

## ABSTRACT

MAXWELL, ASHLEY BROOKE. Biomechanical Stress: A Comparative Analysis of Sexual Dimorphism in Prehistoric Tennessee Populations. (Under the direction of Dr. Ann Ross, Dr. Troy Case, and Dr. Scott Fitzpatrick)

Bioarchaeological studies can provide biological information on sex differences/similarities in subsistence patterns and labor intensification through the analysis of sexual dimorphism and bilateral asymmetry of specific skeletal elements of a population. Current research suggests that sexual dimorphism and bilateral asymmetry has decreased over time due to a shift in subsistence patterns (hunter-gathering to agriculture) that requires both sexes to participate in similar activities, and the utilization of both limbs for agricultural production. Also, nutrition can impact the sexual dimorphism of a population, because nutritional deficiencies can decrease cortical bone thickness, and males are more physically impacted by environmental stressors than females.

The purpose of this research is twofold: 1) to explore sexual dimorphism of the upper limbs in the 14<sup>th</sup> Century AD Averbuch skeletal collection (female n=62, male n=75), Mouse Creek (3MN3, 4MN3) and Toqua (40MR6) a Late Mississippian (900-1450AD) group from East Tennessee (females n=24, males n=12), and Eva (6BN12), Kays Landing (15HY13), and Big Sandy (25HY18), a Archaic (5000-500 BC) sample from East Tennessee (females n=32, males =17); and 2) to observe bilateral asymmetry in males and females of the Late Mississippian (AD 1300) Averbuch population.

Standard measurements were taken of the humerus, ulna, and radius. Size, defined as the geometric mean, and shape variables, the proportions of the geometric mean or size, were computed. A one-way analysis of variance (ANOVA) was performed on the size and newly

transformed shape variables. Results indicate a significant difference in size between samples ( $p < .0001$ ). An index of sexual dimorphism (ISD) was also calculated and supports the hypothesis that sexual dimorphism decreased with a shift to agriculture, with the Averbuch population representing the least sexually dimorphic group, followed by the Archaic and the East Tennessee Late Mississippian groups. A Mahalanobis  $D^2$  statistic was computed and graphed to show significant differences in bone shape among the groups. The results confirm the index of sexual dimorphism, and show that the Averbuch males and females are not significantly different in shape, thus indicating that they were participating in similar activities. Also, the Averbuch population was severely stressed, which contributes to the decrease in sexual dimorphism. This study provides a better understanding of how the shift from hunter-gathering to agriculture production has changed the sexual division of labor in past societies.

Biomechanical Stress: A Comparative Analysis of Sexual Dimorphism in Prehistoric  
Tennessee Populations

by  
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## DEDICATION

To Tiger “Kitty” Maxwell, for always being the one thing that could make me smile.

## BIOGRAPHY

Ashley Brooke Maxwell grew up in Las Vegas, NV and began her undergraduate studies as a secondary education major. After taking one anthropology course, Ashley switched her major to anthropology and never looked back. Her undergraduate studies at the University of Nevada, Las Vegas allowed her to explore ideas of sexual dimorphism and pathology in past populations, which continued on into her graduate career. As a graduate student, Ashley really became interested in skeletal biology and the changes in sexual dimorphism that occurred during the major shifts in subsistence strategies over time. Through working as a research assistant, Ashley also developed an interest in radiography studies, specifically for the identification of individuals in a death investigation. Hopefully, her future studies will utilize radiographic information and skeletal biology in both forensic applications and physical anthropology.

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## INTRODUCTION

Bioarchaeological studies can provide biological information on sex differences/similarities in subsistence patterns and labor intensification through the analysis of sexual dimorphism and bilateral asymmetry of specific skeletal elements of a population (Stock and Pfeiffer 2004; Larson 1995; Gruelich 1951). Sexual dimorphism is generally the difference between male and female shape and size; however this study will focus on differences in upper limb robustness and diaphyseal shape between the sexes (Stock and Pfeiffer 2004). According to Mosimann and colleagues, *size* is defined as the geometric mean of all variables and *shape* as the proportion of the geometric mean or size ( $\text{bone1} + \text{bone2} + \text{bone3} / 3 = \text{size}$ ) (Mosimann and James 1979; Darroch and Mosimann 1985). Bilateral asymmetry measures the variation in use and size between the left and right sides of the body (Auerbach and Ruff 2006). Current research suggests that sexual dimorphism and bilateral asymmetry has decreased over time due to a shift in subsistence patterns that requires both sexes to participate in activities that utilize both sides of the body (Stock and Pfeiffer 2004). In this study, differences in upper limb robustness due to subsistence related specialized tasks such as corn grinding, hunting, and agriculture production will be examined in the Late Mississippian Averbuch population (Stock and Pfeiffer 2004).

This group is distinguished, in part, by the “stone box” phenomenon called the Middle Cumberland Culture (due to the large number of stone lined graves) that lasted from the 13<sup>th</sup>-15<sup>th</sup> century AD (Berryman 1983). The Averbuch population used maize agriculture as a means of food production that required the participation of both sexes. Therefore, males and females were partaking in similar subsistence tasks that could affect the degree of sexual

dimorphism and bilateral asymmetry in the population. The Averbuch site was located in an area where agriculturally poor soil limited the nutritional intake of both males and females. Males in the population appear to be more stressed than females, also suggesting that sexual dimorphism should be decreased (Berryman 1983). Generally, males are more physically impacted by environmental stress, such as nutritional deficiencies, than females (Greulich 1951). The complex interaction between genetics and environmental effects influence bone shape and size, thus diet, activity, and disease are factors that can alter bone morphology (Ruff 1996). One way to assess and compare changes in sexual dimorphism and bilateral asymmetry is to take cross sectional measurements of the upper limbs because bone is highly responsive to mechanical stress and loading.

The purpose of this research is twofold: 1) to observe and perform a comparative analysis on sexual dimorphism of the upper limbs in the Late Mississippian (AD 1300) Averbuch skeletal collection, in Mouse Creek (3MN3, 4MN3) and Toqua (40MR6) a Late Mississippian (AD 900-1450) group from East Tennessee, and in Eva (6BN12), Kays Landing (15HY13), and Big Sandy (25HY18), Archaic (5000-500 BC) samples from East Tennessee; and 2) to explore bilateral asymmetry in males and females of the Late Mississippian (AD 1300) Averbuch population. The goal is to test the hypothesis that sexual dimorphism will decrease from the Archaic to the Late Mississippian Averbuch population, and between the Late Mississippian Averbuch population and the other Late Mississippian populations from a study conducted by Ross et al. (2003), due to a less pronounced division of labor and nutritional stress. It is also expected that bilateral asymmetry should be less

pronounced in males and females due to regulated tasks (corn grinding, hoeing) associated with agriculture.

## LITERATURE REVIEW

### **Skeletal Biology and Biomechanical Loading**

It is important to understand the process of bone osteogenesis (formation) in order to recognize the effects of biomechanical loading. Long bones develop through endochondral ossification, which is the creation of an organic matrix, cartilage development, and the formation of specialized cells that create and model bone (White 1991; Schwartz 2007). The organic matrix consists of proteins (collagen, which contributes to the strength of bone), calcium, and phosphate ions that make up hydroxyapatite crystals (Schwartz 2007). Cartilage forms through the interaction of cartilage cells and perivascular connective tissue (Schwartz 2007). Ossification begins as blood vessels penetrate the cartilage creating a membrane called the perichondrium (White 1991). Cartilage then transforms into bone by forming specialized cells (osteoblasts and osteoclasts) beneath the perichondrium. Specialized cells, osteoblasts, deposit bone around the cartilage shaft creating the periosteum (fibrous connective tissue) and osteoclasts remove old bone as the diameter of the shaft increases (White 1999; Schwartz 2007).

Biomechanical loading is the imposition of mechanical forces on bone from activity related stressors such as corn grinding, wood chopping, and traveling long distances on foot (Mays 1999). Bone is highly sensitive to nutritional stress and mechanical loading during skeletal growth, which forces bone to develop an adaptive response. This adaptive response is instantaneous and only requires a short amount of mechanical loading to initiate adaptive changes (Turner 1998). Once initiated, osteoclasts remove bone and osteoblasts replace it in areas where muscle and load stress occur (Collier 1993). With dynamic mechanical loading

on bone, certain areas will undergo this renewal process and accrue more bone, thus creating differences in robusticity. Larson (1995) states, “The external surface (subperiosteum) and internal surface (endosteum) of cortical bone continue to expand or become more outwardly distributed throughout adulthood. This expansion is influenced strongly by the level of mechanical or functional demand that occurs during one's lifetime,” (Larson 1995, 191). This indicates that bone diaphyseal size and shape are affected by habitual mechanical loading (Trinkaus et al. 1999).

Biomechanical loading has been compared to beam theory developed by mechanical engineers, although not all researchers are in agreement. Under this hypothesis, mechanical loading occurs on the long bones from muscular contraction, body mass, and momentum, which are similar to a hollow beam that undergoes bending, torsion, and axial compressive loading (Trinkaus et al. 1999). Engineers use cross-sectional data to estimate the resistance of certain forces applied to a beam (Bridges 1989). Basically, when a long bone is subject to bending or torsion, this triggers an increase in mechanical stress that begins at a central point and expands throughout the shaft of the bone (Larson 1995), which then causes changes in both bone size and shape (Bridges 1989). For example, in a study conducted by Lieberman (1996), it was found that exercise is correlated with thicker cortical bone development in rats. Ruben et al. (2001) focused on localized habitual behavior and found increased osteoblastic activity and thus, increased robusticity.

### **Biomechanical Loading and Sexual Dimorphism**

Biomechanical loading affects the degree of sexual dimorphism in robusticity between males and females. Larson (1995) suggests that sexual dimorphism in robusticity

has decreased over time because of a shift from hunting and gathering to agriculture. Males seem to have remained fairly consistent in size while females have become more robust due to an increase in labor intensive activities (Larson 1995). In hunting and gathering societies, males usually travel long distances to hunt, while females stay close to home and participate in various domestic activities, including child care and gathering. With a shift to agriculture, females began partaking in similar, if not more, activities than males (Larson 1995). In historic and modern Southeastern Native American groups, females are responsible for agricultural work, including hoeing and corn processing (Bridges 1989), while males perform tasks such as hunting, clearing fields, planting, and harvesting; however, males on average participate in fewer daily domestic chores than females (Bridges 1989).

Ruff (2000) also suggests that with similar task related specializations, sexual dimorphism is reduced. Studies conducted on populations from the prehistoric Georgia Coast show a decline in robustness with the introduction of agriculture. This is attributed to a decrease in mechanical loading due to a reliance on maize production (Larson 1995). Ross et al. (2003) analyzed muscle development in the forearms of Archaic (5000-500 BC) males and females from East Tennessee and found a contradiction to these earlier studies. They showed that the Archaic group was less sexually dimorphic, suggesting that females participated in physical activities that caused greater muscle development.

### **Shape Changes**

The amount of biomechanical loading required for different subsistence related tasks, such as an increase/decrease in mobility and intensification, affects the diaphyseal shape of

limb bones (Ruff 2006; Ross et al. 2003). Cross-sectional diaphyseal shape is assessed based on the distribution of bone in the antero-posterior and medio-lateral planes at midshaft (Ruff 2006). Generally, the adoption of agriculture leads to a rounder diaphysis in cross-section due to a decrease in relative bone strength (Ruff 2006). This is more marked among males due to a reduction in mobility and a focus on agricultural production. Larson (1995) suggests that this is a worldwide trend that has persisted since the late Pleistocene. Ross et al. (2003) found shape-related sexual dimorphism in the forearm among males and females of an East Tennessee Mississippian agricultural population, implying changes in subsistence patterns. Females exhibit larger interosseous crest development, while males have smaller interosseous crest development. Overall, there is great variability in subsistence-related activities among populations (Larson 1995).

### **Bilateral Asymmetry**

Bilateral asymmetry reflects the difference in mechanical loading placed on the upper limbs (Stock and Pfeiffer 2004; Auerbach and Ruff 2006). There is supporting evidence for a direct association of mechanical bone growth and modeling with behavioral activities with regards to the degree of asymmetry (Auerbach and Ruff 2006). It appears that the greatest asymmetry occurs in the diaphyseal breadths of upper limb bones (Auerbach and Ruff 2006). Auerbach and Ruff (2006) support this conclusion with their study of a sample of 780 Holocene preindustrial and industrial groups. The researchers found that the greatest individual variation and asymmetry occurred in upper limb diaphyseal breadths in males, which may be due to greater muscle development from biomechanical loading, further supporting the relative independence of bone length and breadth. On the other hand, females

exhibit greater asymmetry in maximum lengths of the upper limbs. They also compared the level of sexual dimorphism between industrialized and pre-industrialized groups and found that industrial Europeans showed reduced sexual dimorphism and concluded that this reduction was the result of decreased activity levels or homogeneity of activity patterns.

Certain subsistence activities require the repetitive use of one side of the body as opposed to the other. For example, spear throwing in hunting societies along with the preparation of hides is usually done with one limb as opposed to both (Larson 1995). Also, Haaspasalo et al. (1996) and Ruff (1992) studied bilateral asymmetry in professional tennis players and found localized differences in robusticity in the upper limbs. Mays (1999) analyzed an 11<sup>th</sup>-16<sup>th</sup> century cemetery from York and found that males exhibited greater bilateral asymmetry in the upper limbs due to specialized craft making of iron, wood, and stone that required the use of one arm. Trinkaus et al. (1994) and Churchill et al. (1996b) looked at bilateral asymmetry in Neanderthals and Upper Paleolithic groups and found variations in robustness and asymmetry between the upper and lower limbs, concluding that this can be correlated with terrestrial mobility and habitual behaviors. This is further support that hunter-gatherer groups participating in different activity patterns should show greater bilateral asymmetry due to differential limb use required for specific subsistence strategies.

Alternatively, agricultural groups should show a decrease in bilateral asymmetry, because the tasks associated with agriculture often require the use of both arms. For example, the bow and arrow, which imposed forces on both the left and right arms, replaced the Archaic atlatl, which was used by just one arm (Bridges 1989). Comparisons of left and right humeri from the American Southeast show a reduction in bilateral asymmetry due to a more

evenly distributed mechanical load because of the shift to agriculture (Larson 1995). Larson (1995) states that it is common for women to exhibit bilateral elbow osteoarthritis from the use of grinding stones in American Southwest Native Americans. Agricultural activities such as corn grinding and hoeing require the usage of both limbs, thus decreasing bilateral asymmetry (Larson 1995). Bridges (1985) saw a decrease in bilateral asymmetry in humeral strength in a prehistoric population in Alabama that participated in activities such as pounding maize (Larson 1995).

### **Nutrition**

Nutritional intake is important, especially during critical developmental periods, such as adolescence. In an ideal environment, the pattern of growth of males and females should be parallel to a particular canal on the human growth curve (Cameron 2006). Unfortunately, childhood diseases and inadequate nutritional intake impact childhood growth causing a deviation from the human growth curve (Cameron 2006). Usually, once the insult subsides, catch-up growth occurs and the individual returns to the normal growth curve (Cameron 2006).

Boys and girls differ significantly in growth and nutritional requirements during the onset of puberty (WHO 2005). Girls begin puberty around age 10 and require increases in protein and iron, while boys begin puberty around age 12 and gain a significant amount of muscle mass and bone density (WHO 2005). If males and females do not receive adequate nutrition, bone mass is acquired at a slower rate leading to lower bone density as an adult (WHO 2010).

Nutrition affects cortical bone composition, which may also explain differences in sexual dimorphism (Larson 1995). Generally, if males are more stressed in a population, sexual dimorphism should be decreased because male growth is more impacted by environmental stress (Greulich 1951). On the other hand, if nutrition is plentiful, sexual dimorphism might increase because males tend to benefit more than females from nutritional abundance (Holden and Mace 1999). Females are less affected by nutritional stress because of reproductive demands (childbirth and lactation stabilize females in nutritionally stressed populations), storage of more subcutaneous fat, and overall body size (Greulich 1951; Frayer and Wolpoff 1985; Hamilton 1982).

These hypotheses will be tested on the Late Mississippian (AD 1300) Averbuch population. Thus, along with biomechanical loading, nutrition can impact the composition of bones. Larson (1995) discusses how a shift in agriculture has led to a decrease in nutritional quality of foods because plant diversity is reduced. For example, Larson (1995) notes that in Asia, rice became the staple agricultural food while maize was a dominant food source in the New World. Maize is considered an inadequate source of many amino acids, especially protein, and can cause nutritional problems when it is the main food source (Bridges 1989). It has been noted that cortical thickness of the bone decreases during poor nutritional intake because bone resorption occurs during periods of stress (Bridges 1989). This process usually affects the endosteal portion of bone leaving the external dimensions unchanged (Bridges 1989).

## Case Studies

It has been documented that the shift from hunter-gathering to agriculture changed the body composition of both males and females (Bridges 1989; Larson 1995; Stock and Pfeiffer 2001; Ruff and Larson 1990; Ross et al. 2003). This change in body composition has led to a decrease in sexual dimorphism due to the increased biomechanical loading on females and nutritional deficiencies in males, along with a decrease in bilateral asymmetry. A few studies tested this hypothesis on various populations.

Stock and Pfeiffer (2001) investigated differences in postcranial robustness between African Later Stone Age hunter-gatherers and 19<sup>th</sup> century indigenous Andaman Islander foragers. The researchers were analyzing differences in upper versus lower body localizations between the populations based on different subsistence patterns. Populations with known habitual behaviors were specifically used to correlate robustness. The African Later Stone Age group hunted small game, exploited coastal marine resources, and also foraged on an area of 2,000-3,000 square miles. The Andaman Island foragers exploited wild pigs, honey, fruits, and yams and hunted fish, dugong, and sea turtles, and their land use was restricted to 40 square km. Measurements were taken at the midshaft of the femur, humerus, clavicle, and first metatarsals. The tibiae were measured at the foramina. Half of the African Later Stone Age group dimensions were taken from CT scans and biplanar radiographs were used to measure the cortical thickness of each bone. The results showed that the African Later Stone Age group was more robust in the lower limb bones than in the upper limb bones in both sexes. On the other hand, the Andaman Island foragers showed more upper body robustness in both sexes. Stock and Pfeiffer (2001) concluded that while the African Later

Stone Age and Andaman Island foragers exhibited differential areas of robusticity, males and females show similar patterns of robustness within each group, indicating they were participating in similar activities.

Bridges (1989) performed a study on sexual dimorphism, bilateral asymmetry, and task related changes in the long bones of a Mississippian population to assess whether the introduction of maize agriculture changed the sexual division of labor. A comparison between Middle Archaic hunter-gatherers and Mature Mississippian agriculturists was completed on 1,937 individuals. Standard measurements of the diaphyseal diameters and circumferences of the femur, tibia, humerus, radius, and ulna were taken on both sides. The results illustrated that the midshaft circumferences of both left and right sides of the femur, tibia, humerus, radius, and ulna were larger in both males and females of the Mississippian agriculturists than the Archaic hunter-gatherers. Specifically, Mississippian females exhibited stronger humeri and femora than Archaic females at the central and distal areas of the bone, indicating a change in activities that involved torsion and minimum and maximum bending strength. Mississippian females also showed a decrease in bilateral asymmetry. On the other hand, there was no significant difference in humeral strength between Archaic and Mississippian males; however femoral strength increased indicating a change in activities involving the legs. Mississippian males also exhibited a decrease in bilateral asymmetry though it was less pronounced than that of the Mississippian females.

Ruff and Larson (1990) analyzed temporal biomechanical adaptations of the diaphyseal shape of the humerus and femur as related to different subsistence activities on three Georgia coastal populations. These three populations consisted of a precontact

preagricultural, precontact agricultural and a contact group. The results indicated a decrease in overall body size from precontact preagricultural to precontact agricultural groups. Surprisingly, they found that during the contact period, bone size increased to about the same size it had been in the precontact preagricultural groups. They noticed upper versus lower limb differences between males and females during the different time periods. Women showed a decline through all time periods in humeral strength, while femoral strength increased in the contact period. Males showed an initial decrease in femoral and humeral strength and then a steady increase. Sexual dimorphism declined from the precontact preagricultural group to the precontact agricultural group. However, sexual dimorphism increased greatly in the contact period. Bone shape in the femur of both sexes showed more circularity suggesting a decrease in general activity as opposed to frequent mobility. The increase in femur size in males during the contact period is a result of being forced into a labor system that required long distance travel. Nevertheless, actual mechanical loading decreased as seen in the circular shape of the femur.

Ross et al. (2003) conducted a study on bone shape and size among males and females of Archaic, Mississippian, and contemporary groups from East Tennessee. Bone measurements were taken on the ulna and radius and size and shape variables were computed. With regard to size, the researchers found a trend that suggests an increase in sexual dimorphism across subsistence strategies, while shape increased between the Archaic and Mississippian populations and decreased between Mississippian and contemporary groups. These results are contra to the notion that sexual dimorphism decreased with a shift in subsistence patterns. The Archaic males and females exhibited the least amount of sexual

dimorphism. They concluded that the Archaic males and females were performing similar tasks, while the Mississippian males and females had a greater division of labor with the transition to agriculture.

A few studies tested cortical bone thickness in relation to poor nutritional intake. Mays (1999) studied a Medieval site from Wharram Percey, England and found that the population was stressed from a high disease load and poor nutrition. Cortical bone was found to be thinner in this population, indicating that bone apposition was arrested due to nutritional stress. Adams and Berridge (1969) researched the effects of Kwashiorkor, a protein deficient disorder, on cortical bone thickness and found a substantial difference between children with this disorder and healthy children. Perzigian (1971) compared cortical bone density in the distal radius of the Middle Archaic Indian Knoll series and the Klunk Middle Woodland series and found bone loss occurred more frequently in the Klunk Middle Woodland series.

## **RESEARCH BACKGROUND**

### **Prehistoric Tennessee American Indian Background**

#### *Archaic Period*

The Archaic period in Tennessee contains numerous sites located in alluvial floodplains and river bottoms (Chapman 2009). The settlement patterns during the Early Archaic period (8700-6000 BC) consists of band-macroband groups that were seasonally mobile, and had provisioned base camps during cold weather periods, and short-term camps during warm weather periods (Emerson 2009). The Middle Archaic period (6000-4000 BC) transitioned into a more sedentary population, which led to plant manipulations, such as seeds from weedy plants (chenopod, sumpweed) (Emerson 2009). The Late Archaic period (4000-1400 BC) continued plant domestication with more evidence of genetic alterations of seeds produced by wild plants (Emerson 2009)

The material culture of the Archaic period consists of stone and bone tools (projectile points) for hunting, food processing, subsistence, and warfare (evidenced by projectile points embedded in remains) (Chapman 2009). Subsistence during the Archaic period consisted of hunting white-tailed deer, turkey, pigeons, fish (drumfish and catfish), and gathering freshwater mussels, hickory nuts, acorns, squash, and sunflower seeds (Chapman 2009).

During the Late Archaic period, around 6,000 years ago, populations began to grow due to the increased availability of resources, thus noticeable differences in relative social status began to develop (Chapman 2009). High levels of physical violence and warfare also occurred during this time evidenced by skeletal trauma such as penetrating wounds, blunt force trauma, and scalping (Mensforth 2001).

### *Late Mississippian Culture*

In general, the Mississippian period is recognized by the construction of earthen platforms with erected temples, elite residences and organized chiefdoms, increased population resulting in more stabilized settlements, increased warfare (towns were surrounded by palisades and moats), and the use of agriculture with a dependence on new strains of corn and beans (Chapman 2009; Cobb 2003). Symbolism became more complex with the depiction of deities in stone, shell, textiles, copper, and iconography (Chapman 2009).

The Mississippian culture is generally defined by an increase in social complexity where political leaders controlled economic, political, and religious practices (Cobb 2003). This is seen in the site distributions where large chiefdoms have multi-mound centers followed by subsidiary centers with a few mounds, villages with plazas, and smaller settlements (Cobb 2003). The labor system of the Mississippian period is composed of mound developers, farmers, and those that participate in craft specialization, including the production of hoes, shell beads, copper plates, and textiles (Cobb 2003). Another aspect of the Mississippian period is the distribution of food resources, where elites acquired preferred cuts of meat and edible portions of maize, while the outlier sites receive cob and cupule remains along with skewed portions of the faunal assemblage (Cobb 2003).

The cultural chronology for the Mississippian period consists of three cultural phases: Mouse Creek, Dallas, and Middle Cumberland Culture (Polhemus 1987). These phases are differentiated by community plans, subsistence, architecture, burial customs, and classes of material culture (Polhemus 1987). The Dallas Phase sites are considered ranked chiefdoms

with ascribed statuses, where the elite typically reside on flat-topped mounds that flanked the central plaza (Smith 2003). The Dallas Phase is usually comprised of; community plans that contain closely grouped dwelling houses with stockades, subsistence related to maize production, hunting, gathering, and freshwater mussels, architecture consisting of log construction, and rectangular community buildings, burials located close to dwellings and interred in substructures, and materials for weaving (Polhemus 1987). The burial mounds were differentiated by the elite and village groups, where individuals were buried in flexed positions with grave goods (Smith 2003). The Mouse Creek phase is similar to the Dallas Phase with square floorplans and palisades, although only the Dallas Phase contains substructure mounds (Boyd and Boyd 1991). Instead, the Mouse Creek sites contain large ground-level presumptive community buildings. Individuals are buried adjacent to residential structures in extended positions, with grave goods that indicate less social distinctions (Smith 2003). The Middle Cumberland Culture is differentiated from these two phases due to the presence of wall-trench structures. These three cultural phases are contemporaneous and similar in their material culture. However, Boyd and Boyd (1991) performed a multivariate craniometric study and found that these three cultural groups were biologically different (Boyd and Boyd 1991).

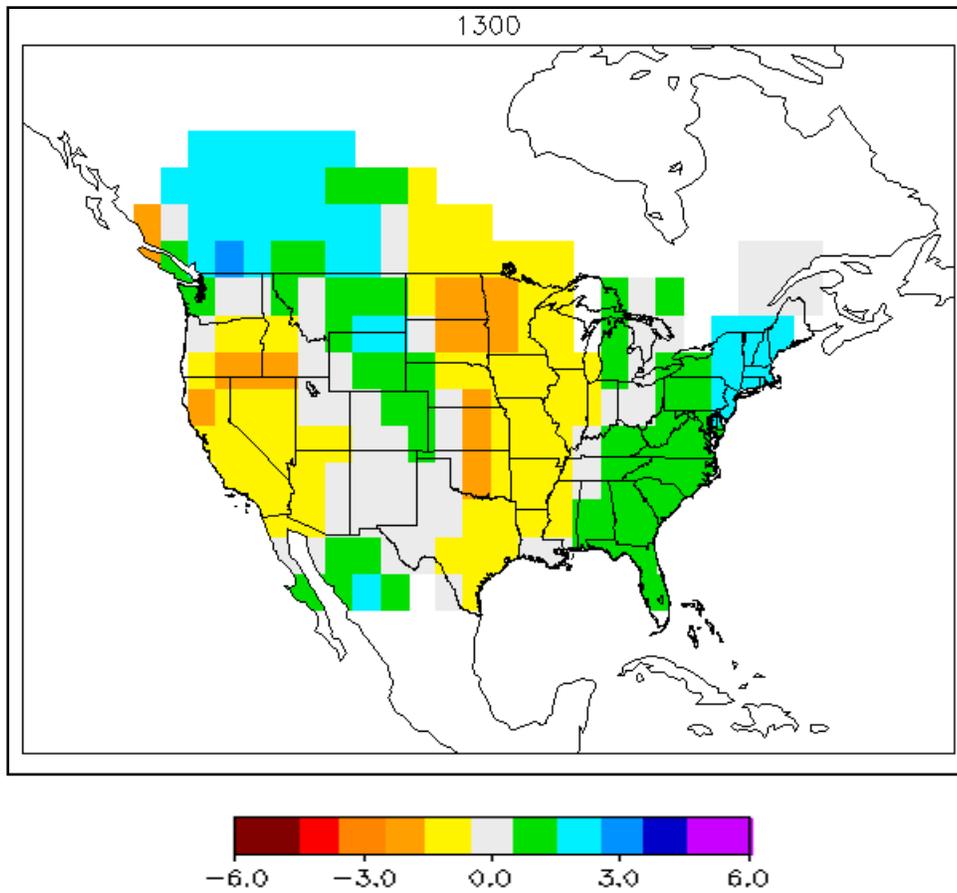
## **Environmental Background**

### ***Regional Climate***

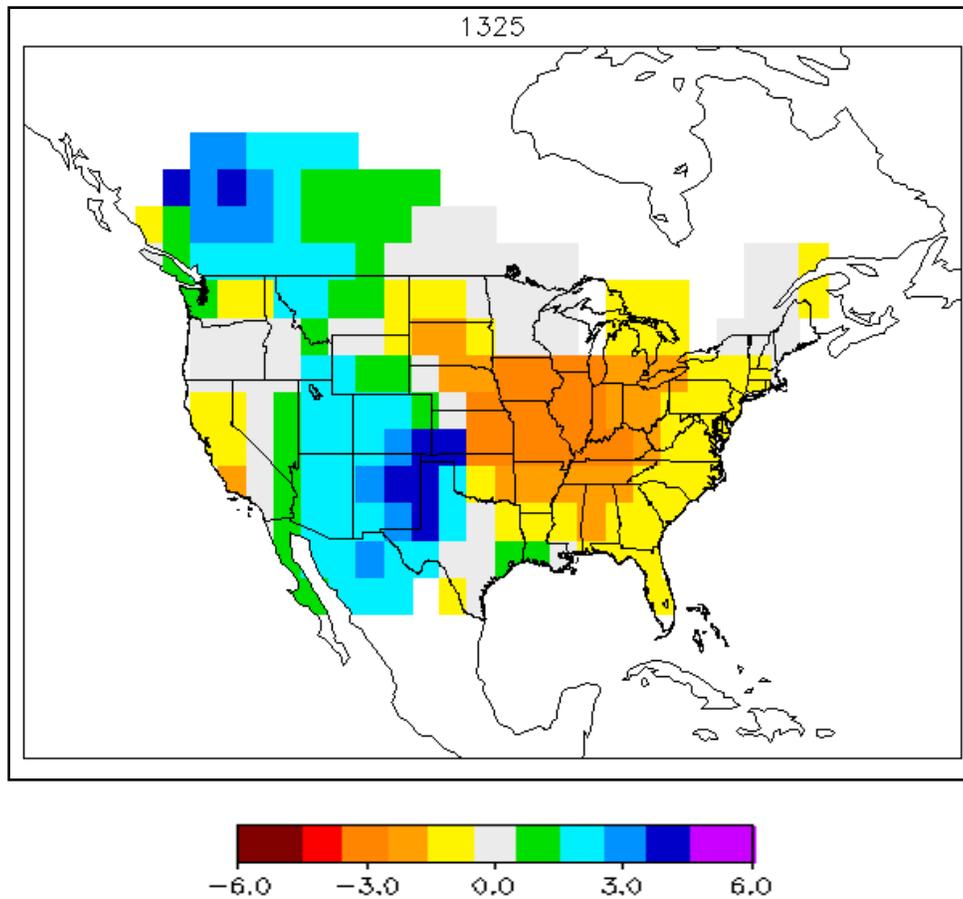
The contemporary climate in the Nashville Basin along with paleoclimate drought data can provide insight into the environmental conditions/stress the Averbuch population was experiencing. As of 1973, the mean annual temperature for the Nashville Basin was

15.5° C (59.9°F), with an annual range of near freezing to 32.2°C (89.9°F) (Klippel and Bass 1984). Mean annual soil temperatures were 15.5°C (59.9°F) with an annual range of 15°C (59°F) to 10.5°C (50.9°F); however, during the winter season (late October through early May) the ground freezes from 6 to 10 cm deep, limiting the growing season to about 200 days (Klippel and Bass 1984). Current data also shows that fall is the driest season and drought conditions occur every 6 to 7 years (Klippel and Bass 1984).

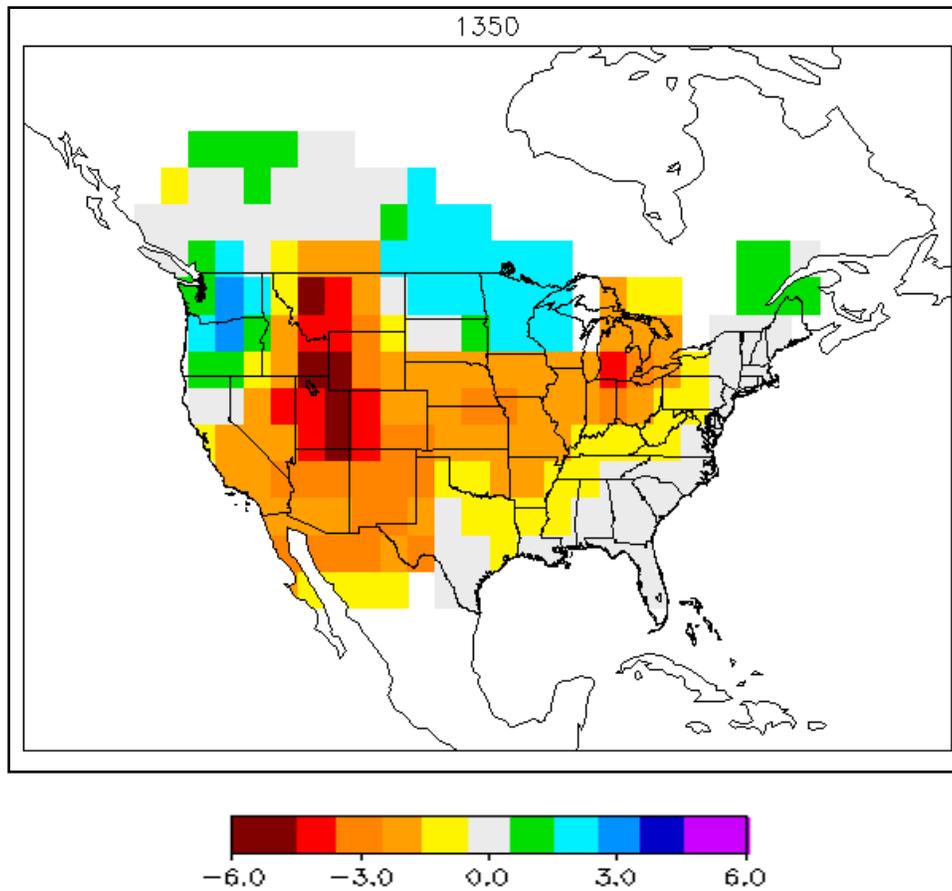
Paleoclimate data on drought conditions from AD 1300-1400 is available in 25 year intervals (Figures 1-5) (Cook et al. 2004). The drought indices color bar uses negative numbers to show less precipitation and drought conditions, while positive numbers indicate periods of increased precipitation (Cook et al. 2004).



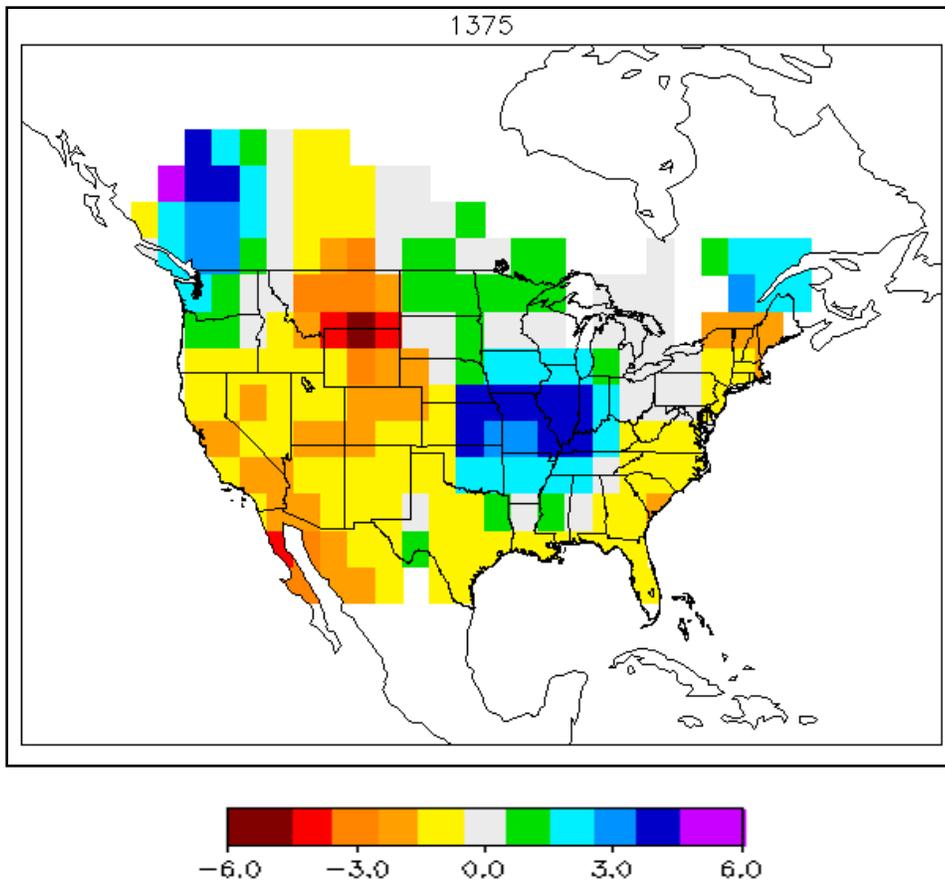
**Figure 1. Drought Index for AD 1300 (Cook et al. 2004, NOAA <http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl> 09/04/2010)**



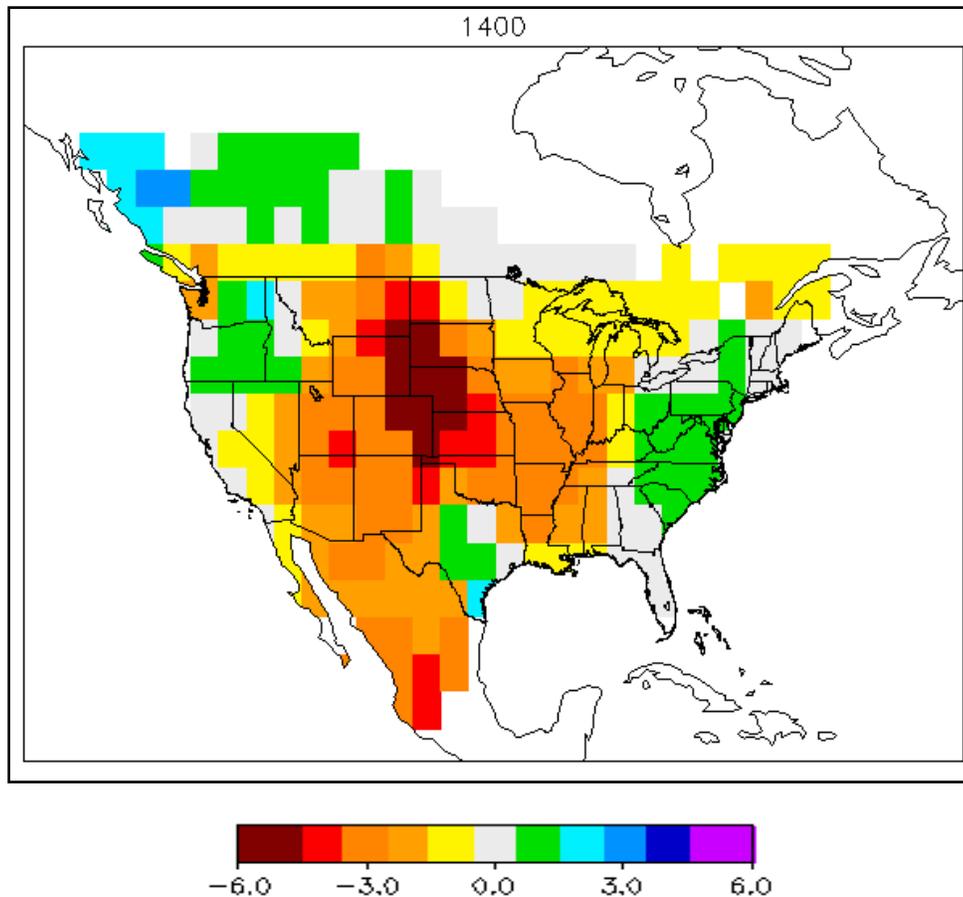
**Figure 2. Drought Index for AD 1325 (Cook et al. 2004, NOAA <http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl> 09/04/2010)**



**Figure 3. Drought Index for AD 1350 (Cook et al. 2004, NOAA <http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl> 09/04/2010)**



**Figure 4. Drought Index for AD 1375 (Cook et al. 2004, NOAA <http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl> 09/04/2010)**



**Figure 5. Drought Index for AD 1400 (Cook et al. 2004, NOAA <http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl> 09/04/2010)**

The figures show that during the first and last 25 years of the 14<sup>th</sup> Century there was an increase in precipitation (Cook et al. 2004). While the next 50 years show a major decrease in precipitation indicating the persistence of drought conditions (Cook et al. 2004). This may explain why the Averbuch population was under nutritional stress due to less than ideal environmental conditions for agricultural production.

## ARCHAEOLOGICAL BACKGROUND

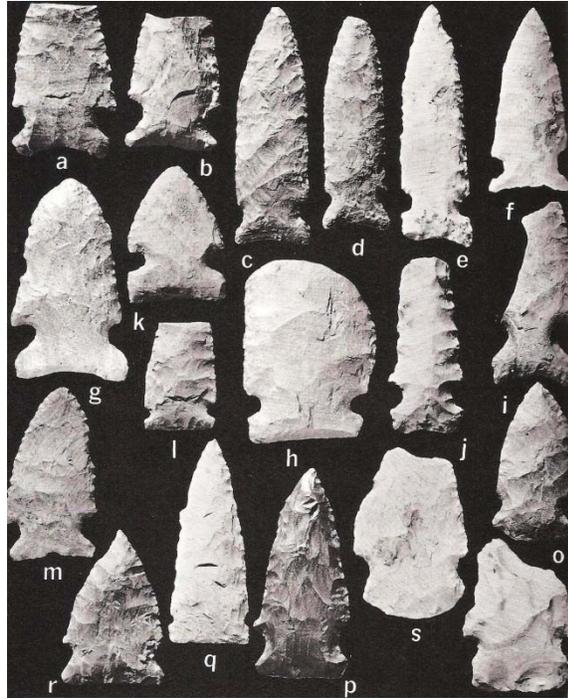
### East Tennessee Archaic (5000-500 BC) Period Archaeological Sites

#### *Eva (6BN12) and Big Sandy (25HY18)*

Eva was an Archaic site located in Benton County, Tennessee near an ancient river bank and close to a wide swale called Three Mile Slough (Figure 13) (Lewis 1896). Big Sandy was a later component of the site residing in stratum 1, while Eva was an earlier component located in strata 4 and 5 (Lewis 1896). The populations that resided in this area were sedentary hunters and gatherers; however, there is no paleobotanical data available at this site (Lewis 1896). The excavation of the site consisted of three foot wide trenches that were further broken down into thirty two ten foot squares. The faunal data recovered at the site represents half of the total recovered material, because unclassified fragments were not included (Lewis 1896). The data described next was summarized by Lewis (1896).

The analysis for Eva indicated that 94% of the remains were mammals with 92% of the mammal bones consisting of deer, while Big Sandy was significantly lower with 83% containing mammal remains and 88% consisting of deer. This may indicate a decline in the deer population possibly due to exploitation, a change in climatic conditions, or an increase in wolves and bears in the area. The majority of small mammal remains in both sites were raccoon bones, with 64% in Eva and 56% in Big Sandy. The utilization of fish and birds actually increased in frequency from Eva (fish = 0.83%, birds = 0.2%) to Big Sandy (fish = 6.1%, birds = 1.7%), although freshwater mussel shells disappear in the Big Sandy stratum, possibly as an adaptive response to environmental change (such as flooding and a change in river flow).

Throughout the site occupation, it appears that most of the tool use was directed towards deer hunting and processing (leather working tools and projectile points). The Eva component contains more artifacts associated with hunting than the Big Sandy component indicating a decline in hunting in the later phase. A total of 204 projectile points were found in the Eva component (42.3% of the assemblage), while 132 projectile points were found in Big Sandy (71.7% of the assemblage) (Figure 6). Biface blades, used as knives and other utensils for cutting, were found in abundance in the Eva component totaling 174 (36.1% of the assemblage), with only 12 in the Big Sandy component (6.5% of the assemblage). Numbers of choppers, which were used as butchering implements, are similar in both components (Eva 4.1%, Big Sandy 3.2%). Bone was also used to make fishhooks which were abundant in the Big Sandy component and rare in the Eva component, indicating that the population in the Big Sandy component was utilizing more marine resources.



**Figure 6. Big Sandy Projectile Points**

### **East Tennessee Mississippian Period Archaeological Sites**

#### ***Toqua (40MR6) and Mouse Creek (3MN3, 4MN3)***

Toqua is located on the south bank of the Little Tennessee River in Monroe County, Tennessee and dates back to the early Archaic period (Figure 13) (Polhemus 1987). The area is ideal for agricultural production due to well suited soils and also contains a wide range of floral, faunal, and other natural resources. The climate for the area is humid and temperate with moderate winters and hot summers, and 191 days of frost free season (Polhemus 1987). The occupants of this site during the Late Mississippian period (AD 1300-1600) participated in hunting, gathering, and agricultural production as seen in the faunal, botanical, and lithic remains (Polhemus 1987). The excavation techniques used to recover the faunal remains consisted of waterscreening features and structure floor fill, while the later excavations only

sorted remains with a trowel and shovel (Polhemus 1987). This may have led to possible sample biases. The following data was summarized by Polhemus (1987).

The faunal remains consisted of mammals (57%), birds (6%, mostly turkey), reptiles (13%, mainly turtles), amphibians (.5%), fish (11%), and shell (13%) (Polhemus 1987). Of the mammals, 37.5% of the remains consisted of white tailed deer, while the remainder was bison, bear, raccoon, opossum, rabbit, and squirrel. The lithic tools associated with hunting and fishing are projectile points (1,385), large lanceolate bifaces (2,198), ovate knives (137), projectile points on blades, hooks, spears, poison, and nets.

Paleobotanical remains found at Toqua contain both domesticated and wild remains. Domesticated remains consist of maize kernels, beans, squash, sunflower seeds, sump weed seeds, and tubers, while wild remains utilized are acorn, crab, apple, blackberry, wild rice, grass grains, and honey locust pods. The primary food substances found at this site are maize, beans, squash, peaches, and nuts, while secondary food supplements are sunflower, sumpweed, grape, and persimmon. Tools associated with agricultural production are chipped hoes, choppers, spatulate axes, pitted manos, and tapered bar abraders. Also, ethnohistoric data of the Mississippian and Cherokee occupations show that women pounded and processed maize into bread, processed the meats of nuts, and ground sunflower seeds for flour and oil.

The health profile of Toqua shows a few similarities to the Averbuch population. For example, Toqua also has its peak mortality rate at the 20-25 year mark for males and females, which could be due to the rigors/complications of childbirth for females and hunting/warfare activities for males. However, the overall population appears to be in good nutritional health.

The Mouse Creek sites are located where the North Mouse Creek and South Mouse Creek enter the Hiwassee River (Figure 13) (Lewis and Lewis 1995). Mouse Creek sites (AD 1400-1600) were contemporaneous with the Late Mississippian period sites, such as Toqua, and exhibited similarities in technology. Projectile points, blades, knives, and scraping tools were commonly used for hunting while abraders, mortars and pestles, and polishers were used for agricultural production (Lewis and Lewis 1995). The health profile of the Mouse Creek sites shows a prevalence of nutritional diseases like rickets and scurvy (Lewis and Lewis 1995).

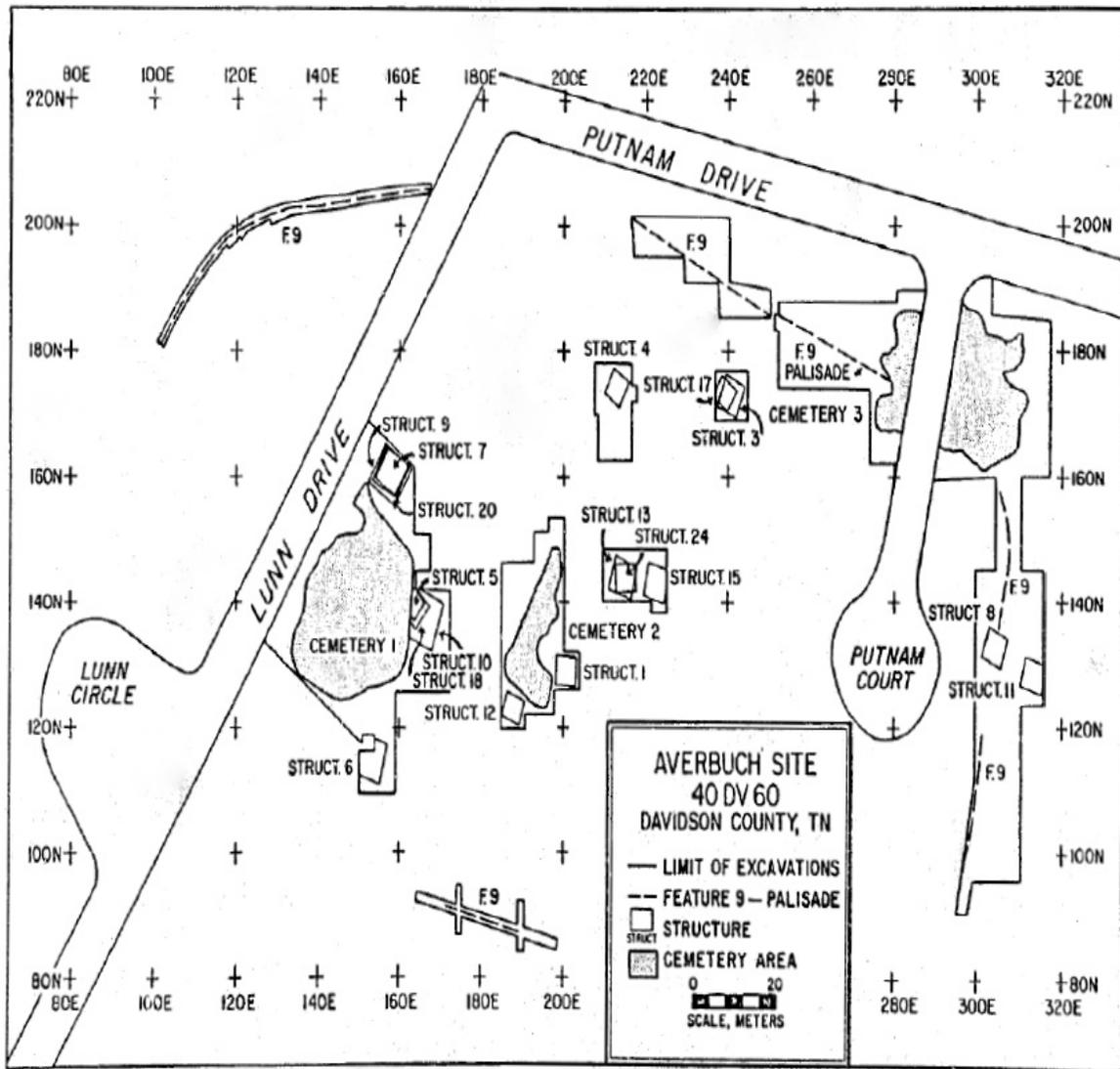
### **Central Tennessee Late Mississippian Archaeological site**

#### ***Averbuch (40DV60) site and population***

The Averbuch site is located in a transitional zone between the Nashville Basin and Highland Rim in Tennessee. It is situated on a south slope located 300 meters east of Drake Branch and 4 km from the rich alluvial bottoms of the Cumberland River Valley (Figure 13) (Klippel and Bass 1984). This less than ideal location is assumed to have been occupied because of population pressure in the Middle Cumberland River drainage (Klippel and Bass 1984).

Averbuch was a stockade village with three cemeteries surrounded by a palisade wall 330 meters by 200 meters. Occupants of the site were part of the Late Mississippian “stone box” phenomenon called the Middle Cumberland Culture that lasted from the 13<sup>th</sup>-15<sup>th</sup> Century AD. Berryman (1983) estimates site occupation from 15-25 years based on mortuary analysis and the lack of rebuilding in the village. Reasons for abandonment are assumed to

be epidemic diseases or possible Iroquois conquest (Berryman 1983). Figure 7 is a map of the Averbuch archaeological site which outlines features, structures, and the cemeteries.



**Figure 7. Averbuch Site Map from Klippel and Bass (1984)**

The site consists of three cemeteries with an estimated total of 1,296 remains. A total of 645 graves were excavated producing a sample of 887 individuals. The first cemetery

revealed 172 individuals while the second contained 72 individuals. The third cemetery had 190 individuals and was located partially under the palisade, leading Berryman (1983) to believe that the third cemetery predated the other two. Both sexes are represented fairly evenly in the sample, with 285 males and 251 females. The remaining 409 individuals could not be excavated because of site destruction by cultivation and/or lack of time. Figure 8 shows the excavation of the Averbuch cemeteries.



**Figure 8. Averbuch Cemetery Excavation from Klippel and Bass (1984)**

A common phenomenon of the Middle Cumberland Culture and seen at the Averbuch site is the reuse of graves. Reasons for reuse may be conjugal affinity, consanguinity, or convenience (Berryman 1983). Graves were usually lined with limestone and grave goods were frequently absent. However, when grave goods were present they consisted of a variety

of objects including; awls, potters anvils, blades, celts, ear plugs, hair pins, ceramic vessels, effigy vessels, and shell spoons (Berryman 1983).

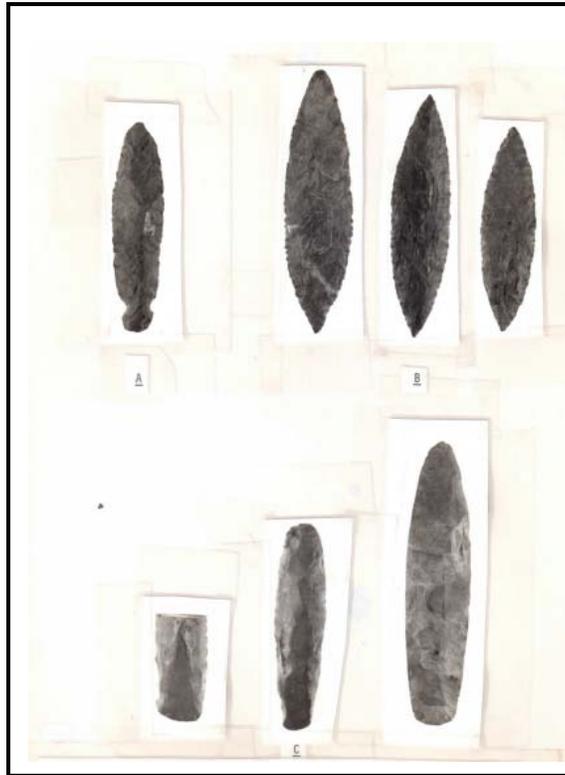
### *Faunal Assemblage*

The Averbuch population participated in a mixed subsistence economy that included hunting and gathering and agricultural production. Faunal remains from the site include over 60,000 pieces of bone and shell (Klippel and Bass 1984). Mammals represent 54.5% of the faunal assemblage and include three elk, 15.6% white-tailed deer, one black bear, one mountain lion, one beaver, one woodchuck, three raccoon, and 10% rabbit (Klippel and Bass 1984). The bones of the large mammals show evidence of butchering such as partial skeletal remains and small cut pieces of bone (Klippel and Bass 1984). Birds represented 12.9% of the assemblage with wild turkey being the most common. Fish comprised 16.3% of the vertebral population with the majority being catfish and drum (Klippel and Bass 1984). Reptiles account for 19.1% of bone with turtles (67.8%) and snakes (33.3%) making up the majority. Amphibians and freshwater and bivalve shells make up the rest of the assemblage (Klippel and Bass 1984).

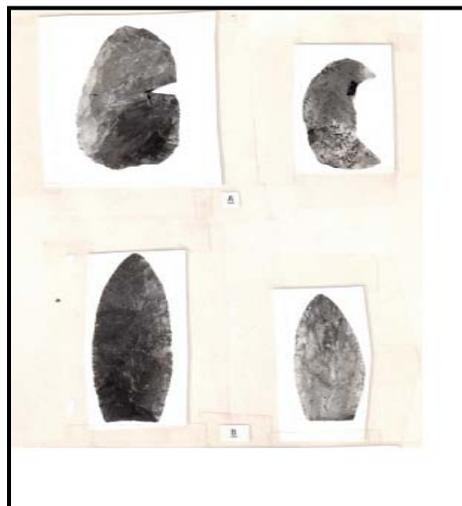
Modified bone and shell artifacts were also found, mainly in burials, including tools and ornaments such as bone pins and hooks, needles, awls, disc beads, pendants, gorgets, earplugs, and spoons. Shell was also used as temper for pottery (Klippel and Bass 1984).

Numerous tools were found associated with hunting. About 2,143 cores made from chert were found, with 19 of these showing signs of use as heavy chipping tools (Klippel and Bass 1984). Other tools, such as hammerstones (n=28) had generalized pounding/battering functions that may have been used to make other tools (Klippel and Bass 1984). Along with

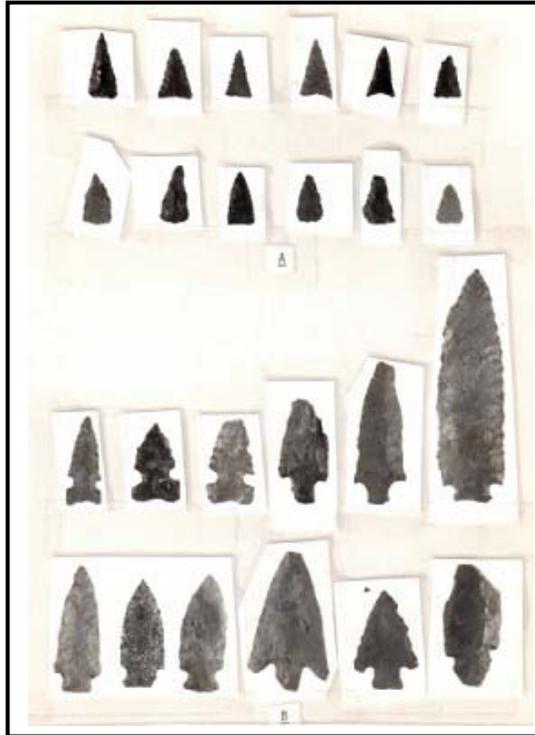
the faunal remains, other evidence for hunting is indicated by side unifacial modified flakes (n=203), and end modified flakes (n=112) that could be used for butchering, hide working, bone working, or woodworking (Klippel and Bass 1984). Also, side bifacial modified flakes (n=33), modified bifacial tabular pieces (n=11), and side and end modified bifacial flakes (n=8) indicate light to medium cutting and slicing tools that could also have been used in butchering or crop production (Figure 9) (Klippel and Bass 1984). Another tool used is the spokeshave (n=38) which is a stone tool used for scraping to smooth bone, antler, and wood. Thin biface/knives (n=27) are also used for hunting and butchering (Figure 10) (Klippel and Bass 1984). Both Mississippian (n=30) and non-Mississippian projectile points (n=104) are also found. The non-Mississippian projectile points were most likely collected during land cultivation and belong to earlier prehistoric periods (Figure 11) (Klippel and Bass 1984).



**Figure 9. Specialized Biface Form from Klippel and Bass (1984)**



**Figure 10. Thin Biface/Knives from Klippel and Bass (1984)**



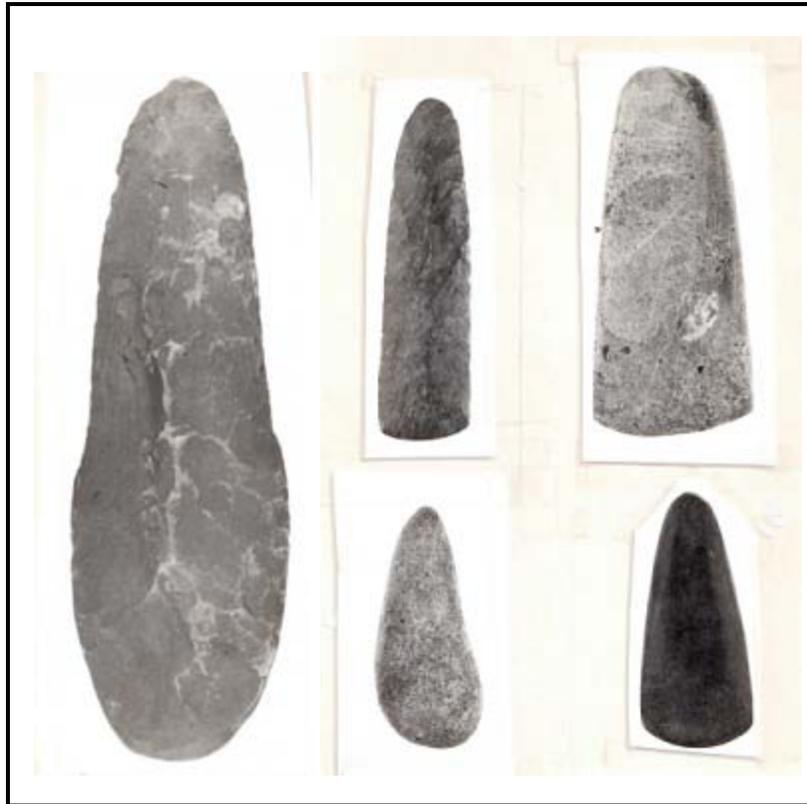
**Figure 11. Mississippian Projectile Points/Non-Mississippian Projectile Points from Klippel and Bass (1984)**

***Botanical Assemblage***

Carbonized plant remains were collected and waterscreened from the floors of 10 structures (Klippel and Bass 1984). There were 4,146.8 grams of charred plant remains representing 20 genera collected from this process. Flotation samples were also taken from six of the 10 structures, and three of these structures had been burned (Klippel and Bass 1984). Plant foods were scarce in many of the structures; however the burned structures contained the most plant remains. The plant remains found in the flotation samples consisted of maize, hickory nut, and persimmon and honey locust seeds. However, 99.41% of the plant remains consisted of maize (Klippel and Bass 1984).

Fill from 46 features were also subject to waterscreening and flotation (Klippel and Bass 1984). Waterscreening led to the identification of 13 genera of plants, while floated feature fill only recovered hickory nut and maize (Klippel and Bass 1984). Again, maize accounted for most of the flotation plant remains (99.88%) and the waterscreened plant remains (79.15%) (Klippel and Bass 1984). It appears that hickory nut was the second largest (15.7%) contributor to the plant remains overall (Klippel and Bass 1984).

Numerous tools were found associated with agricultural production. Denticulate tools (n=18) have a serrated edge, are made of chert, and are associated with shredding vegetable fiber or coarse cutting/sawing (Klippel and Bass 1984). Digging tools and hoes (n=9) made of limestone (Figure 12) were also used for agriculture and spatulate in form (Klippel and Bass 1984). Sandstone and limestone cobbles and metates were used for grinding plant foods (Klippel and Bass 1984). Another processing tool is a kind of pitted stone which is sometimes referred to as a “nuttingstones” because of its use in processing nuts (Klippel and Bass 1984).



**Figure 12. Hoe and Celt from Klippel and Bass (1984)**

### *Averbuch Subsistence*

Subsistence activities played an important role in the health of the Averbuch population. Agriculture was especially difficult due to the location of the site. The soil composition at this site is known as the Mimosa series which contains plastic clay that limits agricultural production (Klippel and Bass 1984). This, along with overuse of the land, resulted in depleted soil quality and led to food shortages. This increase in food shortages may have forced an increase in labor involved in food production, forcing younger and older individuals to help (Berryman 1983). Females had the highest mortality rate around the ages of 20-25, possibly due to venturing out for food procurement activities (open to attack from

neighboring groups) or because of childbirth (Berryman 1983). Berryman (1983) suggested that the decrease in mortality after this age category may be due to a change in subsistence activities. Archaeological evidence provides information on the types of foods that were hunted, gathered, and produced at the Averbuch site.

### ***Health***

Berryman (1983) performed a study to determine if the Averbuch population was under environmental stress. Harris lines (interruptions in longitudinal bone growth), linear enamel hypoplasia (deficiency in enamel thickness), and stature were used as stress markers to evaluate health (Mays 1999; Hillson 1996). According to Berryman (1983), harris lines and linear enamel hypoplasias indicated a widespread environmental stress, such as malnutrition, that occurred over sporadic acute periods in early childhood (Hillson 2008). Males showed greater signs of stress than females. Interestingly, stature (estimated from the femur and tibia) was recorded as being the highest for an American Indian skeletal collection series, which could be attributed to catch up growth (Cameron 2006). Vital statistics showed that for both sexes, mortality reached its highest peak at age 20-25 and then proceeded to decline thereafter.

Overall, the Averbuch population appeared to have been under environmental stress due to being forced into an undesirable location because of population expansion (Berryman 1983). Males were found to have been under greater stress than females. Based on these findings, the present study expects to find evidence of decreased sexual dimorphism because of poor nutrition and similar subsistence activities between both sexes. In addition, bilateral asymmetry is expected to be minimal based on agricultural activities practiced by this group.

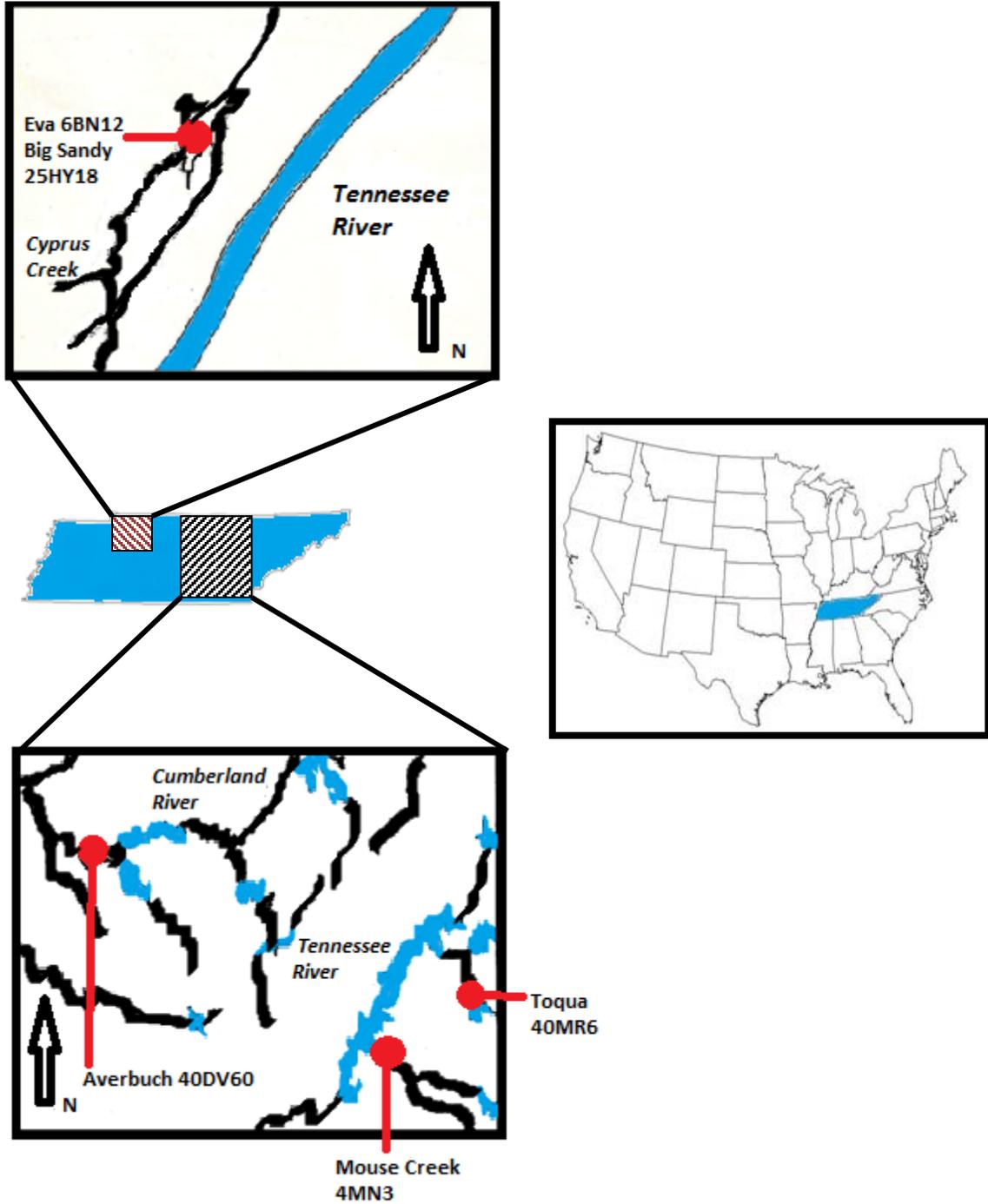


Figure 13. Map of the Archaic and Late Mississippian Sites

## MATERIALS AND METHODS

### Samples

The Averbuch skeletal collection is housed at the McClung Museum at The University of Tennessee, Knoxville. This Late MISSISSIPPIAN (14<sup>th</sup> Century AD) collection is well preserved with over 400 individuals available for study.

Age and sex determination of the Averbuch population was performed by Berryman (1983) on individual remains. Berryman (1983) classified age from birth in six month intervals until the age of one. After the age of one, ages were reported in one year increments. Berryman (1983) used two techniques for age estimation in subadults: dental eruption and epiphyseal fusion. He used the Moorees et al. (1963) method for tooth eruption, and pooled male and female standards due to the unknown sex of subadults. To support his age estimations, Berryman (1983) used Krogman (1962) and McKern and Stewart (1957) for epiphyseal closure. Sex estimation was only performed on adults due to the lack of reliable techniques for subadults (Berryman 1983). Nonmetric and metric standards were utilized. Nonmetric pelvic standards included evaluating the ventral arc, subpubic concavity, medial aspect of ishiopubic ramus, pubic length, subpubic angle, sciatic notch, sacroiliac articulation, pits of parturition, and sacrum curvature. The cranial traits evaluated included the bluntness of subraorbital margin, size of supraorbital ridge, palate, occipital muscle markings, supramastoid ridge, and mastoid process. Metric standards included measures of the humeral (Dwight 1905) and femoral head (Pearson and Bell 1919).

Only adult individuals over the age of 18 were used in this study, even though growth does continue, 18+ is standard for inclusion in most population studies. In a study of

Pecos Pueblo juveniles, sexual dimorphism was already seen in adolescents (15-19), indicating that adult patterns of behavior is expressed in individuals at least by age 18 (Ruff 2008). The sample used numbered 137 individuals consisting of 62 females and 75 males drawn from all three cemeteries (cemetery 1: n=100, cemetery 2: n=18, cemetery 3: n=19).

Samples previously collected by Ross et al. (2003) were used for comparison. These samples consist of 32 females and 17 males from the East Tennessee Archaic (5000-500 BC) period sites of Eva (6BN12), Kays Landing (15HY13), and Big Sandy (25HY18), and an East Tennessee Late Mississippian (900-1450 AD) sample of 24 females and 12 males from Mouse Creek (3MN3, 4MN3), and Toqua (40MR6).

### **Measurements**

Standard measurements were taken of the humerus, ulna, and radius, as described in Moore-Jansen et al. (1994). Table 1 presents the standard measurements used in this study and figures 13-15 depict these measurements. Measurements were taken on both the left and right sides using an osteometric board and digital sliding calipers.

**Table 1. Standard Measurements Used for the Humerus, Ulna, and Radius from Moore-Jansen et al. (1994)**

<b>Humerus</b>	
<b>Maximum length of the humerus</b>	most superior point of the head to the most inferior point of the trochlea. Figure 14 (40)
<b>Epicondylar breadth</b>	the distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle. Figure 14 (41)
<b>Head diameter</b>	the direct distance between the most superior and inferior points on the border of the articular surface. Figure 14 (42)
<b>Maximum diameter of the humerus at midshaft</b>	taken a few millimeters below the inferior margin of the deltoid tuberosity and turned until the maximum diameter is reached
<b>Minimum diameter of the humerus at midshaft</b>	taken at midshaft and turned until minimum diameter is reached
<b>Radius</b>	
<b>Maximum length of the radius</b>	taken from the most superior point of the head to the tip of the styloid process. Figure 15 (45)
<b>Sagittal diameter of the radius at midshaft</b>	anterio-posterior diameter. Figure 15 (47)
<b>Transverse diameter of the radius at midshaft</b>	taken from the maximum medial surface to the maximum lateral surface. Figure 15 (46)
<b>Ulna</b>	
<b>Maximum length of the ulna</b>	taken from the most superior part of the olecranon to the most inferior point on the styloid process. Figure 16 (48)
<b>Dorso-volar diameter of the ulna</b>	taken where the greatest development is observed on the shaft in an anterior to posterior orientation. Figure 16 (50)
<b>Transverse diameter of the ulna</b>	taken perpendicular to the dorso-volar diameter from the medial to lateral orientation. Figure 16 (49)

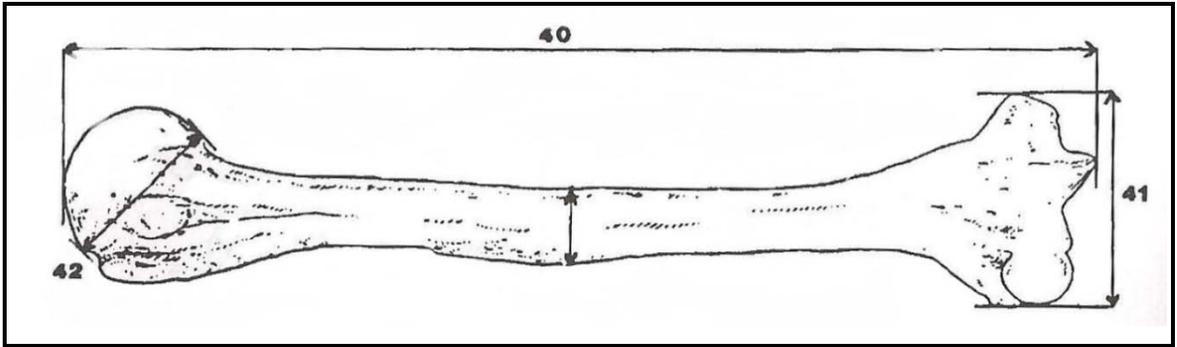


Figure 14. Humerus (Moore-Jansen et al (1994))

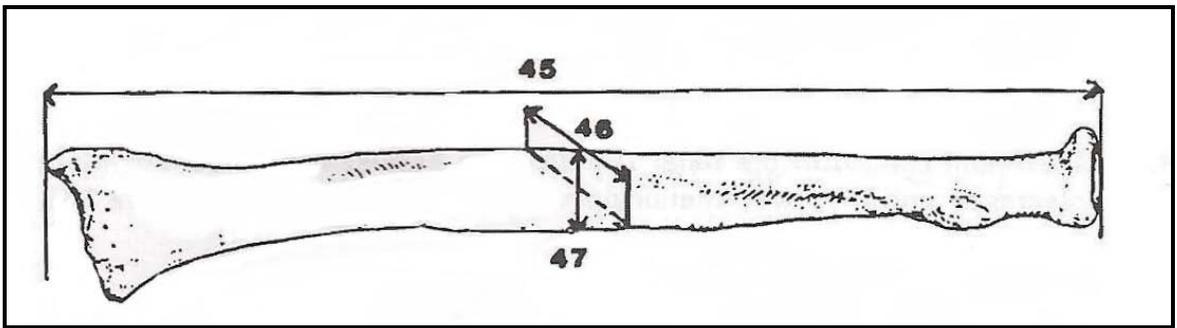


Figure 15. Radius (Moore-Jansen et al (1994))

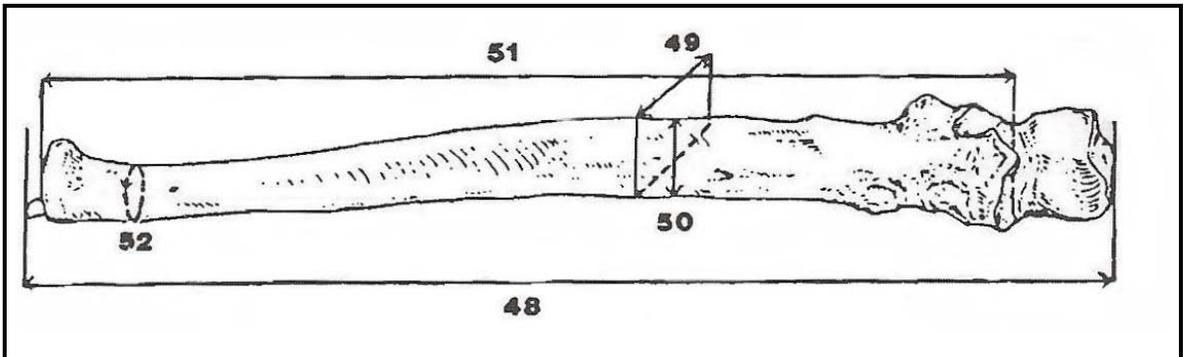


Figure 16. Ulna (Moore-Jansen et al (1994))

## Statistics

### *Sexual Dimorphism Statistics*

Size, defined as the geometric mean, and shape variables, the proportions of the geometric mean or size, were computed according to Mosimann and co-workers (Mosimann and James 1979; Darroch and Misimann 1985) on the left measurements of the ulna and radius for each population. Size is calculated as follows:

$$\text{SIZE} = (\prod_{i=1}^n X_i)^{1/n}$$

In other words, SIZE= the product of all variables divided by the number of variables.

An index of sexual dimorphism (ISD) was calculated on the size and shape variables for the ulna and radius to test the hypothesis that sexual dimorphism has decreased with a shift to agriculture. ISD calculates the percentage of how much larger males are than females. T-tests were calculated on the ISD values to determine if there is a significant difference between the values. ISD is calculated as follows:

$$\text{ISD} = ([\text{male mean}/\text{female mean}] - 1) \times 100$$

A one-way analysis of variance (ANOVA) was performed using the statistical software SAS 9.1 to test the null hypothesis that the overall mean size of the ulna and radius is not significantly different among the groups. An ANOVA was also performed on each shape variable to test the null hypothesis that each overall mean shape variable is not significantly different among the groups.

In addition, canonical variates analysis (CVA) was computed to examine between-group differences relative to within-group variation (Ross et al. 2003). This function extracts canonical variates, which are linear combinations of predictor variables that summarize

between population variations (Ross et al. 2003). A Mahalanobis  $D^2$  is used to maximize the differences between groups, which then maximizes the between-group variance to the pooled within-group variance (Pietrusewsky 2008). This process transforms the original set of variables into a new set, which then removes the correlation with the remaining variables (Pietrusewsky 2008). Ultimately, this represents the summed squared differences between the transformed mean values of the groups being compared (Pietrusewsky 2008). A Mahalanobis  $D^2$  matrix was used to measure the degree of differentiation among the group means and their pooled variances and covariances to test whether the populations are significantly different (Ross et al. 2003). The samples with the greater  $D^2$  are going to be significantly different (Collier 1993). Using the computed canonical variates, it was then possible to determine the significant canonical axes and the total canonical structure allowing one to discern the significant shape variables. Class means from the canonical variates analysis were used to graphically represent population and sex differences.

A Pearson's product-moment correlation coefficient was computed for each sex on both the size and shape variables to understand the relationship between their canonical variates. This was further analyzed by computing a Pearson's correlation coefficient for each cemetery in order to see if there were differences between males and females in their size and shape variables.

### ***Bilateral Asymmetry Statistics***

Because of its larger sample size, the humerus was selected to evaluate bilateral asymmetry. The Averbuch collection was the only population used for this computation because measurements were taken for both the left and right sides. A two-tailed t-test was

used in Microsoft Excel 2007 to compare left and right means of the humerus length, epicondylar breadth, head diameter, maximum diameter at midshaft, and minimum diameter at midshaft. The two-tailed t-test was used because not all of the values are paired (the sample size was too small for the comparison of left and right sides of each individual) and no assumptions were made.

## RESULTS

### Overall Population Means

Summary statistics are presented in Table 2.

**Table 2. Descriptive Summary Statistics.**

*Archaic Females (5000-500 BC)*

<b>Variable</b>	<b>N</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Min</b>	<b>Max</b>
<b><i>Radius</i></b>					
<b>Max. Length</b>	23	224.478	16.197	196	261
<b>Saggital diameter</b>	33	9.455	0.971	8	12
<b>Transverse diameter</b>	33	12.333	1.633	9	17
<b><i>Ulna</i></b>					
<b>Max. Length</b>	22	247.227	17.904	225	280
<b>Dorso-volar diameter</b>	36	11.306	0.951	9	13
<b>Transverse diameter</b>	36	13.222	1.658	11	18
<b>Size variable</b>	32	11.494	0.984	9.716	13.819
<b><i>Radius shape</i></b>					
<b>Saggital shape</b>	32	0.825	0.068	0.707	1.024
<b>Transverse shape</b>	32	1.073	0.096	0.865	1.285
<b><i>Ulna Shape</i></b>					
<b>Dorso-volar shape</b>	32	0.986	0.056	0.868	1.107
<b>Transverse shape</b>	32	1.158	0.076	1.024	1.416

**Table 2 Continued**

*Archaic Males (5000-500 BC)*

<b>Variable</b>	<b>N</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Min</b>	<b>Max</b>
<b><i>Radius</i></b>					
<b>Max. Length</b>	14	248.071	10.111	231	264
<b>Saggital diameter</b>	18	11.167	1.295	9	15
<b>Transverse diameter</b>	18	13.333	1.610	11	17
<b><i>Ulna</i></b>					
<b>Max. Length</b>	12	257.75	15.737	230	279
<b>Dorso-volar diameter</b>	20	13	1.373	11	15
<b>Transverse diameter</b>	20	12.35	1.310	11	17
<b>Size variable</b>	17	12.830	0.833	11.623	14.322
<b><i>Radius shape</i></b>					
<b>Saggital shape</b>	17	0.873	0.110	0.768	1.184
<b>Transverse shape</b>	17	1.039	0.091	0.937	1.230
<b><i>Ulna Shape</i></b>					
<b>Dorso-volar shape</b>	17	1.012	0.067	0.868	1.099
<b>Transverse shape</b>	17	1.110	0.078	.939	1.250

Table 2 Continued

*East Tennessee Late Mississippian Females (AD 900-1450)*

Variable	N	Mean	Std Dev	Min	Max
<i>Radius</i>					
<b>Max. Length</b>	15	225.267	10.512	205	240
<b>Saggital diameter</b>	25	10.24	0.926	9	12
<b>Transverse diameter</b>	25	13.52	1.584	11	16
<i>Ulna</i>					
<b>Max. Length</b>	9	246.444	8.064	236	256
<b>Dorso-volar diameter</b>	24	11.125	1.076	9	13
<b>Transverse diameter</b>	24	14.833	1.857	11	19
<b>Size variable</b>	24	12.289	0.787	11.039	14.352
<i>Radius Shape</i>					
<b>Saggital shape</b>	24	0.837	0.070	0.710	1.005
<b>Transverse shape</b>	24	1.11	0.066	0.731	1.025
<i>Ulna Shape</i>					
<b>Dorso-volar shape</b>	24	0.905	0.066	0.731	1.025
<b>Transverse shape</b>	24	1.206	0.119	0.921	1.477

**Table 2 Continued**

*East Tennessee Late Mississippian Males (AD 900-1450)*

<b>Variable</b>	<b>N</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Min</b>	<b>Max</b>
<i>Radius</i>					
<b>Max. Length</b>	12	244.5	14.113	223	263
<b>Saggital diameter</b>	12	11.583	1.084	9	13
<b>Transverse diameter</b>	12	14.583	1.311	13	17
<i>Ulna</i>					
<b>Max. Length</b>	15	267	10.325	249	280
<b>Dorso-volar diameter</b>	15	14.2	1.373	11	16
<b>Transverse diameter</b>	12	16	1.558	13	18
<b>Size variable</b>	12	13.987	1.021	11.373	15.394
<i>Radius Shape</i>					
<b>Saggital shape</b>	12	0.828	0.037	0.772	0.885
<b>Transverse shape</b>	12	1.044	0.080	0.951	1.192
<i>Ulna Shape</i>					
<b>Dorso-volar shape</b>	12	1.025	0.070	0.912	1.170
<b>Tranvshape ul.</b>	12	1.137	0.061	1.024	1.210

**Table 2 Continued**

*Averbuch Mississippian Females (14<sup>th</sup> Century)*

<b>Variable</b>	<b>N</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Min</b>	<b>Max</b>
<i>Radius</i>					
<b>Max. Length</b>	28	228.643	11.480	205	254
<b>Saggital diameter</b>	51	11.761	0.995	9.7	14.9
<b>Transverse diameter</b>	51	14.475	1.695	10	19
<i>Ulna</i>					
<b>Max. Length</b>	22	247.455	13.585	219	277
<b>Dorso-volar diameter</b>	50	12.116	1.163	10.4	17.1
<b>Transverse diameter</b>	50	15.826	1.591	11.9	19.6
<b>Size variable</b>	46	13.707	0.962	11.133	15.135
<i>Radius Shape</i>					
<b>Saggital shape</b>	46	.875	0.962	11.133	15.135
<b>Transverse shape</b>	46	1.084	0.066	0.095	1.265
<i>Ulna Shape</i>					
<b>Dorso-volar shape</b>	46	0.904	0.074	0.774	1.174
<b>Transverse shape</b>	46	1.177	0.081	1.045	1.376

Table 2 Continued

*Averbuch Mississippian Males (14<sup>th</sup> Century)*

Variable	N	Mean	Std Dev	Min	Max
<i>Radius</i>					
Max. Length	42	249.905	9.840	227	271
Saggital diameter	66	12.820	0.977	10.5	14.7
Transverse diameter	67	14.772	1.558	11.7	18.4
<i>Ulna</i>					
Max. Length	31	237.813	87.463	15	294
Dorso-volar diameter	71	14.386	1.353	11.1	17.9
Transverse diameter	69	17.179	3.63	12.3	43
Size variable	63	14.649	4.318	12.457	21.002
<i>Radius Shape</i>					
Saggital shape	63	0.876	0.051	0.676	0.973
Tranvshape shape	63	1.011	0.061	0.848	1.183
<i>Ulna Shape</i>					
Dorso-volar shape	63	0.978	0.069	0.838	1.232
Transverse shape	63	1.168	0.137	0.908	2.047

## Sexual Dimorphism

### *Index of Sexual Dimorphism*

The Index of Sexual Dimorphism (ISD) was calculated on the newly derived size variables within each population to test the hypothesis that sexual dimorphism decreased with a shift to agriculture. The results are presented in Table 3.

**Table 3. Index of Sexual Dimorphism (Significance designated by \*)**

Group	Radius Saggital Shape	Radius Transverse Shape	Ulna Dorso-volar Shape	Ulna Transverse Shape	Size
Archaic	5.82%	<b>2.64%*</b>	<b>2.64%*</b>	4.14%	11.60%
Averbuch	<b>0.11%*</b>	6.73%	8.18%	<b>0.76%*</b>	<b>9.26%*</b>
East TN Miss.	1.08%	5.95%	13.26%	5.72%	14.20%

Based on the ISD values for size, the Averbuch sample is the least sexually dimorphic (9.2%), followed by the Archaic sample (11.6%), and the East Tennessee Late Mississippian sample (14.2%). The Averbuch population is also the least sexually dimorphic in radius saggital shape (0.11%) and ulna transverse shape (0.76%), while the Archaic sample is the least sexually dimorphic for radius transverse shape (2.64%) and ulna dorso-volar shape (2.64%).

**Table 4. T-test Results for the Index of Sexual Dimorphism (significance is designated by \*  $p < 0.05$ )**

Group comparisons	T-test p-values
Archaic and Averbuch	0.485
Averbuch and East TN	<b>0.035*</b>
Archaic and East TN	0.151

The t-test results for the ISD values indicate a significant difference between the Averbuch and East Tennessee Mississippian samples and no significant difference between the Averbuch and Archaic samples.

***Analysis of Variance (ANOVA) and T-test Results***

The ANOVA for size indicated a significant difference among the groups ( $r = .360$ ,  $p\text{-value} = <.0001$ ). T-tests on the size variable for each cemetery comparison are significant at the .05 level. An ANOVA was also performed on each shape variable. Significant differences among the groups were found for saggital radial shape ( $r = .433$ ,  $p\text{-value} = <.0001$ ), transverse radial shape ( $r = .204$ ,  $p\text{-value} = <.0001$ ), transverse ulna shape ( $r = .201$ ,  $p\text{-value} = <.0001$ ), and dorso-volar ulna shape ( $r = .152$ ,  $p\text{-value} = <.0001$ ). T-tests for all shape variables for each cemetery are significant at the .05 level.

***Squared Mahalanobis Distances or Mahalanobis  $D^2$***

A Mahalanobis  $D^2$  was used to measure the degree of differentiation among the group means and their pooled variances and covariances to test whether populations are significantly different. The results are presented in Table 5.

**Table 5. Mahalanobis  $D^2$  (Significant differences designated by \*  $p < 0.05$ )**

<b>From Group</b>	<b>Archaic F</b>	<b>Archaic M</b>	<b>East Miss F</b>	<b>East Miss M</b>	<b>Aver Miss F</b>	<b>Aver Miss M</b>
<b>Archaic F</b>	0 (1)					
<b>Archaic M</b>	<b>1.20945*</b> (0.0122)	0 (1)				
<b>East Miss F</b>	<b>1.81261*</b> (0.0001)	<b>3.18601*</b> (0.0307)	0 (1)			
<b>East Miss M</b>	<b>1.14829*</b> ( $<.0001$ )	<b>0.82861*</b> ( $<.0001$ )	<b>1.5887*</b> ( $<.0001$ )	0 (1)		
<b>Aver Miss F</b>	<b>1.28643*</b> (0.0032)	<b>3.36946*</b> ( $<.0001$ )	<b>0.57887*</b> ( $<.0001$ )	<b>2.34882*</b> (0.0802)	0 (1)	
<b>Aver Miss M</b>	0.37842 (0.5188)	0.75948 (0.2664)	<b>3.35888</b> (0.0193)	<b>1.21704*</b> ( $<.0001$ )	<b>2.98475*</b> (0.0002)	0 (1)

Archaic females are significantly different from Archaic males, East Tennessee Late Mississippian males and females, and Averbuch females. However, Archaic females are not significantly different from Averbuch males. Archaic males are significantly different from East Tennessee Late Mississippian males and females and the Averbuch females. However, Archaic males are not significantly different from the Averbuch males. East Tennessee Late

Mississippian females are significantly different from East Tennessee Late Mississippian males, Archaic males and females, and Averbuch males and females. East Tennessee Late Mississippian males are significantly different from Archaic males and females and Averbuch males, but not significantly different from Averbuch females. Averbuch males and females are significantly different from each other, while Averbuch males are not significantly different from Archaic males and females.

***Canonical Variates***

Two significant canonical axes were extracted and are presented in Table 6 and the total canonical structures are presented in Table 7.

**Table 6. Significant Canonical Axes.**

Canonical	Eigenvalue	Proportion	Likelihood Ratio	Approx. F	Num. DF	Pr. > F
1	0.4245	0.6466	0.56552376	5.7	20	<.0001*
2	0.1844	0.2809	0.80557204	3.46	12	<.0001*

CAN 1 is significant ( $p\text{-value} = <.0001$ ) and accounts for 65% of among group variation while CAN 2 is also significant ( $p\text{-value} = <.0001$ ) and accounts for 28% of the among group variation. A total variation of 93% is accounted for on CAN 1 and 2.

**Table 7. Total Canonical Structure (significance designated by \*)**

<b>Variable</b>	<b>CAN1</b>	<b>CAN2</b>
<b>Saggital rad.</b>	-0.020197	<b>-0.83636*</b>
<b>Transverse rad.</b>	<b>-0.609871*</b>	<b>0.62199*</b>
<b>Dorso-volar ul.</b>	<b>0.958902*</b>	0.232007
<b>Transverse ul.</b>	-0.308574	-0.053595

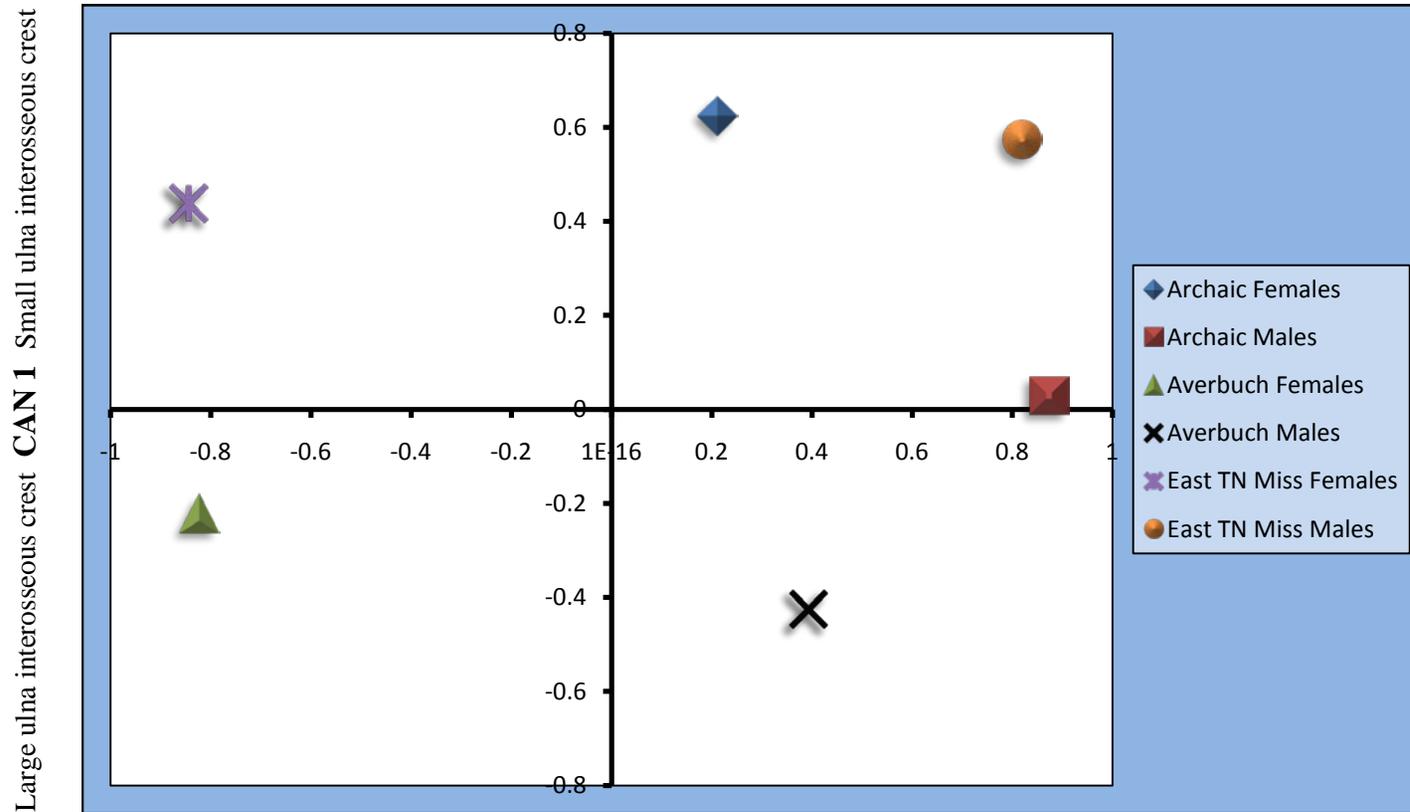
The first canonical axis is responsible for between group differences with regard to the transverse radial shape and dorso-volar ulna shape whereas the second canonical axis separates the groups on saggital and transverse radial shape.

***Class Means on Canonical Variates and Shape-Related Sexual Dimorphism***

The class means of the canonical variates (Table 8) are graphically represented in Figure 17 to show population and sex differences on the canonical axes with regard to shape-related sexual dimorphism.

**Table 8. Class Means on Canonical Variates**

<b>Group</b>	<b>CAN1</b>	<b>CAN2</b>
<b>Archaic Females</b>	0.21211	0.62404
<b>Archaic Males</b>	0.87378	0.02933
<b>Averbuch Females</b>	-0.8208	-0.22197
<b>Averbuch Males</b>	0.39426	-0.42508
<b>East Tennessee Late Mississippian Females</b>	-0.844	0.43831
<b>East Tennessee Late Mississippian Males</b>	0.8204	0.57336



Large radius transverse diameter at midshaft    **CAN 2**    Large radius saggital diameter at midshaft  
 Small radius saggital diameter at midshaft

**Figure 17. Plot of Class Means Showing Group Differences**

The Archaic males and females are very similar in shape with small interosseous crest development, although the males are slightly more developed than the females. The Archaic sample contains the least amount of shape-related sexual dimorphism. The Archaic males are more similar to the Averbuch males in areas of robusticity.

The East Tennessee Late Mississippian males and females show the most shape-related sexual dimorphism. Males have smaller interosseous crest development, while females show larger interosseous crest development. The East Tennessee Late Mississippian females are more similar in shape to the Averbuch females.

The Averbuch males and females show more robust interosseous crest development than the other samples. Differences between the Averbuch males and females are related to the radial interosseous crest development whereas females show larger development of the radial transverse diameter and males have a larger radial saggital diameter which is more likely related to activity.

Analyzing just the female data, it appears that the Averbuch females are more robust but similar to the East Tennessee Late Mississippian females, with the Archaic females being significantly smaller. The relationship between the male data is somewhat different. Averbuch males are more robust in interosseous crest development, while East Tennessee Late Mississippian males and Archaic males are significantly smaller.

### ***Pearson's Product-Moment Correlation Coefficient***

A Pearson's product-moment correlation coefficient was computed on the size and shape variables to understand the variation between their canonical variates. Table 9

represents the pooled results of each sex, while Table 10 (10.1-10.3) shows the differences within each group.

**Table 9. Pearson Product-Moment Correlation Coefficients (Significance designated with \*  $p < 0.05$ )**

<b>Females</b>	<b>Sagshape rad.</b>	<b>Tranvshape rad.</b>	<b>Dorso-volar shape</b>	<b>Tranvshape ul.</b>	<b>Size</b>
<b>CAN1</b>	-0.15403	-0.57528	0.96787	-0.29046	-0.41782
	(0.126)	(<.0001)*	(<.0001)*	(0.0034)*	(<.0001)*
<b>CAN2</b>	-0.8277	0.63577	0.28837	-0.1512	-0.10952
	(<.0001)*	(<.0001)*	(0.0036)*	(0.1332)	(0.278)
<b>Males</b>					
<b>CAN1</b>	-0.03054	-0.47008	0.93635	-0.29994	-0.27315
	(0.7726)	(<.0001)*	(<.0001)*	(.0037)*	(0.0084)*
<b>CAN2</b>	-0.84142	0.56715	0.38851	-0.01332	0.03589
	(<.0001)*	(<.0001)*	(<.0001)*	(0.8997)	(0.7341)

Both males and females show the same pattern of variation. The variation observed for males and females is due to both *size* and *shape*. The first canonical axis is significant for *size* and *shape* and the *shape* variables that correlate to these differences are the transverse diameter of the radius, dorso-volar diameter of the ulna, and transverse diameter of the ulna. The second canonical axis is correlated to differences in *shape* and not *size*. These *shape* variables are the saggital radial diameter, transverse diameter of the radius, and dorso-volar diameter of the ulna.

**Table 10. Cemetery Pearson Product-Moment Correlation Coefficients (significant values designated by \*  $p < 0.05$ )**

**Table 10.1** *Archaic Population (5000-500 BC)*

<b>Females</b>	<b>Sagshape rad.</b>	<b>Tranvshape rad.</b>	<b>Dorso-volar shape</b>	<b>Tranvshape ul.</b>	<b>Size</b>
<b>CAN1</b>	0.32843	-0.36105	0.71509	-0.54317	-0.48105
	(0.0665)	<b>(0.0423)*</b>	<b>(&lt;.0001)*</b>	<b>(0.0013)*</b>	<b>(0.0053)*</b>
<b>Males</b>					
<b>CAN1</b>	0.67336	-0.30493	-0.15229	-0.53464	-0.00008
	<b>(0.0030)*</b>	(0.2340)	(0.5596)	<b>(0.0270)*</b>	(0.9997)

The Archaic population shows differences in variation between males and females. Females have significant variation on the first canonical axis in the transverse diameter of the

radius, dorso-volar diameter of the ulna, transverse diameter of the ulna, and *size*. This is the same as the overall pooled female variation. On the other hand, males exhibit variation on the first canonical axis in the saggital radial diameter and transverse diameter of the ulna. *Size* is not responsible for significant variation among the males.

**Table 10.2** *East Tennessee Late Mississippian Population (AD 900-1450)*

<b>Females</b>	<b>Sagshape rad.</b>	<b>Tranvshape rad.</b>	<b>Dorso-volar shape</b>	<b>Tranvshape ul.</b>	<b>Size</b>
<b>CAN1</b>	-0.23325	-0.27374	-0.93678	-0.26745	0.06811
	(0.2962)	(0.2177)	(<.0001)*	(0.2289)	(0.7633)
<b>Males</b>					
<b>CAN1</b>	0.57963	-0.68391	0.98308	-0.73564	-0.13035
	(0.0482)*	(0.0142)*	(<.0001)*	(0.0064)*	(0.6864)

Female variation on the first canonical axis is only seen in the dorso-volar diameter of the ulna. However, male variation on the same canonical axis is significant for all four shape variables.

**Table 10.3**

*Averbuch Population (14<sup>th</sup> Century)*

<b>Females</b>	<b>Sagshape rad.</b>	<b>Tranvshape rad.</b>	<b>Dorso-volar shape</b>	<b>Tranvshape ul.</b>	<b>Size</b>
<b>CAN1</b>	0.03155	0.90477	-0.82732	0.13724	0.33895
	(0.8351)	(<.0001)*	(<.0001)*	(0.3631)	(0.0212)*
<b>Males</b>					
<b>CAN1</b>	-0.06092	0.83162	-0.74027	0.02511	0.23169
	(0.6353)	(<.0001)*	(<.0001)*	(0.8451)	(0.0677)

Female variation on the first canonical axis is seen in the transverse diameter of the radius, dorso-volar diameter of the ulna, and size. Male variation is the same except for *size*.

**Bilateral Asymmetry**

The Averbuch collection was the only population used for this computation because measurements were taken for both the left and right sides. Bilateral asymmetry was limited to measurements of the humeri (due to a small sample size of the ulna and radius) of the Averbuch (14<sup>th</sup> Century) population using a two-tailed t-test to test for significant differences between left and right sides. Table 11 presents the *p-values* for males and females.

**Table 11. T-Test Results for Bilateral Asymmetry Humerus (significant values designated by \*  $p < 0.05$ )**

*Averbuch Males*

Variable	N		P-Value
Humerus length	R-57	L-54	0.376
Epicondylar breadth	R-61	L-47	0.185
Head diameter	R-51	L-52	0.614
Maximum diameter at midshaft	R-75	L-71	<b>0.013*</b>
Minimum diameter at midshaft	R-74	L-72	<b>0.00*</b>

*Averbuch Females*

Variable	N		P-Value
Humerus length	R-41	L-42	0.719
Epicondylar breadth	R-42	L-44	0.185
Head diameter	R-45	L-41	0.967
Maximum diameter at midshaft	R-57	L-57	0.724
Minimum diameter at midshaft	R-58	L-58	0.429

Averbuch males show a significant difference between the left and right sides of the humerus with regard to the maximum and minimum diameters at midshaft. These are differences in *shape* rather than size suggesting that these differences are most likely activity related. The Averbuch females show no significant difference in bilateral asymmetry. This suggests that the females were participating in activities that required the habitual use of both limbs.

## DISCUSSION

The focus of this research was to understand changes in bone size and shape with differing subsistence activities, and how this affects the sexual dimorphism and bilateral asymmetry of a population. The results support the aforementioned hypotheses. The Averbuch sample shows the least amount of sexual dimorphism in both size and shape, followed by the Archaic sample, and lastly the East Tennessee Mississippian samples. Also, bilateral asymmetry is not significant in the females of the Averbuch sample; however, there are significant differences in males, which will be discussed later.

### **Sexual Dimorphism**

There are multiple factors that explain the variation in sexual dimorphism found among the samples, such as differences in subsistence tasks and nutritional intake. Differences exhibited in the size of individuals are more likely affected by nutritional intake, while differences in shape are attributed to activity (Ruff 2008). The Archaic groups were hunter-gatherers and based on the zooarchaeological data from these sites, there was an abundance of white tailed deer, smaller mammals, fish, and freshwater mussels which provided the inhabitants with protein and beneficial nutrients such as omega-3 fatty acids (Squires 2006). The Archaic sample exhibits more sexual dimorphism (in size) than the Averbuch population, which could be due to better nutritional intake for males and task differences (less sexually dimorphic than the Averbuch in radius transverse shape and ulna dorso-volar shape). This sample shows less sexual dimorphism (size and shape) than the East Tennessee Mississippian samples which may indicate that the Archaic group was under more

nutritional stress than the East Tennessee sample, or did not have an as marked sexual division of labor.

The Averbuch people were agriculturists involved in tasks that required the participation of both males and females, due to the environmental stress they were under, and as expected, they exhibited the least amount of sexual dimorphism (in size, radius sagittal shape, and ulna transverse shape) (Berryman 1983). The zooarchaeological, botanical, and lithic remains indicate that hunting and gathering was still an important component of food procurement along with agricultural production. The Averbuch population shows evidence of nutritional deficiencies such as cribra orbitalia, enamel hypoplasias, and harris lines, possibly due to periods of unsuccessful hunting or seasonal disease and parasitic load (Berryman 1983). Reasons for poor nutritional intake can also be attributed to poor soil quality making it difficult for agricultural production. Also, the botanical data shows that there was a strong dependence on maize which has poor nutritional, but high caloric value (Bridges 1989; Larson 1995). Unlike other Late Mississippian sites, such as Toqua, the Averbuch population was not located in an ideal area which may explain the short term occupation. One hypothesis is that population expansion forced groups into less than ideal circumstances (Berryman 1983). Berryman (1983) mentioned that males and females of all ages were forced to participate in agricultural activities because of the environmental stress the population was under. The results show that males and females are similar in size and shape, particularly interosseous crest development, which indicates that they were participating in similar activities (thus contributing to a decrease in sexual dimorphism).

The East Tennessee Mississippian groups show the greatest amount of sexual dimorphism (size and shape), indicating that the sample was most likely under less nutritional stress and contained a defined sexual division of labor (Ross et al. 2003). Supporting evidence provided by the zooarchaeological, botanical and lithic data from Toqua and Mouse Creek indicates that there was diversity in food consumption and production. For example, there were various fruits such as cherries, peaches, apples, and blackberries along with nuts, seeds, beans, and squash with different modes of processing (Polhemus 1987). Ethnographic reports indicate that some fruits, such as persimmon, were dried or made into a candy that could be used for a spread or roasted in beverages, while beans, squash, and corn were processed into bread (Polhemus 1987). Squash was also used in soups and dried, while nuts were consumed and processed for oil. Fruits, wild cherries, and plums also provided nutritional value along with beans, blackberries, and raspberries (Polhemus 1987). Hunting was still an important contribution to the diet and the majority of the bones recovered were of white tailed deer (Polhemus 1987). Various tool technologies, such as projectile points and knives, were used for butchering and hide working (Polhemus 1987). Based on this information, it is possible that the various activities performed at these sites and the variety of foods with good nutritional value could explain why the East Tennessee Mississippian samples show an increase in sexual dimorphism.

### **Biomechanics**

The results show that there is variation between the sexes for size and diaphyseal shape of the radius and ulna. This variation may be better understood with an outline of the muscles and movement that would affect the robusticity of bone. The main muscles that

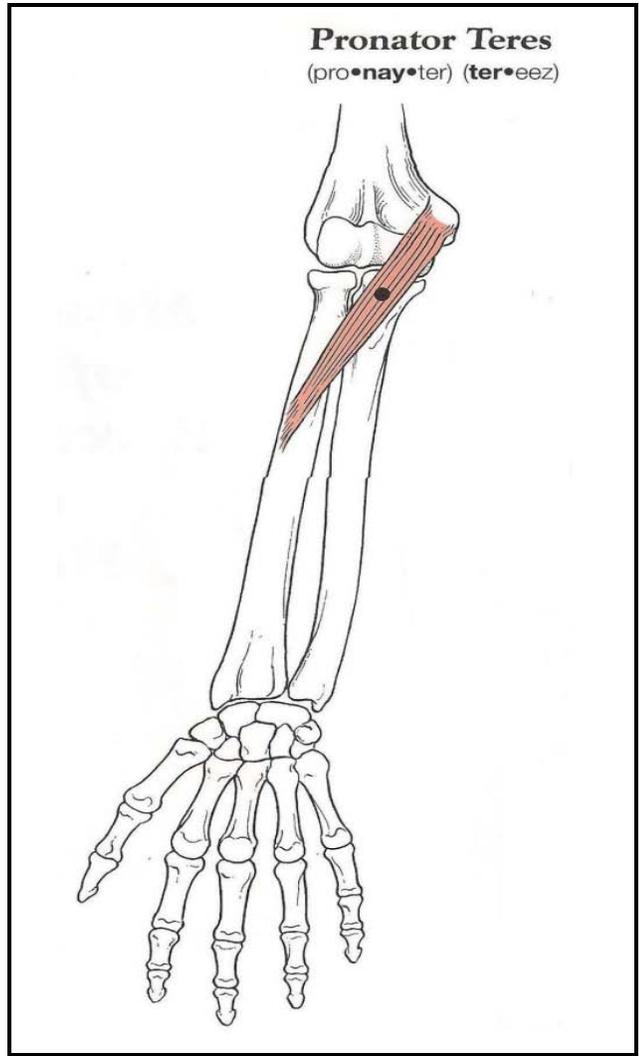
contribute to the areas of robusticity seen in the samples for the forearm are the pronator teres, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, and the supinator (Tyldesley and Grieve 1996; Otis 2004). These muscles perform flexion, extension, abduction, and supination (defined in table 12).

**Table 12. Movement Definitions from Tyldesley and Grieve (1996)**

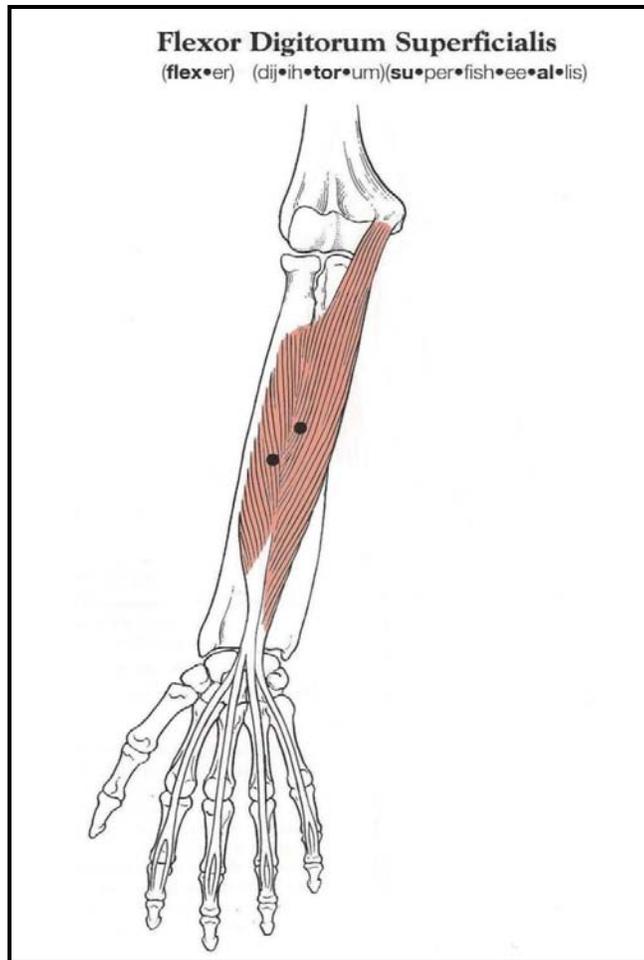
<b>Movement</b>	<b>Definition</b>
<b>Flexion</b>	When the angle between the bones is decreased, bends body part away from anatomical position
<b>Extension</b>	Movement back to anatomical position, stretches the body out
<b>Pronation</b>	The hand turns medially to face backwards from anatomical position, or downwards when the hand is in front of the body
<b>Supination</b>	The hand turns to face forward in the anatomical position, or upwards when the hand is in front of the body
<b>Abduction</b>	When the body part moves away from the midline of the body

The following muscles help the forearm perform the act of flexion. Pronator teres (Figure 18) originates at the medial epicondyle of the humerus and inserts into the lateral shaft of the radius (Tyldesley and Grieve 1996; Otis 2004). This muscle is used during flexion, and counteracts the supination of the biceps when all of the flexor muscles are in

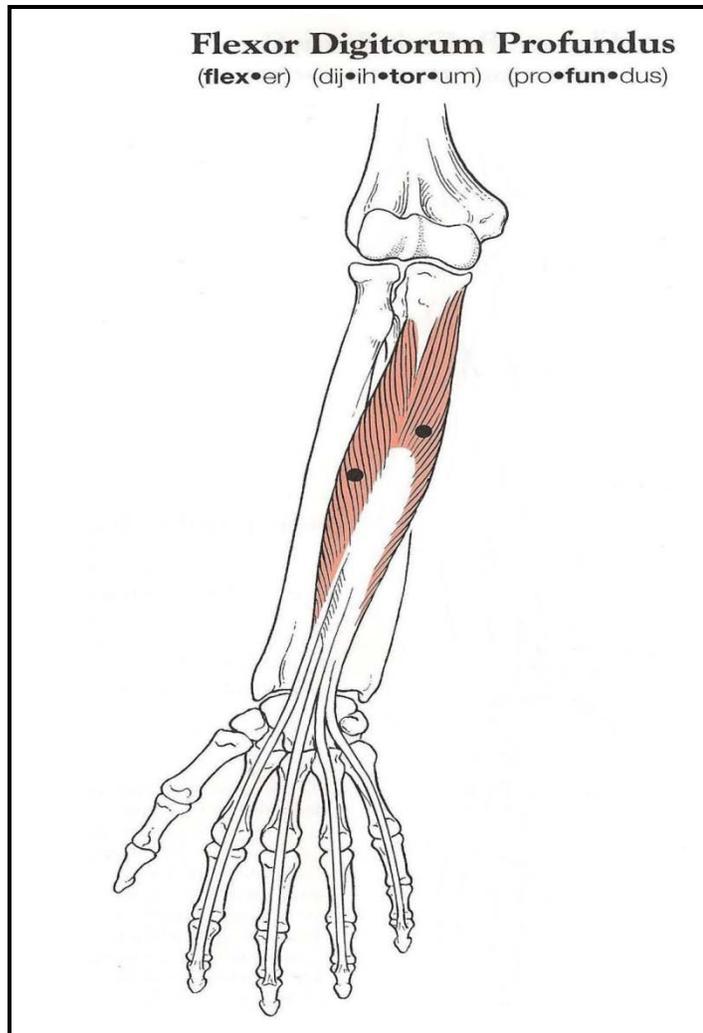
action (Tyldesley and Grieve 1996; Otis 2004). The flexor digitorum superficialis (Figure 19) also originates at the medial epicondyle of the humerus and the coronoid process of the ulna and inserts into the anterior shaft of the radius (Tyldesley and Grieve 1996; Otis 2004). This muscle aids in the closing of the hand, which is important during tool production, food procurement and processing, and other specialized tasks such as pottery production (Tyldesley and Grieve 1996; Otis 2004). The flexor digitorum profundus (Figure 20) originates at the anterior and medial shaft of the ulna and is also involved in the act of closing the hand (Tyldesley and Grieve 1996; Otis 2004). The final flexor muscle is the flexor pollicis longus (Figure 21), which is attached to the anterior shaft of the radius and flexes all the joints in the fingers and thumb (Tyldesley and Grieve 1996; Otis 2004).



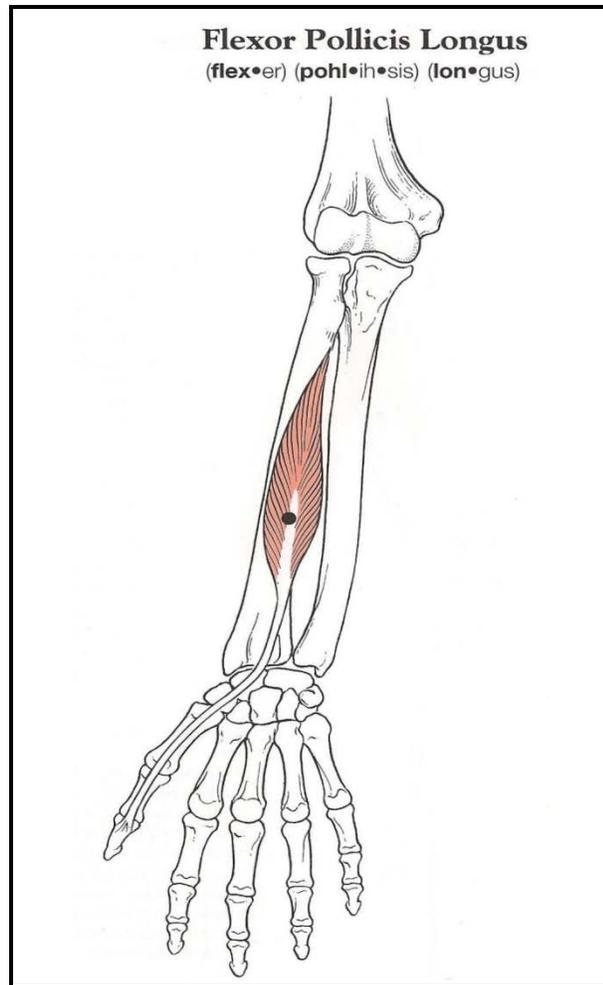
**Figure 18. Pronator Teres (Bowden and Bowden 2005)**



**Figure 19. Flexor Digitorum Superficialis (Bowden and Bowden 2005)**



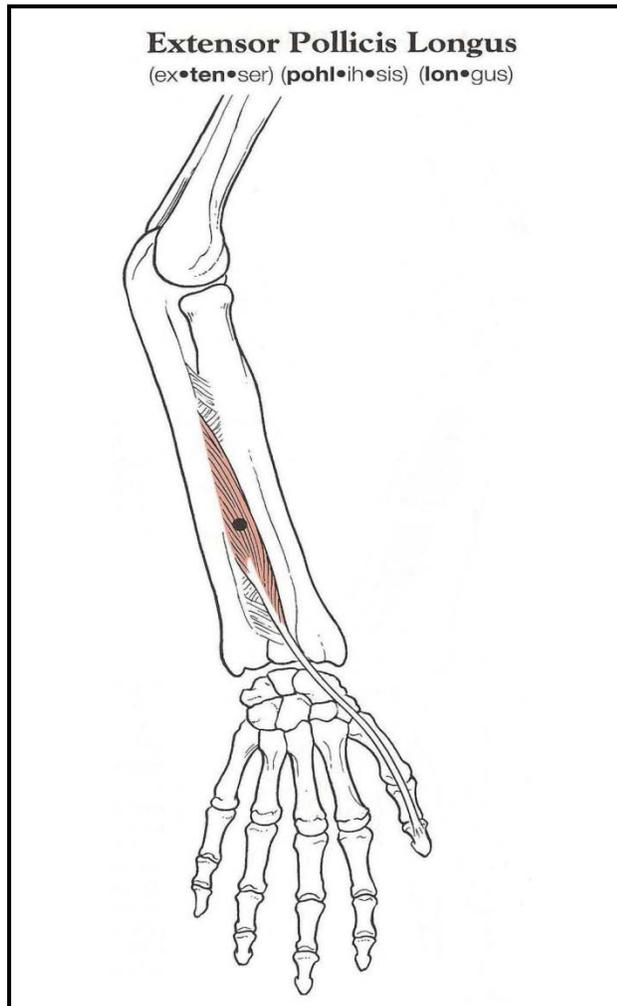
**Figure 20. Flexor Digitorum Profundus (Bowden and Bowden 2005)**



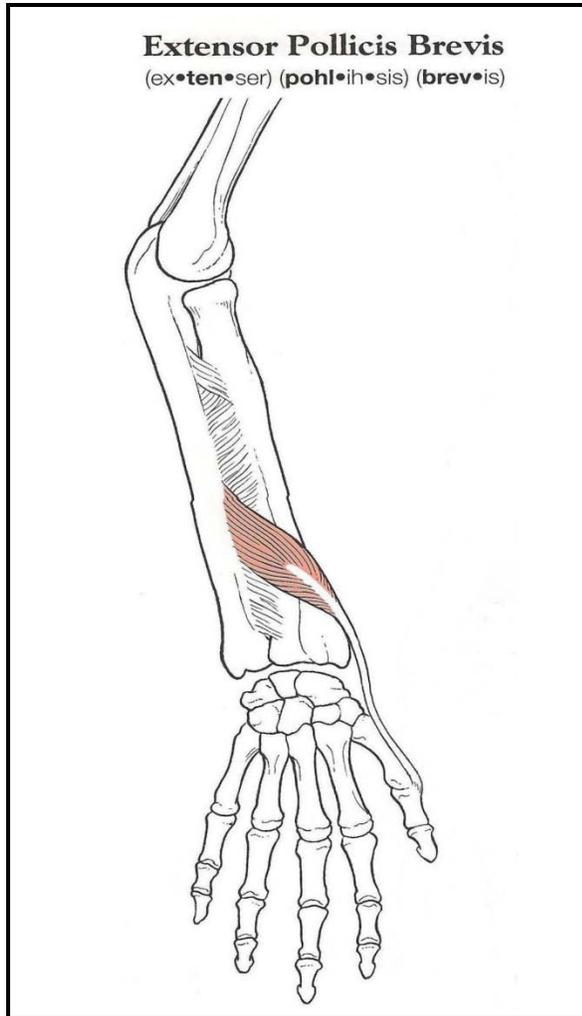
**Figure 21. Flexor Pollicis Longus (Bowden and Bowden 2005)**

There are two muscles involved in extension and one involved in abduction that performs the act of opening of the thumb (Tyldesley and Grieve 1996; Otis 2004). The extensor pollicis longus (Figure 22) originates at the shaft of the ulna and the extensor pollicis brevis (Figure 23) originates at the shaft of the radius (Tyldesley and Grieve 1996; Otis 2004). The abductor pollicis longus (Figure 24) originates on the upper shaft of the radius and ulna (Tyldesley and Grieve 1996; Otis 2004). These three muscles work with the

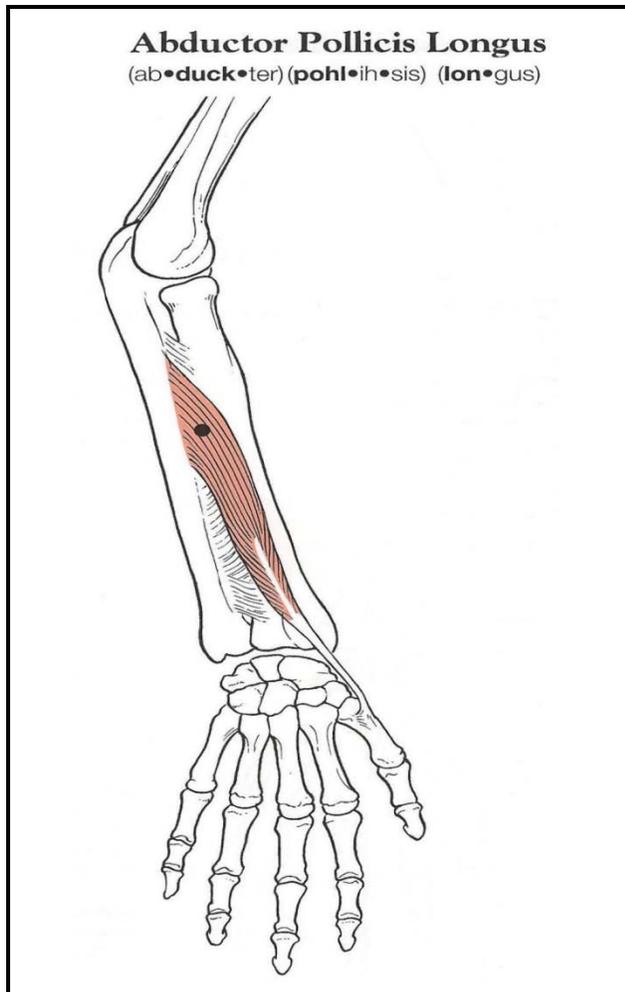
flexor muscles to open and close the hand during everyday activities (Tyldesley and Grieve 1996; Otis 2004).



**Figure 22. Extensor Pollicis Longus (Bowden and Bowden 2005)**

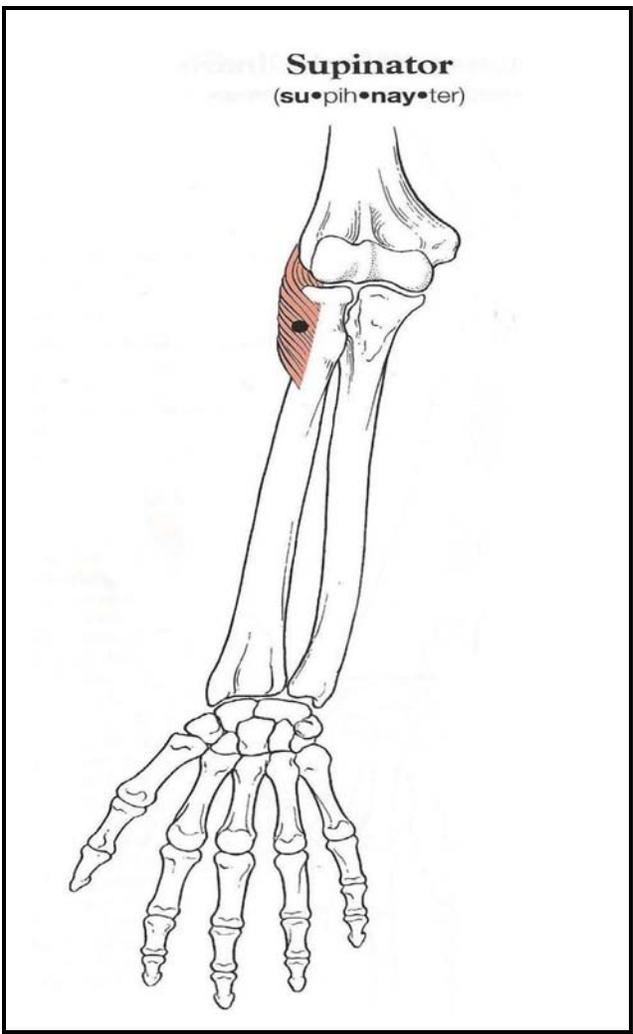


**Figure 23. Extensor Pollicis Brevis (Bowden and Bowden 2005)**



**Figure 24. Abductor Pollicis Longus (Bowden and Bowden 2005)**

The supinator muscle (Figure 25) originates at the lateral epicondyle of the humerus and inserts in the upper lateral side of the radius (Tyldesley and Grieve 1996; Otis 2004). This muscle performs the act of supination. Pronation and supination of the forearm is controlled by the middle radioulnar joint, which is an interosseous membrane that extends along the length of the radius and ulna shafts (Tyldesley and Grieve 1996; Otis 2004).



**Figure 25. Supinator (Bowden and Bowden 2005)**

The Archaic males and females have small interosseous crest development, which indicates that hunting and gathering did not require the same amount of continuous muscle use as agricultural production. Although males and females are similar in shape, this does not necessarily mean they were participating in similar activities. The same muscles could be utilized while performing different tasks (food processing and hide working), therefore

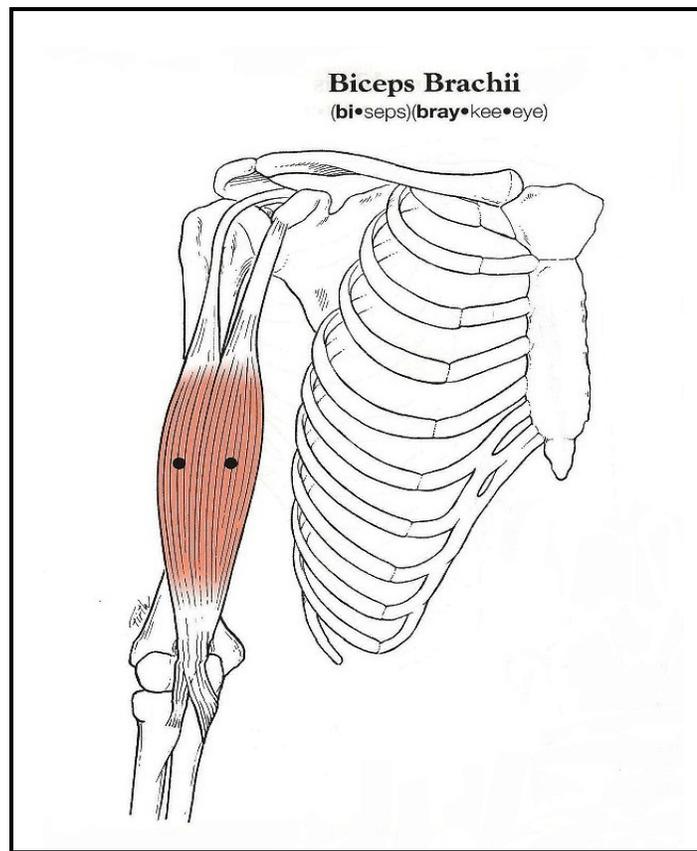
explaining why there is more sexual dimorphism present in this sample than the Averbuch sample.

The males and females of the Averbuch sample have robust interosseous crest development, which indicates that they were performing continuous activities that involved pronation, supination, extension, flexion, and abduction of the fingers such as agricultural work involving hoes, hunting, tool production and maintenance, and food processing. Interestingly, the East Tennessee Late Mississippian males have smaller interosseous crest development than the East Tennessee females, and the East Tennessee females are similar in robustness to the Averbuch females, which suggest that the females were participating in similar activities, while the East Tennessee males were performing activities that did not require the constant use of these muscles. This further supports Berryman's (1983) hypothesis that the Averbuch males and females were participating in similar activities due to environmental stress, since the males and females in the sample exhibit similarities in their skeletal biology. These results also explain why these two Late Mississippian populations exhibit differences in robusticity.

### **Bilateral Asymmetry**

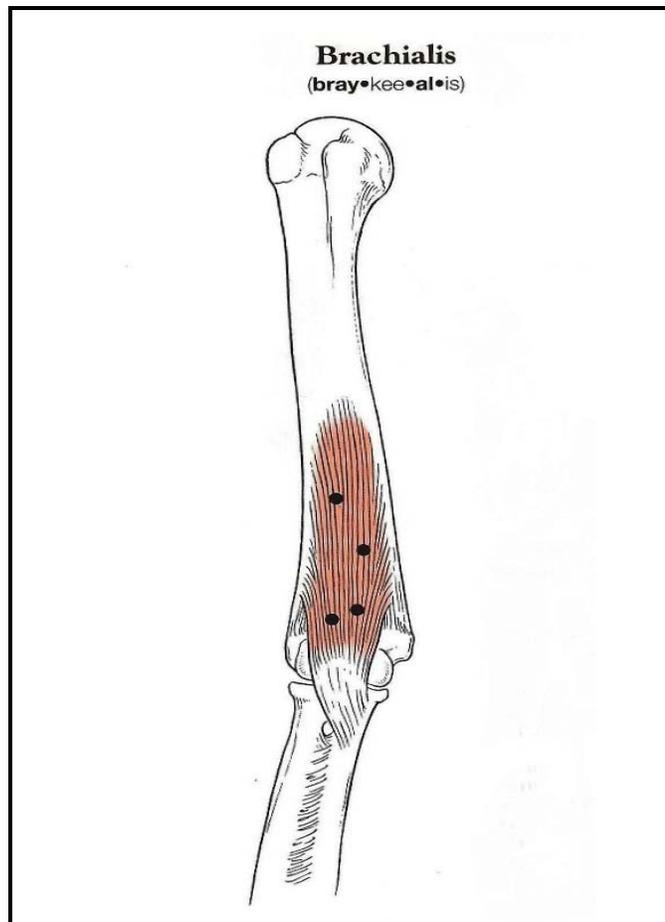
When analyzing the bilateral asymmetry data, it appears that males show asymmetry in the humerus at the maximum and minimum diameters at midshaft, while females do not exhibit asymmetry. This indicates that males and females were still participating in different tasks requiring different usages of the body. Understanding the muscle attachments of the humerus can provide information on the movements that contribute to bone robusticity.

The muscles of the humerus are the biceps brachii, brachialis, triceps brachii, coracobrachialis, and the deltoids, which are involved in flexion, extension, supination, pronation, and abduction of the arm (defined in table 12) (Tyldesley and Grieve 1996; Otis 2004). The biceps brachii (Figure 26) originates at the glenoid cavity, coracoid process, and lies on the bicipital groove of the humerus, and inserts into the radial tuberosity (Tyldesley and Grieve 1996; Otis 2004). This muscle helps perform the act of flexion which is most effective when the arm is in supination and is moving against resistance (Tyldesley and Grieve 1996; Otis 2004). It also controls the lowering of the forearm and hand when holding a tool or utensil, such as in corn grinding or other types of food processing that the Averbuch population were participating in (Tyldesley and Grieve 1996; Otis 2004).



**Figure 26. Biceps Brachii (Bowden and Bowden 2005)**

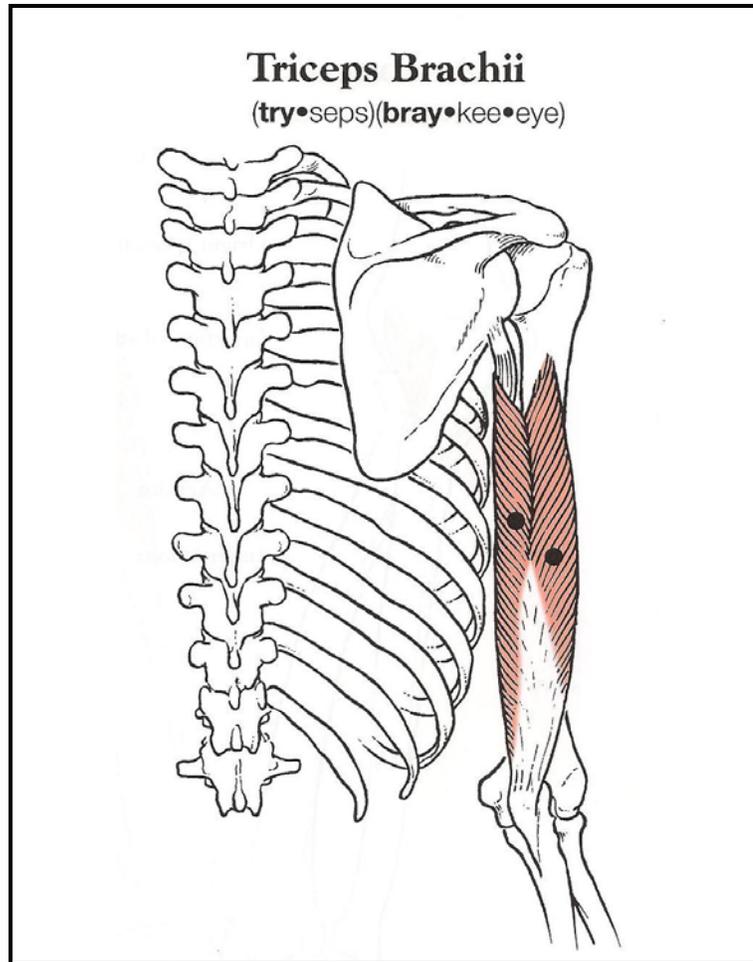
Brachialis (Figure 27) originates on the anterior shaft of the humerus, below the deltoid tuberosity, and inserts on the ulnar tuberosity below the coronoid process of the ulna (Tyldesley and Grieve 1996; Otis 2004). This muscle performs the act of flexion in the forearm and hand, and is responsible for the arm bulge seen in weight lifters (Tyldesley and Grieve 1996; Otis 2004).



**Figure 27. Brachialis (Bowden and Bowden 2005)**

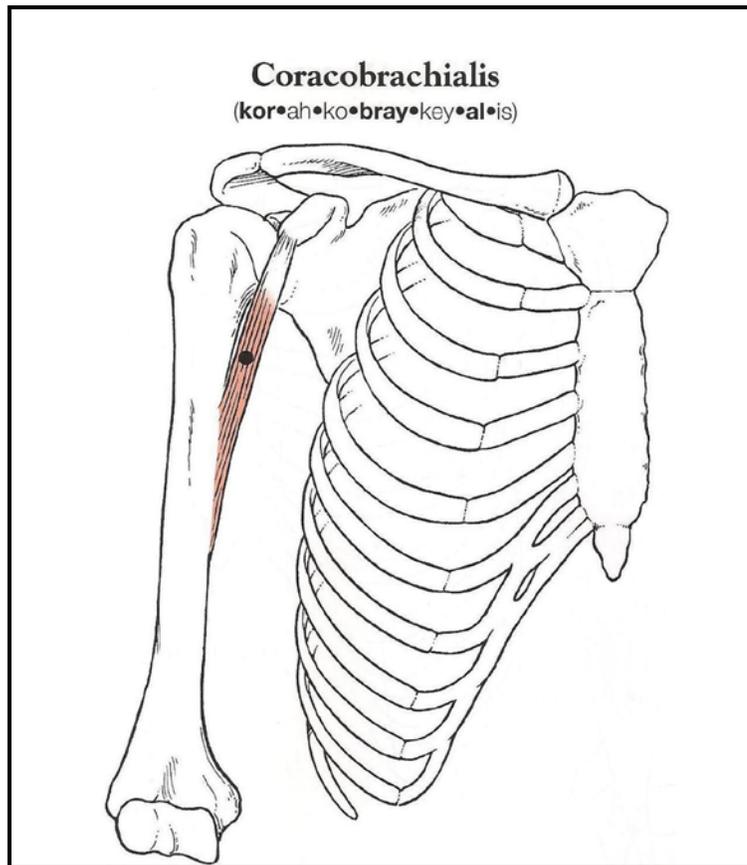
The triceps brachii (Figure 28) has three origins: the long head, which originates at the inferior part of the glenoid cavity and the shaft of the humerus, the lateral head, which is an oblique line below the greater tuberosity, and the medial head, which is attached to the posterior shaft of the humerus (Tyldesley and Grieve 1996; Otis 2004). This muscle inserts into the olecranon of the ulna, and acts in extension and enables the hand to move against resistance. For example, reaching above the head, pushing forward and side to side, this is performed in tasks such as food processing, hide working, and hunting (Tyldesley and Grieve

1996; Otis 2004). This muscle may contribute to the minimum and maximum diameter asymmetry in robusticity seen in the Averbuch males which correlates with the tasks they were likely participating in (hide processing, butchering meat, hunting with the projection of a spear with one limb, and tool making that requires repetitive pounding with one arm).



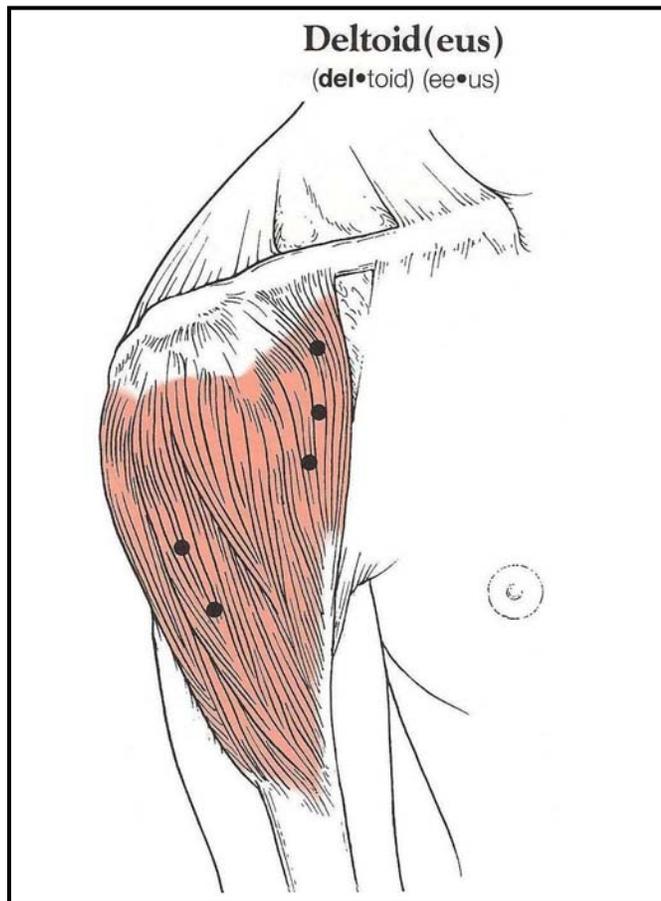
**Figure 28. Triceps Brachii (Bowden and Bowden 2005)**

The coracobrachialis (Figure 29) originates at the tip of the coracoid process of the scapula, and inserts in the anteromedial surface of the humerus at midshaft (Bowden and Bowden 2005). This muscle is involved in flexion and adduction and may also contribute to the minimum and maximum diameter asymmetry seen in the Averbuch males (Bowden and Bowden 2005). Again, there are a multitude of tasks requiring flexion and the utilization of one limb over the other that the Averbuch males would have been performing which is evidenced by the skeletal indicators (asymmetry in robustness), and the lithic, botanical, and zooarchaeological remains.



**Figure 29. Coracobrachialis (Bowden and Bowden 2005)**

The last important muscle of the humerus is the deltoid (Figure 30). This muscle originates at the lateral third of the clavicle, the acromion process, and the spine of the scapula and inserts in the deltoid tuberosity of the humerus (Tyldesley and Grieve 1996; Otis 2004). It aids in flexion and abduction, and is the most active from 90 to 180 degrees, as in the raising of the arm for hunting (Tyldesley and Grieve 1996; Otis 2004).



**Figure 30. Deltoid (Bowden and Bowden 2005)**

Each muscle of the humerus contributes to the movement of the arm during everyday activities. The males of the Averbuch population show significant differences in midshaft robusticity, indicating that the muscles of one arm were utilized more than the other. The zooarchaeological and lithic remains found at the Averbuch site indicate that medium sized mammals were hunted (white tailed deer), which would have required the use of an atlatl or some type of projectile. Women were most likely performing activities where the amount of force was distributed equally between both limbs. For example, plant grinding (corn, nuts, and flour) requires the use of both limbs in a repetitive motion.

## CONCLUSION

This research project has demonstrated that there are multiple factors that cause differences in sexual dimorphism between populations, such as subsistence related activities and nutrition. The skeletal morphology of the upper limbs is affected by both mechanical loading and nutrition; however, the degree to which each mechanism affects robusticity is unclear, although size seems to be more affected by nutrition, and shape by activity (Ruff 2008). As previously stated by Larson (1995), there is great variability in subsistence-related activities among populations, which affects the amount of biomechanical loading placed on the upper limbs. This is seen in the Archaic and the two Late Mississippian samples, where the Averbuch sample exhibits the least amount of sexual dimorphism, followed by the Archaic sample, and lastly the East Tennessee Late Mississippian sample. The archaeological and skeletal analysis indicated that the Archaic and the Averbuch males and females did not have a significant division of labor while the East Tennessee Late Mississippian males and females had a greater division of labor.

Apart from differences in subsistence-related activities, nutritional intake also plays an important role in the sexual dimorphism of a population. Male development (cortical thickness) is affected by nutritional deficiencies more so than females, thus decreasing sexual dimorphism (Greulich 1951; WHO 2005). The skeletal analysis performed by Berryman (1983) indicated that the Averbuch population was under great nutritional stress, although stature was not affected, indicating that stress most likely occurred in childhood and catch up growth occurred (Cameron 2006). The zooarchaeological and botanical remains found at the Archaic and East Tennessee Late Mississippian sites indicated that these

individuals consumed a diverse diet, which would increase sexual dimorphism (Klippel and Bass 1984). This research shows that future studies and the development of more advanced methodologies are needed to further tease apart the affects of nutrition and activity.

Bilateral asymmetry was also examined on the Averbuch sample to gain further insight into the tasks the males and females were performing. The results showed that the females were participating in activities requiring the use of both limbs (plant processing), while males exhibited significant asymmetry indicating the preferential use of one limb for various tasks (hunting, tool production, hide working).

Overall, this research provides more information on the biomechanical impacts on bone that occurs during a shift from hunting and gathering to agricultural production. The decrease in sexual dimorphism exhibited in the Averbuch population suggests that males and females participated in similar subsistence related tasks associated with agriculture. The increase in sexual dimorphism in the East Tennessee Late Mississippian populations may be indicative of a differential subsistence tasks between the sexes. This study also had some limitations. Due to preservation, the sample sizes for the comparison samples were significantly lower than the Averbuch sample.

This research also shows that while comparisons can be made, a more comprehensive understanding of the cultural behaviors that occur within these populations is needed to fully understand changes in sexual dimorphism related to subsistence patterns. While this study provides information on the subsistence patterns and sexual dimorphism of the Archaic and Late Mississippian groups from Tennessee, it cannot be assumed that these patterns will be seen in every Archaic and Late Mississippian culture; therefore future studies should

investigate other populations that shifted from hunting and gathering to agricultural subsistence from a culturally specific perspective.

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## APPENDICES

### APPENDIX I



**Figure 31. Left Transverse Diameter of the Radius at Midshaft (from Moore-Jansen et al. 1994) Female 35-39 (124)**



**Figure 32. Right Transverse Diameter of the Radius at Midshaft (from Moore-Jansen et al. 1994) Male 30-34 (101)**



**Figure 33. Left Transverse Diameter of the Ulna (from Moore-Jansen et al. 1994)  
Female 40-49 (264A)**



**Figure 34. Left Ulna and Radius of an Averbuch Female 25-29 (665)**



**Figure 35. Transverse Diameter of the Radius at Midshaft and Transverse diameter of the ulna (from Moore-Jansen et al. 1994) Female 25-29 (B124)**



**Figure 36. Transverse Diameter of the Ulna (from Moore-Jansen et al. 1994) Male 30-34 (101)**



**Figure 37. Left and Right Upper Limbs of an Averbuch Male 20-24 (B130)**



**Figure 38. Left and Right Humerus of an Averbuch Male 25-29 (248)**