

Temporal changes in Arikara humeral and femoral cross-sectional geometry associated with horticultural intensification

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Abstract

Humeral and femoral cross-sectional properties from three archaeological variants of the Arikara, an American Great Plains Indian tribe, were analyzed for temporal (16th to 19th centuries) changes in long bone architecture, asymmetry, and sexual dimorphism associated with intensification of horticulture during the late protohistoric and early historic periods. There were a number of significant changes in long bone, especially femoral, cross-sectional morphology and asymmetry among females through time that probably reflect increases in the workload necessary to produce surplus crops. Changes in long bone architecture among males are restricted to the humerus and may reflect a greater reliance on firearms. The pattern of sexual dimorphism also changes through time among the Arikara due to a combination of environmental (nutrition and disease) and mechanical factors.

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1. Introduction

This study investigates temporal trends from the mid-sixteenth to the early nineteenth century in humerus and femur diaphyseal cross-sectional property values, bilateral asymmetry, and sexual dimorphism among the Arikara, an American Great Plains (hereafter referred to as the “Plains”) Indian tribe, using a biomechanical approach (i.e., the application of engineering beam theory principles to long bone diaphyseal geometry). According to the biomechanical model, changes in diaphyseal cross-sectional values and asymmetry through time reflect shifts in physical activities within sexes, and patterns of sexual dimorphism provide valuable clues about the sexual division of labor within a population [53,58]. Identifying these trends in the Arikara will help shed light on changes

in their activity, work load, and sexual division of labor through time.

1.1. Arikara

Prehistorically and historically the Arikara resided in villages along the Missouri River in South Dakota, and are represented archaeologically by four variants of the Coalescent tradition: Initial (IC), Extended (EC), Post-contact (PCC) and Disorganized (DC) [26,31,38]. The chronology of the Coalescent period has been modified since its first inception [1,26,36], with archaeologists now confirming that the IC, a northern extension of the Central Plains tradition, dates from A.D. 1300 to 1600, the EC from A.D. 1500 to 1650, the PCC from A.D. 1650 to 1780, and the DC from A.D. 1780 to 1845 [26,31,45].

The Arikara are traditionally considered horticulturalists but they also hunted, fished, and gathered wild plants [19,49,52]. They were also actively involved in intertribal

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trade, serving as intermediaries or middlemen [10,49,52,78]. There is no archaeological or historical evidence of a major change in the subsistence activities among the Arikara from the late prehistoric (EC) to historic (DC variant) period. However, the intensity of some subsistence activities did change from the EC to the DC, especially among females [49]. As intertribal trade networks became more important the Arikara shifted from producing just enough crops for consumption to producing surpluses of corn and other vegetables for trade. In 1853, for example, the Arikara traded nearly 5000 bushels of corn with other native groups and Europeans [49]. Having surplus crops for trade probably became important as the number of nomadic tribes grew on the Plains but became especially beneficial after European contact in the late PCC. All of the additional work necessary to produce surplus crops was conducted exclusively by females, who were responsible for all activities associated with the growing of crops (preparing fields, planting, and harvesting) and processing the harvest [49]. There is no evidence that males participated in farming activities or that hunting and fishing methods changed significantly from the late prehistoric to early historic period [79]. If anything, the importance of hunting may have declined through time because the Arikara became more dependent on trade with nomadic tribes for meat and hides [49]. The main differences in male activities are probably associated with the introduction of horses and rifles and increased warfare after A.D. 1740 [13,19,45]. The horse most likely increased the hunting efficiency of males, and as warfare increased during the DC, males focused more of their energy on combat related activities.

Since horticultural activities require symmetrical use of the upper limbs [5,53] and was exclusively the responsibility of females among the Arikara [49], the intensification of horticultural products for trade should be reflected in changes in long bone cross-sectional variables and asymmetry among females from the EC to the DC. Specifically, there should be an increase in female long bone strength from the EC to the DC. Since the intensity of male activities did not change as significantly as those of females, there should also be a change in the degree of sexual dimorphism within the Arikara through time in many of the cross-sectional properties. The question is, were these changes in work load great enough to cause observable long bone diaphyseal structural changes?

1.2. Biomechanical analyses

As a biological material, bone tissue continuously modifies itself throughout the life of an individual in response to normal physiological processes and mechanical loads placed on it by activity [34,58]. The processes of modeling modify the diaphyseal cross-section throughout life, especially during the sub-adult period, so that the long bone's diameter, cross-sectional shape, and cortical thickness reflect the manner and magnitude of the mechanical forces placed on the bone. This results in an adult skeleton that is sufficiently strong to resist the mechanical loads imposed on it due to normal activities [16,17,58].

Table 1
Geometric properties determined for humeral and femoral cross-sections

Property	Code	Relevance
Subperiosteal area	TA	Total cross-sectional size
Cortical area	CA	Tensile and compressive strength
Anteroposterior second moment of area	I_{ap}	Anteroposterior bending strength
Mediolateral second moment of area	I_{ml}	Mediolateral bending strength
Maximum second moment of area	I_{max}	Maximum bending strength
Minimum second moment of area	I_{min}	Minimum bending strength
Diaphyseal shape index	I_{ap}/I_{ml}	Relative AP to ML bending rigidity
Diaphyseal bending rigidity	I_{max}/I_{min}	Relative max. to min. bending rigidity
Polar second moment of area	J	Torsional strength

The geometric properties (Table 1) of a long bone cross-section act as a measure of the amount and distribution of bone in the section and provide valuable information about the bone's resistance to mechanical forces (i.e., the bone's strength) [34,58,59]. The subperiosteal or total area (TA) of a cross-section is a measure of the total diaphyseal cross-sectional size, while the cortical area (CA), the amount of cortical bone in a section, acts as a gauge of the bone's resistance to direct axial loadings (i.e., tensile and compressive). Second moments of area (I and J) are measures that approximate the bone's ability to resist bending and torsional forces applied about a neutral axis. Both the cross-sectional area and the distribution of cortical bone are accounted for in second moments of area. The bending second moment of area (I) can be calculated around any neutral plane in a cross-section. Conventionally, the bending second moment of area is calculated about the anteroposterior (I_{ap}) and mediolateral (I_{ml}) axes and the minimum (I_{min}) and maximum (I_{max}) axes. The I_{ap}/I_{ml} ratio provides an estimate of the cross-sectional shape and the direction of mechanical forces (relative anteroposterior to mediolateral bending strength) that were placed on the long bone diaphysis during life [53,58]. A value of 1.0 indicates a circular cross-sectional shape. Values greater than 1.0 indicate that the cross-section is more elongated in the anteroposterior (AP) plane, and values less than 1.0 indicate that the cross-section is expanded mediolaterally (ML) [34,53]. The I_{max}/I_{min} ratio is a measure of the relative maximum to minimum bending strength [57,58]. The torsional or polar second moment of area (J) is equivalent to the sum of any two perpendicular values of I ($I_{max} + I_{min}$ in this study), and provides an estimate of the bone's resistance to torque [58].

The use of long bone cross-sectional geometry to infer activity patterns has not gone without criticism [3,18,27,40,41,75,77]. Numerous cultural (e.g., age when adult activities commence and logistic and residential mobility patterns), environmental (e.g., physical terrain and nutritional deficits), and biological factors (e.g., genetics, hormone levels and disease) can affect long bone geometry and are difficult to control for in biomechanical studies of archaeological populations.

However, these criticisms focus on studies that compare biologically and culturally unrelated populations or populations with significantly different economic patterns. This study focuses on changes within a single population through time living in the same geographical region, which helps control for many of the cultural, environmental, and biological factors.

1.3. Previous research in the American Great Plains

While a number of studies have addressed changes in long bone asymmetry and sexual dimorphism associated with major shifts in subsistence strategies among American Indians (e.g., [4–7,11,15,53,55,59,60,62,63,65,75,76]), few have focused on changes in long bone cross-sectional asymmetry and sexual dimorphism within a narrowly defined temporal period in a population experiencing only minor economic shifts (i.e., intensification of horticultural output). Furthermore, investigations of long bone cross-sectional properties are limited for populations from the Plains, especially the analysis of short-term temporal changes in a population practicing the same basic subsistence strategy.

Over the past 50 years, human skeletal remains from the Plains have been extensively excavated and studied, but rarely have the postcranial remains been analyzed in a systematic fashion. Most studies of Plains Indian skeletal remains have utilized crania to address questions concerning secular change within and biological relationships within and between Plains groups (e.g., [9,21–23,28,29,42,46–48]). When adult postcranial remains are employed, they are generally only used to help reconstruct the stature and demographic details (e.g., age and sex) of individuals at a particular site. Rarely have adult postcranial remains from the Plains been used to address specific scientific questions regarding activity patterns as they have in other geographical areas.

Only Cole [11], Ruff [55], and Wescott [75] have addressed long bone cross-sectional variation among Plains groups using a biomechanical approach. Cole [11] examined variation in external diaphyseal measurements of the lower limb bones among northern Plains Woodland, Middle Missouri, and Coalescent samples. He found no significant differences between subsistence groups in long bone size, shape or sexual dimorphism based on subsistence strategy in the northern Plains. Ruff [55] examined cut femoral midshaft cross-sections of Woodland, Middle Missouri, and Post-contact Coalescent populations from the northern Plains and a Washita River phase sample from the southern Plains. He discovered that sexual dimorphism in femur cross-sectional size declined with time in the northern Plains, that there were no differences in femur cross-sectional properties between pre-horse and post-horse Arikara, and that northern Plains populations exhibit more circular femoral midshaft shapes than do populations of the southern Plains. He attributed the latter to a high degree of mobility among both males and females from the southern Plains. Finally, Wescott [75] examined femora and humeri from the northern, central, and southern Plains ranging in time from the Archaic to historic periods using a combination of variables derived from external dimensions and computed tomography (CT) diaphyseal

cross-sections. He found relatively little change in femoral or humeral cross-sectional size or shape within sex-specific groups and few significant alterations in sexual dimorphism with changes in subsistence. He did discover that equestrian hunter-gatherers (e.g., Apache, Cheyenne, Sioux, and Crow) exhibit significantly longer and more robust long bones with a slightly more circular femoral midshaft shape. Furthermore, like Ruff [55], he found that southern Plains groups differ significantly in femoral cross-sectional shape, with southern Plains groups exhibiting greater anteroposterior bending strength compared to central and northern Plains populations.

2. Materials and methods

Paired adult humeri and femora from archaeological sites (or components within) representing three Coalescent tradition variants (EC, PCC, and DC) attributed to the Arikara were used (Table 2). Bones were selected based on accessibility, completeness, absence of pathology, and epiphyseal closure. Age and sex were estimated for individuals using standard osteological methods [2,73]. The bones were first measured for length (abbreviated as HL and FL for the humerus and femur, respectively) and maximum head diameter (abbreviated as HHD and FHD for the humerus and femur, respectively) [44].

Computed tomography (CT) cross-sectional images were then collected at midshaft and subtrochanteric locations from femora and at 35% from the distal end (mid-distal) from humeri. Prior to scanning, the bones were oriented in standard sagittal and coronal planes [64,75], and cross-sectional images were taken perpendicular to both planes. The bones were scanned in air with a 1 mm slice thickness. The CT images

Table 2
Sites representing archaeological variants

Variant	Site name	Site no.
Extended (EC)	Fairbanks Village	39SL2
	Norvold 2/3	39CO32/3
	Mobridge 1	39WW1-1
	Rygh	39CA4
	Sully A	39SL4A
	Sully D	39SL4D
	White Tail	39WW303
Post-contact (PCC)	Buffalo Pasture	39ST216
	Cheyenne River	39ST1
	Four Bear	39DW2
	Indian Creek	39ST15
	Larson	39WW2
	Leavitt	39ST215
	Mobridge 2	39WW1-2
	Norvold 1	39CO31
	Oacoma	39LM26
	Oahe Village	39HU2
	Stony Point	39ST235
	Sully B	39SL4B
	Sully E	39SL4D
Swan Creek	39WW7	
Disorganized (DC)	Leavenworth	39CO9
	Ashley Island	39CO11
	Medicine Crow	39BF2A

were converted to TIFF files, and the internal and external boundaries were digitized using the auto-trace function of Scion Image. Boundary coordinates were used to calculate geometric properties (Table 1) with Momentmacro [74]. Cross-sectional properties were then standardized for body size by dividing cortical area by bone length cubed (length^3) and moments of area by bone length to the power 5.33 ($\text{length}^{5.33}$) following the recommendations of Ruff [58]. This method of standardization is appropriate when comparing groups of similar size [58]. A similar body size between archaeological variants was confirmed by examining the ratio of FHD/FL. There were no significant differences between variants ($p = 0.65$) or for the interaction of sex and variant ($p = 0.57$).

The percent of bilateral asymmetry was determined using the formula: % asymmetry = $100 \times (\text{Abs}[(R - L)] / (R + L) / 2)$ [43]. This formula for determining asymmetry circumvents the problem of not knowing the handedness of each individual.

Several statistical methods were employed to examine the data. First, standard descriptive statistics for the various measurements, structural properties, and indices were calculated. Analysis of variance (ANOVA) procedures were used to investigate variation between variants in same-sex samples and sexual dimorphism within and between variants. Cross-sectional properties and indices were used as dependent variables in all ANOVA procedures. Archaeological variant was used as the main factor to explore sex-specific variation between temporal periods, and sex was used as the main factor to examine sexual dimorphism within archaeological variants. Interactions between the two factors (sex \times variant) were examined to test for significant differences in sexual dimorphism between Coalescent variants. The ANOVA procedure evaluates if the variation due to group differences is larger than expected, but does not provide information on which groups differ. Therefore, variables that differed significantly by archaeological variant were further examined using post-hoc multiple comparison tests. A probability level of 0.05 or less was considered statistically significant, while a probability level between 0.05 and 0.1 was regarded as nearly significant.

3. Results

The data were examined for sex-specific differences between variants and then for within variant and between variant sexual dimorphism. Sex-specific summary statistics and ANOVA results are presented in Tables 3 and 4 for female humeri and femora respectively and in Tables 5 and 6 for male humeri and femora. Differences in sexual dimorphism within and between Coalescent variants are presented in Table 7.

3.1. Sex-specific variation between archaeological variants

There are a number of significant variant differences within both sexes (Tables 3–6). Females in the DC have longer right humeri with larger head diameters than females from the EC or PCC, and significantly larger left humeral head diameters than PCC females (Table 3). There are no significant differences in

females by variant in any of the cross-sectional properties or indices of the humerus. The major difference in females is associated with asymmetry of the femoral cross-sectional properties, primarily due to changes in the left femur during the DC (Table 4). Disorganized Coalescent females have significantly greater asymmetry in all subtrochanteric (Table 4 and Fig. 1) and midshaft (Table 4 and Fig. 2) cross-sectional properties and indices. The EC and PCC females do not differ in femoral size, strength, or shape, with the exception of right subtrochanteric $I_{\text{ap}}/I_{\text{ml}}$ (Table 4). During the DC, femur subtrochanteric shape becomes more platymeric (AP flattened) on the left side. Furthermore, left femur subtrochanteric TA, I_{ml} , I_{min} , and J and midshaft TA, I_{ap} , I_{ml} , I_{max} , I_{min} , and J increases significantly during the DC. There are no significant variant differences in right femur midshaft cross-sectional properties or indices among females, and only two (I_{ap} and $I_{\text{ap}}/I_{\text{ml}}$) among subtrochanteric cross-sectional properties (Table 4).

The pattern of long bone cross-sectional variables by variant is quite different for males (Tables 5 and 6). The DC males have longer left humeri and greater humeral asymmetry in I_{max} and $I_{\text{ap}}/I_{\text{ml}}$ compared to the other two variants. During the DC, males also exhibit greater humeral asymmetry in CA, I_{ml} , and J compared to males from the EC but do not differ significantly from males in the PCC in these measures. The primary cause for these differences is an increase in strength of the right humerus through time (Fig. 3). There are no significant differences between EC and PCC male humeri. As seen in Table 6, males from the DC have longer femora and a greater left side midshaft $I_{\text{max}}/I_{\text{min}}$ value compared to EC and PCC males, while males from the EC have the largest subtrochanteric $I_{\text{max}}/I_{\text{min}}$ ratio values followed by males from the PCC and then the DC. Males from the DC have an overall greater value for left subtrochanteric I_{min} than EC males but do not differ significantly from PCC males in this measure (Table 6).

3.2. Sexual dimorphism within and between archaeological variants

Table 7 presents the pattern and direction of sexual dimorphism within and between archaeological variants. The primary differences between male and female humeri during the EC are in cross-sectional values of the left humerus and cross-sectional asymmetry. Females have relatively stronger left humeri but males have greater asymmetry in humeral I_{ap} , I_{max} , and $I_{\text{ap}}/I_{\text{ml}}$. Sexual dimorphism in the femoral cross-sectional properties during the EC is less pronounced. During the PCC, males have significantly or nearly significantly larger values for cross-sectional properties in the right humerus but smaller values for the left humerus (Table 7). Males have significantly greater values than females in many subtrochanteric and all midshaft femoral properties during the PCC. However, there are few significant sex differences in femoral asymmetry during the PCC. In the DC there are few significant differences between males and females in right or left humeral cross-sectional properties, but males have significantly or nearly significantly greater asymmetry in variables associated with AP bending and torsional

Table 3
Summary statistics and ANOVA results of female humeral variables

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
Extended coalescent							
HL	30	299.3	14.3	292.7	13.9	2.2	0.8
HHD	30	41.2	1.5	41.1	1.4	1.1	1.5
TA	30	918.4	117.8	964.3	134.0	5.7	2.7
CA	30	623.6	96.6	662.7	113.6	7.1	5.4
I_{ap}	30	289.5	60.9	316.7	78.0	10.2	6.7
I_{ml}	30	274.4	69.9	299.1	88.5	10.6	6.7
I_{max}	30	313.8	65.9	335.7	84.4	7.9	6.7
I_{min}	30	250.0	65.5	280.1	82.3	13.4	6.3
I_{ap}/I_{ml}	30	1.1	0.1	1.1	0.1	6.0	5.6
I_{max}/I_{min}	30	1.3	0.2	1.2	0.1	7.5	5.6
J	30	563.9	128.0	615.8	163.9	9.9	6.0
Post-contact coalescent							
HL	53	300.5	12.8	293.7	12.0	2.2	0.9
HHD	53	40.1	1.9	40.2	2.0	1.1	1.5
TA	53	860.2	122.4	904.3	134.3	6.4	4.4
CA	53	595.5	80.7	637.2	82.4	7.7	5.3
I_{ap}	53	265.1	64.2	292.2	75.4	12.1	8.8
I_{ml}	53	237.1	62.0	256.5	65.5	12.3	7.7
I_{max}	53	282.0	66.6	303.6	75.6	9.9	8.3
I_{min}	53	220.3	59.1	245.1	65.3	14.3	10.0
I_{ap}/I_{ml}	53	1.1	0.1	1.1	0.1	6.3	4.3
I_{max}/I_{min}	53	1.3	0.1	1.2	0.1	7.6	6.5
J	53	502.3	122.5	548.7	137.6	11.7	8.0
Disorganized coalescent							
HL	12	313.7 ^{E,P}	14.0	306.3	12.0	2.3	0.9
HHD	12	42.5 ^{E,P}	1.2	42.7 ^P	2.1	1.7	1.9
TA	12	868.5	91.9	908.5	86.6	4.8	2.8
CA	12	589.0	74.7	621.7	75.3	5.6	3.9
I_{ap}	12	273.6	50.6	296.9	50.3	9.4	6.5
I_{ml}	12	248.7	54.2	266.6	47.7	9.6	4.7
I_{max}	12	292.6	60.8	315.0	52.2	10.6	6.2
I_{min}	12	229.7	46.8	248.4	46.1	8.2	5.6
I_{ap}/I_{ml}	12	1.1	0.1	1.1	0.1	4.5	3.0
I_{max}/I_{min}	12	1.3	0.1	1.3	0.1	6.1	3.9
J	12	522.4	102.4	563.4	94.4	9.5	5.0

The abbreviations HL and HHD denote humerus length and humerus head diameter, respectively. Other abbreviations can be found in Table 1. Bold mean indicates a significant difference and the superscript letter after the mean denotes the variant that differs (E, ECC; P, PCC; D, DC).

strength. Significant sexual dimorphism in the femur during the DC is apparent in many of the subtrochanteric and mid-shaft cross-sectional properties with females having greater asymmetry.

The primary differences in sexual dimorphism between variants are in femoral cross-sectional properties (Table 7). There are only two significant sex \times variant interactions for humeral cross-sectional properties: right I_{min} and shape (I_{ap}/I_{ml}) asymmetry. Sexual dimorphism is present in right humerus minimum bending strength during the PCC but not the EC or DC. The interaction effect for humeral shape asymmetry is due to a significant increase in humeral asymmetry among males from the PCC to the DC but no significant change among females. Humeral I_{ap}/I_{ml} asymmetry changes from approximately 6% in females during the EC and PCC and to 4.5% in the DC (Table 3), but is not a significant change. In males, on the other hand, the percent

asymmetry in humeral I_{ap}/I_{ml} changes significantly from approximately 11% in the EC and PCC to 17% in the DC (Table 5). In the femur, however, there are significant sex \times variant interactions for many of the cross-sectional properties, especially at subtrochanteric. These significant differences in sexual dimorphism between variants generally reflect greater sexual dimorphism during the PCC or changes caused by increases in the strength of the femur in females during the DC. The primary pattern is an increase in sexual dimorphism from the EC to the PCC followed by a slight decrease in the DC (Table 7).

4. Discussion

Previous biomechanical studies of archaeologically derived human remains suggest a strong correlation between long bone cross-sectional properties and activity patterns

Table 4
Summary statistics and ANOVA results of female femoral variables

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
Extended coalescent							
FL	28	413.1	17.2	413.8	15.8	0.7	0.4
FHD	28	43.1	1.9	42.7	1.8	1.4	2.4
Subtrochanteric							
TA	28	757.6	93.1	780.7	93.3	4.8	3.9
CA	28	516.7	75.2	535.9	75.7	5.3	4.6
I_{ap}	28	263.1	59.9	249.1	50.4	12.7	9.9
I_{ml}	28	231.2	60.0	274.4	70.8	18.9	15.2
I_{max}	28	327.9	74.0	341.6	72.5	9.7	7.2
I_{min}	28	166.4	42.0	181.8	45.1	10.9	8.7
I_{ap}/I_{ml}	28	1.2	0.2	0.9	0.2	26.7	19.4
I_{max}/I_{min}	28	2.0	0.3	1.9	0.3	7.8	5.4
J	28	494.3	109.4	523.5	111.1	9.4	7.6
Midshaft							
TA	29	649.4	79.3	670.9	74.4	5.3	5.0
CA	29	479.2	77.0	498.5	73.6	74.3	6.7
I_{ap}	29	188.5	47.0	201.2	49.2	9.7	9.2
I_{ml}	29	173.8	45.4	186.8	41.2	13.3	10.6
I_{max}	29	197.8	52.0	213.5	52.5	11.2	10.8
I_{min}	29	164.5	37.8	174.4	35.4	11.1	8.9
I_{ap}/I_{ml}	29	1.1	0.2	1.1	0.2	7.3	4.9
I_{max}/I_{min}	29	1.2	0.1	1.2	0.1	6.0	3.6
J	29	362.4	87.6	388.0	84.8	9.4	7.6
Post-contact coalescent							
FL	72	414.7	14.7	415.3	14.9	0.7	0.5
FHD	72	42.3	2.3	42.7	4.1	2.0	6.6
Subtrochanteric							
TA	72	748.9	86.1	755.8	88.0	4.0	3.0
CA	72	528.3	69.6	541.9	75.7	5.3	5.4
I_{ap}	72	245.0	48.0	240.8	58.4	9.1	9.4
I_{ml}	72	246.6	63.6	267.0	66.3	14.6	10.8
I_{max}	72	323.6	67.4	333.1	74.2	7.7	6.2
I_{min}	72	168.0	40.4	171.1	38.1	8.9	7.5
I_{ap}/I_{ml}	72	1.0 ^{E,D}	0.2	0.9	0.2	18.7	13.9
I_{max}/I_{min}	72	2.0	0.3	2.0	0.3	6.7	6.1
J	72	491.6	102.7	504.2	106.8	7.6	5.7
Midshaft							
TA	71	645.8	64.3	653.3	64.4	4.2	3.0
CA	71	485.9	63.2	498.7	60.2	76.5	5.6
I_{ap}	71	187.4	35.5	189.8	36.3	6.9	5.7
I_{ml}	71	175.0	39.3	181.8	37.5	11.2	8.0
I_{max}	71	197.6	39.8	203.1	38.7	8.8	7.8
I_{min}	71	164.1	32.6	170.7	32.0	9.7	9.5
I_{ap}/I_{ml}	71	1.1	0.2	1.1	0.2	8.4	7.1
I_{max}/I_{min}	71	1.2	0.1	1.2	0.1	5.7	5.0
J	71	361.7	70.6	373.8	68.8	7.6	5.7
Disorganized coalescent							
FL	13	414.8	17.9	414.5	18.2	0.7	0.4
FHD	13	42.9	1.8	44.7	9.1	6.8	14.9
Subtrochanteric							
TA	13	798.0	96.9	836.6 ^{E,P}	113.8	6.9 ^{E,P}	4.7
CA	13	532.9	80.5	567.8	104.4	9.7 ^{E,P}	5.6
I_{ap}	13	290.5 ^P	65.1	243.2	52.5	21.7 ^{E,P}	15.4
I_{ml}	13	248.3	70.7	354.5 ^{E,P}	111.8	40.0 ^{E,P}	19.1
I_{max}	13	355.1	75.2	386.1	106.0	16.2 ^{E,P}	11.1
I_{min}	13	183.9	47.1	211.6 ^{E,P}	56.6	17.8 ^{E,P}	11.5
I_{ap}/I_{ml}	13	1.2	0.4	0.7 ^{E,P}	0.2	54.4 ^{E,P}	31.5

(continued on next page)

Table 4 (continued)

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
I_{\max}/I_{\min}	13	2.0	0.3	1.8	0.2	13.6 ^{E,P}	14.9
J	13	539.0	114.2	597.7 ^{E,P}	158.5	15.3 ^{E,P}	9.0
Midshaft							
TA	13	651.2	90.4	728.9 ^{E,P}	98.2	11.4 ^{E,P}	7.0
CA	13	484.7	77.9	527.7	94.7	72.2 ^{E,P}	6.3
I_{ap}	13	196.0	50.7	232.3 ^{E,P}	70.0	18.0 ^{E,P}	11.8
I_{ml}	13	176.6	48.0	226.5 ^{E,P}	61.0	27.0 ^{E,P}	16.8
I_{max}	13	201.0	51.9	256.7 ^{E,P}	71.5	24.3 ^{E,P}	16.1
I_{min}	13	166.8	47.5	202.1 ^{E,P}	55.0	20.1 ^{E,P}	11.6
$I_{\text{ap}}/I_{\text{ml}}$	13	1.1	0.2	1.0	0.2	13.3 ^{E,P}	9.4
$I_{\text{max}}/I_{\text{min}}$	13	1.2	0.1	1.3	0.1	9.4 ^{E,P}	8.8
J	13	367.8	97.7	458.8 ^{E,P}	124.2	15.3 ^{E,P}	9.0

The abbreviations FL and FHD denote femur length and femur head diameter, respectively. Other abbreviations can be found in Table 1. Bold mean indicates a significant difference and the superscript letter after the mean denotes the variant that differs (E, EC; P, PCC; D, DC).

and intensity. Unfortunately, however, there are many potential problems with comparing groups based on broad subsistence strategies [7,70,77], especially in the Plains [11,75]. This may be in part because there is distinct regional variation in the pattern of change in long bone cross-sectional variables associated with the shift from hunting-gathering to horticulture in North America [7]. For example, in the southeast United States, long bone strength increases among interior populations [5–7] as they change from hunting-gathering to horticulture but decreases among coastal populations when they undergo the same subsistence shift [62–65]. These differences may be associated with local variation in the level of physical activity conducted in different regions or due to changes in the local genetic structure. Furthermore, contrary to results from other geographical regions [5–8,15,32,35,57,59,60,62,63,65] there is little change in long bone morphology with the transition from hunting-gathering to horticulture in the Plains [11,55,75]. This is not surprising considering the unique subsistence pattern of Plains villagers. As Lehmer and Wood [39] point out, Plains horticulturalists were more like the mixed horticultural and pastoral societies of the Old World than they were like other American Indian groups.

As emphasized by Bridges et al. [7] and Stock [70], to fully understand biomechanical changes we must examine the changes in activity levels *within* populations or subsistence groups rather than variation between broadly defined subsistence practices. Only by examining specific shifts in work load and using samples from genetically homogeneous populations with reliable ethnographic and archaeological evidence of habitual behavior will we gain a sufficient understanding of the complex interrelationship between behavior and long bone morphology. This study does this by examining changes in humeral and femoral cross-sectional geometry associated with increased work loads among the Arikara that produced surplus crops for trade.

Throughout the period investigated in this study, the Arikara were engaged in a mixed subsistence economy involving

growing domesticated crops, gathering wild fruits and roots, hunting, and fishing [79]. Archaeological and historical evidence suggests that there were no major changes in the activities conducted by the Arikara from late prehistoric (EC) to historic times (DC), but that the intensity of the activities did change, especially among females [49]. All of the additional work necessary to produce surplus crops was conducted by females. If the biomechanical analysis of long bone diaphyses can be used to infer changes in the level of physical activity, then there should be significant changes in long bone cross-sectional properties among the Arikara females associated with the increased work load necessary to grow surplus crops. Specifically, there should be significant differences between the EC and DC females in humeral and femoral diaphyseal variables, with the PCC falling somewhere in the middle. Since work loads increased among females but stayed relatively stable in males, sexual dimorphism should also change markedly from the mid sixteenth to early nineteenth centuries.

The results of this study confirm these expectations and reveal that there were significant changes in proximal long bone strength and asymmetry, especially among females, from the mid sixteenth to the early nineteenth century. Furthermore, there are significant temporal changes in the pattern of sexual dimorphism.

Bridges et al. [7] found that femoral and left humeral strength increased in females from west-central Illinois with the intensification of native seed crops and then declined with the intensification of maize production. They argued that this pattern of change reflects the greater strength needed to process native seeds compared to maize. In this study, we found no significant changes in female humeral strength or asymmetry but did find a significant increase in left femoral subtrochanteric and midshaft strength and femoral diaphyseal asymmetry from the EC to the DC in females. Humeral bilateral asymmetry is reduced from the EC to the DC, but not significantly, and humeral strength and cross-sectional size is slightly greater (but not significantly) in

Table 5
Summary statistics and ANOVA results of male humeral variables

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
Extended coalescent							
HL	44	323.8	11.4	317.7	12.3	2.0	1.0
HHD	44	46.8	2.5	45.6	4.1	3.9	11.3
TA	44	862.7	95.6	833.2	108.0	6.2	4.7
CA	44	605.5	75.0	606.8	81.0	5.6	3.2
I_{ap}	44	271.3	51.9	244.9	58.3	15.0	10.0
I_{ml}	44	256.4	47.8	251.7	57.7	9.6	7.4
I_{max}	44	291.9	53.5	271.5	60.2	11.8	9.2
I_{min}	44	235.7	44.1	225.2	54.9	11.8	8.5
I_{ap}/I_{ml}	44	1.1	0.1	1.0	0.1	11.0	8.1
I_{max}/I_{min}	44	1.2	0.1	1.2	0.1	8.8	6.6
J	44	527.6	94.5	496.7	112.9	11.0	8.3
Post-contact coalescent							
HL	66	322.4	12.7	316.9	12.9	1.8	1.1
HHD	66	46.4	2.4	45.9	2.4	1.6	1.6
TA	66	878.7	123.0	831.7	126.2	7.7	4.6
CA	66	616.9	101.1	598.2	99.4	6.6	5.1
I_{ap}	66	282.4	69.4	246.0	74.7	18.0	10.7
I_{ml}	66	267.1	75.0	248.3	68.9	12.0	8.9
I_{max}	66	305.5	75.6	276.4	78.4	13.7	9.3
I_{min}	66	244.0	67.8	218.0	62.5	16.9	9.8
I_{ap}/I_{ml}	66	1.1	0.1	1.0	0.1	11.1	7.8
I_{max}/I_{min}	66	1.3	0.2	1.3	0.2	9.2	8.3
J	66	549.5	139.8	494.4	137.5	14.5	8.7
Disorganized coalescent							
HL	17	326.8	16.5	322.2 ^{E,P}	16.0	1.9	0.8
HHD	17	46.2	2.4	46.2	2.1	2.0	2.8
TA	17	890.4	123.5	836.7	121.8	7.8	7.3
CA	17	635.9	96.3	589.0	75.9	8.9 ^E	7.7
I_{ap}	17	302.6	85.0	246.6	67.6	20.6	15.5
I_{ml}	17	272.6	66.4	254.5	62.7	15.8 ^E	13.6
I_{max}	17	322.6	84.7	285.0	74.4	20.0 ^{E,P}	15.8
I_{min}	17	252.6	61.2	227.6	60.5	14.8	13.8
I_{ap}/I_{ml}	17	1.1	0.2	1.0	0.2	17.1 ^{E,P}	9.4
I_{max}/I_{min}	17	1.3	0.1	1.3	0.1	10.4	7.9
J	17	575.2	141.9	512.5	131.1	17.4 ^E	14.2

The abbreviations HL and HHD denote humerus length and humerus head diameter, respectively. Other abbreviations can be found in Table 1. Bold mean indicates a significant difference and the superscript letter after the mean denotes the variant that differs (E, EC; P, PCC; D, DC).

the EC compared to PCC and DC. This pattern seems contradictory, but might actually be expected based on a biomechanical model. Decreases in humeral asymmetry and increases in diaphyseal strength among horticulturalists have been linked to the processing of seeds (e.g., grinding and pounding) [5,7], but the Arikara were probably not trading processed corn and other vegetables (W.R. Wood, personal communication). Therefore, it is not surprising that there are no significant changes in humeral strength or asymmetry through time in females. Instead, the increased work load associated with growing surplus crops probably involved activities related to field preparation, planting, and harvesting. Arikara females prepared their fields by cutting the brush close to the ground and then removed roots with a digging stick [49]. Planting activities involved making rows of approximately 18 inch diameter hills with hoes and working the soil in each hill to

a fine texture with their hands [49]. These type of activities might actually result in greater increases in femoral than humeral strength.

Most human populations show slight left lower limb dominance [12,60,61,67]. That is, the left femur tends to be longer and stronger than the right. The reason for this is unknown, but may be due to placing greater mechanical loads on the left leg when standing and performing right-handed activities [12,54,60,66]. If so, intensifying field preparation and planting activities would have produced greater mechanical loads on the left femur resulting in the pattern seen in Arikara females. Hoeing and raking, for example, would result in one leg receiving greater mechanical loads. Furthermore, a work load increase rather than a change in activity would result in greater increases in the cross-sectional size rather than shape, especially at mid-shaft [54], which is the pattern we observe in this study.

Table 6
Summary statistics and ANOVA results of male femoral variables

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
Extended coalescent							
FL	50	446.1	18.1	448.0	18.3	0.8	0.9
FHD	50	46.7	2.4	46.6	2.4	1.0	1.5
Subtrochanteric							
TA	49	731.3	81.0	747.4	85.8	4.6	3.5
CA	49	507.1	64.3	521.3	61.9	5.7	4.0
I_{ap}	49	242.6	50.5	247.7	52.6	9.4	6.9
I_{ml}	49	251.1	56.3	268.7	57.6	12.3	8.9
I_{max}	49	332.3	65.7	346.0	72.4	8.7	5.9
I_{min}	49	161.4	36.9	170.5	36.9	11.4	7.9
I_{ap}/I_{ml}	51	1.0	0.3	0.9	0.2	12.5	11.0
I_{max}/I_{min}	51	2.1 ^{D,P}	0.4	2.1 ^{D,P}	0.4	8.6	7.3
J	49	493.7	95.1	516.5	101.6	8.4	6.3
Midshaft							
TA	50	648.9	75.0	654.4	71.6	3.8	3.5
CA	50	488.7	61.4	494.6	57.9	4.2	3.8
I_{ap}	50	211.6	50.0	209.3	44.4	8.2	7.3
I_{ml}	50	177.7	40.8	186.9	41.4	10.1	8.1
I_{max}	50	223.2	52.3	224.6	48.0	8.8	8.3
I_{min}	50	166.1	35.1	171.6	33.2	7.8	7.0
I_{ap}/I_{ml}	50	1.2	0.2	1.1	0.2	11.4	9.0
I_{max}/I_{min}	50	1.3	0.2	1.3	0.2	9.3	9.2
J	50	389.4	84.2	396.2	77.1	8.4	6.3
Post-contact coalescent							
FL	98	444.8	18.4	447.4	18.7	0.8	0.7
FHD	98	46.5	3.0	46.5	2.9	1.2	1.4
Subtrochanteric							
TA	97	764.6	97.5	769.5	95.2	4.5	3.7
CA	97	522.4	80.0	536.4	86.2	5.5	4.6
I_{ap}	97	263.7	69.0	262.9	66.1	9.8	7.3
I_{ml}	97	263.4	65.3	275.5	67.1	12.8	8.4
I_{max}	97	345.3	81.9	347.3	76.5	9.0	7.9
I_{min}	97	181.8	46.0	191.2	53.6	10.5	8.2
I_{ap}/I_{ml}	101	1.0	0.2	1.0	0.2	12.6	9.5
I_{max}/I_{min}	101	1.9 ^{D,E}	0.3	1.9 ^{D,E}	0.3	8.3	7.4
J	97	527.1	121.8	538.5	123.3	8.7	7.1
Midshaft							
TA	98	669.9	80.0	676.0	77.0	3.6	3.0
CA	98	503.7	71.0	508.7	74.6	4.7	3.3
I_{ap}	98	223.1	53.2	222.9	49.9	7.5	5.5
I_{ml}	98	189.1	46.2	196.1	47.1	9.9	7.6
I_{max}	98	235.7	57.6	236.9	54.3	8.3	5.6
I_{min}	98	176.5	39.7	182.2	41.1	8.0	6.8
I_{ap}/I_{ml}	101	1.2	0.2	1.2	0.2	9.6	7.5
I_{max}/I_{min}	101	1.3	0.2	1.3	0.2	7.8	5.8
J	98	412.2	91.2	419.0	89.9	8.7	7.1
Disorganized coalescent							
FL	11	460.1 ^{E,P}	18.4	457.7	20.8	0.4	0.4
FHD	11	47.7	2.8	47.2	2.4	1.4	1.9
Subtrochanteric							
TA	11	720.9	76.1	780.0	75.9	6.9	4.5
CA	11	495.9	52.7	530.0	78.3	5.6	6.2
I_{ap}	11	244.2	38.0	272.6	46.2	10.7	7.7
I_{ml}	11	227.6	50.0	269.9	64.2	14.2	10.5
I_{max}	11	294.8	54.9	333.7	63.5	10.6	4.2
I_{min}	11	177.0	34.7	208.8 ^{E,P}	38.8	16.3	12.7
I_{ap}/I_{ml}	13	1.0	0.2	1.0	0.3	12.9	7.8

Table 6 (continued)

Property	N	Right		Left		Asymmetry (%)	
		Mean	SD	Mean	SD	Mean	SD
I_{\max}/I_{\min}	13	1.7^{E,P}	0.2	1.6^{E,P}	0.2	11.2	9.1
J	11	400.7	53.6	424.5	87.8	11.6	7.5
Midshaft							
TA	11	651.0	52.2	669.4	72.5	4.3	4.1
CA	11	487.1	53.4	507.9	75.5	5.1	6.1
I_{ap}	11	227.9	29.2	235.5	55.6	11.8	11.6
I_{ml}	11	172.8	35.1	188.9	43.3	7.6	8.3
I_{max}	11	234.5	30.4	247.7	53.0	9.6	8.9
I_{min}	11	166.2	33.1	176.8	43.7	9.2	8.5
$I_{\text{ap}}/I_{\text{ml}}$	13	1.3	0.3	1.3	0.3	9.9	9.2
$I_{\text{max}}/I_{\text{min}}$	13	1.4	0.3	1.4^{E,P}	0.3	5.4	5.4
J	11	400.7	53.6	424.4	87.8	11.6	7.5

The abbreviations FL and FHD denote femur length and femur head diameter, respectively. Other abbreviations can be found in Table 1. Bold mean indicates a significant difference and the superscript letter after the mean denotes the variant that differs (E, EC; P, PCC; D, DC).

While the pattern of change in humeral and femoral diaphyseal morphology among Arikara females appears consistent with an increased workload related to horticultural intensification, it is also possible that the changes are due to a temporal pattern in the age at which particular adult activities commenced, or that they reflect changes in subadult activities. That is, the age at which females began working in the garden may have decreased through time, or early historic period (DC) subadult females may have been involved in activities that were not practiced by earlier groups. Knüsel [30] argued that population differences in the age at which adult activities commence may be more important in determining adult long bone architecture than the actual intensity of the activities. Furthermore, as the skeleton reaches maturity, modeling, the primary process responsible for long bone cross-sectional shape, decreases significantly [16]. This suggests that the cross-sectional architecture of a long bone may reflect pre-adult activities more than adult activities [50]. Unfortunately, there is no historical or archaeological evidence that can confirm or refute whether or not Arikara females began adult activities at an earlier age through time or that there was a temporal change in their play behavior.

In males there are relatively few changes in long bone diaphyseal strength or asymmetry over time. The only significant changes are in humeral asymmetry, femoral subtrochanteric I_{\max}/I_{\min} , and left femur midshaft I_{\max}/I_{\min} . In general, these results are relatively consistent with those seen in other studies (see [34] for an overview). The increase in humeral asymmetry is primarily due to greater right humeral strength among the DC males. This change in asymmetry and right humeral strength could be due to an increased reliance on firearms during hunting and warfare. Bridges and colleagues [5–7] found that increases in male humeral strength and symmetry from the middle to late Woodland period in the south-eastern United States corresponded with the replacement of the spear and atlatl with the bow. Stirland [69] also found greater humeral strength and symmetry in medieval British

archers compared to non-archers. In the Arikara, there was most likely a shift away from the bow as firearms became more abundant after A.D. 1750 [52]. While the Arikara had access to firearms in the post-contact period, dependable rifles were not available until later in the historic period [19]. The greater reliance of firearms, especially in the DC, may be responsible for the pattern of humeral asymmetry seen among the Arikara males. However, Parks [49] remarked that even in historic times Arikara males almost always carried a bow and quiver over their left shoulder, which might suggest that firearms were more important to the Arikara as trade items than as weapons. Then again, bows may have been carried by Arikara males as an alternate for when their rifles failed, which was a common occurrence (W.R. Wood, personal communication).

With one exception, there are almost no femoral changes in Arikara males during the period investigated. The change in femoral subtrochanteric I_{\max}/I_{\min} ratio is difficult to explain but may be related to a greater reliance on the horse as a pack animal. Proximal femur shape and strength is thought to primarily reflect differences in pelvic morphology [56]. While these types of data were not collected for the present study, it is unlikely that there was a significant change during the time period examined [51]. On the other hand, the subtrochanteric I_{\max}/I_{\min} ratio should also be affected by carrying heavy weights, such as bison meat and hides, on one's back. The pattern of decreased I_{\max}/I_{\min} may reflect a reduction in loads carried from the kill site to the village. However, there is no direct evidence that Arikara males carried bison meat and hides from the kill site to the village on their backs. Prior to the horse, hunting products were transported to the village by canoes paddled by women [14] or by dogs [19]. Therefore, it is not known what is responsible for the change in the relative maximum to minimum bending strength through time at subtrochanteric in males.

Researchers (e.g., [20,33,53,55,57,71,72]) have suggested that femoral midshaft shape is associated with terrestrial mobility, with more mobile populations exhibiting larger

Table 7
ANOVA results for sexual dimorphism within and between archaeological variants

Property	EC			PCC			DC		
	Right	Left	Asym	Right	Left	Asym	Right	Left	Asym
Humerus									
HL	S	S	–	S	S	–	S	S	–
HHD	S	S	–	S	S	S	S	S	–
TA	S	S	–	–	S	–	–	N	–
CA	–	S	–	–	S	–	–	N	–
I_{ap}	–	S	S	–	S	S	–	S	S
I_{ml}	–	S	–	S	–	–	–	–	–
I_{max}	–	S	S	N	N	S	–	–	N
I_{min}^1	–	–	–	S	S	–	–	–	–
I_{ap}/I_{ml}^3	–	S	S	S	S	S	–	S	S
I_{max}/I_{min}	–	–	–	–	–	–	–	–	N
J	–	S	–	N	S	N	–	–	N
Femur subtrochanteric									
FL	S	S	–	S	S	–	S	S	–
FHD	S	S	–	S	S	–	S	–	–
TA ¹	–	–	–	–	–	–	S	–	–
CA	–	–	–	–	–	–	–	–	–
$I_{ap}^{1,3}$	–	–	S	S	–	–	S	–	S
$I_{ml}^{2,3}$	–	–	N	N	S	S	–	S	S
I_{max}^1	–	–	–	N	–	–	S	–	–
I_{min}^2	–	–	–	S	S	–	–	–	–
$I_{ap}/I_{ml}^{1,2,3}$	S	–	S	–	S	S	–	S	S
$I_{max}/I_{min}^{1,2}$	–	S	–	–	S	–	S	S	–
J	–	–	–	S	N	–	–	–	–
Femur midshaft									
TA ^{2,3}	–	–	–	S	S	–	–	–	S
CA ³	–	–	–	N	–	–	S	–	N
I_{ap}	S	–	–	S	S	–	–	–	–
$I_{ml}^{2,3}$	–	–	–	S	S	–	–	S	S
I_{max}^3	S	–	–	S	S	–	S	–	S
I_{min}^3	–	–	N	S	S	–	–	–	S
I_{ap}/I_{ml}	–	–	S	S	S	–	S	S	–
I_{max}/I_{min}^3	S	S	S	S	S	S	S	–	–
J^2	–	–	–	S	S	–	–	–	–

“S” equals statistically significant ($p \leq 0.05$) and “N” signifies nearly significant ($0.051 \leq p \leq 0.1$). Bold letters indicate that males are larger than females. The superscript 1 after the property signifies a significant sex \times variant interaction for the right bone, 2 indicate a significant interaction for the left bone, and 3 denote a significant interaction for asymmetry.

midshaft I_{ap}/I_{ml} ratios. While Arikara males hunted throughout the period examined, they probably became more reliant on horses as a means of terrestrial mobility after A.D. 1740 [13,45], which should result in a greater femoral midshaft circularity or even a ML expansion through time [55,75]. However, no significant changes in femur midshaft shape (I_{ap}/I_{ml}) were observed through time in the Arikara. It is possible that the changes were not significant enough to result in observable changes or that the I_{ap}/I_{ml} ratio is not a sensitive indicator of mobility levels [75,77].

The level of sexual dimorphism within and between populations has been used as an indicator of the degree of sexual division of labor. Nevertheless, in the Arikara the pattern of sexual dimorphism through time is complex and may reflect a combination of environmental and mechanical factors. In the PCC, for example, males have significantly stronger right and left femora than females, especially at midshaft. However,

during the DC females have relatively stronger left femora (when standardized for body size) than males. This change also resulted in greater sexual dimorphism in femoral asymmetry. Furthermore, sexual dimorphism in femur midshaft shape changes from insignificant in the EC to significant in the PCC and DC. However, asymmetry in femur midshaft shape dimorphism decreases significantly from the EC to the PCC and DC. These changes in sexual dimorphism probably reflect changes in the activity patterns or the level of activity among males and females.

However, the overall pattern of sexual dimorphism between temporal periods is an increase in sexual dimorphism from the EC to the PCC followed by a slight decrease in sexual dimorphism in the DC. This overall pattern is interesting and may reflect environmental (health and nutrition) rather than work load changes. Multiple lines of evidence [24,25,37,45] have demonstrated that groups from the EC,

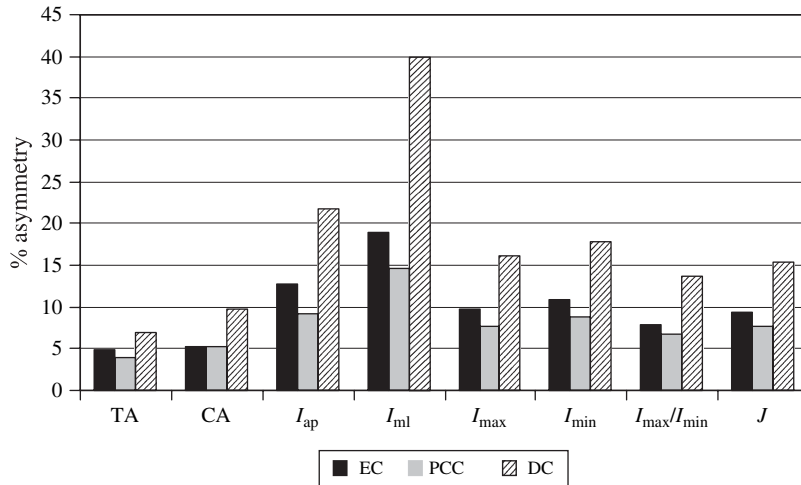


Fig. 1. Femoral subtochanteric asymmetry among females. DC females differ significantly from PCC and EC females for all variables but PCC and EC females do not differ significantly.

PCC, and DC variants experienced considerable differences in health and nutritional status due to climatic factors, intertribal conflict, and European contact, with individuals during the EC experiencing the worst conditions [25]. During the EC, the Arikara experienced periods of undernutrition due to shorter growing seasons and fewer bison herds [37]. Horticultural productivity and village size increased dramatically during the PCC, but during the DC the Arikara experienced high rates of mortality and morbidity due to disease and intertribal conflict [26,45]. Studies have demonstrated that sexual dimorphism is reduced in populations undergoing environmental stress [68]. In this study, it was found that sexual dimorphism in both the humeral and femoral properties increased from the EC to the PCC and then declined again in the DC. This pattern may be more consistent with the hypothesis that long bone cross-sectional sexual

dimorphism among the Arikara is a reflection of health and nutrition rather than evidence for significant changes in the sexual division of labor.

In conclusion, this study examined within-sex and between-sex differences in humeral and femoral cross-sectional morphology and asymmetry in three variants of Coalescent period attributed to the Arikara. Significant changes were observed in long bone cross-sectional morphology from late prehistoric to early historic periods, especially in females. Many of these changes are likely due to the increased workload necessary to produce surplus crops for trade. Significant changes in males are primarily restricted to the humerus and may reflect a greater reliance on firearms over the bow. The temporal patterns of sexual dimorphism among the Arikara are complex and probably reflect both changes in health and the intensity of sex-specific tasks.

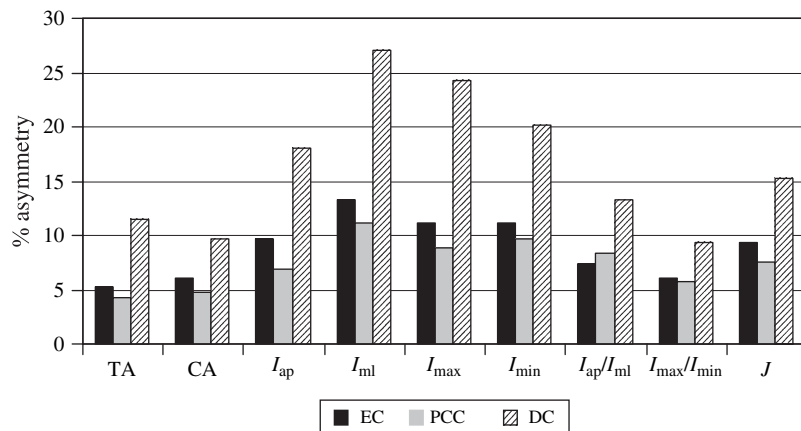


Fig. 2. Femoral midshaft asymmetry among females. DC females differ significantly from PCC and EC females for all variables but PCC and EC females do not differ significantly.

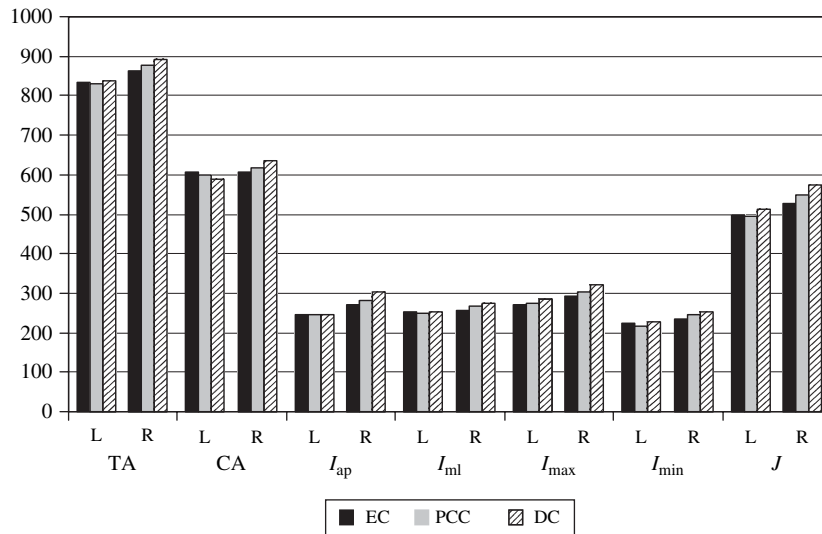


Fig. 3. Left and right humerus cross-sectional properties in males. There are no significant differences among males from the three variants of Arikara.

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