresses caused by different activity patterns. Different cortical bone thickness at the origin and insertion sites of muscles, as a result, reveal which muscles place stresses on the bones due to specific activities throughout an individual's life, and that leads to an understanding of what activities an individual engaged in on a regular basis. For example, a lower limb bone is most in danger of being broken by bending stresses; therefore, femora should remodel most in order to prevent breakage from the bending stress (Alexander 1968). Thus, a femur that experiences bending stresses caused by extensive use of muscles that attach on the linea aspera, which is located on the posterior side of the femur, should have thick cortical bone on the posterior side of the femur. This bone remodeling at the femur increases bending strength. By comparing male cortical bone thickness with female cortical bone thickness using computer tomography (CT) scans, one can determine whether males and females were engaging in different activities.

Anthropologists, such as Bridges (1997) and Ruff (1987), took cross-sections of limb bones with CT scans to determine if there were sexual differences in populations from different periods of time that reflected changes in subsistence patterns, such as from hunting and gathering to agriculture. Sexual division of labor has been demonstrated by Ruff and Hayes (1983b) and Bridges (1989) in preagricultural and agricultural populations, but whether sexual division of labor intensified with the introduction of agriculture is still being questioned. Since the archaeological record of California is replete with skeletal remains of hunter-gatherers, an investigation determining whether a preagricultural population had a sexual division of labor helped answer whether a strong sexual division of labor was present prior to the use of agriculture. The data gathered with this project, furthermore, was compared to other preagricultural, agricultural, and industrial populations to try to determine whether division of labor according to sex has decreased or increased with shifts in subsistence patterns.

Materials and Methods

The skeletal sample used in this project came from two different cemeteries located in the San Joaquin Valley in Central California. The sample contains 34 adult males and 30 adult females. Age was determined by the presence of molars and whether fusion had occurred at the epiphyses. The better preserved femur from each individual was used for the CT scans for this project.

The Native Americans who occupied the San Joaquin Valley from 3000-1300 BP belonged to a branch of the Yokut tribe (Wait et al. 1994) that was known for having a social hierarchy based on heredity (Hague 1972). Furthermore, females seemed to have had a lower status than did males, and thus a sexual division in labor may have been the norm (Hague 1972). To explore this, sexual division of labor among the Yokuts was determined by examining the cross-sections of femora in a group from the two cemeteries in the San Joaquin Valley, which are collectively referred to as CA-SJO-91.

Two cross-sectional diagrams, one at 50% of bone length (midshaft) and the other at 80% of bone length (subtrochanteric), were taken following Brock and Ruff (1988) (Figure 1). Previous cross-sectional analyses on femora show that these two locations experience the most bending stresses throughout a lifetime (Runestad et al. 1993). The femoral lengths were measured using an osteometric board to derive the cross-sectional locations. Bones were oriented with respect to anatomical reference planes described by Ruff and Hayes (1983a) to ensure accurate measurements and systematic scanning (Figure 1).

To measure bending strength for this project, the moment of inertia (I), which is the distance from the end of the medullary cavity to the end of the cortical bone, was measured to determine whether a sexual division of labor existed. Four moments of inertia were taken for each cross-section: 1) Imax, 2) Imin, 3) Ix, and 4) Iy (Figure 2). The first moment of inertia, Imax, is the measurement of the thickest cortical layer (Figure 2a, c). The next measurement, Imin, is where the cortical layer is the thinnest (Figure 2a, c). Ix is measured from the anterior to posterior side with the subtraction of the medullary cavity, and Iy is the length of the cross-section from the medial to lateral sides minus the medullary cavity (Figure 2b, d). These four measurements were later used to calculate the two ratios used to determine bending strength.

Two types of cross-sectional ratios using the moment of inertia prove useful for inferring activity patterns (Ruff 1987; Bridges 1989). The first is the ratio of the maximum moment of inertia to the minimum moment of inertia, Imax/Imin. This ratio estimates the relative maximum bending strength of the bone at any location. A value larger than 1 for the Imax/Imin ratio indicates an strong tendency of bending strength. The second ratio is of the moments of inertia about the X (anteroposterior, A-P) and Y (mediolateral, M-L) axes, Ix/Iy. The Ix/Iy ratio measures the bending strength in the A-P plane relative to the M-L plane. An Ix/Iy equal to 1 reflects a circular cross-section; an Ix/Iy larger than one should be seen when there are greater A-P bending stresses and a small value for the Ix/Iy reflects greater stress from the M-L direction (Figure 3; Ruff 1987). Ruff (1987) chose these ratios for analysis because: 1) they avoid the complexities of standardizing raw data for differences in body size; 2) they reflect differences

Figure 1: Reference axes and locations on a femur (Buikstra and Ubelaker 1994). On top the two cross-sectional locations, midshaft and subtrochanteric, are marked. The bottom diagram shows the anteroposterior (Y) and mediolateral (X) planes.

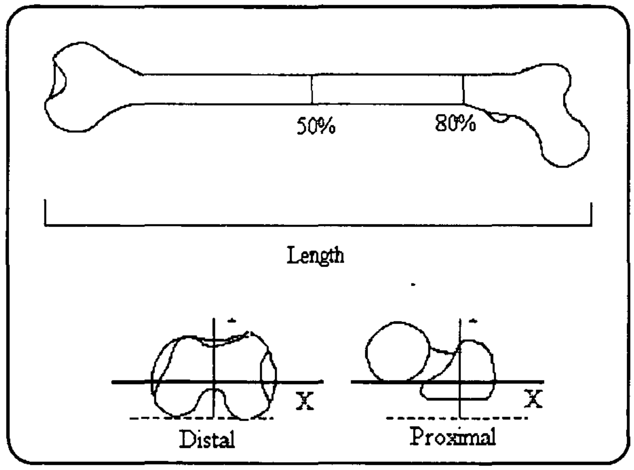
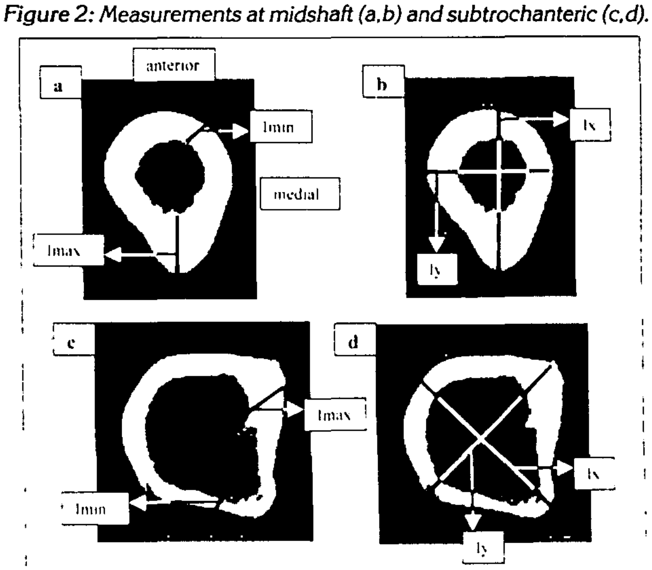


Figure 2: Measurements at midshaft (a,b) and subtrochanteric (c,d).



in specific mechanical loading and behavioral patterns; and, 3) they are easy to understand.

For this project, cross-sectional data were gathered by taking 1-mm thick CT scans of the femora. The CT scans were done at the University of California, Davis Medical Center. The CT scanner was a Toshiba TCT-900S. The high resolution scans took two seconds to capture with a bone filter. The bones were placed so that the proximal end of the femur was closest to the scanner and the anterior surface of the femur faced upwards. A computer image of the scan appeared upon capture and measurements were taken with a built-in digitizer. *Ratios were calculated from cortical thickness measurements using the spreadsheet program Excel.*

In summary, two ratios were constructed at the two cross-sectional planes; thus, four ratios were gathered per specimen. Descriptive statistics (i.e., means and standard deviations) of the ratios were generated for the sex-specific samples. The cross-sectional ratios were analyzed using the statistical software program, SYSTAT (Version 7.01). The Student's t-test and the Analysis of Variance (ANOVA) test were used to analyze the data. The Student's t-test was used because it enabled assessment of whether differences between the sex-specific sample means of the ratios were significant. The ANOVA was used to test differences in variance. For both tests, the confidence level was set at 90%. (Sokal and Rohlf 1981)

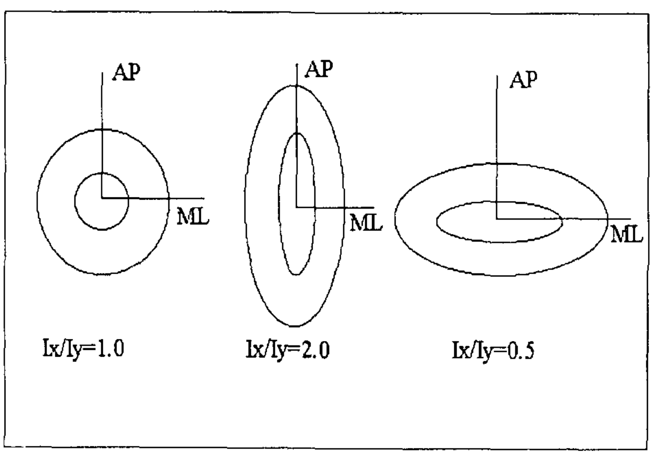


Figure 3: Effects of varying cross-sectional shape. The ML axis presents the mediolateral axis; thus, great values of Ix/Iy reflect great teroposterior bending strength. Taken from Ruff (1987).

Results

Table 1 provides the averages for the two ratios at both locations. These averages were then used to calculate the sex differences at each location.

Both the Imax/Imin at 50% and 80% of femoral length provide no significant evidence that femoral cross-sections from males differ from female femoral cross-sections. While female femoral cross-sections have a greater range as well as a lower absolute value for Imax/Imin at midshaft than do male femoral cross-sections, both female and male femoral cross-sections have much variation (Figure 4; Table 1). Consequently, the probabilities associated with both statistical tests of the difference in the two samples' means prove insignificant (Table 1). The same is true for Imax/Imin at the subtrochanteric location, except at this location the female femoral cross-sections have higher absolute values than do the male femoral cross-sections (Figure 4).

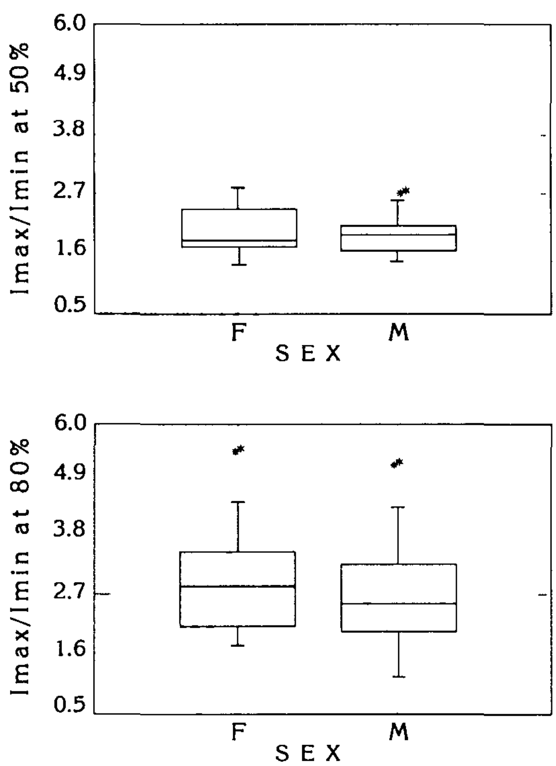
Table 1: Sex differences in Imax/Imin and Ix/Iy of CA-SJO-91 femoral cross-sections from males (M) and females (F). Mean, S.D., standard deviation of mean

Ratio	Section	Mean M	S.D.	Mean F	S.D.	M-F/F*100
Imax/Imin	50%[1]	1.90	0.343	1.98	0.430	4%
	80%[2]	2.73	0.839	2.96	0.847	-8%
Ix/Iy	50%[3]	1.12	0.096	1.02	0.083	10%
	80%[4]	1.02	0.181	0.92	0.230	11%

[1] Student's t-value=0.825, P=0.412; F ratio=0.681; P=0.412
[2] Student's t-value=1.061, P=0.293; F ratio=1.127; P=0.293
[3] Student's t-value=-4.323, P=0.000; F ratio=18.691; P=0.001
[4] Student's t-value=-1.881, P=0.065; F ratio=3.537; P=0.065

The Ix/Iy values at both cross-sectional locations, however, show significant differences between male and female femora. Male femoral cross-sections have higher absolute values for Ix/Iy at midshaft than do female femoral cross-sections (Figure 5; Table 1), and there is a significant difference in their mean values as well (Table 1). The ANOVA test results support that male and female femoral cross-sections vary significantly at both locations. Furthermore, within group variations at both locations are low (Figure 5; Table 1). Consequently, the statistical tests of the difference in the two samples' means for Ix/Iy ratio at midshaft are significant and the mean value of the difference in the sample means is great (Table 1). Like the midshaft location, female femoral cross-sections have lower absolute values for Ix/Iy at 80% of femoral length than do male femoral cross-sections (Table 1). At Ix/Iy at 80% of femoral length, however, female femoral cross-sections have a greater range than do male femoral cross-sections, but the statistical tests of the difference in the two samples' means for Ix/Iy ratio at the subtrochanteric location still show significance and the mean value of the difference in the sample means is large (Figure 5; Table 1). Male femoral cross-sections, thus, are significantly more anteroposteriorly oriented at both Ix/Iy ratios for 50% and 80% of femoral length than are female femoral cross-sections.

Figure 4: Box-and-whisker plots of Imax/Imin ratios at 50% (left) and 80% (right) femoral length for female (F) compared to male (M) femora. Sex is on the X-axis and the Imax/Imin values are on the Y-axis. Box, interquartile range. Horizontal line within box, median. End of whiskers, adjacent outside values. (*) outside values.

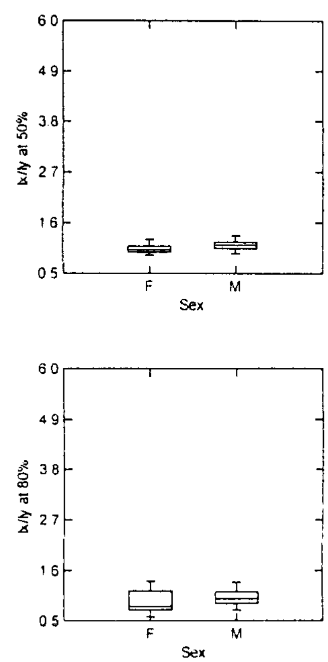


Discussion

Statistical analysis of femoral cross-sectional ratios from population CA-SJO-91 show that male and female femora have different Ix/Iy orientations, which indicate that males and females participated in different activity patterns. Male femoral cross-sections at both locations were more anteroposteriorly oriented than were the female femoral cross-sections. The anteroposterior orientation of male femoral cross-sections was probably caused by stresses coming from the anterior and posterior directions (Kapit and Elson 1993). Muscles that attach on the anterior and posterior sides of the femur may have caused these bending stresses and thus the cortical bone remodeled in order to increase bending strength and prevent bone breakage. The gluteus maximus, the gluteus medius, the biceps femoris, the vastus medialis, and the vastus lateralis all attach on the anterior and posterior sides of the femur (Kapit and Elson 1993). These five muscles are important muscles for bipedal locomotion (Duvall 1959). Ergo, an anteroposteriorly oriented femoral cross-section points to the likelihood that the males from the CA-SJO-91 population engaged in considerable long distance travel (Ruff 1987). The purpose of this travel may be found by looking at the archaeological record.

In the CA-SJO-91 collection, hunting artifacts suggest that at least some of the population hunted for meat (Hague 1972). Remnants, such as elk bones, also point to hunting activity

Figure 5: Box-and-whisker plots of Ix/Iy ratios a 50% (left) and 80% (right) femoral length for female (F) compared to male (M) femora. Sex is on the X-axis and the Ix/Iy values are on the Y-axis. Box, interquartile range. Horizontal like within box, median. End of whiskers, adjacent outside values.



among the CA-SJO-91 population (Hague 1972). Thus, the males were most likely traveling to hunt.

Female femoral cross-sections from population CA-SJO-91, on the other hand, are more mediolaterally oriented than are those of males. The lack of a strong anteroposterior orientation in female femoral cross-sections at both midshaft and subtrochanteric locations is evidence that females were not using the same muscles as extensively as were males. Thus, females were most likely less mobile than were males. At the subtrochanteric cross-sectional location, furthermore, the female femora are decidedly mediolaterally oriented as opposed to the more circular orientation at the midshaft cross-section. The mediolateral orientation of the subtrochanteric cross-section may be due to carrying children and other objects on the hip, which may have caused stress on the femur. Unfortunately, most of the muscles of the femur attach on the anterior and posterior sides of the femur. Archaeological evidence, however, can add further clues to female labor.

Mortars and pestles were found at the CA-SJO-91 site; these artifacts and the environmental information of oak tree availability suggest that acorn grinding took place (Hague 1972). Food preparation, such as acorn grinding, consumed a great deal of time and was most likely done at a home base (Hague 1972). Food preparation, furthermore, would be more compatible with childcare than would hunting (Buikstra 1976).

The picture revealed here of the CA-SJO-91 preagricultural population is that males were traveling to hunt and females were caring for children and preparing foods at a home base. The data from the CA-SJO-91 population do not differ much from that of other preagricultural populations (Table 2). The amount of sex differences measured in femoral cross-sections were compared to the results of previous studies that examined populations from Tennessee and Georgia, which inhabited similar environments as CA-SJO-91 (Table 2; Ruff 1987). The two ratios that are statistically significant in the CA-SJO-91 population appear to be comparable to the Tennessee and Georgia preagricultural populations.For example, in the Tennessee population the sexual difference at midshaft for Ix/Iy is 14% and for the CA-SJO-91 population the sexual difference for this same location and ratio is 10% (Table 2; Ruff 1987). The Tennessee agricultural population, on the other hand, has a sexual difference of only 5% at the midshaft (Table 2; Ruff 1987). For the CA-SJO-91 and Georgia preagricultural populations the sexual differences for the Ix/Iy ratio at midshaft are 10%; for the same ratio the sexual difference in the agricultural population from the Georgia site is barely 5% (Table 2; Ruff 1987). The results, therefore, provide evidence that the statistically significant Ix/Iy ratios at midshaft accord well with other preagricultural populations that inhabited similar environments. These preagricultural populations, thus, probably had a similar division of labor. Preagricultural populations from Georgia, Tennessee, and CA-SJO-91, furthermore, have significantly higher levels of sexual differences in femoral cross-sections than do the agricultural populations from Georgia and Tennessee.

In this study and others like it, the data reveal that sex differences between male and female femoral cross-sections decreased through time with hunter-gatherers being the most sexually dimorphic (Table 2; Brock 1985; Ruff 1987). Femoral cross-sections of both sexes became more circular due to a more sedentary lifestyle with the introduction of agriculture and industry (Kimura and Takahashi 1982; Ruff 1987). Preagricultural populations, such as the CA-SJO-91 population, have very sexually dimorphic femora, which suggests a strong sexual division of labor. The male femoral cross-sections from preagricultural populations, including CA-SJO-91, are more anteroposteriorly oriented than female femoral cross-sections (Table 2; Bridges 1989; Kimura and Takahasi 1984; Ruff 1987). Males in preagricultural populations probably traveled more than did females. Male femoral stresses underwent the greatest changes through time (Table 2; Ruff 1987). In the industrial age, no difference is seen between the femoral cross-sections of the sexes and males have approached the more feminine femoral cross-sectional shape (Table 2; Ruff 1987).

Summary

In summary, this project used CT scans of femoral cross-sections to determine whether a preagricultural population from the San Joaquin Valley had a sexual division of labor. The data was then compared to other populations in order to conclude whether sexual division of labor has increased or decreased with subsistence patterns changes.

Male femora from the CA-SJO-91 population are more anteroposteriorly oriented than are female femora. This anteroposterior orientation of male femora was probably caused by muscles used for bipedalism that attach to the anterior and posterior sides of the femur (Kapit and Elson 1993). Thus, males from the CA-SJO-91 population probably engaged in more extensive travel than did females. The males may have been traveling to hunt; hunting artifacts, such as elk bones and weapons, are abundant in the CA-SJO-91 archaeological collection (Hague 1972).

Female femoral cross-sections from population CA-SJO-91 are more mediolaterally oriented than are those of males. Thus, females were most likely less mobile than were males. Mortars and pestles found at the CA-SJO-91 site, along with mediolaterally oriented female femoral cross-sections, indicate that females most likely ground acorns (Hague 1972). This food preparation consumed a great deal of time and was probably done at a home base. Hunting, furthermore, is not compatible with childcare (Buikstra 1976).

The picture of the CA-SJO-91 preagricultural population reveals that males were likely traveling to hunt and females were preparing foods and caring for children at a home base. The statistical results of femoral cross-sectional data of the CA-SJO-91 population do not differ much from other preagricultural populations, which probably had a similar division of labor (Ruff 1987).

Previous research by anthropologists, such as Ruff (1987) and Cole (1994), have found that differences in cross-sections between males' and females' femora decrease when populations transition from hunting-gathering to industry. With the use of agriculture and industry, femoral cross-sections of both sexes become more circular, most likely due to sedentary lifestyles (Brock 1985; Kimura and Takahashi 1982; Ruff 1987). In preagricultural populations, such as the CA-SJO-91 population, male femoral cross-sections have vastly different orientations than female femoral cross-sections, which suggests a strong sexual division of labor. The male femoral cross-sections have orientations that point to extensive application of muscles used in bipedal walking. Male femoral stress underwent great changes connected with the decline in hunting activity due to the cultivation of foods. In the industrial age, no difference is seen between the femoral cross-sections of the sexes; both the males and females have circular femoral cross-sections (Ruff 1987).

Table 2: Sex differences in Imax/Imin and Ix/Iy of femoral cross- sections in archaeological and autopsy samples.

			Preagricultural			Agricultural			Industrial		
Sect.	Ratio	Sample	M	F	% diff.[9]	M	F	% diff.	M	F	% diff.
50%	Imax/Imin	Georgia[2]	1.34	1.22	9.83	1.28	1.23	4.07			
		Tennessee[3]	1.41	1.14	23.68	1.30	1.30	0			
		N. Mexico[4]		1.66	1.42	16.90	1.40	1.32	6.01		
		Pecos[5]				1.48	1.29	14.70			
		Mississippi[6]		1.41	1.13	24.78	1.29	1.31	-1.53		
		Villagers[7]	1.75	1.49	17.45	1.40	1.32	6.06			
		U.S. White[5]							1.29	1.27	1.57
80%	Imax/Imin	Georgia	2.09	2.14	-2.33	1.82	2.10	-13.00			
		N. Mexico	1.54	1.92	-19.79	1.68	1.83	-8.20			
		Pecos				1.89	1.93	-2.10			
		Mississippi		1 36	1.75	-22.29	1.37	1.41	-2.84		
		Villagers	1.63	1.91	-14.66	1.68	1.83	-8.19			
		U.S. White							1.35	1.39	-2.88
50%	Ix/Iy[1]	Georgia	1.28	1.16	10.34	1.08	1.03	4.85			
		Tennessee	1.21	1.06	14.15	1.06	1.01	4.95			
		N. Mexico	1.28	1.18	8.47	1.24	1.21	2.48			
		Japanese[8]	1.50	1.10	36.36				1.06	1.06	0
		Pecos				1.14	1.05	8.57			
		Villagers	1.28	1.22	4.92	1.24	1.11	11.71			
		U.S. White							1.21	1.23	-1.63
80%	Ix/Iy	Georgia	0 88	1.14	-22.81	1.08	1.03	4 85			
		Pecos				0 90	0.86	4.65			
		U.S. White									

[1] Ix Iy mediolateral orientation < 1; anteroposterior orientation > 1.
[2] Ruff et al. 1984, [3] Bridges 1985, [4] Brock 1985, [5] Ruff 1987, [6] Bridges 1989, [7] Brock and Ruff 1988, and [8] Kimura and Takahashi 1982.
[9] (Mean Male ratio)-(Mean Female ratio)/(Female ratioX100).

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