Changes in Long Bone Diaphyseal Strength With Horticultural Intensification in West-Central Illinois

PATRICIA S. BRIDGES,[1] JOHN H. BLITZ,[2] AND MARTIN C. SOLANO[3*]
[1]*Department of Anthropology, Queens College and Graduate Center, CUNY, Flushing, New York 11367*
[2]*Department of Anthropology, University of Alabama, Tuscaloosa, Alabama 35487-0210*
[3]*Department of Anthropology, University at Albany, SUNY, Albany, New York 12222*

KEY WORDS biomechanics; agriculture; Lower Illinois Valley

ABSTRACT This study examines changes in long bone diaphyseal strength in west-central Illinois from the Middle Woodland through the Mississippian periods. Significant differences occur between the Middle Woodland and the Late Woodland periods, at the time when use of native seed crops intensifies. In females, both humeral and femoral strength increases, which may be related to their role in growing and processing these crops. In males, right arm strength declines, which may be tied in part to the replacement of the atlatl by the bow. Fewer significant changes occur between the earlier and later Late Woodland periods, at the time when maize is introduced as a dietary staple, possibly because maize is at first grown as only one of a series of other starchy seeds. Finally, in the Mississippian period, when maize use intensifies, female left arm strength declines. This may be because maize is easier to process than native seeds, or it may reflect innovations in processing technology in the Mississippian period. External dimensions and shape indices, in part, reflect the trends seen in biomechanical strength. Comparisons are made to similar studies in other regions. Am J Phys Anthropol 112:217–238, 2000.

In recent years, biomechanical analyses of long bone diaphyses have provided insights into changes in the level of physical activities in prehistory, especially in association with the adoption of maize agriculture in eastern North America. In general, these studies show that changes in subsistence technology, associated with modifications of behavior (e.g., processing, mobility), resulted in the remodeling of bone to meet the changes in physical demands on the skeleton. However, these studies have yielded conflicting results. On the Georgia coast, long bone strength declines with the introduction of agriculture (Ruff and Larsen, 1990; Ruff et al., 1984), while in northwestern Alabama, the opposite is true (Bridges, 1989). Moreover, these regions show variable changes between the sexes and for different bones. This diversity is likely due to a combination of factors: variability in environment, cultural systems, and subsistence practices in agricultural groups, among other reasons. Variability in the preagricultural samples is even greater, since these studies utilize groups from different time periods and of differing adaptations to compare with later agriculturalists.

Grant sponsor: PSC-CUNY Research Awards; Grant sponsor: Queens College Research Award in Social Sciences; Grant sponsor: Wenner-Gren Foundation for Anthropological Research.

Dr. Bridges deceased.

*Correspondence to: Martin C. Solano, Department of Anthropology, University at Albany, SUNY, Albany, NY 12222.
E-mail: ms6248@cnsvax.albany.edu

Received 2 October 1998; accepted 12 February 2000.

This study attempts to resolve some, though not all, of these problems by examining long bone diaphyseal dimensions and structure in several cultural groups from west-central Illinois, dating from the Middle Woodland (50 BC–AD 200), the Late Woodland (AD 600–1050), and the Mississippian (AD 1050–1250) periods. All of these groups grew at least some food crops by hoe cultivation, although their reliance on them increased over time (Asch and Asch, 1985a; Asch et al., 1979). Native seed crops were cultivated in the Middle Woodland period. Maize was present in small quantities before AD 600 in this region, but stable carbon isotope studies have revealed that it did not become a measurable part of the diet until after AD 800. Later, maize use rose sharply in Mississippian times (Bender et al., 1981; Buikstra, 1992; Buikstra et al., 1987; van der Merwe and Vogel, 1978). Because the timing of these events is relatively well-known in this region, it is possible to examine more closely activity levels associated with native seed horticulture, early maize growing, and maize intensification.

This study concentrates on the transition in hoe cultivation from small-scale crop production ("horticulture") through large-scale crop production ("agriculture"). Previous studies assumed that the introduction of maize agriculture was the seminal event in causing changes in activities in late prehistory. In order to best characterize this change, studies of biomechanical variables largely focused on the ends of the spectrum (hunter-gatherers vs. full-scale maize agriculturalists), ignoring transitional horticultural societies. As a result, earlier biomechanical studies do not provide an analysis of the process of initial introduction compared to later intensification of food crops. Because of the fine-grained chronology present in this region, it can distinguish between: 1) low-level horticulturalists relying on native seeds (Middle Woodland period), 2) intensive horticulturalists using the same crops ("earlier" Late Woodland period), 3) societies which relied on native seeds but also incorporated some maize into the diet ("later" Late Woodland period), and 4) intensive maize agriculturalists (Mississippian period). Therefore, this study can link activity levels with specific subsistence economies, rather than with somewhat simplistic categories such as "agriculturalists." If the assumption that the introduction of maize caused a radical change in usual activities is correct, diaphyseal strength should change most at that time, or perhaps later, when its use intensified.

MATERIALS AND METHODS

West-central Illinois has been the site of extensive archaeological excavations for many years, and has yielded a large quantity of human skeletal remains. These collections consist primarily of burials from the Middle Woodland through the Mississippian periods, although a few Archaic individuals are represented as well. Inventories for the majority of the remains are available at the Universities of Chicago and Indiana, where the remains are curated, and include previously determined age and sex assessments. The sample for this study is drawn primarily from sites which lie within the Lower Illinois Valley, although a few, such as Kuhlmann, lie within the nearby section of the Mississippi River Valley. Middle Woodland sites include Pete Klunk, Gibson, and L'Orient (Buikstra, 1976; Perino, 1968). Late Woodland remains also come from Pete Klunk, as well as Koster, Schild, Yokem, Ledders, Hacker, and Kuhlmann (Atwell and Conner, 1991; Conner, 1984; Perino, 1971a, 1973a–c). The large Mississippian cemetery at the Schild site is the single source for burials of that period (Perino, 1971b).

Several studies have linked a decline in health, especially in children, during the Late Woodland period with the introduction of maize as a dietary staple (Cook, 1979, 1984). Since maize becomes a dietary staple midway through the Late Woodland period, it is important to subdivide Late Woodland samples into "pre-" and "postmaize," with circa AD 800 as the dividing point. However, subdividing the Late Woodland period can be problematic, given the error ranges seen in radiocarbon dates. One additional problem is that the earliest Late Woodland period is not represented by significant skeletal remains in this region. Nonetheless, it is possible to sort Late Woodland societies into earlier and later subsamples. A review of calibrated radiocarbon dates (Conner, 1984) from the sites in question reaffirms that the majority of the Late Woodland at the Pete Klunk Mounds comes from the earlier part of this period (between AD 600–800). The Koster Mounds Late Woodland dates largely overlap this period, falling between the late 600s and late 800s. In this study, these sites will be referred as "earlier Late Woodland." Other Late Woodland sites in this study are younger in age (with radiocarbon dates mostly falling after AD 900), and are designated "later Late Woodland."

The sample used in this research is composed primarily of adults under the age of 50 years. (Although some adults over the age of 50 years were measured, they are not included in the biomechanical analysis to avoid the possibility of age-related osteoporosis.) For the purposes of this study, "adult" is taken to represent any individual with at least one long bone with both epiphyses fused. Each individual measured had to contain at least one complete long bone. Age and sex determinations were made under the direction of Jane Buikstra (previously of Northwestern University and the University of Chicago), and Della Cook (Indiana University).

From the entire collection, 372 individuals were chosen for osteometric analysis. Measurements included standard lengths, and diaphyseal and articular dimensions. Bones with pathological conditions were excluded from the sample, whether or not the site of measurement was affected. When a pathology affected a large portion of the skeleton, the entire individual was dropped from the sample. From this larger sample, a smaller group was selected for computed tomographic (CT) scanning and subsequent biomechanical analysis. This subsample comprised 80 individuals, 20 from each time period (Middle Woodland, earlier Late Woodland, later Late Woodland, and Mississippian periods), half of which were of each sex. To be selected for this subsample, each individual had to possess at least one complete femur. The left femur was used if present and in good condition. If not, the right femur was substituted for it. In addition, each individual had to have a right humerus. When present and in good condition, both humeri were included, to allow for an examination of bilateral asymmetry.

Next, the humeri and femora of the 80 individuals chosen for biomechanical analysis had to be oriented properly to ensure that the resulting CT scans would be taken in the appropriate plane. This process, which follows the procedures of Ruff (1981) and Ruff and Hayes (1983), is described in more detail elsewhere (Bridges, 1985). Essentially, it involves aligning the femora and humeri along three reference axes: the longitudinal axis of the diaphysis, the anteroposterior axis, and the mediolateral axis. All bones to be scanned for each individual were aligned together on a single sheet of heavy cardboard, and firmly affixed in place. Leveling of the bones was achieved with the use of individually cut Styrofoam cubes. The midshaft of each bone was aligned along the same plane so that a single CT image could be taken of each individual at midshaft, reducing scanning time. Bones were scanned at the Department of Radiology, Indiana University Medical Center (Indianapolis, IN), using a GE 9800 CT scanner. Each scan was reproduced as an enlarged X-ray image.

The images were digitized on a SummaSketch II Plus 12″ × 12″ graphics pad, using a program called SLCOMM, modified by Peter Eschman from the program SLICE (Eschman, 1990). Before digitizing the images, an error analysis was performed on both a series of standardized circles and on nine bone cross sections (three femora and six humeri). The average error in area for the standard circles was less than 2%. Variation in cortical area of the nine cross sections averaged less than 3%. A subsequent error analysis was also performed at the end of the digitizing process on 14 sections. This yielded an average error of only 1.2% in cortical area. Together, these tests indicate that the level of error in digitizing was acceptably low.

Data from the digitized images are used by the SLCOMM program to produce estimates of mechanical rigidity, or what is commonly referred to as "strength" under various kinds of forces. Cross-sectional area is a measure of resistance to compression.

TABLE 1. Femoral midshaft cross-sectional properties[1]

	Males				Females			
	MW	eLW	lLW	Miss	MW	eLW	lLW	Miss
Unstandardized (raw) cross-sectional variables								
Cortical area, mean	400	418	424	428	278	316	299	311
SE	18.3	14.9	11.7	18.1	8.4	10.9	9.5	16.9
Imin, mean	20,675	19,268	23,064	22,552	11,471	13,500	12,517	13,412
SE	1,568	1,225	1,252	1,501	666	597	685	1,281
Imax, mean	28,392	27,505	29,601	33,050	14,535	17,731	14,850	17,132
SE	3,075	1,822	1,875	2,526	718	950	848	1,903
J, mean	49,066	46,773	52,665	55,602	26,006	31,231	27,367	30,545
SE	4,558	2,605	2,979	3,766	1,234	1,336	1,426	3,158
Size-standardized cross-sectional variables[2]								
Cortical area, mean	435	437	444	429	367	414	434*	401
SE	16.4	21.8	14.6	14.0	18.7	14.4	11.6	13.8
Min bending strength, mean	145.3	129.5	153.0	139.1	114.5	133.9	150.5*	127.8
SE	8.2	12.2	8.8	9.2	8.3	6.1	10.4	7.2
Max bending strength, mean	194.8	179.6	194.1	203.5	146.1	174.8	175.8	162.0
SE	9.6	11.3	9.0	13.9	10.7	7.7	7.9	11.7
Torsional strength, mean	340.2	309.1	347.1	342.6	260.6	308.8	326.4*	289.8
SE	15.9	22.5	16.8	21.4	18.0	11.4	17.8	18.5
Shape index, Imax/Imin, mean	135	146	128	147	129	132	119	126
SE	6.3	11.2	4.7	7.5	7.2	7.6	4.7	3.6

[1] MW, Middle Woodland; eLW, earlier Late Woodland; lLW, later Late Woodland; Miss, Mississippian; L, left; R, right; Max, maximum; Min, minimum. Sample size for each group = 10.
[2] Cortical area (in mm^2) divided by $length^3$ and multiplied by 10^8; I and J (in mm^4) divided by $length^{5.33}$ and multiplied by 10^{12}.
* Significantly different ($P < 0.05$) from the Middle Woodland.
** Significantly different ($P < 0.05$) from the early Late Woodland.
*** Significantly different ($P < 0.05$) from the late Late Woodland.

Second moments of area (designated "I") estimate resistance to various bending forces (Lovejoy et al., 1976). Commonly used I values include Iap and Iml (resistance to bending forces around the anteroposterior and mediolateral axes), or Imax and Imin (maximum and minimum second moments of area). The polar second moment of area (J) estimates the section's strength under torsional or twisting forces, and is computed by adding I values from axes at right angles (i.e., Iap + Iml = J).

The resistance of a long bone is also influenced by its length; therefore, biomechanical values must be size-standardized. However, there is some controversy, especially regarding the humerus, as to what constitutes the most appropriate means of standardization. One possibility is to divide area by $length^2$, and I or J by $length^4$ (Churchill, 1994). This study follows Ruff et al. (1993) in dividing I and J by bone $length^{5.33}$, to create a standardized estimate of bending strength. Cortical area is divided by bone $length^3$. Size standardization of external diaphyseal measurements is accomplished by computing standard indices, such as the robusticity index (circumference/length × 100). To determine whether groups were significantly different from each other, Tukey's HSD tests were performed at a 95% confidence interval.

RESULTS

Femur

Males show no significant differences among time periods for any size-standardized femoral midshaft cross-sectional properties (Table 1). Male femoral external measurements, however, reveal a significant increase in size for three variables in the Mississippian samples compared to Middle Woodland samples: midshaft AP diameter, subtrochanteric ML diameter, and subtrochanteric circumference (Table 2).

Females, on the other hand, show a greater number of significant differences over time, both in external dimensions and structural variables. For three of the biomechanical variables (cortical area, minimum bending strength, and torsional strength),

TABLE 2. Femoral dimensional data (in mm) and indices[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Bicondylar length, mean	453	448	459	453	451	448	451	446
SE	3.7	3.6	4.0	4.2	3.0	3.0	3.6	3.6
N	(27)	(24)	(27)	(15)	(44)	(38)	(34)	(35)
Midshaft								
AP diameter, mean	29.0	29.3	30.5	30.1	29.9	29.6	31.0*	30.0
SE	0.54	0.53	0.52	0.48	0.42	0.41	0.46	0.36
N	(27)	(27)	(28)	(24)	(43)	(35)	(33)	(35)
ML diameter, mean	26.2	25.2	26.1	25.6	26.7	26.0	26.4	26.1
SE	0.37	0.30	0.36	0.33	0.25	0.28	0.27	0.25
N	(27)	(27)	(28)	(25)	(43)	(35)	(33)	(35)
Circumference, mean	86.9	86.1	88.5	86.7	88.3	87.3	89.8	88.1
SE	1.13	1.08	0.95	0.90	0.87	0.87	0.84	0.82
N	(27)	(27)	(27)	(22)	(41)	(35)	(33)	(35)
Subtrochanteric								
AP diameter, mean	24.9	25.0	25.5	25.0	25.2	24.7	25.5	25.0
SE	0.34	0.32	0.36	0.29	0.25	0.29	0.33	0.29
N	(36)	(37)	(34)	(37)	(52)	(47)	(37)	(39)
ML diameter, mean	33.4	32.8	34.0	33.5	34.3	33.8	34.0	34.2*
SE	0.30	0.30	0.39	0.46	0.34	0.33	0.37	0.33
N	(36)	(36)	(33)	(37)	(51)	(47)	(37)	(39)
Circumference, mean	91.9	91.0	93.9	92.8	94.8	93.0	94.4	94.1*
SE	0.83	0.88	0.94	0.96	0.82	0.82	0.82	0.74
N	(35)	(36)	(51)	(34)	(47)	(45)	(36)	(39)
Vertical head diameter, mean	45.4	45.3	46.1	46.1	46.3	46.2	46.1	46.1
SE	0.32	0.32	0.41	0.33	0.32	0.37	0.40	0.34
N	(29)	(30)	(26)	(33)	(36)	(31)	(31)	(32)
Shape indices								
Pilasteric, mean	111	117	117	117	112	114	118	115
SE	2.1	2.3	2.1	2.3	1.6	1.7	2.0	1.4
N	(27)	(27)	(28)	(24)	(43)	(35)	(33)	(35)
Platymeric, mean	75	76	75	75	74	73	75	73
SE	0.96	0.95	0.83	0.87	0.78	0.96	0.98	0.91
N	(36)	(36)	(33)	(37)	(51)	(47)	(37)	(39)
Females								
Bicondylar length, mean	421	420	421	421	418	415	418	417
SE	2.8	4.9	2.9	4.0	3.3	2.8	3.2	3.4
N	(29)	(19)	(30)	(23)	(38)	(42)	(37)	(37)
Midshaft								
AP diameter, mean	25.6	24.7	26.2	25.7	25.7	25.8	26.8	26.5*
SE	0.36	0.40	0.37	0.37	0.36	0.32	0.30	0.31
N	(29)	(21)	(31)	(29)	(36)	(43)	(37)	(37)
ML diameter, mean	24.2	23.4	24.7	24.4	24.8	24.4	24.7	23.9
SE	0.30	0.34	0.31	0.29	0.26	0.22	0.29	0.32
N	(29)	(21)	(31)	(29)	(36)	(42)	(37)	(37)
Circumference, mean	77.4	75.5	79.3	78.3	79.2	78.6	80.3	79.2*
SE	0.81	1.04	0.87	0.86	0.93	0.82	0.78	0.82
N	(29)	(21)	(29)	(29)	(33)	(40)	(37)	(37)
Subtrochanteric								
AP diameter, mean	22.0	22.1	22.7	22.4	22.3	22.2	22.6	22.6
SE	0.30	0.26	0.26	0.29	0.22	0.21	0.25	0.27
N	(40)	(41)	(36)	(35)	(56)	(58)	(39)	(40)
ML diameter, mean	30.2	30.3	31.2	30.8	30.8	30.8	31.0	31.0
SE	0.23	0.22	0.26	0.27	0.28	0.26	0.31	0.32
N	(40)	(41)	(37)	(34)	(55)	(58)	(39)	(41)
Circumference, mean	83.1	83.1	85.4	84.5	83.9	84.4	85.1	85.1
SE	0.69	0.65	0.69	0.82	0.71	0.70	0.79	0.84
N	(39)	(40)	(35)	(31)	(49)	(51)	(39)	(40)
Vertical head, mean	40.6	40.7	41.5	41.2	40.8	40.6	40.1**	40.0
SE	0.27	0.31	0.40	0.39	0.39	0.33	0.37	0.40
N	(36)	(35)	(31)	(34)	(38)	(42)	(35)	(38)
Shape indices								
Pilasteric, mean	106	106	106	105	104	106	109***	112*,**,***
SE	1.7	1.6	1.5	1.3	1.1	1.2	1.3	1.5
N	(29)	(21)	(31)	(29)	(36)	(42)	(37)	(37)
Platymeric, mean	73	73	73	73	73	72	73	73
SE	0.97	0.86	0.83	0.86	0.78	0.68	0.83	0.85
N	(40)	(41)	(36)	(34)	(55)	(58)	(39)	(40)

[1] See Table 1 for notes.

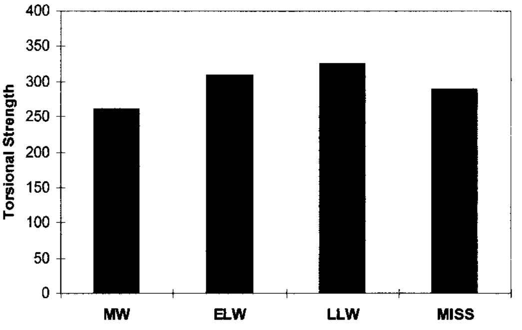

Fig. 1. Torsional strength (standardized) of female femora. Means. MW, Middle Woodland; ELW, early Late Woodland; LLW, late Late Woodland; MISS, Mississippian.

there is a significant increase in strength in later Late Woodland females in comparison to Middle Woodland females (Table 1). Though the early Late Woodland is not significantly different from these adjacent periods, it exhibits intermediate values between the two, supporting a trend of increased strength through the late Late Woodland. The trend in torsional strength of female femora is also expressed in Figure 1. In the dimensional data, female midshaft AP diameter and circumference both increase significantly on the right side in Mississippian times compared to earlier Late Woodland samples. The pilasteric index indicates a left-side significant difference between later Late Woodland and Mississippian females, and a right-side significant difference between Mississippian and all other period samples. Thus there appears to be increased stress at the female femoral midshaft up to the later Late Woodland in terms of biomechanical variables, but with a continued increase only in external dimensions at midshaft in Mississippian times. Together, these data suggest an increase in femoral strength through the chronological sequence, though this trend is more dramatic for females.

Tibia

Following from the femoral data, one would expect relatively few differences in male tibial measurements, but somewhat surprisingly, there are a number of significant changes in external dimensions (as noted above, tibiae were not selected for biomechanical analysis). For males, midshaft AP diameters increase and ML diameters decrease significantly in the earlier Late Woodland period (Table 3). As a result, there are also a number of significant changes in shape indices of the tibial diaphysis, all indicating an increase in forces placed along the anteroposterior direction during the earlier Late Woodland, and continuing into the later Late Woodland period. Mississippian males show significant increases in both midshaft and minimum shaft dimensions. Coinciding with these changes, shape indices of the middle and distal diaphysis more closely approach 100, indicating more rounded diaphyses in Mississippian males.

Female tibiae also show increased diaphyseal dimensions and indices, but significant change occurs somewhat later than males, in the later Late Woodland period (Table 3), which was unexpected considering the data on femoral external dimensions. For Mississippian females, the contrast with Middle Woodland females is even greater, with significant changes in more dimensions, particularly midshaft and minimum shaft variables. Both the left and right sides are affected. However, in contrast to males, Mississippian female tibial shape indices register little change, except that the shape index of the distal diaphysis increases at this time, indicating a more rounded shaft (as was the case for the males).

Humerus

Biomechanical measures of male humeral strength fail to show significant change through time (Table 4), a parallel to the lack of significant change in structural measures of male femora. Similarly, there are relatively few significant changes in male diaphyseal external dimensions (Table 5). However, these data show subtle indications of a trend towards bilateral symmetry in male humeral torsional strength through time, due to a decline in overall forces placed on the right humerus (Fig. 2). Left minimum shaft minimum diameter, and both left and right minimum shaft shape indices, decline significantly in earlier Late

TABLE 3. Tibial dimensional data (in mm) and indices[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Length, mean	387	385	381	380	384	380	382	382
SE	4.3	4.4	3.7	4.0	4.0	3.6	4.3	4.7
N	(23)	(22)	(14)	(16)	(27)	(29)	(19)	(18)
Midshaft								
AP diameter, mean	31.3	31.0	33.0	32.7*	32.6	32.4	33.3*	33.2*
SE	0.43	0.43	0.49	0.43	0.42	0.41	0.34	0.43
N	(21)	(22)	(13)	(15)	(25)	(27)	(19)	(18)
ML diameter, mean	21.6	21.9	20.1*	20.1*	20.8	20.6	22.2**,***	21.9**
SE	0.44	0.47	0.49	0.45	0.25	0.31	0.24	0.34
N	(22)	(22)	(14)	(15)	(26)	(28)	(19)	(18)
Circumference, mean	84.9	84.3	86.1	84.7	85.5	84.6	89.3*,***	88.4*
SE	1.17	1.20	0.84	1.23	1.00	1.17	0.82	0.76
N	(18)	(21)	(11)	(13)	(20)	(22)	(19)	(18)
Nutrient foramen								
AP diameter, mean	35.5	35.5	36.9	36.3	36.2	36.6	37.0	36.6
SE	0.52	0.52	0.56	0.51	0.43	0.42	0.37	0.35
N	(26)	(24)	(15)	(20)	(28)	(33)	(22)	(21)
ML diameter, mean	23.2	24.1	22.6	23.0	23.0	22.9	23.6	23.1
SE	0.43	0.54	0.62	0.42	0.33	0.30	0.39	0.39
N	(26)	(24)	(15)	(20)	(29)	(33)	(22)	(22)
Circumference, mean	92.5	93.4	94.2	93.2	93.5	94.0	96.6	95.2
SE	1.45	1.46	1.37	1.49	0.98	1.24	0.94	0.85
N	(21)	(20)	(12)	(14)	(22)	(24)	(22)	(21)
Minimum shaft								
AP diameter, mean	26.2	26.1	27.3	26.6	27.2	27.5*	27.1	26.7
SE	0.33	0.40	0.64	0.47	0.33	0.31	0.28	0.34
N	(26)	(26)	(15)	(18)	(28)	(29)	(22)	(22)
ML diameter, mean	21.8	21.8	21.2	21.6	21.1	21.6	23.1*,**,***	23.0***
SE	0.35	0.34	0.45	0.48	0.29	0.40	0.34	0.35
N	(26)	(26)	(15)	(18)	(28)	(29)	(22)	(22)
Circumference, mean	76.0	76.2	77.1	76.2	77.2	77.5	79.8*,***	79.6*
SE	0.89	0.89	0.95	0.83	0.66	0.93	0.64	0.83
N	(26)	(26)	(15)	(18)	(28)	(29)	(22)	(22)
Shape indices								
Midshaft, mean	69	71	61*	62*	64*	64*	67	66
SE	1.41	1.69	1.98	1.45	1.09	0.84	0.92	1.37
N	(21)	(22)	(13)	(15)	(25)	(27)	(19)	(18)
Cnemic, mean	66	68	61	64*	64	63*	64	63*
SE	1.04	1.33	1.62	0.96	0.94	0.83	1.10	1.11
N	(26)	(24)	(15)	(20)	(28)	(33)	(22)	(21)
Minimum Shaft, mean	83	84	78	82	78	79	86**,***	86***
SE	1.3	1.5	2.7	2.7	1.5	1.4	1.3	1.6
N	(26)	(26)	(15)	(18)	(28)	(29)	(22)	(22)
Females								
Length, mean	354	351	350	352	347	346	356	354
SE	4.5	4.3	4.0	3.3	2.8	2.7	3.5	3.3
N	(17)	(14)	(18)	(18)	(24)	(28)	(25)	(25)
Midshaft								
AP diameter, mean	26.8	26.6	26.9	27.6	27.9	28.2	28.7*,**	28.6*
SE	0.34	0.58	0.39	0.54	0.35	0.32	0.45	0.42
N	(17)	(14)	(16)	(18)	(23)	(28)	(24)	(25)
ML diameter, mean	18.4	18.7	18.9	18.6	18.9	19.1	19.7*	19.4
SE	0.38	0.44	0.32	0.23	0.29	0.31	0.34	0.33
N	(17)	(14)	(17)	(18)	(24)	(28)	(25)	(25)
Circumference, mean	71.9	71.9	73.8	74.5	75.9*	76.0*	77.1*	77.2*
SE	0.82	1.02	0.66	1.14	0.95	0.86	1.21	1.03
N	(17)	(13)	(15)	(15)	(22)	(27)	(22)	(24)

(*Continued*)

TABLE 3. (continued.)

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Nutrient Foramen								
AP diameter, mean	30.0	30.1	30.2	30.8	31.3	31.5	31.6	32.0*
SE	0.46	0.56	0.40	0.49	0.32	0.33	0.51	0.44
N	(21)	(17)	(18)	(18)	(34)	(38)	(25)	(27)
ML diameter, mean	20.2	20.7	20.2	20.2	20.9	21.0	20.9	20.7
SE	0.34	0.47	0.41	0.35	0.28	0.31	0.40	0.37
N	(21)	(17)	(19)	(18)	(37)	(37)	(25)	(27)
Circumference, mean	80.5	79.7	81.1	81.4	84.2	83.5	84.3	84.0
SE	1.10	1.46	0.94	1.01	1.01	0.88	1.30	1.10
N	(20)	(14)	(15)	(16)	(29)	(33)	(24)	(26)
Minimum shaft								
AP diameter, mean	22.2	22.5	23.3	23.3	23.7*	24.1*	23.6*	24.0*
SE	0.29	0.49	0.25	0.32	0.24	0.27	0.41	0.40
N	(21)	(17)	(18)	(17)	(36)	(36)	(25)	(28)
ML diameter, mean	19.1	19.0	19.2	19.4	19.3	19.3	20.8*,**,***	20.1
SE	0.30	0.32	0.35	0.30	0.28	0.25	0.40	0.32
N	(21)	(17)	(18)	(17)	(36)	(36)	(25)	(28)
Circumference, mean	66.1	66.5	68.1	68.1	68.9*	69.3	71.0*	70.3*
SE	0.76	1.06	0.58	0.91	0.60	0.63	0.99	0.92
N	(21)	(17)	(18)	(17)	(36)	(36)	(25)	(28)
Shape indices								
Midshaft, mean	69	71	71	68	68	68	69	68
SE	1.34	1.87	1.58	1.42	0.98	1.06	1.10	0.85
N	(17)	(14)	(16)	(18)	(23)	(28)	(24)	(25)
Cnemic, mean	68	69	67	66	67	67	66	65
SE	1.16	1.19	1.65	1.74	0.64	0.90	0.99	0.85
N	(21)	(17)	(18)	(18)	(34)	(37)	(25)	(27)
Minimum shaft, mean	86	85	83	83	82	80	88**,***	84
SE	1.5	1.8	1.6	1.4	1.3	1.1	1.3	1.3
N	(21)	(17)	(18)	(17)	(36)	(36)	(25)	(28)

[1] See Table 1 for notes.

Woodland when compared to the preceding Middle Woodland sample.

Compared to males, females show a greater number of significant differences over time, both in structural variables and external dimensions. Several female humeral cross-sectional measures increase significantly from Middle Woodland through later Late Woodland periods, on the left side only (Table 4). Then, in the Mississippian sample, there is a dramatic decrease in most variables in comparison to both Late Woodland periods. Again, this change is significant on the left side only (the trend is apparent on the right side but does not attain significance). The changes in female humeral torsional strength are depicted in Figure 3.

Female humeri increase in external dimensions from the Middle Woodland to the later Late Woodland, but these increases attain significance for the midshaft maximum diameter and minimum shaft circumference only (Table 5). Note that a different set of variables is affected in females than is the case for males. These changes occur variously on both the left and right sides. For Mississippian females, many values are maintained with little change, but there is a significant decrease at right midshaft maximum diameter compared to later Late Woodland. This change is reflected in the Mississippian right midshaft shape index, which shows a significant development towards circularity of shape in comparison to both Late Woodland period samples. So while there is an overall increase in strength affecting both left and right female humeri through time, upper arms apparently experienced less directional stress in Mississippian times. As mentioned above, the biomechanical data show a similar pattern of strength increase in the Late Woodland periods and decrease in Mississippian times, but unlike the external dimensional data, these occur mostly on the left side, and are more obvious in the earlier Late Woodland period. The large increase in cortical area of the left humerus after Middle Woodland times is un-

TABLE 4. Humeral midshaft cross-sectional properties[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Unstandardized (raw) cross-sectional variables								
Cortical area, mean	168	187	163	181	155	172	160	174
SE	10.5	7.7	10.9	9.5	12.2	6.3	7.1	9.3
Imin, mean	4,286	5,371	3,539	4,105	5,275**	5,100	4,755	5,239
SE	430	479	234	313	651	297	373	549
Imax, mean	7,171	9,961	6,227	7,882	7,997	8,758	7,528	9,289
SE	839	1,073	517	401	450	369	564	707
J, mean	11,458	15,332	9,766	11,988	13,272	13,858	12,283	14,528
SE	1,266	1,542	720	688	1,060	620	927	1,239
Size-standardized cross-sectional variables								
Cortical area, mean	171	188	163	182	153	172	159	172
SE	8.1	6.0	11.5	10.1	9.2	6.7	4.9	8.8
Min bending strength, mean	167	204	128	152	186	184	166	181
SE	15.6	15.7	12.7	16.1	30.2	14.9	7.9	20.8
Max bending strength, mean	277	376	225	288	280	316	262	321
SE	29.8	32.5	23.9	21.5	33.5	23.6	8.6	26.7
Torsional strength, mean	445	580	353	440	466	499	429	502
SE	44.8	47.5	35.8	37.2	62.0	37.4	16.1	46.9
Shape Index, Imax/Imin mean	165	184	176	195	156	174	159	182
SE	5.3	5.5	8.9	7.4	11.2	7.0	3.4	6.7
N	6	10	9	10	4	10	7	10
Females								
Unstandarsized (raw) cross-sectional variables								
Cortical area, mean	103	120	125*	121	123	120	97**,***	116
SE	4.6	6.9	5.0	6.2	4.3	3.7	7.2	8.2
Imin, mean	2,056	2,442	2,560	2,552	2,679	2,570	2,238	2,555
SE	117	194	206	199	183	162	136	244
Imax, mean	3,518	4,832	4,820*	5,240	4,816	5,217	3,503**	4,482
SE	195	433	340	409	394	350	345	524
J, mean	5,574	7,274	7,379*	7,792	7,495*	7,787	5,742	7,037
SE	307	611	524	589	519	489	471	756
Size-standardized cross-sectional variables								
Cortical area, mean	113	129	138	131	138*	131	105**,***	125
SE	5.7	6.9	4.7	6.3	3.5	3.5	7.5	8.0
Min bending strength, mean	121	131	148	135	178*	154	127***	141
SE	6.3	10.4	6.4	7.3	14.2	11.6	16.3	14.0
Max bending strength, mean	208	257	280*	278	315*	310	194**,***	241
SE	14.5	17.5	11.1	16.3	20.0	20.8	23.9	22.6
Torsional strength, mean	330	388	428	413	493*	464	321**,***	382
SE	20.6	26.6	14.6	21.6	31.4	31.3	39.6	35.4
Shape index, Imax/Imin mean	171	198	191	209	182	204	155**	174
SE	4.0	8.6	9.1	12.1	13.3	8.3	8.0	8.7
N	7	10	9	10	7	10	7	10

[1] See Table 1 for notes.

doubtedly a factor in overall greater strength. External dimensions, while correlated with diaphyseal strength, ignore internal structural features such as cortical area, and are therefore an imperfect reflection of bone strength.

In summary, the greatest number of changes in both male and female humeri occur after the Middle Woodland period, in the earlier Late Woodland period. Males decline in right humeral strength, while at the same time females increase in strength on the left side. As a result, earlier Late Woodland women have left humeri that are, on average, stronger than their right humeri. Female biomechanical strength decreases in Mississip-

TABLE 5. Humeral dimensional data (in mm) and indices[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Length, mean	330	329	332	332	327	330	325	327
SE	3.1	2.8	2.2	2.4	2.1	2.0	2.5	2.2
N	(26)	(27)	(28)	(27)	(33)	(36)	(30)	(35)
Midshaft								
Max diameter, mean	21.9	23.0	22.3	23.0	21.9	22.8	22.3	22.9
SE	0.36	0.35	0.34	0.29	0.32	0.26	0.28	0.27
N	(25)	(28)	(28)	(30)	(32)	(37)	(30)	(35)
Min diameter, mean	16.6	17.1	16.3	16.6	16.5	17.0	16.8	16.9
SE	0.27	0.24	0.27	0.23	0.27	0.22	0.24	0.23
N	(25)	(28)	(28)	(30)	(32)	(37)	(30)	(35)
Circumference, mean	64.2	67.0	65.0	66.8	64.0	66.7	65.2	67.0
SE	1.01	0.98	1.00	0.85	0.80	0.70	0.71	0.71
N	(24)	(28)	(26)	(29)	(32)	(35)	(30)	(35)
Minimum shaft								
Max diameter, mean	18.5	19.2	19.0	19.5	18.5	19.1	18.9	19.6
SE	0.23	0.21	0.17	0.20	0.15	0.15	0.22	0.25
N	(35)	(34)	(31)	(35)	(42)	(47)	(34)	(36)
Min diameter, mean	19.5	20.4	18.9*	19.2	19.2	19.5	19.5	19.7
SE	0.30	0.30	0.37	0.31	0.27	0.26	0.28	0.26
N	(35)	(34)	(31)	(35)	(42)	(47)	(34)	(36)
Circumference, mean	60.2	62.7	61.0	61.9	60.3	61.7	61.6	62.9
SE	0.61	0.57	0.71	0.65	0.54	0.51	0.57	0.59
N	(35)	(34)	(31)	(35)	(42)	(47)	(34)	(36)
Shape indices								
Midshaft, mean	76	75	73	72	75	75	76	74
SE	1.07	0.84	0.76	0.80	0.78	0.79	0.96	0.74
N	(25)	(28)	(28)	(30)	(32)	(37)	(30)	(35)
Minimum shaft, mean	105	107	100*	99*	104	102	103	101*
SE	1.5	1.8	1.8	1.5	1.4	1.2	1.3	1.3
N	(35)	(34)	(31)	(35)	(42)	(47)	(34)	(36)
Females								
Length, mean	303	307	304	308	302	304	302	307
SE	2.7	2.4	2.3	2.2	2.2	2.1	2.3	2.5
N	(25)	(25)	(26)	(33)	(43)	(38)	(34)	(39)
Midshaft								
Max diameter, mean	19.6	20.1	20.7	21.1*	20.6*	21.3*	20.0	20.3*
SE	0.27	0.27	0.27	0.24	0.25	0.24	0.32	0.30
N	(28)	(29)	(26)	(35)	(43)	(42)	(34)	(38)
Min diameter, mean	14.5	14.6	15.0	14.8	15.0	14.9	15.0	15.2
SE	0.27	0.22	0.29	0.21	0.19	0.15	0.26	0.20
N	(28)	(29)	(26)	(35)	(43)	(42)	(34)	(38)
Circumference, mean	57.1	59.0	59.3	61.0	59.6	61.2	58.9	60.0
SE	0.65	0.71	0.82	0.71	0.70	0.62	0.82	0.72
N	(28)	(28)	(24)	(34)	(42)	(40)	(34)	(38)
Minimum shaft								
Max diameter, mean	16.4	16.8	17.0	17.2	16.9	17.2	17.2	17.5
SE	0.21	0.21	0.25	0.25	0.15	0.17	0.28	0.24
N	(33)	(36)	(29)	(34)	(54)	(51)	(38)	(41)
Min diameter, mean	16.7	16.9	17.4	17.4	17.5	17.5	17.1	17.2
SE	0.27	0.24	0.34	0.26	0.18	0.19	0.29	0.24
N	(33)	(36)	(29)	(34)	(54)	(51)	(38)	(41)
Circumference, mean	53.6	54.1	55.6	56.0	55.7*	55.9	55.6	56.1*
SE	0.54	0.53	0.66	0.62	0.45	0.41	0.71	0.61
N	(33)	(36)	(29)	(34)	(54)	(51)	(38)	(41)
Shape indices								
Midshaft, mean	74	73	73	70	73	70	75	75**,***
SE	1.42	1.12	1.21	1.07	0.90	0.67	1.06	1.02
N	(28)	(29)	(26)	(35)	(43)	(42)	(34)	(38)
Minimum shaft, mean	102	101	103	102	104	102	99	99
SE	2.0	1.6	2.1	1.8	1.2	1.2	1.5	1.4
N	(33)	(36)	(29)	(34)	(54)	(51)	(38)	(41)

[1] See Table 1 for notes.

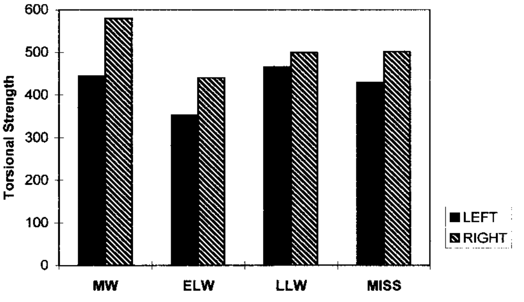

Fig. 2. Torsional strength (standardized) of male humeri. Means. (See Fig. 1 for notes.)

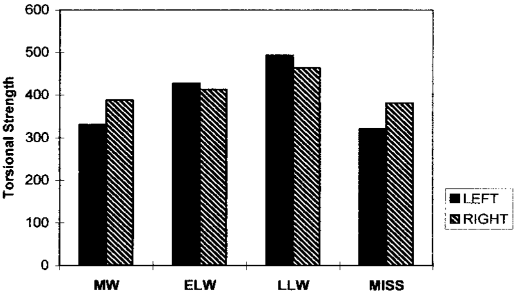

Fig. 3. Torsional strength (standardized) of female humeri. Means. (See Fig. 1 for notes.)

pian times, with a concomitant change in the shape of the right midshaft suggesting a reduction of stress at that point, while other external dimensions are maintained compared to the preceding time period.

Radius and ulna

Males show few significant changes in radial diaphyseal dimensions (Table 6). Left maximum shaft minimum diameter increases significantly in Mississippian males compared to earlier Late Woodland males. Correspondingly, left radial shape indices also register significant increases in Mississippian males compared to earlier Late Woodland samples. Taken together, these data suggest more robust distal forearms in Mississippian times. There are no significant changes in male ulna through time (Table 7).

Females show a variety of differences in forearm properties which are only partially predicted by the humeral biomechanical data. Neither the radius nor the ulna changes significantly in the earlier Late Woodland period (with the exception of right side ulna length), though the trend is towards an increase, as in the humeral and femoral data. However, in the later Late Woodland, numerous ulnar variables increase significantly in females, mostly when compared to the Middle Woodland. Interestingly, this trend towards greatest size dimensions in the late Late Woodland also occurs when female humeral biomechanical strength is at its greatest. However, radial dimensions exhibit few significant changes through the late Late Woodland, indicating that activities may have differentially affected areas of the arm and forearm, or perhaps indicating a lack of correspondence between external dimensions and internal diaphyseal structure.

For Mississippian females, there is a steep decline in radial maximum shaft dimensions compared to the Late Woodland samples. At the same time, radial shape indices for Mississippian females increase on both sides, a development towards circularity of shape. This pattern parallels female humeral strength, again suggesting decreased stress on the upper limb. As for the ulna, two right-side midshaft dimensions decrease significantly in Mississippian females compared to earlier periods. Ulna shape indices of Mississippian females maintain the significant decrease of the later Late Woodland over earlier samples.

DISCUSSION

Diaphyseal measurements and biomechanical variables reveal a complex pattern of changes over the time span from the Middle Woodland to the Mississippian periods in west-central Illinois, a pattern that is not identical to that seen in other areas of the Eastern Woodlands for which similar studies have been carried out. One expected finding is that the sexes differ in the nature and timing of changes in strength indicators. Generally, these differences are less pronounced for the lower limb than for the upper limb, and less pervasive for males than for females. Females show significant increases in lower limb strength over the time span examined, with the greatest differences occurring between the Middle Woodland and the earlier Late Woodland periods. Males, on the other hand, show no

TABLE 6. Radial dimensional data (in mm) and indices[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Length, mean	258	254	261	260	259	260	258	259
SE	3.0	4.2	2.5	2.8	2.4	1.8	2.2	2.0
N	(24)	(15)	(25)	(22)	(28)	(31)	(26)	(31)
Midshaft								
Max diameter, mean	14.9	15.1	15.1	15.1	14.6	14.9	14.5	15.1
SE	0.33	0.48	0.26	0.33	0.20	0.24	0.31	0.29
N	(23)	(15)	(25)	(21)	(28)	(31)	(25)	(30)
Min diameter, mean	12.3	11.8	12.0	11.9	12.1	12.1	12.5	12.1
SE	0.18	0.35	0.21	0.26	0.12	0.16	0.19	0.17
N	(23)	(14)	(25)	(21)	(28)	(31)	(26)	(30)
Circumference, mean	43.4	43.2	43.4	43.7	42.6	43.4	43.2	43.5
SE	0.66	1.07	0.65	0.87	0.42	0.53	0.66	0.61
N	(22)	(14)	(24)	(20)	(28)	(30)	(25)	(29)
Maximum Shaft								
Max diameter, mean	16.4	16.6	16.6	16.8	16.2	16.5	16.5	16.5
SE	0.26	0.27	0.28	0.29	0.18	0.23	0.27	0.26
N	(29)	(27)	(28)	(31)	(42)	(40)	(28)	(34)
Min diameter, mean	12.2	12.4	11.6	11.7	11.9	11.8	12.5**	11.5
SE	0.18	0.29	0.22	0.23	0.14	0.16	0.20	0.24
N	(29)	(27)	(28)	(31)	(42)	(40)	(28)	(34)
Circumference, mean	45.1	46.2	45.0	46.3	44.6	45.5	45.5	45.8
SE	0.57	0.67	0.54	0.59	0.37	0.47	0.62	0.56
N	(29)	(27)	(34)	(30)	(41)	(39)	(28)	(34)
Max head diameter, mean	23.1	22.9	22.9	23.1	23.3	23.5	22.8	23.0
SE	0.28	0.29	0.27	0.21	0.23	0.30	0.44	0.30
N	(15)	(12)	(18)	(22)	(21)	(22)	(10)	(19)
Min head diameter, mean	21.9	21.9	21.7	22.2	22.1	22.3	21.5	21.8
SE	0.24	0.26	0.27	0.23	0.19	0.29	0.38	0.35
N	(13)	(15)	(17)	(21)	(22)	(23)	(15)	(16)
Shape indices								
Midshaft, mean	83	78	80	79	84	81	87**	80
SE	1.6	2.4	1.5	1.9	1.3	1.2	1.6	1.5
N	(23)	(14)	(25)	(21)	(28)	(31)	(25)	(30)
Maxshaft, mean	75	75	70	70	74	72	76**	70
SE	1.4	1.5	1.5	1.5	1.1	1.2	1.4	1.4
N	(29)	(27)	(28)	(31)	(42)	(40)	(28)	(34)
Females								
Length, mean	232	234	239	242	231**	233**	236	237
SE	2.2	1.7	2.4	2.3	1.5	2.0	2.4	2.0
N	(21)	(21)	(25)	(29)	(36)	(31)	(28)	(40)
Midshaft								
Max diameter, mean	13.4	13.7	13.6	14.0	13.6	14.3	13.2	13.6
SE	0.25	0.34	0.29	0.21	0.21	0.22	0.22	0.20
N	(21)	(21)	(24)	(29)	(35)	(30)	(28)	(40)
Min diameter, mean	10.5	10.1	10.8	10.5	10.5	10.5	10.9	10.7
SE	0.19	0.17	0.23	0.13	0.13	0.14	0.21	0.17
N	(21)	(21)	(25)	(28)	(35)	(29)	(28)	(40)
Circumference, mean	38.3	38.5	39.1	40.0	39.0	40.1	39.2	39.1
SE	0.59	0.66	0.55	0.43	0.42	0.48	0.50	0.45
N	(21)	(21)	(24)	(27)	(35)	(29)	(27)	(40)
Maximum shaft								
Max diameter, mean	14.7	14.8	15.2	15.4	15.4	15.6	14.8	14.8***
SE	0.27	0.29	0.24	0.22	0.19	0.19	0.28	0.21
N	(26)	(26)	(28)	(32)	(48)	(42)	(34)	(42)
Min diameter, mean	10.4	10.2	10.6	10.5	10.5	10.4	10.9	10.4
SE	0.16	0.20	0.19	0.13	0.13	0.14	0.21	0.17
N	(26)	(26)	(28)	(32)	(48)	(41)	(34)	(42)
Circumference, mean	40.3	40.8	41.2	42.1	41.5	41.8	40.8	40.8
SE	0.58	0.56	0.44	0.50	0.37	0.40	0.51	0.48
N	(25)	(26)	(27)	(30)	(48)	(40)	(33)	(42)
Max head diameter, mean	20.5	20.4	21.0	21.3	20.7	21.1	19.8**	20.2**
SE	0.25	0.20	0.30	0.29	0.25	0.23	0.26	0.27
N	(18)	(20)	(19)	(17)	(23)	(16)	(15)	(26)
Min head diameter, mean	19.5	19.6	19.8	20.1	19.7	20.0	19.2	19.1**,***
SE	0.22	0.22	0.23	0.22	0.19	0.24	0.28	0.24
N	(20)	(20)	(20)	(20)	(22)	(18)	(19)	(27)
Shape indices								
Midshaft, mean	79	75	80	76	77	74	83***	78***
SE	1.6	1.6	2.0	1.4	1.3	1.2	1.9	1.2
N	(21)	(21)	(24)	(28)	(35)	(29)	(28)	(40)
Maxshaft, mean	71	69	70	69	69	67	74***	70
SE	1.33	1.70	1.09	1.23	0.84	1.07	1.84	1.08
N	(26)	(26)	(28)	(32)	(48)	(41)	(34)	(42)

[1] See Table 1 for notes.

TABLE 7. Ulnar dimensional data (in mm) and indices[1]

	MW		eLW		lLW		Miss	
	L	R	L	R	L	R	L	R
Males								
Length, mean	277	272	281	281	277	282	275	277
SE	3.2	3.6	2.8	3.0	1.9	2.0	2.5	2.3
N	(16)	(17)	(22)	(21)	(27)	(30)	(24)	(30)
Midshaft								
Max diameter, mean	16.4	16.5	16.2	16.8	16.7	16.8	16.5	16.5
SE	0.44	0.34	0.30	0.43	0.24	0.28	0.30	0.23
N	(16)	(15)	(20)	(20)	(27)	(28)	(24)	(29)
Min diameter, mean	12.3	12.3	11.8	12.2	12.4	12.8	11.8	12.5
SE	0.27	0.27	0.20	0.22	0.17	0.15	0.21	0.22
N	(16)	(15)	(20)	(20)	(27)	(29)	(24)	(29)
Circumference, mean	46.9	47.6	47.3	48.9	48.5	49.0	47.8	49.4
SE	0.78	0.91	0.69	0.93	0.50	0.60	0.50	0.57
N	(16)	(14)	(19)	(20)	(26)	(27)	(24)	(29)
Maximum shaft								
Max diameter, mean	17.1	17.1	17.6	17.4	17.6	17.5	17.3	17.5
SE	0.34	0.35	0.39	0.43	0.24	0.22	0.33	0.27
N	(28)	(26)	(27)	(27)	(42)	(39)	(27)	(33)
Min diameter, mean	13.0	13.1	12.6	13.0	12.8	13.4	12.3	12.9
SE	0.20	0.20	0.19	0.18	0.13	0.14	0.23	0.20
N	(28)	(26)	(27)	(27)	(42)	(39)	(27)	(33)
Circumference, mean	49.3	49.7	50.4	50.9	50.5	51.1	49.5	51.1
SE	0.70	0.76	0.86	0.87	0.44	0.48	0.61	0.53
N	(27)	(25)	(26)	(26)	(40)	(39)	(27)	(33)
Shape indices								
Midshaft, mean	75	75	74	73	74	76	73	76
SE	1.9	1.2	1.6	1.5	1.5	1.3	1.9	1.6
N	(16)	(15)	(20)	(20)	(27)	(28)	(24)	(29)
Maxshaft, mean	76	77	72	75	73	77	72	74
SE	1.5	1.3	1.5	1.6	1.2	1.2	1.9	1.3
N	(28)	(26)	(27)	(27)	(42)	(39)	(27)	(33)
Females								
Length, mean	251	253	260	263*	251**	253**	255	257
SE	2.5	2.8	2.5	2.2	2.1	1.6	2.3	2.3
N	(17)	(15)	(25)	(26)	(29)	(32)	(26)	(33)
Midshaft								
Max diameter, mean	14.9	14.5	15.6	15.5	16.0	16.3*	15.4	15.1***
SE	0.38	0.37	0.32	0.27	0.32	0.26	0.31	0.26
N	(17)	(14)	(25)	(26)	(28)	(32)	(25)	(32)
Min diameter, mean	10.9	11.1	11.0	11.4	10.9	11.0	10.5	10.5**
SE	0.26	0.22	0.18	0.18	0.17	0.15	0.23	0.16
N	(17)	(14)	(25)	(26)	(28)	(32)	(26)	(32)
Circumference, mean	42.5	42.8	44.3	45.0	45.2	46.3*	44.0	44.3
SE	0.79	0.74	0.61	0.57	0.77	0.54	0.61	0.57
N	(16)	(13)	(23)	(26)	(27)	(31)	(24)	(32)
Maximum shaft								
Max diameter, mean	15.4	15.5	16.4	16.3	16.5*	16.7*	16.4	16.0
SE	0.27	0.33	0.29	0.27	0.26	0.23	0.27	0.26
N	(26)	(21)	(26)	(32)	(42)	(41)	(36)	(41)
Min diameter, mean	11.4	11.3	11.5	11.7	11.2	11.2	11.1	11.2
SE	0.20	0.22	0.18	0.18	0.15	0.13	0.16	0.19
N	(26)	(21)	(26)	(32)	(42)	(41)	(36)	(41)
Circumference, mean	44.3	44.5	46.6	46.8	46.5*	47.1*	46.5*	46.1
SE	0.62	0.59	0.60	0.54	0.54	0.50	0.55	0.55
N	(26)	(21)	(26)	(32)	(42)	(39)	(36)	(41)
Shape indices								
Midshaft, mean	74	77	71	74	69	68*,**	68	70*
SE	2.2	2.2	1.7	1.5	1.3	1.1	1.8	1.2
N	(17)	(14)	(25)	(26)	(28)	(32)	(25)	(32)
Max shaft, mean	74	73	71	73	68*	68*,**	68*	70
SE	1.48	2.14	1.66	1.41	1.12	0.98	1.23	1.26
N	(26)	(21)	(26)	(32)	(42)	(41)	(36)	(41)

[1] See Table 1 for notes.

major differences in femoral size or strength throughout all the time periods, and a mixed pattern of a few increases and decreases in various tibial dimensions and indices.

For the upper limb, a different pattern emerges. Females show a large number of significant increases in humeral dimensions and strength indicators in the earlier Late Woodland period. The female ulna is characterized by larger dimensions in the later Late Woodland, as opposed to the earlier part of this period, and the radius exhibits almost no change from Middle Woodland to Late Woodland times. In Mississippian females, all three long bones show a significant decline in a number of external dimensions and strength variables. Males exhibit very few significant changes in the upper limb over time. There is a general pattern of decline in humeral strength from the Middle Woodland to early Late Woodland, though these changes failed to show significance. There are no changes in the ulna, and the radius displays only a few significant differences between the Mississippian and early Late Woodland, but only on the left side.

In short, females exhibit significant increases from Middle Woodland to Late Woodland periods in many measures of long bone strength and external dimensions, and show a decline in the Mississippian period in the arms only; males show very few significant differences over time, restricted mainly to increases in the tibia and radius in the Mississippian period. One of the major implications from this work is that many changes in activities do not occur with the adoption of maize agriculture, but rather predate this event. In order to understand the timing of the changes in activities, it is necessary to examine more closely specific food-production activities in prehistoric Illinois, both predating and postdating the use of maize.

The Late Woodland period: intensification of native seeds

The results described here show that significant changes in (female) diaphyseal dimensions and strength occurred before the adoption of maize as a dietary staple. This discovery could, of course, reflect imprecision in the radiocarbon dates assigned to these sites or perhaps an insufficient understanding of the process of maize adoption. It is equally plausible that in this region the initial introduction of maize was less important in terms of workload than was the intensification of other cultivated crops. In other words, the focus on maize ignores the significant antecedent role played by native cultigens in a number of prehistoric societies in the Midwest (Illinois, Missouri) and Midsouth (Kentucky, Tennessee).

Intentional cultivation of a variety of hard-shelled squash began during the Middle Archaic period (circa 5000 BC) in west-central Illinois. By the Middle Woodland period in the Midwest, a variety of native seed crops were also grown. In west-central Illinois, these included two oily seeded annuals, sumpweed or marsh elder (*Iva annua*) and sunflower (*Helianthus*), and four starchy seeds, goosefoot (*Chenopodium berlandieri*), erect knotweed (*Polygonum erectum*), maygrass (*Phalaris caroliniana*), and little barley (*Hordeum pusillum*), as well as squash (*Cucurbita pepo*) (Asch and Asch, 1985a). Several of these plants (squash, sumpweed, sunflower, and goosefoot) show signs of domestication, and it is now widely accepted that independent domestication of native plants occurred in the Midwest and Midsouth regions prior to the introduction of maize and other tropical domesticates from Mesoamerica (Smith, 1989).

Although there is no dramatic change in the nature of botanical assemblages between the Middle Woodland and Late Woodland periods, there is evidence for increasing intensification of existing crops by Late Woodland times. Caches of seeds first appear in the archaeological record of west-central Illinois during the early Late Woodland period, pointing to an increase in both storage and use of cultigens (Asch and Asch, 1981; Johannessen, 1993; Styles, 1981, 1985). Significantly, the increase in female femoral and humeral strength occurs at the time of intensification of native seed crops, suggesting that females played a major role in this process.

Other bioarchaeological studies also indicate changes in activities in the Late Woodland period. In a study on cortical thickness and remodeling rates of the femur based on the same groups used in the current work, Hanson (1988) found a significant increase in female cortical area in the earlier Late Woodland, similar to that seen in this study. Deltoid tuberosity rugosity in females also increases greatly at this time, leading to a reduction in sexual dimorphism of this feature (Hamilton, 1982).

In addition, fertility rates increase with the onset of the Late Woodland period, coinciding with a rise in juvenile caries, and often coincident with enamel hypoplasia (Buikstra et al., 1986; Cook and Buikstra, 1979). This increase in caries may be due to a change in weaning diet, which correlates with the introduction of pottery types designed for efficient boiling (Buikstra et al., 1986). Innovations in pottery include thinner vessel walls, finer temper, and different vessel forms, all of which suggest that resistance to thermal stress was the most important factor in their manufacture (Braun, 1983). Therefore, in the Late Woodland period, a number of interrelated factors may be seen: an increase in the use of starchy seeds, an increase in female arm strength (possibly linked with growing or processing these seeds), a transition to pottery vessels better suited for boiling (resulting in softer foods such as gruel), a concomitant increase in juvenile caries, and finally, increased fertility related to the introduction of an appropriate food (gruel) for early weaning of infants (Buikstra et al., 1986). Given the temporal changes in bone rigidity, perhaps these data reflect the assumption of female subsistence activities at an earlier age, resulting in attainment of greater bone mass. There appears to be a fundamental shift in the life history pattern associated with the Late Woodland intensification of starchy seeds: early weaning and assumption of food-production tasks by females at an earlier age. These life history changes are consonant with intensification of hoe cultivation cross-culturally (Cohen and Armelagos, 1984; Ember, 1983).

Another technological change of the Late Woodland period is the introduction of the bow-and-arrow (Blitz, 1988). Small triangular arrowpoints are present even at the earliest Late Woodland sites in this sample, dating to shortly after AD 600 (Perino, 1973c). Besides documenting the introduction of the bow, these points suggest an increase in interpersonal violence at this time (Milner, 1995). The Koster Mounds, for example, of earlier Late Woodland age, contain several multiple burials with associated points, some embedded in bone (Perino, 1973c). The introduction of the bow coincides with a decrease in right humeral strength in males in the earlier Late Woodland period. This skeletal change is consistent with that expected when the atlatl (spearthrower) is replaced by the bow, since the atlatl presumably would have placed greater forces on the throwing arm. Because the bow imposes forces on both the left and right sides, a decline in bilateral asymmetry should occur (Bridges, 1990). Although humeral torsional strength does become more equivalent in both arms in earlier Late Woodland, left arm strength does not increase as expected. Instead, left arm strength is at its lowest levels in the earlier Late Woodland period, when the bow is introduced. Therefore, although decreased male right arm strength is consistent with replacement of the atlatl by the bow, other changes in left arm strength are not, but rather postdate this event. This suggests that weapon technology can account for at most only part of the change in male arm strength in these groups; other activities must also be responsible.

The later Late Woodland period: the adoption of maize as a dietary staple

Although maize has been found in Middle Woodland contexts in the Eastern Woodlands (Riley et al., 1994; Smith, 1989), its first appearance at archaeological sites in this region occurs well into the Late Woodland period, at about AD 580 (Asch and Asch, 1985b). Carbon isotope analyses demonstrate that maize is not a measurable part of the diet until after AD 800 (Bender et al., 1981; Buikstra et al., 1987; van der Merwe and Vogel, 1978). Although maize is widely grown after that time, it does not totally displace the native crops grown earlier. When maize is initially adopted, it seems to be added to the preexisting suite of native crops and treated as just another starchy seed (Rindos and Johannessen, 1991; Watson, 1988). If this scenario is correct, it would go far towards explaining the relative dearth of changes in diaphyseal strength between the earlier and later Late Woodland periods. Because maize is incorporated into an already operational horticultural system, its initial cultivation and processing may have been similar to those of the starchy seeds that had been grown for thousands of years. In short, fewer changes in activities, especially female activities, occur with the initial introduction of maize as a staple crop because the physical activities involved in its cultivation and processing (at least in the beginning) are similar to those employed for growing native crops. This conclusion is also supported by other research on femoral cortical area (Hanson, 1988) and humeral rugosity (Hamilton, 1982), which found no significant differences occurring at this time.

Pickering (1984) found an increase in female arthritis which apparently occurs at the time of the introduction of maize. However, that study lumped Middle Woodland and earlier late Woodland periods into a "premaize" sample, and later Late Woodland and Mississippian periods into a "postmaize" grouping. Although there is a clear increase in female arthritis over time, these gross temporal groupings make it difficult to ascertain exactly when in the sequence this change occurred.

The Mississippian period: intensification of maize

Carbon isotope analysis indicates that maize use increases strongly in the Mississippian period (Bender et al., 1981; van der Merwe and Vogel, 1978). Native crops continue to constitute a significant part of the diet as well (Asch and Asch, 1985a). Sunflower and sumpweed achenes reach their largest size in the Mississippian period, indicating that selection for favored native cultigens operates into late prehistory (Yarnell, 1978). One native plant, erect knotweed, may even be initially domesticated during Mississippian times (Asch and Asch, 1985a).

The increasing reliance on starchy seeds, especially maize, in the Mississippian period would be expected to coincide with a greater need for processing, a chore traditionally carried out by females. If so, female arm strength should continue to increase in the Mississippian period. That it did not, but actually decreases, requires rethinking this hypothesis. Several alternative explanations are possible: that maize is physically less demanding to grow or process than native seeds; that processing becomes more efficient in the Mississippian era (perhaps through soaking, boiling, or parching the maize prior to pounding it in a wooden mortar); or that other activities unrelated to maize agriculture decrease significantly at this time.

In historic times, the hard kernels of dried or stored corn had to be softened or ground before use, a process that required considerable time and physical strength. It is not clear how the earlier seeds were prepared, but historic analogues are available for maize processing in Mississippian societies. Throughout the Eastern Woodlands, the wooden mortar and pestle were used by intensive maize farmers for this chore. One early observer likened pounding corn in wooden mortars to blacksmithing (Tuggle, 1973). Ethnographically, women in societies that utilize simple technology for processing maize have been observed to spend, on the average, 2 hr a day in pounding or grinding corn (Foster, 1967). A recipe for making hominy from prepared corn in a wooden mortar, published in the 1978 *Choctaw News Fair Edition*, instructs one to "beat it with a pestle for at least six hours . . ." Maize processing would have been even more rigorous if Eastern Woodland Indian societies had not adopted several key advances in soaking and cooking technology that significantly reduced the amount of pounding and grinding required: lye processing and boiling.

Many groups, as part of the initial processing, first soaked the kernels overnight, sometimes in a lye (alkali) solution made of wood or other ashes, to remove their outer hull (e.g., Campbell, 1959; Swanton, 1979; Tuggle, 1973). Processing in this manner would have lessened the need for pounding or grinding corn. Although wood-ash lye processing is well-established for historic Indian societies in the Eastern Woodlands (Linton, 1924), it may not require any distinctive artifacts, and therefore, may be difficult to confirm prehistorically. However, there are two forms of evidence for prehistoric lye processing. One clue comes from carbonized corn kernels preserved at archaeological sites. The majority of kernels from late prehistoric archaeological sites closely resemble hominy, or maize that is either boiled or treated with alkali processing, rather than unprocessed corn (King, 1994). This suggests that some kind of initial soaking process softened the kernels prior to pounding or grinding them. A second possible indicator of prehistoric lye processing is the distinctive pottery artifacts known as "stumpware" and "juice presses." In form, these artifacts appear to be funnels and strainers. Although their function is not definitely established, these ceramic containers have been interpreted as artifacts used in lye-processing maize (Emerson and Jackson, 1984), and first appear in Mississippian times.

Alkali processing of corn, or nixtamalization, has been suggested to improve the quality of protein in maize, and increase the availability of niacin (Katz et al., 1974). However, its overall effect on nutrients is unclear. Certainly, any cooking or soaking technique tends to remove nutrients, especially water-soluble vitamins (Penny, 1983). Mississippian diets, at least in this region, were diverse enough that pellagra and other nutritional deficiencies associated with corn were unlikely to have posed a serious problem. Therefore, there is no reason to suspect that nixtamalization was adopted in this region primarily as a nutritional strategy. Instead, it functioned to aid processing, possibly adapted from earlier techniques associated with either leaching tannins from acorns, or processing native seed crops (Blitz and Welch, 1998; Linton, 1924).

Along with innovations in food preparation involving soaking, boiling technology is enhanced in late prehistoric societies. In west-central Illinois, thin-walled pottery vessels adapted to boiling appear prior to significant maize use, in the Late Woodland period, coincident with the increase in native seed production. With maize intensification, Mississippian pottery was produced in more diverse forms, and included innovative wide-mouth globular pots suitable for boiling large quantities. Analysis of Mississippian pottery technology supports historic reports that indigenous diets emphasized boiling, which would have resulted in softer, more palatable foods (Hally, 1986; Swanton, 1979). Clearly, Mississippian populations continued and may even have expanded the Late Woodland emphasis on boiling as maize production was intensified.

In short, in historic times, and by extension, prehistoric Mississippian societies, a variety of methods for processing or cooking maize were in use, supplementing the necessary but physically strenuous pounding of corn. Of course, the starchy seeds used by earlier Woodland peoples might also have required tremendous amounts of processing or boiling. Maize may have been originally prepared in a similar way as the native seeds it supplemented, but perhaps advances in processing technology (wooden mortar and pestle, more efficient cooking pots, nixtamalization) meant that less physical labor was required to render it palatable. Regardless, at the time of intensification of maize, female arm strength declines. Innovations in processing technology are a plausible reason for this change, but other factors, including greater ease of cultivation, may have been responsible as well.

This summary of the prehistory of west-central Illinois shows that many of the changes in activity patterns may be linked to local subsistence or technological changes. With these in mind, the findings may be compared with other regions, which have shown different results.

Comparisons with other regions

Similar biomechanical studies have been carried out for two other regions of the Eastern Woodlands: northwestern Alabama and coastal Georgia. These two previous studies came to vastly different conclusions: one found that activities increased with agriculture, and the other that they decreased. In addition, changes differed between the sexes. The results from the current study do not completely match either of the previous two, but there are some similarities with each.

In northwestern Alabama, Archaic-period skeletons were compared to a Mississippian skeletal sample (there being no large collections of Woodland burials in the region). Although Archaic groups in this region may have cultivated some plants, their subsistence was largely based on hunting and gathering. The Mississippians in this sample are thought to have been intensive maize agriculturalists (Walthall, 1980). Mississippian males had much stronger legs than Archaic males, but relatively few changes occurred between the male samples in the arms (Bridges, 1985, 1989). Females showed increases in both arm and leg strength in the later period, but the more striking difference between groups was in the arms, especially on the left side. The more widespread nature of the changes in female strength was attributed to their greater participation in agricultural tasks, while the specific patterning of arm robusticity in Mississippian females (reduced bilateral asymmetry and a strengthening centered around the left elbow region) was suggested to be related to pounding maize in wooden mortars (Bridges, 1985, 1989).

The coastal Georgia study came to very different conclusions. There, a spectrum of preagricultural skeletal samples was compared with maize agriculturalists (Ruff and Larsen, 1990; Ruff et al., 1984). The later group showed declines in both leg and arm strength, compared to the preagricultural sample. Also in contrast to the Alabama study, males showed the most significant changes, not females. Males decreased in strength at the subtrochanteric level of the femur and the distal humerus. Females had no significant changes in size-standardized strength measures for either the humerus or femur. The coastal Georgia study suggests a major decrease in male activities with the introduction of agriculture, but little or no change in female chores (Ruff and Larsen, 1990; Ruff et al., 1984).

The results from the present study, while not identical to those from either Alabama or Georgia, show some similarities with each. Change in female strength in Illinois in many ways mirrors that from Alabama, although the timing of events is either somewhat different, or perhaps obscured in the Alabama study by the fact that only two ends of the spectrum (hunter-gatherers vs. agriculturalists) are represented, rather than intermediate horticultural groups. In both regions, females showed more differences over time than males, encompassing both the arms and legs. In both places, an increase in female strength in the legs, and the left arm, was associated with either intensification of local seeds (Illinois) or adoption of maize agriculture (Alabama). However, the drop in female arm strength in Illinois with maize intensification is puzzling. As discussed above, it may be that the native seeds grown in Illinois are simply more difficult to grow or process than maize, or that cultivation and processing techniques improve in that region at the time that maize use intensifies.

Unfortunately, we cannot yet compare the relative importance of maize in west-central Illinois with northwestern Alabama, since appropriate isotopic studies have not yet been carried out in the latter region. West-central Illinois societies, although relying on maize to a large degree in the Mississippian period, did not utilize it to the same extent as Fort Ancient and other societies to the east and south (Buikstra, 1992; Buikstra et al., 1987). If the northwestern Alabama groups shared this characteristic with Fort Ancient and nearby Tennessee Mississippian populations, some of the variation between them and Illinois Mississippian societies may be due to the relative importance of maize in the diet. If true, this regional variation in maize production intensity could also explain some of the differences in activity levels between females in the Alabama and Georgia studies, since the amount of corn consumption, as judged by carbon isotope levels, is lower in both coastal and inland Georgia groups than in those from Tennessee (Buikstra, 1992; Hutchinson et al., 1998).

Changes in male strength in Illinois, which mostly involve a decline in right arm strength, are not congruent with those from Alabama. However, the studies are not completely comparable, since only left (not right) humeri were analyzed biomechanically from Alabama. However, external diaphyseal dimensions actually increase somewhat in agricultural males from Alabama, further supporting the idea that changes in male strength are different from those in Illinois. For Illinois males, the data are more similar to those from coastal Georgia, which show a decline in male humeral strength (left and right sides combined) over time. Once again, this change occurs in Illinois populations with the early Late Woodland period, prior to the adoption of maize agriculture, and coincident with the introduction of the bow-and-arrow. Like the Alabama agriculturalists, male leg strength in the Illinois sample increases (although less dramatically); such was not the case for the Georgia coast.

It is likely that a number of reasons may account for the differences in results between these studies. The environment, agricultural practices, and processing techniques may have varied in different regions. And, as noted above, significant regional variation in maize use may correlate with activity levels, especially for females. At least as important is the fact that the premaize groups used for comparison differed dramatically—from Archaic hunter-gatherers to Woodland horticulturalists to coastal fisherfolk. In spite of the variation seen in these three studies, there is an important commonality. The point at which activities change in all three regions is similar: the change occurred when use of crops intensified, either as a result of a long endemic process, or as the result of a relatively rapid, full-scale introduction of maize agriculture. Recent comparative research has revealed that intensive cultivation of native seed crops was primarily a Midwestern (including Kentucky and Tennessee) phenomenon (Fritz, 1993). In the Southeast, on the coastal plain, the native crops were not cultivated, at least not to the extent seen in the Midwest. In other words, there were really two crop-intensification transitions in the Midwest, the first with native seed crops and the second with maize, whereas coastal Georgia populations participated in only the single food-production transition to maize (there are no data on premaize cultivation in northwestern Alabama).

The current study, while not conforming completely to either of the previous works in terms of results, may help to clarify the observed differences in regional activity patterns. The primary factors affecting regional activity variation are the agricultural intensification process and the differential participation of males and females in the new activities that accompany the process. For example, the crucial event in Illinois in changing activities may not have occurred at the moment of initial adoption of maize agriculture, but as a process of intensification of plant husbandry that occurred throughout the Woodland and into the Mississippian periods in this region. As individuals began to increase food production, activity levels may have risen early in the process. It is possible that, as more efficient means of growing and processing crops developed, activities may have later declined.

In all three regions, males and females show differing patterns of change with the introduction or intensification of agriculture. While male arm strength either declines or remains the same, changes in male leg strength are highly variable, possibly due to differences in male mobility among regions. Changes in female strength may depend more on the degree of reliance on agriculture, with more intensive maize agriculturalists showing greater increases than those groups with less reliance on maize. For example, the decrease in male arm strength in the earlier Late Woodland period of west-central Illinois occurs at the same time as a number of female strength measures increase, clearly indicating that changes in male and female activities are not closely linked. Overall, male and female changes in strength occur largely independent of each other, suggesting that their roles in society differed as well, as is supported by early ethnographic accounts (Swanton, 1979). Given that females historically conducted the majority of agricultural tasks, including both growing and processing crops, and that variation in female strength in this study fits well with the observed archaeological sequence of subsistence change, it can be assumed that females were also largely responsible for growing crops in the Woodland period as well as later in Mississippian times. For this reason, it is highly probable that most of the changes seen in subsistence and processing technology are female innovations (Watson and Kennedy, 1991).

CONCLUSIONS

In west-central Illinois, the level of physical activities does not change with the adoption of maize as a staple crop, but prior to this time, when use of native seed crops intensifies. Femoral and left humeral strength increase in females at this time, corresponding with historical evidence that females are the primary individuals responsible for growing and processing of crops in prehistoric Eastern Woodland societies. Male changes are fewer in number, and are largely restricted to a decrease in the right humerus, which may be tied to the replacement of the atlatl by the bow.

Fewer changes in activities occur when maize becomes a dietary staple in the later Late Woodland period, possibly because maize is at first treated as just another seed crop. Later, female left humeral strength declines significantly in the Mississippian period when maize use intensifies. This could occur because maize is easier to cultivate or process than native small seeds, or as a result of significant improvements in processing, or changes in other types of activities.

Results from this study differ from those seen in previous research on skeletal samples from Alabama and Georgia, supporting the notion that significant regional diversity is present in levels of activity associated with prehistoric agriculture. This variability is of particular interest, since it may correlate with differences in the nature or intensity of food production across the Eastern Woodlands, which in turn has fundamental implications for the interpretation of prehistoric health, demography, sexual division of labor, and sociopolitical development. Additional comparative work on these topics is necessary to resolve these issues.

ACKNOWLEDGMENTS

The Pete Klunk, Koster, Yokem, and Schild sites were excavated by Gregory Perino of the Gilcrease Institute (Tulsa, OK). This material is housed at Indiana University, and curated by Dr. Della Cook. Dr. Jane Buikstra directed the excavation of the other sites, first at Northwestern University, and later at the University of Chicago. We thank Drs. Buikstra and Cook for their aid and hospitality while gathering data at their institutions. Dr. Ethan Braunstein of the Department of Radiology, Indiana University Medical Center in Indianapolis, directed the computed tomographic scans at that facility. Drs. Warren DeBoer, Paul Welch, and our other colleagues at Queens College endured endless questions on archaeology, agricultural intensification, and food preparation. An earlier version of this paper was delivered by Dr. Bridges at a festschrift in honor of Dr. C. Loring Brace at the 64th Annual Meeting of the AAPA in 1995. Final revisions of the manuscript were completed by John H. Blitz and Martin C. Solano, after the death of Dr. Bridges.

LITERATURE CITED

Asch DL, Asch NB. 1985a. Prehistoric plant cultivation in west-central Illinois. In: Ford RI, editor. Prehistoric food production in North America. Univ Mich Mus Anthropol Anthropol Papers 75:149–203.

Asch NB, Asch DL. 1981. Archeobotany of Newbridge, Carlin, and Weitzer sites—the White Hall components. Faunal exploitation and resource selection. Early Late Woodland subsistence in the Lower Illinois Valley. Northwest Univ Archaeol Progr Sci Papers 3:275–291.

Asch NB, Asch DL. 1985b. Archeobotany. In: McGimsey CR, Conner MD, editors. Deer Track. a Late Woodland village in the Mississippi Valley. Center Am Archeol Tech Rep 1:44–117.

Asch DL, Farnsworth KB, Asch NB. 1979. Woodland subsistence and settlement in west-central Illinois. In: Brose DS, Greber N, editors. Hopewell archaeology. The Chillicothe Conference. Kent, OH: Kent State University Press. p 80–85.

Atwell KA, Conner MD. 1991. The Kuhlman Mound Group and Late Woodland mortuary behavior in the Mississippi River Valley of West-Central Illinois. Center Am Archeol Res Ser 9:1–335.

Bender MM, Baerreis DA, Steventon RL. 1981. Further light on carbon isotopes and Hopewell agriculture. Am Antiquity 46:346–353.

Blitz JH. 1988. Adoption of the bow in prehistoric North America. North Am Archaeol 9:123–145.

Blitz JH, Welch PD. 1998. Why lye? Does lye treatment make it easier to pound maize? Electronic document. http://www.qc.edu/ANTHRO/welch/maize/index.htm

Braun DP. 1983. Pots as tools. In: Moore JA, Keene AS, editors. Archaeological hammers and theories. New York: Academic Press. p 107–136.

Bridges PS. 1985. Changes in long bone structure with the transition to agriculture: implications for prehistoric activities. Ph.D. dissertation, University of Michigan, Ann Arbor.

Bridges PS. 1989. Changes in activities with the shift to agriculture in the Southeastern United States. Curr Anthropol 30:385–394.

Bridges PS. 1990. Osteological correlates of weapon use. In Buikstra JE, editor. A life in science papers in honor of J. Laurence Angel. Center Am Archaeol Sci Papers 6:87–98.

Buikstra J. 1976. Hopewell in the Lower Illinois Valley. A regional approach to the study of human biological variability and prehistoric behavior. Northwestern Univ Archaeol Progr Sci Papers 2:1–90.

Buikstra J. 1992. Diet and disease in late prehistory. In: Verano JW, Ubelaker DH, editors. Disease and demography in the Americas. Washington, DC: Smithsonian Institution Press. p 87–101.

Buikstra JE, Cook DC. 1981. Pre-Columbian tuberculosis in west-central Illinois: prehistoric disease in biocultural perspective. In: Buikstra JE, editor. Prehistoric tuberculosis in the Americas. Northwestern Univ Archeol Progr Sci Papers 5:115–139.

Buikstra JE, Konigsberg LW, Bullington J. 1986. Fertility and the development of agriculture in the prehistoric Midwest. Am Antiquity 51:528–546.

Buikstra JE, Bullington J, Charles DK, Cook DC, Frankenberg SR, Konigsberg LW, Lambert JB, Xue L. 1987. Diet, demography, and the development of horticulture. Center Archaeol Invest Occasional Paper 7:67–85.

Campbell TN. 1959. Choctaw subsistence: ethnographic notes from the Lincecum manuscript. Florida Anthropol 12:9–24.

Churchill SE. 1994. Human upper body evolution in the Eurasian Later Pleistocene. Ph.D. dissertation, University of New Mexico, Albuquerque.

Cohen MN, Armelagos GJ. 1984. Paleopathology at the origins of agriculture: editor's summation. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the origins of agriculture. New York: Academic Press. p 585–601.

Conner MD. 1984. Population structure and biological variation in the Late Woodland of West-Central Illinois. Ph.D. dissertation, University of Chicago.

Cook DC. 1979. Subsistence base and health in prehistoric Illinois Valley: evidence from the human skeleton. Med Anthropol 3:109–124.

Cook DC. 1984. Subsistence and health in the Lower Illinois Valley: osteological evidence. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the origins of agriculture. New York: Academic Press. p 235–269.

Cook DC, Buikstra JE. 1979. Health and differential survival in prehistoric populations: prenatal dental defects. Am J Phys Anthropol 51:649–664.

Ember CR. 1983. The relative decline in women's contribution to agriculture with intensification. Am Anthropol 85:285–304.

Emerson TE, Jackson DK. 1984. The BBB motor site. Urbana: University of Illinois Press.

Eschman PN. 1990. SLCOMM user's manual. Albuquerque: Eschman Archeological Services.

Foster GM. 1967. Tzintzuntzan. Mexican peasants in a changing world. New York: Elsevier.

Fritz GT. 1993. Early and Middle Woodland period paleoethnobotany. In: Scarry CM, editor. Foraging and farming in the Eastern Woodlands. Gainesville: University Press of Florida. p 39–56.

Hally DJ. 1986. The identification of vessel function: a case study from northwest Georgia. Am Antiquity 51:267–295.

Hamilton ME. 1982. Sexual dimorphism in skeletal samples. In: Hall RL, editor. Sexual dimorphism in *Homo sapiens*: a question of size. New York: Praeger. p 107–163.

Hanson DB. 1988. Subsistence change and biological adaptation: a microradiographic analysis of cortical bone remodeling in three prehistoric populations from the Lower Illinois Valley. Ph.D. dissertation, Cornell University, Ithaca, NY.

Hutchinson DL, Larsen CS, Schoeninger MJ, Norr L. 1998. Regional variation in the pattern of maize adoption and use in Florida and Georgia. Am Antiquity 63:397–416.

Johannessen S. 1993. Farmers of the Late Woodland. In: Scarry CM, editor. Foraging and Farming in the Eastern Woodlands. Gainesville: University Press of Florida. p 55–77.

Katz SH, Hediger ML, Valleroy LA. 1974. Traditional maize processing techniques in the New World. Science 184:765–773.

King FB. 1994. Variability in cob and kernel characteristics of North American maize cultivars. In: Johannessen S, Hastorf CA, editors. Corn and culture in the prehistoric New World. Boulder, CO: Westview Press. p 37–54.

Linton R. 1924. The significance of certain traits in North American maize culture. Am Anthropol 26: 345–349.

Lovejoy CO, Burstein AH, Heiple KG. 1976. The biomechanical analysis of bone strength: a method and its application to platycnemia. Am J Phys Anthropol 44: 489–506.

Milner GR. 1995. An osteological perspective on prehistoric warfare. In: Beck LA, editor. Regional approaches to mortuary analysis. New York: Plenum Press. p 221–244.

Penny JM. 1983. The raw and the cooked: nutritional evaluation of a prehistoric Mississippian diet. M.A. thesis, Southern Illinois University, Carbondale, IL.

Perino G. 1968. The Pete Klunk Mound Group, Calhoun County, Illinois: the Archaic and Hopewell occupations (with an appendix on the Gibson Mound Group). Illinois Archaeol Surv Bull 6:9–124.

Perino G. 1971a. The Yokem site, Pike County, Illinois. Illinois Archaeol Surv Bull 8:149–186.

Perino G. 1971b. The Mississippian component at the Schild site (no. 4), Greene County, Illinois. Illinois Archaeol Surv Bull 8:1–148.

Perino G. 1973a. The Late Woodland component at the Pete Klunk site, Calhoun County, Illinois. Illinois Archaeol Surv Bull 9:58–89.

Perino G. 1973b. The Late Woodland component at the Schild sites, Greene County, Illinois. Illinois Archaeol Surv Bull 9:90–140.

Perino G. 1973c. The Koster Mounds, Greene County, Illinois. Illinois Archaeol Surv Bull 9:141–210.

Pickering RB. 1984. Patterns of degenerative joint disease in Middle Woodland, Late Woodland, and Mississippian skeletal series from the Lower Illinois Valley. Ph.D. dissertation, Northwestern University, Evanston, IL.

Riley TJ, Walz GR, Bareis CJ, Fortier AC, Parker KE. 1994. Accelerator mass spectometry (AMS) dates confirm early Zea Mays in the Mississippi River Valley. Am Antiquity 59:490–498.

Rindos D, Johannessen S. 1991. Human-plant interactions and cultural change in the American bottom. In: Emerson TE, Lewis RB, editors. Cahokia and the hinterlands: Middle Mississippian cultures of the

Midwest. Urbana: University of Illinois Press. p 35–45.
Ruff CB. 1981. Structural changes in the lower limb bones with aging at Pecos Pueblo. Ph.D. dissertation, University of Pennsylvania, Philadelphia.
Ruff CB, Hayes WC. 1983. Cross-sectional geometry of Pecos Pueblo femora and tibiae—a biomechanical investigation. I. Method and general patterns of variation. Am J Phys Anthropol 60:359–381.
Ruff CB, Larsen CS. 1990. Postcranial biomechanical adaptations to subsistence strategy changes on the Georgia coast. In: Larsen CS, editor. The archaeology of Mission Santa Catalina de Guale:2. Anthropol Papers Am Mus Nat Hist 68:94–120.
Ruff CB, Larsen CS, Hayes WC. 1984. Structural changes in the femur with the transition to agriculture on the Georgia coast. Am J Phys Anthropol 64: 125–136.
Ruff CB, Trinkaus E, Walker A, Larsen CS. 1993. Postcranial robusticity in *Homo* I: temporal trends and mechanical interpretation. Am J Phys Anthropol 91: 21–53.
Smith BD. 1989. Origins of agriculture in eastern North America. Science 246:1566–1571.
Styles BW. 1981. Faunal exploitation and resource selection. Early Late Woodland subsistence in the Lower Illinois Valley. Northwestern Univ Archaeol Progr Sci Papers 3:1–273.
Styles BW. 1985. Reconstruction of availability and utilization of food resources. In: Gilbert RI Jr, Mielke JH, editors. The analysis of prehistoric diets. Orlando, FL: Academic Press. p 21–59.
Swanton JR. 1979. The Indians of the Southeastern United States. Washington, DC: Smithsonian Institution Press.
Tuggle WO. 1973. Shem, Ham and Japheth. The papers of W.O. Tuggle. Current-Garcia E, editor. Athens, GA: University of Georgia Press.
van der Merwe NJ, Vogel JC. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. Nature 276:815–816.
Watson PJ. 1988. Prehistoric gardening and agriculture in the Midwest and Midsouth. In: Yerkes R, editor. Interpretations of culture change in the Eastern Woodlands during the Late Woodland. Occasional papers in anthropology 3. Columbus: Ohio State University. p 39–67.
Watson PJ, Kennedy MC. 1991. The development of horticulture in the Eastern Woodlands of North America: women's role. In: Gero JM, Conkey MW, editors. Engendering archaeology, women and prehistory. Cambridge, MA: Basil Blackwell. p 255–275.
Walthall JA. 1980. Prehistoric Indians of the Southeast. Archaeology of Alabama and the Middle South. Tuscaloosa: University of Alabama Press.
Yarnell RA. 1978. Domestication of sunflower and sumpweed in eastern North America. In: Ford RJ, editor. The nature and status of ethnobotany. Univ Mich Anthropol Papers 67:289–299.