To the Graduate Council:

I am submitting herewith a dissertation written by Daniel J. Wescott entitled "Structural Variation in the Humerus and Femur in the American Great Plains and Adjacent Regions: Differences in Subsistence Strategy and Physical Terrain." I have examined the final paper copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

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Structural Variation in the Humerus and Femur in the American Great Plains and Adjacent Regions: Differences in Subsistence Strategy and Physical Terrain

A Dissertation
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Doctor of Philosophy
Degree
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Daniel J. Wescott
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ABSTRACT

Analysis of long bone cross-sectional architecture has been increasingly used in the last three decades to help reconstruct behavior, especially activity patterns, from archaeologically derived skeletal material. This research has shown a strong correlation between cross-sectional geometric properties and mobility and terrain. However, few studies have focused on the American Great Plains or looked at hypotheses using a large dataset with considerable spatial distribution and time depth.

The purpose of this research project is to examine structural variation and sexual dimorphism in the humerus and femur within and among groups from the American Great Plains and adjacent regions. The goals are threefold. The first goal is to investigate the degree to which long bone external dimensions can be used to predict diaphyseal cross-sectional properties (e.g., total periosteal area and moments of area). The second goal is to examine the effects of activity level, mobility, and terrain type on the cross-sectional morphology of proximal limb bones. The final goal is to inspect the pattern of structural variation in the American Great Plains.

Two sources of data were used in this study. The primary source is external dimensions of humeri and femora from the Great Plains, Great Basin, Southwest, Southeast, Texas Gulf Coast, and recent dissection room and medicolegal specimens. The second source of data is cross-sectional computed tomography scans of humeri and femora from the Great Plains, Southeast, and Texas Gulf Coast.

In this study, the degree to which external dimensions of long bone diaphyses can be used to predict cross-sectional properties was investigated. The results show that many

of the cross-sectional geometric properties of long bone diaphyses can be reliably predicted using external dimensions. The strong correlation between external measurements and cross-sectional properties suggest that both types of data will provide similar results in biomechanical investigations.

Within the American Great Plains, long bone size and shape is relatively homogeneous, but significant differences do exist between Northern and Southern Plains groups, especially in the femur, and between equestrian and non-equestrian groups. Northern Plains groups exhibit greater platymeria and rounder femoral midshafts than Southern Plains groups, although they were practicing similar types of subsistence. Equestrian groups are generally larger, more robust, and exhibit rounder femoral midshafts than non-equestrian groups.

Long bone size and shape appears to be a reflection of multiple determinants, including biomechanical loading, growth and development constraints, diet, and health factors. When examined over a wide geographical distribution, long bone morphology does not correlate with level of mobility or terrain type. There is, however, a slight correlation between humeral and femoral morphology and level of activity. These results suggest that broad generalizations about activities associated with subsistence strategy should be viewed with caution.

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LIST OF ABBREVIATIONS

Cultural Area

CP	Central Plains
EW	Eastern Woodlands
GB	Great Basin
GC	Gulf Coast
NP	Northern Plains
NW	Northwest
PR	Prairie
SP	Southern Plains
SW	Southwest

Tribe / Population

ANA	Anasazi
APA	Apache
ARK	Arikara
BFT	Blackfoot
BLK	Black American
CAD	Caddo
CHY	Cheyenne
COA	Coahuiltecan
COM	Comanche
CRW	Crow
EAN	East Asian
FRE	Fremont
HOP	Hopi
KAN	Kansa
KAR	Karankawa
MAN	Mandan
NUM	Numic
OMA	Omaha
PAW	Pawnee
PAI	Paiute
PB	Pueblo
PON	Ponca
SHO	Shoshone
SHW	Shawnee
SIU	Sioux
UTE	Ute
WAS	Washoe
WHT	White American
WIC	Wichita

Cultural Periods

AR	Archaic
BKM	Basket Maker
CO	Plains Coalescent
CPT	Central Plains Tradition
FRE	Fremont
HIST	Historic
LP	Southern Plains Late Prehistoric
MM	Middle Missouri
ON	Oneota
PA	Paleoamerican
PB	Pueblo
WD	Woodland

Subsistence Stragegies

AGR	Agriculturalists
BSHG	Broad-spectrum hunter-gatherers
CHG	Coastal hunter-gatherers
EHG	Equestrian hunter-gatherers
EMI	Early modern industrialists (pre 1900)
IH	Incipient horticulturalist
LMI	Late modern industrialists (post 1900)
VHH	Village horticulturalist / hunter
WDHG	Woodland hunter-gatherer.

Measurements and Properties fo the Humerus

HML	Maximum length
BUE	Proximal epiphyseal breadth
MDS	Maximum midshaft diameter
MDM	Minimum midshaft diameter
MDH	Vertical head diameter
EBR	Epicondylar breadth
HMS	Midshaft shape
HMR	Midshaft robusticity
HMTA	Midshaft total area
HDS	Mid-distal (35%) shape
HDR	Mid-distal (35%) robusticity
HDTA	Mid-distal (35%) total area

Measurements and Properties of the Femur

FML	Femur maximum length
FTL	Femur trochanteric length
APD	Femur midshaft anteroposterior diameter
MLD	Femur midshaft mediolateral diameter
APS	Femur subtrochanteric anteroposterior diameter
MLS	Femur subtrochanteric mediolateral diameter
VHD	Femur vertical head diameter
HHD	Femur horizontal head diameter
FEB	Femur epicondylar breadth
BCB	Femur biocondylar breadth
FSS	Femur subtrochanteric shape
FSR	Femur subtrochanteric robusticity
FSTA	Femur subtrochanteric total area
FMS	Femur midshaft shape
FMR	Femur midshaft robusticity
FMTA	Femur midshaft total area

CHAPTER 1

INTRODUCTION

Behavioral Interpretations from Long Bones

In physical anthropology, the application of engineering principles to long bone diaphyseal geometry has been extensively used to infer behavior, especially activity patterns, from archaeological human remains (Bridges, 1989a, 1989b, 1996; Bridges et al., 2000; Brock and Ruff, 1988; Fresia et al., 1990; Larsen, 1995; Larsen and Ruff, 1994; Ruff, 1987, 1999; Ruff and Hayes, 1983a, 1983b; Ruff and Jones, 1981; Ruff and Larsen, 1990; Ruff et al., 1993; Ruff et al., 1994; Trinkaus, 1999; Trinkaus et al., 1994, 1999). Most of these studies have focused on changes in physical activities associated with the transition from hunting and gathering to maize agriculture or on evolutionary trends in fossil remains. Cross-sectional geometry of the femoral midshaft has received the most attention, but the tibia and humerus have also been studied in this manner. Few studies have focused on cross-sectional properties of the radius or ulna—probably because they are much less informative (Stock and Pfeiffer, 2001).

Researchers concentrating on the differences in hunting-gathering and agricultural groups in the same geographical region have reported marked differences in diaphyseal strength, cross-sectional shape, and robusticity between these two subsistence groups. Differences in sexual dimorphism and bilateral asymmetry are also frequently observed. In general, hunter-gatherers appear to exhibit stronger and more robust bones, more

pronounced bilateral asymmetry, greater sexual dimorphism in shape, and a femoral midshaft shape that is less round (more anteroposteriorly elongated) (Larsen, 1997; Ruff, 1987, 2000a).

In a comparative study of archaeological and recent cadaver samples, Ruff (1987) found that hunter-gatherers exhibit marked sexual dimorphism in femoral midshaft cross-sectional shape, agriculturalists less dimorphism, and industrialists almost no dimorphism. Ruff (1987) argued that hunter-gatherer males placed significantly greater anteroposterior bending loads on their midshaft femora than hunter-gatherer females or agriculturalists and industrialists of either sex. Ruff (1987) attributed this difference to more frequent sex-specific activities in hunter-gatherers, the most important activity difference being relatively high mobility among male hunter-gatherers.

More recently, Ruff (1999, 2000a) argues that terrain might play a greater role in determining long bone cross-sectional strength than subsistence patterns, writing "Within populations of the last few thousand years, physical terrain may be the most important single variable in determining robusticity (bone strength relative to body size) of the lower limb bones" (Ruff, 2000a:95). In a comparison of populations from the Great Basin and Southwest (mountain dwellers), Great Plains, and Coastal Plains of Georgia, Ruff (1999) found significant differences in the polar second moment of area (J, a measure of torsional strength) between mountain dwellers and those of the Great Plains and Coastal Plains. However, Ruff (1999) found no significant difference in femoral strength between Great Plains and Coastal Plains populations.

While there appears to be significant theoretical evidence for the relationship between long bone cross-sectional shape and the mechanical load placed on the bone due to activity and terrain, Jurmain (1999:250) states, "It is difficult to imagine that activity pattern would be so consistently linked to such extremely rough categories of subsistence adaptation." He correctly argues that there is great variability in the activity patterns within the traditional categories of subsistence strategy. For example, the Inuit are extremely mobile but the hunter-gatherers of Central California are semi-sedentary (Jurmain, 1999; Kelly, 1995). Furthermore, some horticulturalists, such as those from the Great Plains, are extremely mobile. Most Plains horticulturalists abandoned their village twice yearly to embark on long distance bison hunts (O'Shea and Ludwickson, 1992).

It is easy to see how Jurmain's (1999) argument would also pertain to the broad categories of terrain used by Ruff (1999, 2000a). The Great Plains, for example, varies from extremely level regions (Central Kansas and Nebraska) to steep river valleys (Missouri River Valley) to small mountains (Black Hills). Additionally, it appears unlikely that all groups in the same region would navigate the terrain in an identical manner. Southwest and Great Basin groups are both considered mountain dwellers by Ruff (1999), yet Southwest Indians probably spent more time mountaineering than did the Great Basin Indians because Southwest groups frequently built living structures in steep canyon cliffs, forcing them to climb the canyon walls frequently. Populations living near the Stillwater Marsh area of the western Great Basin (sample used by Ruff, 1999), on the other hand, may have rarely left the relatively flat marsh (Heiser, 1967; Heizer and Napton, 1970). Because the marsh provided sufficient food for Great Basin

hunter-gatherers, only logistic forays into the mountains were necessary (Kelly, 1995a). Ethnographic descriptions of the Shoshone illustrate another use of the Great Basin mountain terrain. The Shoshone would winter in villages located in the mountain forests, move to the valley floors during the spring, move to the rivers during the summer, and move back into the mountains in the fall (Kelly, 1995b).

Other problems with using the generalizations postulated by Ruff and others are that the type, duration, and amplitude of the loading, as well as the age at which a particular activity began or ceased, complicate the interpretations (Frost, 1997; Jurmain, 1999). Furthermore, genetic and developmental factors, hormonal differences, diet, age, and numerous other factors affect long bone geometric properties. Jurmain (1999:253) contends that Ruff and others assume that activity explains most of the variation in cross-sectional morphology, while what they should be doing is demonstrating what effect activity has on cross-sectional morphology. He argues that Ruff has "constructed 'best fit' activity-based scenarios to explain skeletal variation," (Jurmain, 1999:253) and that others have essentially accepted Ruff's interpretations without any critical evaluation. Jurmain (1999:249) writes, "What is most disturbing is that this very tentative interpretation of the etiology of altered femoral shaft shape, i.e., A/P expansion due *specifically* to long-distance travel, has been repeated numerous times elsewhere (e.g., Fresia et al., 1990; Larsen and Ruff, 1994; Bridges 1996b). Given enough repetitions, the hypothesis now appears to be accepted (uncritically) as established."

Recently, Ohman and Lovejoy (2001) have also been critical of the use of long bone geometry to interpret activity patterns. Using femoral midshaft data of chimpanzees

and gorillas, Ohman and Lovejoy (2001) argue that diaphyseal morphology is primarily influenced by epiphyseal shape rather than activity. They assert that while bone cells are sensitive to mechanical stimuli, the cross-sectional morphology of an adult bone shaft are not a simple reflection of the mechanical loads placed on the bone.

Statement of Purpose

The purpose of this study is to examine variation in long bone strength, shape, robusticity and sexual dimorphism within and among groups from the American Great Plains and adjacent areas using a biomechanical approach. The main goals are to (1) investigate the degree to which long bone external dimensions can be used to predict diaphyseal cross-sectional properties, (2) examine the effects of activity, mobility and terrain on the cross-sectional morphology of the humerus and femur, and (3) analyze the pattern of humeral and femoral cross-sectional morphology within the American Great Plains

Several specific questions will be addressed regarding each major goal. For the first goal, the questions include: (1) Do agricultural populations, in general, exhibit relatively rounder femoral midshafts than hunter-gatherers do? (2) Does sexual dimorphism, especially in shape, decrease with the adoption of agriculture, and do recent industrial populations from the United States show less sexual dimorphism than hunter-gatherers and agriculturalists? (3) Do populations from mountainous regions consistently exhibit greater skeletal robusticity than populations from the Great Plains and coastal plains? With regard to the second goal, additional questions include: (1) Are there

significant differences in cross-sectional shape between equestrian and non-equestrian groups? (2) Why do Southern Plains groups consistently display greater anteroposterior elongation of the femoral midshaft? (3) Do Plains groups with different subsistence strategies follow the hypothesized pattern of morphology?

To accomplish the goals of this study, the data will be examined within an archaeological and historical framework using external measurements and computed tomography (CT) cross-sectional scans of humeri and femora. A wide variety of subsistence patterns is represented in the data used in this study. These include: broad-spectrum hunter-gatherers, coastal hunter-gatherers, woodland hunter-gatherers, incipient horticulturalists, horticulturalists / bison hunters, equestrian bison hunters, agriculturalists, early modern industrialists, and late modern industrialists. The data also represents individuals from four geographical cultural areas (Great Plains, Great Basin, Southwest, and Texas Gulf Coast).

There are a number of reasons for primarily using data from the American Great Plains in this study. First, there is a significant body of archaeological, ethnographical, historical, and biological data available on many of Plains samples, which allows for the examination of considerably more time depth than has been completed in other biomechanical studies and greater refinement of subsistence activities. Second, while a number of biomechanical studies have looked at groups from the American Southwest (Brock and Ruff, 1988; Ruff and Hayes, 1983; Ruff and Jones, 1981), Great Basin (Larsen et al., 1995; Ruff, 1999), Georgia Coast (Ruff and Larsen, 1990; Ruff et al., 1984), and Eastern Woodlands (Bridges, 1985; Bridges et al., 2000), only two studies

(Cole, 1994; Ruff, 1994) have tested the applicability of biomechanical properties to populations from the American Great Plains. Furthermore, because of reburial issues, many of the samples used in this study have now been repatriated or are no longer available for study. Finally, no biomechanical study has ever been conducted using skeletal material of Equestrian hunter-gatherers, which is primarily a Plains cultural adaptation. Ruff (1994) tested for differences between pre-horse and post-horse Arikara populations, but this tribe primarily practiced an horticultural subsistence and little is known about how frequently they actually rode horses. The Sioux, Crow, Blackfeet, and other Plains nomads used in this study, however, spent a considerable amount of time on their horses (Carlson, 1998; Denig, 2000).

CHAPTER 2

PREVIOUS POSTCRANIAL RESEARCH IN THE AMERICAN GREAT PLAINS

Over the last 50 years, human skeletal remains from the American Great Plains have been extensively excavated and measured, but rarely have the postcranial remains been analyzed in a systematic fashion. Most studies of Plains skeletal remains have utilized crania to address questions concerning secular change within and biological relationships within and among Plains groups (Byrd and Jantz, 1994; Jantz, 1970, 1972, 1973, 1974, 1977, 1994; Jantz et al., 1981; Key, 1983, 1994; Owsley and Jantz, 1978; Owsley et al., 1981; Ubelaker and Jantz, 1979). When adult postcranial remains are employed, they are generally only used to help reconstruct the stature and demographic details of individuals at a particular site. Rarely have adult postcranial remains from the Plains been used to address specific scientific questions as they have in other geographical areas (Bridges, 1989, 1991; Bridges et al., 2000; Fresia et al., 1990; Larsen et al., 1996; Ruff and Hayes, 1983a, 1983b; Ruff and Larsen, 1990; Ruff et al., 1984). A few exceptions can be found in the work of Zobeck (1983), Puskarich (1984), Crumbley (1986), Owsley (1991), Redmond (1997), Cole (1994), Ruff (1994), and Owsley and Jantz (1999).

Zobeck (1983) examined both within- and among-group variation in Coalescent tradition (CT) groups using measurements of the clavicle, scapula, humerus, radius, femur, tibia, and fibula. The primary purpose of Zobeck's (1983) work was to

investigate patterns of sexual dimorphism and to determine whether postcranial morphology would provide the same pattern of biological relationships as does cranial morphology. Unlike previous cranial studies (Jantz, 1972; Key, 1983), Zobeck found little heterogeneity among Coalescent groups. He also was unable to detect any significant changes in sexual dimorphism through time despite strong archaeological evidence for temporal changes in the health and nutrition of Coalescent tradition groups.

Puskarich (1984) and Crumbley (1986) also examined biological relationships among Coalescent tradition groups utilizing measurements of the pelvis and tibia, respectively. The results of these two studies generally support the findings of Zobeck (1983). However, both studies detected a significant temporal pattern in bone size, but the authors were unable to explain the cause of this temporal trend.

Owsley (1991) used femoral cortical bone thickness obtained from radiographs to investigate changes in the nutritional status of Coalescent tradition groups. Previous archaeological evidence suggested that the Extended (EC) and Disorganized Coalescent (DC) groups had a relatively poor health and nutritional status compared to Postcontact Coalescent (PC) groups. Poor climatic conditions probably played a key role during the EC, while the introduction and diffusion of infectious diseases and increased inter-tribal conflict were primarily responsible for the decline in health during the DC. Owsley (1991) hypothesized that cortical bone thickness would be greater during the PC than the EC or DC because of improved nutritional status, and his results seem to support this hypothesis.

Redmond (1997) expanded on Owsley's (1991) study by adding data from Central Plains Tradition sites, Initial Middle Missouri variant sites, protohistoric Pawnee, and historic Crow. However, her results were not as clear-cut as Owsley's (1991). Like Owsley (1991), Redmond (1997) discovered that the Coalescent groups followed the expected pattern. That is, she observed an increase in cortical bone thickness from the Extended to the Postcontact Coalescent and a decrease from the Postcontact to the Disorganized Coalescent. Observations of the Crow also follow the expected pattern. The Crow are known to have suffered high levels of nutritional stress, and they were observed to have relatively thin cortical bone. However, for the Central Plains tradition (CPT) and Initial Middle Missouri (IMM), the evidence was less straightforward. The CPT and IMM groups are also thought to have exhibited high nutritional stress, but they exhibited relatively thick cortical bone. Redmond (1997) concluded that biomechanical differences among the groups might have played a role in the disparity between her observations and her expectations.

Cole (1994) and Ruff (1994) both examined long bones from the Plains in order to investigate group differences due to activity patterns. Cole (1994) augmented Zobeck's (1983) external measurement data with Woodland and Middle Missouri tradition samples to examine postcranial changes associated with the transition from hunting and gathering to agriculture in the Northern Plains. His results suggest that the pattern of variation in the Northern Plains does not follow subsistence patterns, contrary to work in other geographical areas (Bridges, 1989a, 1989b; Bridges et al., 2000; Larsen and Ruff, 1994; Ruff, 1999). While Cole (1994) found few size differences in same sex

samples between hunter-gatherers and horticulturalists, in other geographical regions, hunter-gatherers are generally larger and more robust (Ruff, 2000a). Sexual dimorphism also appears to be similar in both subsistence groups in the Northern Plains, but in other regions, sexual dimorphism is generally greater in hunters and gatherers (Larsen and Ruff, 1991; Larsen et al., 1995; Ruff, 1999, 2000a; Ruff and Hayes, 1983a, 1983b; Ruff et al., 1984).

Ruff (1994) examined cross-sectional morphology of the femur in a Plains sample consisting of Woodland, Middle Missouri, and Post-contact Coalescent from the Northern Plains and a Washita River phase population from the Southern Plains. Ruff (1994) conducted two analyses. The first analysis compared cultural-temporal groups, while the second compared pre-horse and post-horse groups. Ruff's (1994) results indicate that sexual dimorphism in cross-sectional size declines with time. Early horticulturalists on the Plains exhibit about the same degree of sexual dimorphism as hunter-gatherer groups in other regions, but later horticulturalists show a reduction in sexual dimorphism (Ruff, 1994). The most significant result of Ruff's (1994) study was that femoral midshaft cross-sections from the Southern Plains exhibit significantly more anteroposterior elongation than femoral cross-sections from the Northern Plains. Owsley and Jantz (1999) found similar results using external dimensions when they compared femora from the Southern and Northern Plains.

In general, postcranial studies from the Plains have raised more questions than they have answered. Why do femora from Central Plains Tradition sites exhibit thicker cortical bone than expected? Why is there little size and shape difference between

hunters-gatherers and horticulturalists on the Northern Plains when there are significant differences between these two subsistence groups in other geographical regions? Why do Southern Plains femora exhibit more anterioposterior elongation when the subsistence patterns in the Southern Plains were not markedly different from those in the Northern Plains? A comprehensive analysis of Plains postcranial remains is necessary to address these questions and others. Owsley and Jantz (1999) point out the need to evaluate hypotheses concerning human adaptation and environmental response. Particularly, the relationship between subsistence strategies and variation in long bone size, robusticity, sexual dimorphism, and asymmetry need further analysis. Ruff (1994) also suggests that a study including larger samples and cross-sections of the upper limb is needed. This study fills these gaps in our knowledge of structural variation in Plains postcrania.

CHAPTER 3

BONE STRUCTURE AND BONE BIOMECHANICS

Numerous factors contribute to the development of healthy long bones including genetics, diet, hormones, and mechanical loading. Ruff and colleagues (Larsen, 1997; Ruff, 2000a; Ruff and Hayes, 1983a, 1983b; Ruff et al., 1994; Trinkaus, 1999; Trinkaus et al., 1994, 1999) have argued that mechanical usage is probably the most important factor in determining long bone morphology, and therefore the application of engineering principles to long bone cross-sectional properties can be very beneficial in reconstructing behavior from archaeological populations. This chapter outlines the function of bones and the biological processes responsible for bone size, shape, and robusticity. In addition, the biomechanical model is discussed, as are the effects of subsistence strategy, terrain, climate, health, nutrition, and sex on long bone cross-sectional morphology.

Function of Bone

Bone is a dynamic connective tissue that has both metabolic and structural (mechanical) functions. Metabolically, the skeletal system plays an integral role in the production of blood cells and the storage of fat and mineral salts, especially calcium, phosphorous, and magnesium. However, the primary role of the skeleton system is mechanical (Frost, 1987; Martin et al., 1998). Structurally, the skeleton provides protection of vital organs, supports the body against gravity, and provides a rigid lever system for movement. All of the structural functions of bone require that it endure high

mechanical loads without permanent deformation. In order to achieve this, bone constantly adjusts to its mechanical environment by changing its size, shape, mass, and mineral composition. However, change in bone architecture primarily occurs during childhood and adolescents when modeling is most active.

The primary loading forces on bone are tension, compression, bending, and torsion, with the latter two being the most important in long bones (Larsen 1997). Torsional and compressive loadings occur when equal and opposite forces are directed away from and toward the section of bone being loaded, respectively (Figure 3.1). Bending force involves compression on the concave surface and tension on the convex surface of the bone. Torsion, on the other hand, is a combination of compression, tension, and shear, and occurs when the bone is twisted (Figure 3.1).

Bone Biomechanics

Skeletal morphology is determined by the interaction of numerous factors, but the interdependence between bone morphology and function has long been known (Wolff 1870) and is well substantiated in the literature (Frost, 1987, 1988; Lanyon et al., 1982; Martens et al., 1980; Martin et al., 1998). Researchers have demonstrated that a bone's architecture (i.e., size, shape, and distribution of structural tissue) is adapted to meet the functional demands placed on it during normal physical activities (Frost, 1985, 1987, 1997).

Modeling and remodeling are the biological mechanisms responsible for determining the size and architecture of a bone (Martin et al., 1998). During growth and

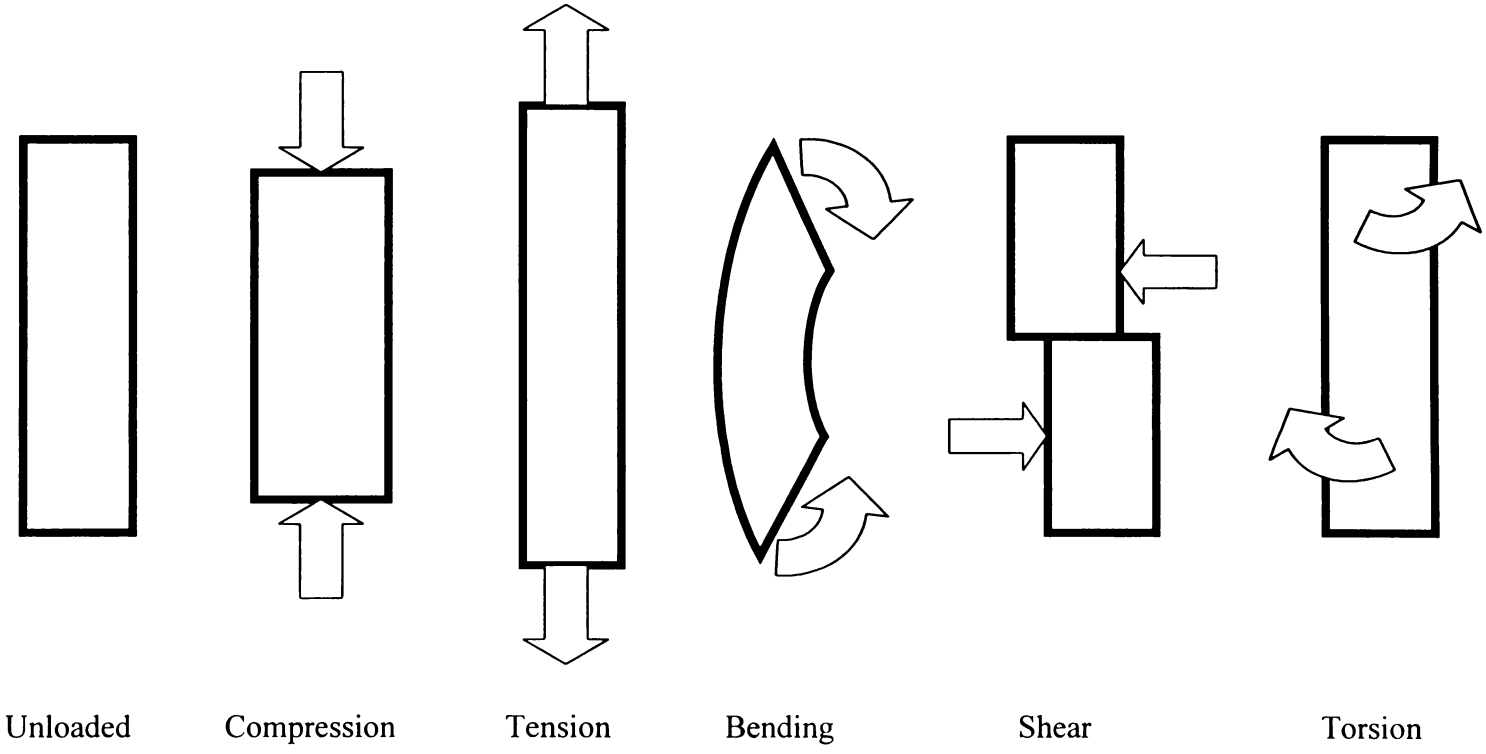


Figure 3.1. Loading forces that affect long bones.

development, the skeleton models according to the mechanical demands placed on it, resulting in an adult skeleton that is "biomechanically adapted" (Frost, 1985, 1988, 1997). In adulthood, the skeleton remodels in response to mechanical forces in such a way that bone is either maintained or lost. Because of the importance of modeling and remodeling in determining bone size and shape, a more detailed explanation of each concept is needed.

Modeling

Modeling is the biological process of shaping or sculpting bones, and ultimately determines the size and shape of adult skeletal structures. According to Frost (1985:213), "The major purpose of bone modeling is the sizing and shaping of intact bones, and the amount of compact bone in them in order to meet the needs of their typical peak mechanical loads" (Frost, 1985:213). Specifically, bone is modeled in such a way so that normal daily activities do not produce strains that exceed the minimum effective strain (discussed below).

In order to shape a bone, modeling removes bone from some surfaces and adds bone to others. Unlike remodeling, modeling involves the activation of osteoclasts and subsequent resorption of bone or activation of osteoblasts and subsequent formation, but not both at the same locus. Osteoclastic activity at a locus will result in a resorption drift, while osteoblastic activity causes a formation drift (Figure 3.2).

Modeling appears to first respond to growth, second to increases in body mass and muscle strength, and finally to mechanical usage (Frost, 1985). During growth, the

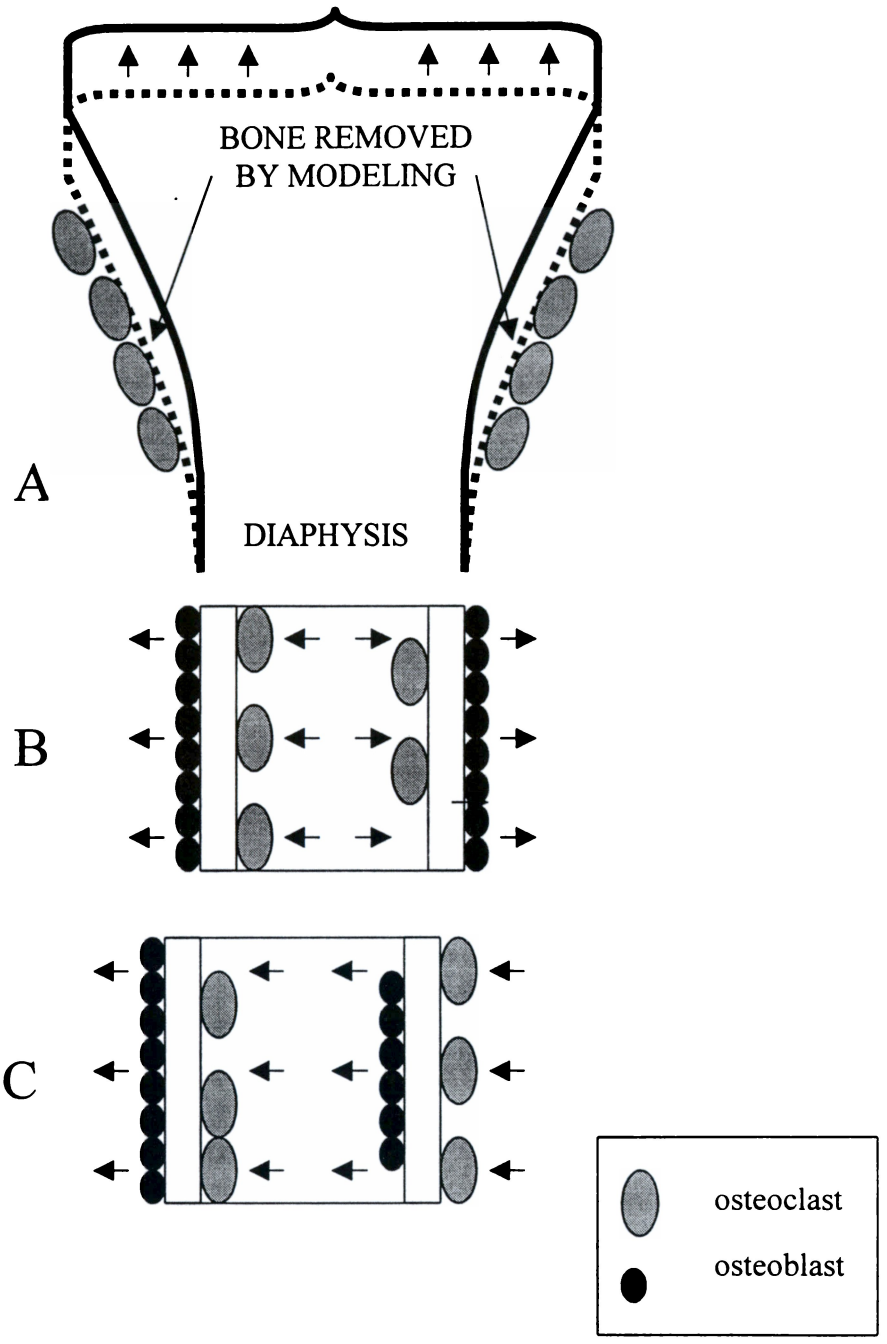


Figure 3.2. Bone Modeling. (A) As a child's bone grows, resorptive modeling (osteoclastic activity) beneath the growth plate forms the diaphysis from the metaphysis. (B) Formation drift (osteoblastic activity) on the periosteal surface and resorption drift (osteoclastic activity) on the endosteal surface enlarge the cross-sectional size of the diaphysis. (C) Diaphyseal curvature is altered by formation and resorption drift acting to "drift" the diaphysis. After Martin et al. (1998: Figure 2.19). Skeletal Tissue Mechanics. New York: Springer.

basic shape of a bone must be maintained as it increases in length. That is, bone produced at the metaphysis must be reduced to create a narrower diaphysis (Martin et al., 1998) (Figure 3.2). This is accomplished by osteoclastic resorption of bone on the periosteal surface of the metaphysis. Modeling also increases the diameter of a growing diaphysis by adding new bone to the periosteal surface and removing bone on the endosteal surface. In a bone that receives high mechanical usage, bone is laid down on the periosteal surface more rapidly than bone is absorbed on the endosteal surface, resulting in a diaphysis with greater cortical area.

Interestingly, modeling is primarily a phenomenon of growth (Frost, 1985). As the skeleton reaches maturity, modeling drift decreases to a trivial level. This is primarily because body mass and muscle strength plateau at maturity (Frost, 1997). In the healthy adult skeleton, modeling only occurs in cases where mechanical usage is radically altered (Frost, 1997). The adult skeleton is primarily affected by the process of remodeling.

Remodeling

Remodeling is the biological process that repairs bone microdamage by removing small packages or portions of older bone and replacing them with new bone (Frost, 1987; Martin et al., 1998). Unlike modeling, remodeling involves the coupled actions of osteoblasts and osteoclasts at the same locus in an "activation → resorption → formation" sequence (ARF). Frost (1987) has termed osteoblasts and osteoclasts the basic multicellular units (BMU) of remodeling. During remodeling, osteoclasts are activated, forming a resorption cavity about 200 micrometers in diameter by removing bone.

Several days later, osteoblasts enter the resorption cavity and begin to replace the resorbed bone, resulting in the production of a secondary osteon (Figure 3.3). The entire remodeling process takes approximately four months in humans—approximately three weeks for resorption and twelve weeks for formation (Frost, 1997; Martin et al., 1998).

Mechanostat and Minimum Effective Strain

Frost (1983a, 1983b, 1987) developed a theory that explains bone architecture in terms of the mechanical loading environment. This theory has been coined the "mechanostat" model. Mechanostat is analogous to a thermostat in which the mechanisms for bone modeling and remodeling are turned "ON" and "OFF" depending on the magnitude of strain caused by mechanical loading (Frost, 1987). Modeling is activated when strains exceed a particular threshold and remodeling is triggered when strains fall below a lower threshold. Figure 3.4 illustrates the effect of mechanical loading on bone modeling and remodeling.

The modeling threshold or minimum effective strain for modeling (MESm) is reached when loads exceed 2000 microstrains (Frost, 1973, 1983a, 1987). Activities that generate strains above the MESm will evoke architectural changes via modeling. During vigorous mechanical usage, modeling increases accumulation of compact bone (Table 3.1). As a result, the external diameter of the bone increases and the marrow cavity remains relatively small (Frost, 1985, 1987). Strains below the MESm do not activate modeling, and if strains remain below the MESm, modeling will remain dormant and the bone is considered biomechanically adapted.

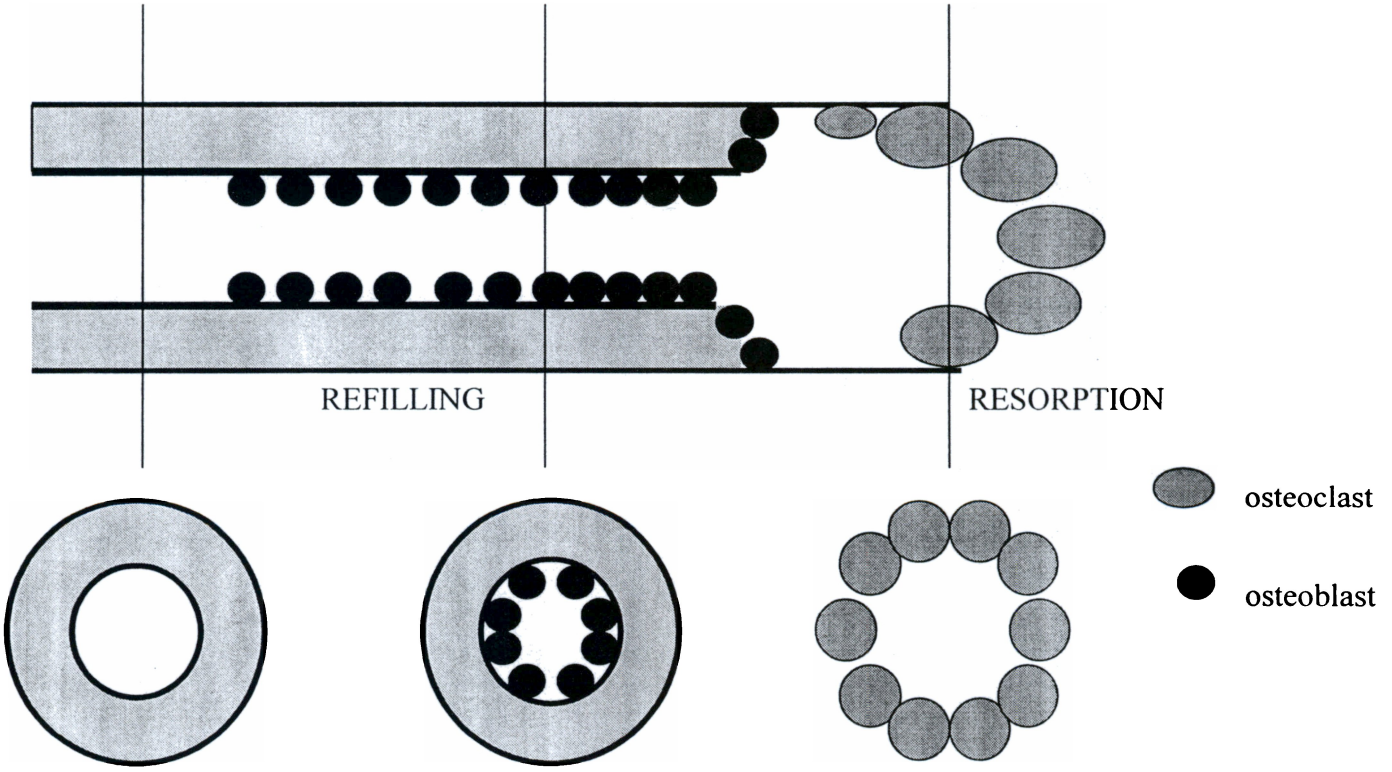


Figure 3.3. Schematic diagram of the sequential osteonal basic multicellular unit (BMU) process in cortical bone remodeling. Remodeling involves activation, followed by resorption by osteoclasts, followed by formation by osteoblasts.

Figure 3.4. The effects of modeling and remodeling on diaphyseal strength. The solid outline curves illustrate the combined effect of modeling and remodeling on bone strength. Remodeling permanently removes bone when bone strains are below the MESr or in the disuse window (DW), but conserves bone at strains above the MESr. Strains above the MESr and below MESm are within the adaptive window (AP) or "comfort zone." Modeling and remodeling maintain bone mass and strength in the adaptive window. Mild overloading occurs when strains exceed MESm. In the mild overload window (MOW), modeling responses strengthen the diaphysis through lamellar bone drift. Pathological levels of strain can cause microscopic fatigue damage (i.e., strain levels at or above MESp) and eventually bone failure (Fx). In the pathological overload window (POW), woven bone formation replaces lamellar bone formation. Adapted from Frost HM (1997; Figure 1) Why do marathon runners have less bone than weight lifters? A vital-biomechanical view and explanation. Bone 20:183-189.

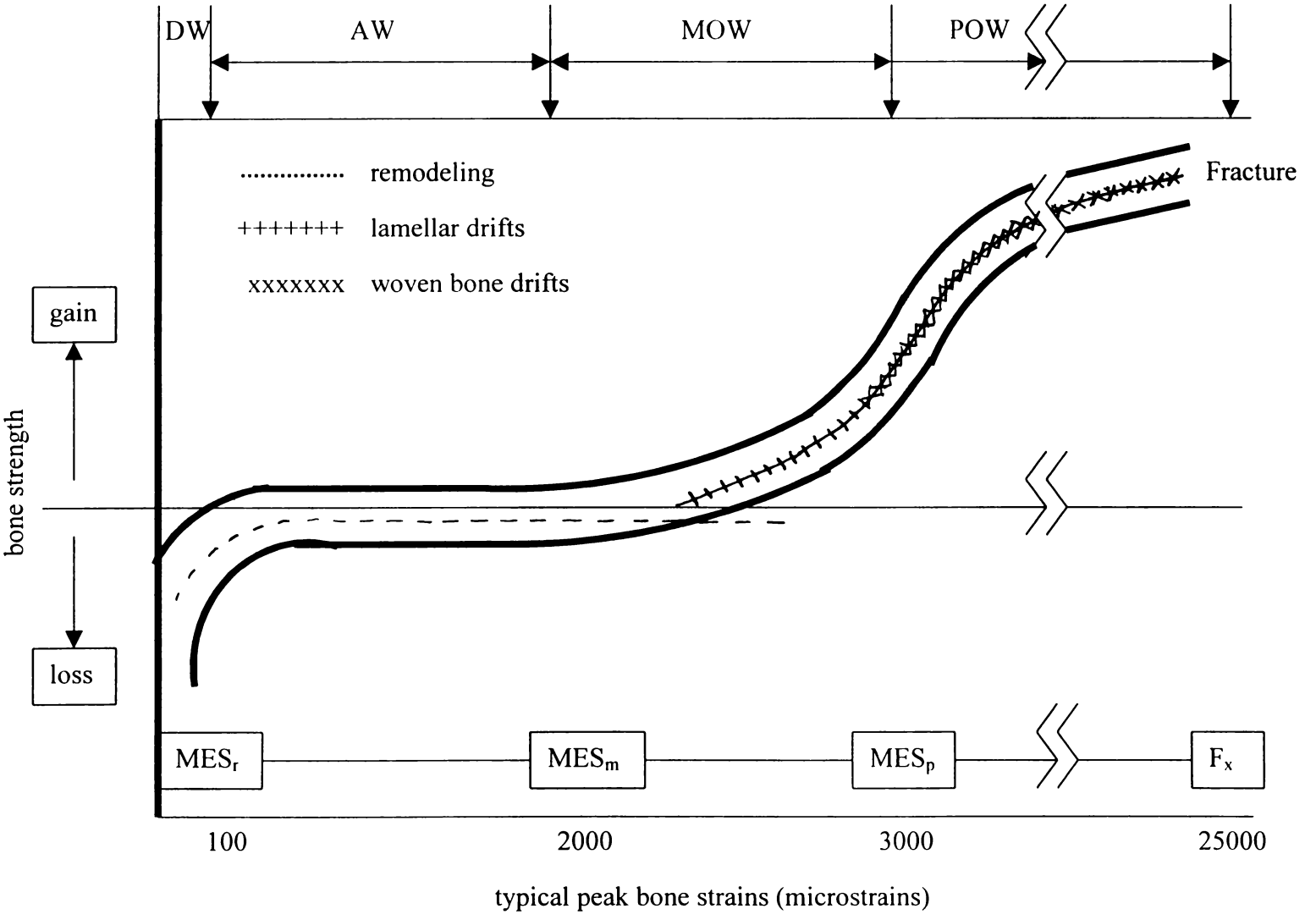

DW
AW
MOW
POW
remodeling
lamellar drifts
woven bone drifts
Fracture
gain
loss
bone strength
MES$_r$
MES$_m$
MES$_p$
F$_x$
100
2000
3000
25000
typical peak bone strains (microstrains)

Table 3.1. Mechanical usage (MU) effects on bone growth, modeling, and global remodeling.

MU Response	***Effect on Growth, Modeling, and Global Remodeling***	***Effects on Long Bone Mass and Architecture in Adults and Children***
Increases	growth and modeling increase, global remodeling decreases	Adults: bone mass conserved Children: bone mass, external diameter, cortical area, diaphyseal strength, and growth in length increased, marrow cavity reduced, denser spongiosa
Decreases	growth and modeling decrease, global remodeling increases	Adults: mass decreases due to marrow cavity expansion, osteopenic spongiosa Children: gains in mass, external diameter, cortical area, Diaphyseal strength, and growth in length decreased

Frost (1997) argues that remodeling has "disuse" and "conservative" modes. When loads fall below 50 to 100 microstrains or the minimum effective strain for remodeling (MESr), remodeling will result in permanent bone loss (osteopenia) on the endosteal surface because osteoclastic activity exceeds osteoblastic bone formation (Figure 3.4) (Frost, 1987; 1997). In the conservative mode, osteoclastic and osteoblastic activities are nearly equal and bone mass and strength are preserved. During the conservative mode, remodeling is primarily functioning to repair microdamage caused by repeated mechanical loads.

The processes of modeling and remodeling, which are controlled by mechanical usage, work together to determine the size and shape of long bone diaphyses (Table 3.1). If mechanical usage produces large loads, modeling will increase. When mechanical usage is low, remodeling removes more bone than it produces and modeling is disengaged. Loads above 100 microstrains but below 2000 microstrains are in the "comfort zone" and bone mass is maintained during the remodeling process. In subadults, mechanical usage above the MESm results in an increase in diaphyseal external diameter, cortical cross-sectional area, and strength. Applied compressive and tensional strains result in an increase in outside diameter and cortical thickness that is equally distributed along the diameter. If bending is involved, formation drift adds new bone to surfaces under concave-bending flexure and resorption drift removes bone under convex-bending flexure. Mechanical usage below the MESm in subadults will maintain present cross-sectional properties. In adults with high mechanical usage, remodeling will conserve

cortical and trabecular bone, while low mechanical usage will result in a loss of cortical bone due to expansion of the medullary cavity (Frost, 1997; Ruff et al., 1991).

Frost's mechanostat theory easily explains why modeling is primarily a phenomenon of growth, why bone mass is reduced in immobilized individuals, and why, for example, weight lifters exhibit more robust bones than distance runners. The largest mechanical loads placed on bones are from the contraction of muscles (Frost, 1997). In rapidly growing children, body mass and increased muscle strength quickly exceed bone strength, and therefore loads beyond the MESm are common (Frost, 1997). By the time an individual reaches approximately 20 years of age, body mass and muscle strength begin to level out or equalize and bone mass, strength, and architecture can finally catch-up with body mass and muscle strength (Frost, 1997). Similarly, activities such as weight lifting cause strains that frequently exceed the MESm, while running does not. Modeling responds to the magnitude of the load and not its frequency (Frost, 1997). Weight lifting requires large, strong muscles that produce considerable loads on long bones. Runners, on the other hand, have leaner and weaker muscles that do not regularly produce loads greater than the MESm. The frequent loading on the lower limbs caused by running would intensify microdamage and therefore increase remodeling, but loads would not be great enough to activate modeling. Frost (1997:186) points out "bones do not need greater strength to endure more numerous loads as long as strains stay below the microdamage threshold and microdamage repair works properly." Individuals that run long distances should exhibit relatively more gracile bones than weight lifters and show evidence of increased remodeling in the lower limbs only.

Biomechanical Model

Biomechanics is the application of engineering principles to biological systems. In a biomechanical model, a long bone is modeled as a beam, and bone is treated as a dynamic tissue that continuously modifies itself in relation to the types and magnitude of mechanical loads placed on it during life. In the last two decades, researchers have extensively used engineering principles to address the relationship between long bone cross-sectional geometric properties and biomechanical force. The results suggest that modeling and remodeling modify the basically tubular shaped long bone with a circular cross-section so that the long bone's midshaft diameter, cross-sectional shape, and cortical thickness reflect the manner and magnitude of the biomechanical forces placed on the bone during life. While bone density changes in response to mechanical loading, the major response to increases in mechanical loading of long bones is in its cross-sectional distribution (Larsen, 1997). Since the level of mechanical force is proportional to the distance from the neutral axis, long bones are more resistant to bending if the cross-sectional distribution of the bone is oriented further away from the neutral axis (Larsen, 1997; Ruff, 2000).

Cross-Sectional Properties of Long Bones

If a long bone cross-section is considered, its geometric properties act as a measure of the amount and the distribution of bone in the section and provide valuable information about a bone's resistance to mechanical forces. Cortical area (CA), the amount of bone in a section, acts as a gauge of the bone's resistance to direct tensile and

compressive loadings (axial loadings). To derive cortical area, the endosteal or medullary cavity area (MA) is subtracted from the total subperiosteal area (TA) of the section (CA = TA – MA).

Second moments of area approximate a long bone's ability to resist bending and torsional forces applied about a neutral axis. Both the cross-sectional area and the distribution of cortical bone are measured in second moments of area. The bending second moment of area (I) is calculated by:

$$I = \int_A y^2 dA$$

where dA is a small uniform area and y is the perpendicular distance of the center of dA from a neutral axis. In other words, I is calculated by dividing the cross-section into a series of uniformly sized areas, multiplying each area by the squared distance from the neutral axis, and integrating this over the entire cross-section (Figure 3.5). The bending second moment of area (I) can be calculated about any neutral plane in a cross-section. Conventionally, the second moment of area is calculated about the anteroposterior (I_{AP}) and mediolateral (I_{ML}) axes and the minimum (I_{min}) and maximum (I_{max}) axes.

The ratio of I_{AP} / I_{ML} has been labeled the "mobility index" by Larsen (1997). A value of 1.0 for the mobility index indicates a round cross-sectional shape, while values greater than 1.0 indicate the cross-section is more elongated in the anteroposterior plane (Ruff, 1987). Likewise, a value less than 1.0 indicates the cross-section is expanded mediolaterally. The ratio of I_{AP} / I_{ML} provides a good estimate of the direction of mechanical forces placed on a long bone diaphysis.

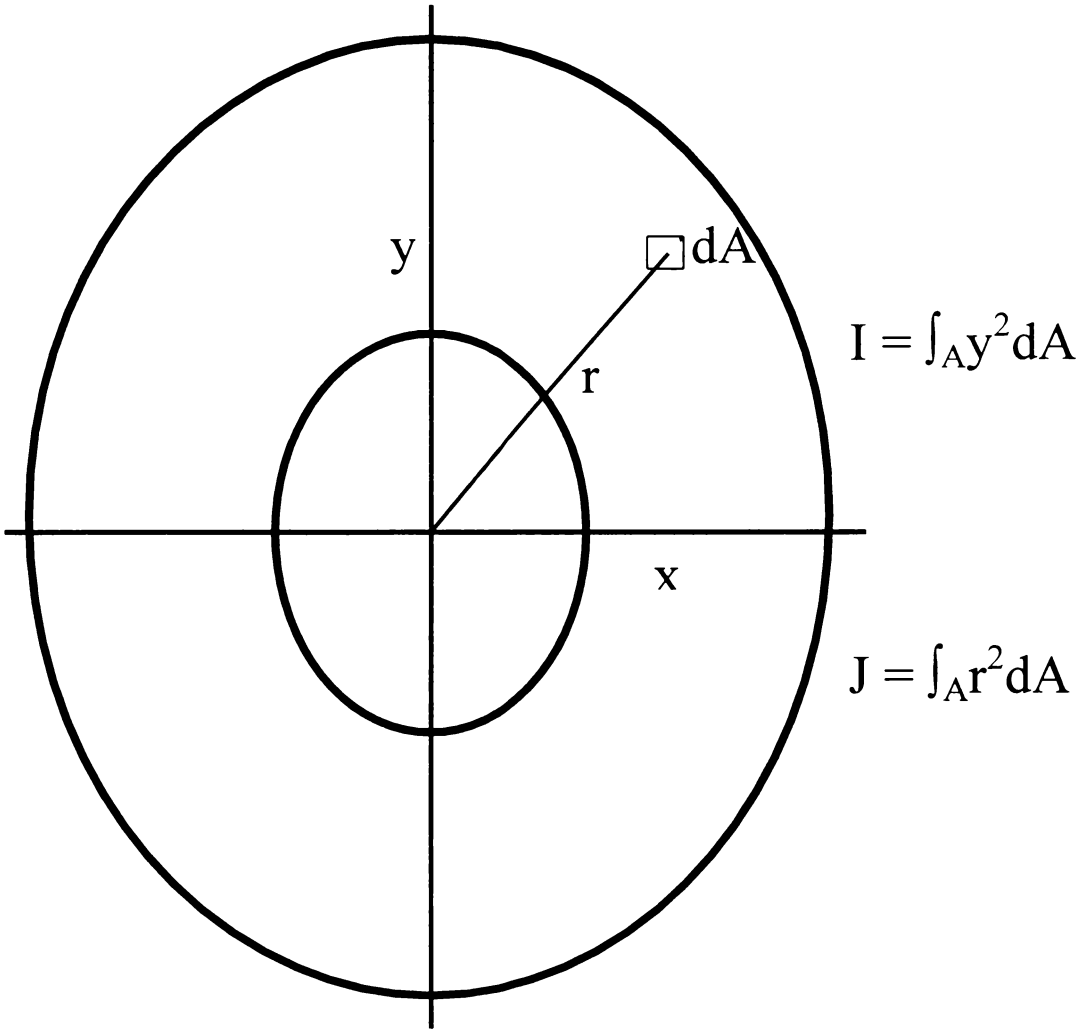


Figure 3.5. Calculation of cross-sectional moment of area (I) and polar moment of area (J).

Calculation of the torsional second moment of area, or polar second moment of area (J), is similar to the calculation of the bending moment of area except that dA is multiplied by the squared distance from the center of the cross-section (r) instead of the squared distance from the neutral axis:

$$J = \int_A r^2 dA$$

The polar second moment of area is also equivalent to the sum of any two perpendicular values of the bending second moment of area (I) (e.g., $I_{max} + I_{min}$).

Factors Affecting Geometric Properties

Cortical bone is significantly affected by body mass, while second moments of area are significantly affected by both body mass and bone length (Ruff, 2000b; Ruff et al. 1991). Therefore, when using bone cross-sectional structure to interpret physical activity, it is necessary to control for body size and mass because heavier and/or taller individuals will exhibit greater second moments of area and appear to be more robust or physically active. Ruff (Ruff et al.,1993; Ruff, 2000a, 2000b) has shown that when body mass is factored out, cortical area is proportional to bone length cubed ($length^3$) and moments of area are proportional to length to the 5.33 power ($length^{5.33}$). As a result, Ruff (2000a) suggests dividing cortical area by bone length cubed and second moments of area by bone length to the power 5.33 when groups of different body size are compared.

Cross-sectional properties of long bones can also be affected by age. Final maturation of the human skeleton generally occurs during the second and third decades of

life, but the adult skeleton is not the static structure once thought. Continued growth or expansion of the skull, humerus, femur, and tibia has been documented through a series of longitudinal and cross-sectional studies (Adeloye et al., 1975; Baer, 1956; Behrents, 1985, 1990; Israel, 1973, 1977; Martin et al., 1980; Pfeiffer, 1980; Ruff, 1980; Ruff and Hayes, 1983b; Smith and Walker, 1964). These studies have shown that expansion of adult bones is caused by continued deposition of new lamellar bone. Feik et al. (2000) found, using a modern Anglo-Celtic Australian population, that the femoral midshaft becomes larger and rounder with age in both sexes, but the greatest change occurring between young (20-40 yrs.) and middle (41-60 yrs.) aged males and between middle and old (61+) aged females. That is, femoral midshaft geometry appear to vary most in the middle years of life.

It is possible that part of the changes seen by Feik et al. (2000) is associated with secular change. Rockhold (1998), in her study of secular change in the femoral midshaft shape in modern American whites and blacks, discovered a significant increase in anterioposterior elongation (due to mediolateral narrowing) of the femoral cross-section from 1840 to the mid 1970s. Rockhold (1998) also tested for age differences by controlling for date of birth. Her results indicated midshaft circumference, subtrochanteric anterioposterior dimension, and subtrochanteric shape are significantly affected by age, but midshaft shape was not.

These studies indicate that mechanical compensation is the most likely cause of adult bone growth. As the skeleton ages, endosteal resorption reduces bone volume and thus decreases bone strength. To compensate for the loss of strength, new lamellar bone

is laid down on the periosteal surface causing the bone to expand away from the central axis. Therefore, in studies using a biomechanical approach, it is important to account for age differences in the samples being analyzed as age-related bone expansion increases the second moments of area.

Estimation of Cross-Sectional Properties from External Dimensions

While cross-sectional analysis requires the use of nearly complete bones, external dimensions can be obtained from less well-preserved bones. As a result, a more complete assessment of population variability can often be attained with external dimensions than with cross-sectional data, as archaeological skeletal collections are replete with fragmentary bones. External dimensions are limited in a biomechanical approach, but they do provide a good estimate of the cross-sectional properties of long bones (Jungers and Minns, 1979). The division of the anteroposterior diameter by the mediolateral diameter of a diaphysis can be used to estimate the mobility index. Rockhold (1998) compared the I_{AP} / I_{ML} ratio to the externally derived ratio on Ruff's (1994) Plains sample and found a high correlation (R^2 = 0.82). Robusticity of a long bone, which measures the average resistance to bending, can also be calculated as the sum of the diaphyseal mediolateral and anteroposterior breadths divided by bone length ([AP + ML] / Length), or as the square root of the product of the mediolateral and anteroposterior breadths divided by bone length ($\sqrt{AP*ML}$ / Length). The polar second moment of area (J) can also be reasonably estimated using external measurements. Pearson (2000) found the

relationship between external midshaft diameters to be highly correlated ($R^2 = 0.89$) with J calculated from cross-sectional data.

Anthropological Studies in Bone Biomechanics

Over the last 3 decades, biomechanical theory has been applied extensively in investigations of archaeological skeletal material to help reconstruct behavioral patterns (Bridges, 1989; Bridges et al., 2000; Brock and Ruff, 1988; Fresia et al., 1990; Larsen et al., 1992; Ruff, 1994, 1999; Ruff and Hayes, 1983; Ruff et al., 1984, 1994; Trinkaus et al, 1991; Van Gerven et al., 1985; Wescott, 2001). These studies have shown a correlation between long bone cross-sectional properties and subsistence strategies, terrain, climate, and diet.

Investigations of long bone morphology have also shown that the use of both upper and lower limb bones provide a greater understanding of behavioral patterns than do the use of lower limb bones alone (Bridges et al., 2000; Larsen, 1989). This section discusses anthropological studies using biomechanical models and the importance of using both upper and lower limb bones.

Long-Term Evolutionary Trends

Studies comparing femora and humeri of recent and fossilized humans show several significant temporal trends. Over the past two million years of *Homo* evolution, femoral midshaft robusticity (i.e., diaphyseal cortical area and strength relative to length) has steadily declined, while femoral head diameter has not changed significantly (Ruff,

2000a; Ruff et al., 1993). Ruff et al. (1993) link the temporal decline in femoral cross-sectional properties to improved cultural technology for interacting with the environment. The most significant evolutionary trend in the humerus is a reduction in bilateral asymmetry of diaphyseal strength (Trinkaus et al., 1994; Ruff, 2000a). On average, Paleolithic samples exhibit more than 30% asymmetry, while modern populations rarely exceed 15% asymmetry in shaft strength. However, asymmetry of the humeral distal articular surface has not significantly changed from the Middle Paleolithic to modern times. Based on these observations and those from the femur, Trinkaus et al. (1994) argue that articular surface size is much less plastic than diaphyseal cross-sectional size. In general, humeral diaphyseal robusticity has not shown the same clear trends as the femur. Trinkaus and Ruff (1999) found that European Upper Paleolithic specimens have more gracile (based on cortical area) and rounder proximal (65% from distal end) humeral diaphyses than Middle Paleolithic specimens, but there is no significant difference in cortical area or shape at the distal end (35% from distal end).

Trinkaus and Ruff (1999) compared femora of archaic and early modern Near East Middle Paleolithic fossils and Eurasian Upper Paleolithic specimens. Their results showed no significant differences in skeletal robusticity between late archaic and early modern fossils when scaled for bone length and body mass, but femoral midshaft diaphyseal shape was different. The late archaic specimens from Amud, Kebara, Shanidar and Tabun exhibit mediolaterally strong ovoid cross-sections and no pilaster. The early modern specimens, however, display a clear pilaster and distinct posteromedial and posterolateral flattening. This trait is also observed in Upper Paleolithic specimens.

The modern specimens also exhibit greater anteroposterior bending strength than mediolateral bending strength. Trinkaus and Ruff (1999) also observed femoral subtrochanteric shape differences between the Middle and Late Paleolithic specimens. The Middle Paleolithic proximal femoral diaphyses are relatively round compared to the platymeric shaft of Upper Paleolithic populations. Trinkaus and Ruff (1999) argue that this difference reflects differences in body proportion rather than activity patterns because the proximal femur is influenced by pelvic morphology.

Subsistence Strategy (Activity and Mobility)

The majority of biomechanical studies in anthropology have focused on the transition from a hunting and gathering to a maize agriculture economy in North America. The adoption of agriculture as a primary means of subsistence is accompanied by changes in social organization, material culture, activity levels, activity patterns, and sexual division of labor, and therefore provides a good point to examine structural differences in long bone morphology associated with activity. This section outlines the effect of activity on long bone morphology associated with the intensification of agriculture.

A number of researchers have observed a disparity in long bone robusticity between hunter-gatherers and agriculturalists, although there appears to be distinct regional variability in this pattern (Bridges, 1995). Bridges (1989) observed an increase in bone strength among prehistoric populations in Alabama during the shift to agriculture as a primary means of subsistence. Ruff and Larsen (1990), on the other hand, found that

bone strength declines with the introduction of agriculture along the Georgia coast. In the Great Plains no significant differences were found between pre-agricultural and agricultural groups (Cole, 1994; Ruff, 1994). In west-central Illinois, Bridges et al. (2000) detected an altogether different pattern. They found that the level of physical activity increases in women when the intensive horticulture of native seed crops began, and then declines slightly with the adoption of maize as a staple food.

The most consistent effects of subsistence strategy on cross-sectional properties are shape changes in femoral midshaft and changes in the degree of sexual dimorphism in femoral midshaft shape and robusticity (Ruff, 1987, 1999, 2000a). In general, hunter-gatherers, particularly males, exhibit more anteroposterior bending strength at the femoral midshaft than agriculturalists. As a result, agriculturalists typically have a rounder femoral diaphysis compared to hunter-gatherers. Ruff (1987) also examined sexual dimorphism in femoral midshaft shape by utilizing a large dataset of femoral and tibial cross-sections from a wide variety of archaeological and recent American and Japanese groups. His results suggest sexual dimorphism in cross-sectional shape declines from pre-agriculture to agriculture to industrial subsistence patterns. The interaction between sex and subsistence strategy is only significant in hunting and gathering populations. In other words, there is no significant shape difference between male and female agriculturalists, but there is a significant shape difference between the sexes in preagricultural groups. Ruff (1987, 2000a) argues that the decline in sexual dimorphism is associated with a reduction in the division of labor, especially of differences in mobility. That is, mobility is greatest in hunting-gathering males and declines greatly in

agricultural and industrial males, and therefore hunter-gatherer males exhibit relatively greater anteroposterior bending strength of the lower limbs.

The pattern of a rounder femur and reduced sexual dimorphism associated with the adoption of agriculture has been observed in many regions of the United States including the Southeast (Bridges, 1989; Bridges et al., 2000), Southwest (Brock and Ruff, 1988; Ruff and Hayes, 1983), Great Basin (Larsen et al., 1995; Ruff, 1999) and the Great Plains (Ruff, 1994). Interestingly though, Rockhold's (1998) study of secular change in femoral midshaft dimensions of American whites and blacks from 1840 to the mid-1970s indicate a significant increase in anteroposterior elongation of the femoral shaft. In general, she observed little change in the anteroposterior dimension of the midshaft but did see a significant decrease in the transverse dimension. If the ratio of I_{AP}/I_{ML} truly reflects differences in mobility, then Rockhold's (1998) results are difficult to explain. One would expect the femora to have become more circular as mobility decreased, but the opposite results were observed.

The humerus has not been as extensively studied as the femur, but there also appears to be considerable regional variability in humeral strength and cortical thickness. The most consistent finding in studies of the humerus is a reduction in bilateral asymmetry with the introduction of agriculture, especially in women. This will be discussed more fully below. Bridges (1989) observed increases in humeral strength with the adoption of agriculture in females, and attributed it to the increased mechanical loads associated with corn grinding. Likewise, Larsen (1982) found that among

agriculturalists, humeral strength increased after European contact on the St. Catherines Island probably due to the increased manual labor placed on these people by the Spanish.

Physical Environment (Terrain)

Very little research has been conducted on the relationship between terrain and long bone cross-sectional morphology, but according to Ruff (1999, 2000a), terrain may be one of the most significant factors affecting lower limb bone robusticity and strength. In fact, Ruff (2000a) argues that once terrain is factored out, the effect of subsistence strategy seems to greatly decline. In a comparison of populations from the mountains (Great Basin and Southwest), plains (South Dakota), and coastal (Georgia) regions. Ruff (1999) observed that populations in mountainous regions have significantly stronger (greater values of J) and more robust femora then populations with a similar subsistence economy in the other two regions. Interestingly, terrain appears to have no effect on femoral midshaft shape (I_{AP}/I_{ML}) or cortical area. Great Plains and coastal populations did not significantly differ from one another, but coastal populations do exhibit a lower mean bending and torsional strength compared to populations from the Plains.

Climate

Recently, Pearson (2000) investigated long bone robusticity in groups from different climates and subsistence economies. In general, he found that populations in cold environments are more robust than populations from warm climates.

Furthermore, cold climate hunter-gatherers tended to be more robust than agriculturalists, as would be expected, but in warm environments, hunter-gatherers were normally more gracile than agriculturalists. Pearson (2000) argues that warm climate hunter-gatherers are generally less robust because they have a greater reliance on gathering plant foods compared to hunter-gatherers in cold climates that obtain a significant amount of their daily calories from meat. That is to say, hunter-gatherers in cold climates are much more mobile than hunter-gatherers in warm climates.

Health and Nutrition

The health and nutrition of a population can also have a major effect on bone structure, especially cortical thickness. Malnutrition and chronic disease, particularly during childhood, can cause disruptions in the normal rate and pattern of bone modeling remodeling, resulting in a decreased cortical thickness (Frost, 1997). Nutrition and disease related bone loss occur most dramatically on the endosteal surface. The relationship between malnutrition and cortical bone thickness has been shown in living peoples (Garn, 1970; Garn et al., 1964), and Owsley (1994) and Redmond (1997, 2001) have both demonstrated the usefulness of examining cortical bone loss to detect nutritional stress in Northern Plains populations. Ruff (1999) has conducted the only investigation on the relationship between long bone structural properties and stable carbon isotope data ($\delta^{13}C$). The results of his study show a significant negative correlation between torsional strength (J) and the amount of maize consumption for both the humerus and femur. Individuals with high $\delta^{13}C$ values have relatively longer but less

robust bones. The reduction in robusticity with maize consumption is caused by a reduction in both periosteal and endosteal dimensions. Ruff (1999) observed that standardized cortical area also shows a negative correlation with $\delta^{13}C$ values for the femur but not the humerus. The Ruff (1999:311) concludes, "Together these results indicate that increasing amounts of maize in the diet are associated with *decreasing* femoral and humeral robusticity, at least in males."

Sexual Dimorphism

Besides the studies of cross-sectional shape conducted by Ruff and coworkers (Ruff, 1987; Ruff, 1994; Ruff and Hayes, 1983b; Ruff and Jones, 1981), several other investigations have focused on sexual differences in the postcranial skeleton. In a modern Australian population, Feik et al. (2000) found that males and females have comparably sized femoral midshafts when adjusted for stature, but like Ruff (1987), he found females tend to have cross-sections that are more circular. However, Feik et al. (2000) also found that the femoral midshaft becomes larger and more circular with age, with the greatest changes seen between young and middle aged adult males and middle and old adult females. As a result, middle aged males and females have a greater difference in femoral midshaft shape than do young or old adults. Eveleth (1975) discovered a strong genetic component to the degree of sexual dimorphism in stature, and Gray and Wolfe (1980) observed that societies with poor protein availability exhibit reduced sexual dimorphism in stature because of low mean male heights. However, they conclude that sexual dimorphism in stature cannot be used as a gauge of the nutritional status of a society.

Bilateral Asymmetry

The analysis of asymmetry, especially of the upper limb, can add another layer of information that is useful in the interpretation of behavior from long bone cross-sections (Ruff and Jones, 1981). Because maize agricultural females spent a great deal of time grinding corn, a task that requires equal use of both arms, they are generally more symmetrical than hunter and gatherer females. Repeated tool or weapon use may also affect levels of asymmetry. Bridges (1989) discovered that males become more symmetrical in cross-sectional properties with the introduction of the bow. However, Stirland (1993) found that use of a heavy longbow in medieval British males resulted in asymmetry of the greater tubercle of the humerus, and that the non-drawing shoulder and arm are typically larger.

Genetic Factors

While there is strong research data demonstrating the interdependence between long bone size and shape and biomechanical stress, there may also be a significant genetic component to cross-sectional size and shape. Gill and his students at the University of Wyoming have conducted a number of studies on ancestral differences in femoral subtrochanteric shape (Gilbert and Gill, 1990; Gill and Rhine, 1990; Miller, 1995; Voulgaris, 1999), and they conclude that Northwestern Plains Indians exhibit much greater subtrochanteric flattening or platymeria compared to historic whites and blacks. Miller (1995) argues that the platymeria seen in Northern Plains is apparent during early

growth and development, suggesting platymeria is controlled more by genetics than by biomechanical.

Ohman and Lovejoy (2001) have also argued that cross-sectional shape of the femoral midshaft is greatly influenced by development of the epiphyses. They observed that chimpanzee and gorilla femoral midshafts exhibit their maximum second moment of area along the mediolateral plane, despite the fact that both apes place a significant amount of anteroposterior loading on their femora. Ohman and Lovejoy (2001) argue that the wide mediolateral breadth of the femoral epiphyses in chimpanzees and gorillas causes the midshaft to also exhibit mediolateral expansion.

Advantage of Using of Multiple Bones and Properties

While the type and amount of biomechanical forces placed on a bone has a great effect on its overall cross-sectional size and shape, inferring activity patterns from cross-sectional properties is not a simple endeavor. As has been discussed in this chapter, subsistence strategies, terrain, age structure, health, and nutrition all seem to play a role in the final structure of a bone. In order to understand activity patterns, it is best to use both upper and lower limb bones, both right and left sides, and multiple geometric properties. An example of the advantage of using multiple bones and multiple properties can be seen in the work of Larsen and coworkers (1995), who examined femora and humeri from prehistoric foragers in the American Great Basin. The Great Basin foragers exhibited high values for TA and J in the femur and low values in the humerus. Cortical area and percent cortical area were low in both the upper and lower limbs. Larsen and coworkers

(1995) argue that the high bone strength in the femur is due to the ruggedness of the Great Basin terrain and not subsistence patterns. If this group was placing a large amount of stress on the bones due to regular heavy work, both the upper and lower limb bones should exhibit high values of TA and J. They argue that the thin cortical bone seen in both the humerus and the femur of Great Basin foragers is due to a systemic influence such as malnutrition.

CHAPTER 4

ARCHAEOLOGICAL AND HISTORICAL FRAMEWORK

In order to understand the biological and cultural adaptations of groups to the American Great Plains environment, anthropologists frequently contrast the lifestyles of Plains groups to those present in different geographical regions, or they compare and contrast difference subsistence patterns present within the Plains. For example, the American Great Plains are contrasted with the Southwest, Great Basin, and Eastern Woodlands, and the early Plains hunters are contrasted with the later Plains horticulturists. While an understandable means of describing the differing adaptations to the Plains, these types of dichotomies are probably over emphasized because the Plains have never been isolated (Wood, 1998). Since the earliest times, groups living on the Plains were in constant contact with their neighbors. Additionally, although some major differences exist between the early nomadic Plains hunters and later sedentary horticultural village dwellers, many similarities also exist between these groups. This chapter outlines the culture history of groups on the American Great Plains and adjacent regions (Figure 4.1), focusing on origins, settlement and subsistence patterns, and biological relationships.

Spatial Divisions of the Great Plains

Anthropologists divide the American Great Plains into five major cultural subareas (Figure 4.2) based on unique ecological conditions: Southern Plains, Central Plains, Middle Missouri, Northeastern Plains, and Northwestern Plains (Krause, 1969;

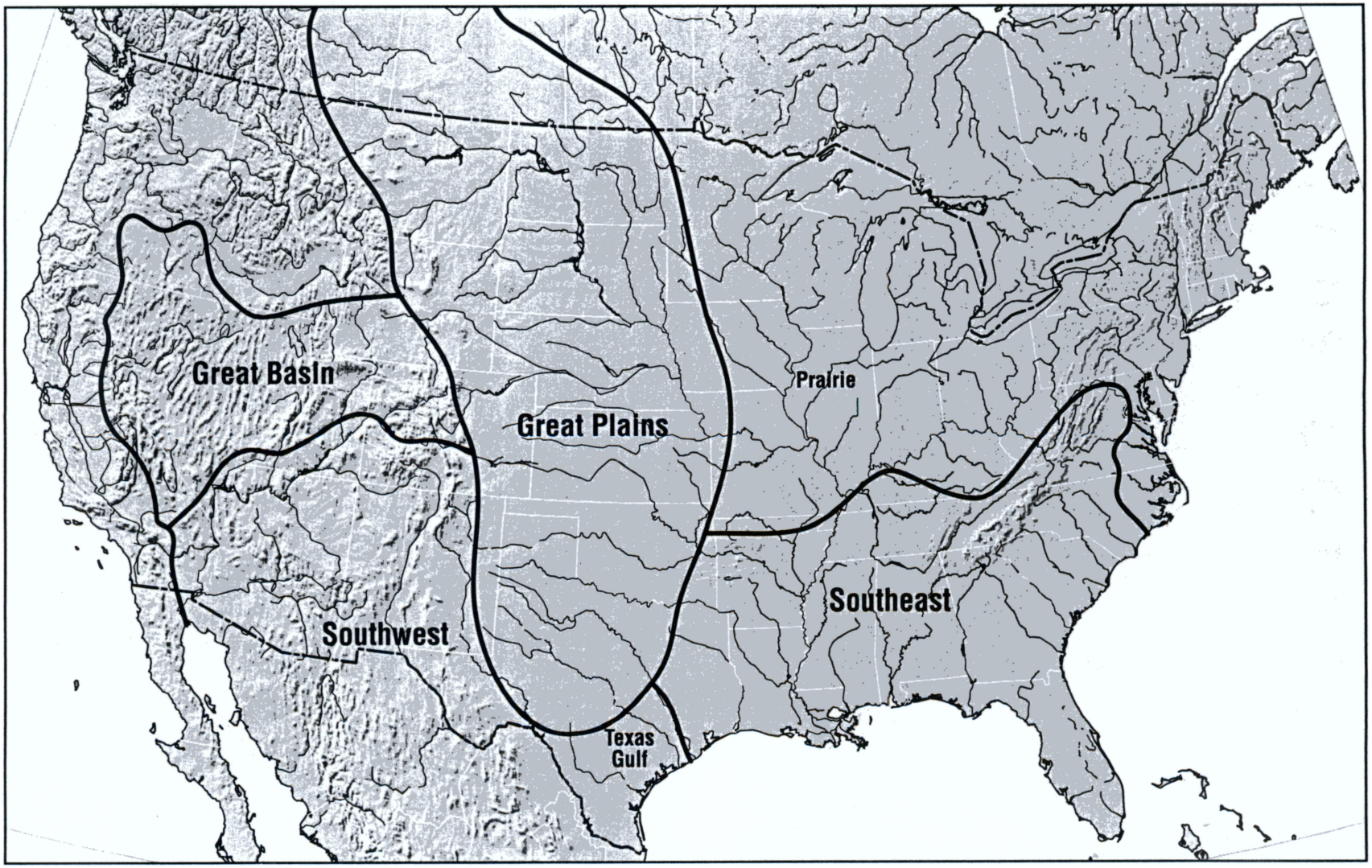


Figure 4.1. Major cultural regions.

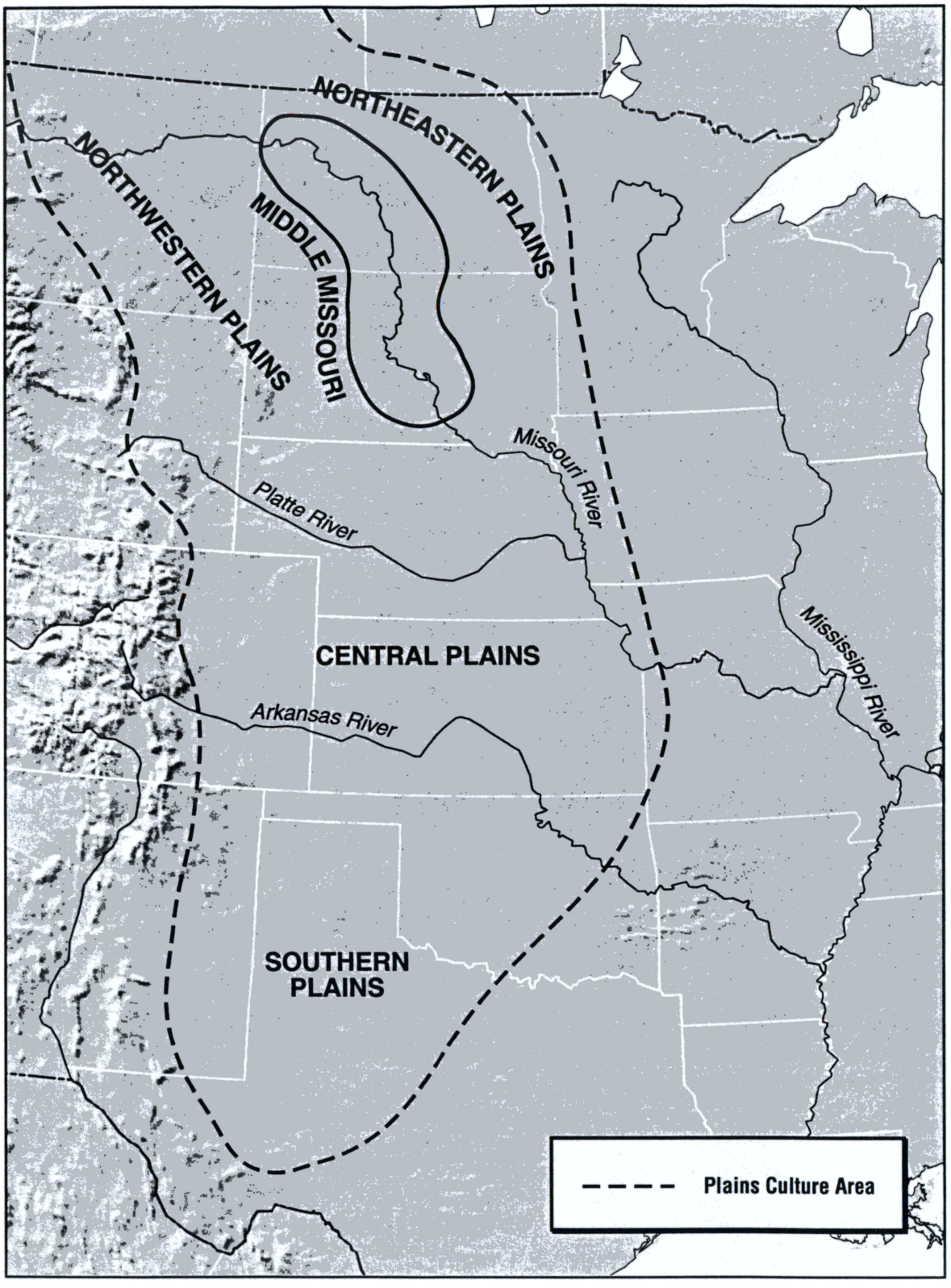


Figure 4.2. Five Major Great Plains cultural subareas. Adapted from DJ Lehmer (1971: Figure 20). Introduction to Middle Missouri Archeology. National Park Services, Anthropological Papers No. 1. Washington, D.C.

Lehmer, 1971; Wedel, 1961; Wood, 1998). Although the Plains subareas can be further divided into archaeological regions and localities, these will not be addressed here. The Southern Plains denotes the area south of the Arkansas River and includes part of present day Kansas, Oklahoma, Texas, and New Mexico. Eastern Nebraska and the adjacent parts of southern South Dakota, western Iowa, western Missouri, and northern Kansas form the Central Plains. The Missouri River Valley from the mouth of the Yellowstone River to the mouth of the White River forms the Middle Missouri subarea. The Northeastern Plains includes the eastern half of North and South Dakota and portions of western Minnesota, southwestern Manitoba, and southeastern Saskatchewan, while the Northwestern Plains is comprised of northern Colorado, Wyoming, Montana, western Nebraska, western South Dakota, southwestern North Dakota, and parts of Alberta and Saskatchewan.

Time Periods of the Great Plains

Besides cultural subareas, the cultural history of the Plains is divided into five major sequential temporal periods: Paleoamerican, Archaic, Plains Woodland, Plains Village and Historic (Table 4.1). These cultural periods represent a unique adaptation to the changing Plains environment and are defined primarily by differences in technology, subsistence strategies, and settlement patterns (Wood, 1998). While sequential, the time frame of each period is generally unique to each cultural subarea. The Paleoamerican period, for example, ends with the extinction of Pleistocene mega-fauna around 7000 BC in the south and 5500 BC in the north (Blakeslee, 1994).

Table 4.1. Archaeological cultural periods of the American Great Plains

Archaeological Period	*Date Range*	*References*
Paleoamerican Period	? – 7000/5500 BC	
Archaic Period (Early, Middle, Late)	7000/5500 BC – AD 500	
Woodland Period	1000 BC – AD 950	
Early	1000 – 50 BC	
Fox Lake Phase		Anfinson, 1979
Middle	50 BC – AD 350	
Kansas City Hopewell		Johnson, 1979
Cuesta Phase		Marshal, 1972; Brogan, 1981
Valley Phase		Ludwickson et al., 1987
Late	AD 350 – 700	
Keith Focus		Kivett, 1952
Held Creek Phase		Benn, 1983
Greenwood Phase		Witty, 1982
Grasshopper Falls Phase		Reynolds, 1979
Late Late	AD 750 – 950	
Loseke Creek Phase		Ludwickson et al., 1987
Lake Benton Phase		Anfinson, 1979
Sterns Creek Phase		Hass, 1980
Great Oasis		Ludwickson et al., 1987

Table 4.1. Continued

Archaeological Period	*Date Range*	*References*
Plains Village Period		
Northern and Central Plains		
Oneota Tradition	AD 1000 – 1800	Henning, 1998
Middle Missouri Tradition	AD 900 – 1600	Winham and Calabrese, 1998
Initial Middle Missouri Variant	AD 900 – 1350	
Western (Chamberlain)		
Anderson Phase		Lemur, 1954; Wood, 1976
Grand Detour Phase		Caldwell and Jensen, 1969
Swanson Phase		Hurt, 1951; Johnson, 1979
Eastern (Mill Creek)		
Cambria Phase		Knudson, 1967
Big Stone Phase		Haug, 1981
Brandon Phase		Over and Meleen, 1941
Lower James Phase		Alex, 1981
Big Sioux Phase		Henning, 1968-1969
Little Sioux Phase		Henning, 1968-1969
Extended Middle Missouri Variant	AD 1100 – 1500	
Northern		
Clark's Creek Phase		Calabrese, 1972
Fort Yates Phase		Lehmer, 1966; Thiessen, 1977
Nailati Phase		Calabrese, 1972
Southern		
Big Bend region sites		Johnson, 1977
Thomas Riggs Phase		Tiffany, 1983
Terminal Middle Missouri Variant	AD 1500 – 1675	
Huff Phase		Lehmer, 1971; Ahler, 1993

Table 4.1. Continued

Archaeological Period	*Date Range*	*References*
Central Plains Tradition	AD 1000-1400	Wedel, 1986
Nebraska Phase		Blakeslee and Caldwell, 1979
Smoky Hill Phase		Steinarcher, 1976
Solomon River Phase		Lippincott, 1978
Classic Republican Phase		Krause, 1969
Itskari Phase		Ludwickson, 1978
St. Helena Phase		Blakeslee, 1988
Coalescent Tradition	AD 1300-1862	Lehmer, 1954; Johnson, 1998
Initial Coalescent Variant	AD 1300-1600	
Anoka Focus		Witty, 1962
Arzberger Phase		Caldwell, 1966
Campbell Creek Phase		Smith, 1977
Extended Coalescent Variant	AD 1500-1650	
Shannon Phase		Smith and Johnson, 1968
Le Compte Phase		Johnson and Hoffman, 1966
La Roche Phase		Hoffman, 1968
Akaska Phase		Hurt, 1957
Post-Contact Coalescent Variant	AD 1650-1862	
Bad River Phase		Lehmer and Jones, 1968
Felicia Phase		Caldwell, 1966; Lehmer, 1971
Le Beau Phase		Lehmer, 1971
Talking Crow Phase		Lehmer and Caldwell, 1966
Heart River Phase		Lehmer, 1971
Knife River Complex		Ahler, 1993
Minnetaree Phase		Ahler, 1993
Willows Phase		Ahler, 1993
Four Bears Phase		Ahler, 1993

Table 4.1. Continued

Archaeological Period	*Date Range*	*References*
Roadmaker Phase		Ahler, 1993
Lower Loup Phase		Wedel, 1986
Redbird Focus		Wood, 1965
Southern Plains		Drass, 1998
Upper Canark Variant	AD 940/1100-1500	
Antelope Creek Phase		Lintz, 1986
Apishapa Phase		Campbell, 1976; Lintz, 1986
Buried City Complex		Hughes, 1991
Zimms Complex		Drass et al., 1987
Redbed Plains Variant	AD 900-1600	
Paoli Phase		Drass, 1995
Washita River Phase		Bell and Baerreis, 1951
Custer Phase		Hofman, 1978
Turkey Creek Phase		Drass, 1995
Henrietta Complex	AD 1100-1600	Krieger, 1946
Great Bend Aspect (Proto-historic Wichita)	AD 1450 - 1700	Wedel, 1959
Historic Period	AD 1780-1850	
Semi-sedentary Horticulturalists		
Arikara		Rogers,1990
Hidatsa		
Kansa		
Mandan		
Omaha		O'Shea and Ludwickson, 1992
Pawnee		Wadel, 1936, 1986
Ponca		
Wichita		

Table 4.1. Continued

Archaeological Period	*Date Range*	*References*
Equestrian Nomads		
Arapahos		Carlson, 1998
Assiniboine		Denig, 1939; Lowie, 1909
Blackfoot (Blackfoot, Blood, Piegan)		Carlson, 1998
Cheyenne		Carlson, 1998
Comanche		Newcomb, 1990
Crow		Carlson, 1998
Gros Ventres (Atsina)		Carlson, 1998
Kiowa		Newcomb, 1990
Kiowa-Apache		Newcomb, 1990
Sioux (Teton, Santee, Yankton, Yanktonai)		Howard, 1966; Hurt, 1974

All of the cultural periods can be further subdivided. For example, the Archaic Period is generally divided into Early, Middle, and Late; the Plains Woodland Period into Early, Middle, Late and Late Late; and the Plains Village Period into Village 1 and 2 (Blakeslee, 1994; Wood, 1998). However, slight sequential disparities from region to region and variation in terminology can cause confusion, making the application of a single set of terms to all subareas difficult. Since the largest portion of the material used in this study comes from the Northern, Central, and Southern Plains, and in order to be consistent with other skeletal biology studies of the Plains, the chronology outlined in Blakeslee (1994) and Wood (1998) is used here (Table 4.1).

Paleoamerican Period

Even though the origin of Native Americans is still a hotly debated question in American archaeology, in the Plains, accepted early Paleoamerican sites do not date to more than 11,500 years ago and are primarily restricted to the Southern Plains and western border (Wood, 1998; Hofman and Graham, 1998). Compared to later periods, Paleoamerican sites are rare, and when they occur, they are generally small campsite or kill sites. As a result, we know very little about Paleoamerican dwellings, group organization, economic-territory size, or other cultural aspects. In general, Paleoamericans appear to have focused much of their energy and resources on hunting large mammals such as mammoth and bison. Their population structure was probably one of small isolated bands of hunter-gatherers that came together occasionally to interact and exchange information (Hofman and Graham, 1998). The Paleoamericans probably

had an extensive mating network in order to maintain a minimum effective breeding population (Key, 1983).

Archaic (Mesoindian) Period

The term Archaic is well ingrained in American archaeological chronology, yet few differences exist in the lifestyle between Paleoamerican and Archaic groups, especially in the Plains (Hofman, 1996). Like their Paleoamerican predecessors, the Archaic people were nomadic hunters and foragers, but they generally had a more limited geographical range and were more adapted to their local environment. Around 6000 BC, climatic changes associated with the Atlantic episode (5950-3050 BC) caused most of North America to become warmer and drier (Blakeslee, 1994; Greiser, 1985). One major result of this climatic change was the decline and/or extinction of Pleistocene megafauna and the emergence of modern faunal and floral species. Consequently, the Archaic hunters focused much of their energy and resources on the more solitary game such as deer, elk, and pronghorn (Wood, 1998). The presence of grinding stones and other plant processing tools also increase substantially during the Archaic Period.

Archaeologists seem to agree that the Archaic people were the direct descendants of the earlier Paleoamericans, but many physical anthropologists feel this question has not been fully addressed. Key (1983) found distinct differences in the cranial morphology of Paleoamericans and Archaics. Known Archaic crania tend to exhibit lower and shorter vaults and a smaller midfacial region compared to Paleoamerican crania (Key, 1983). Other, more recent, studies (Cunningham and Jantz, 2001; Jantz and

Owsley, 2001) suggest that Paleoamerican crania are morphologically distinct from those of modern Amerindians. Late Archaic Indians, on the other hand, more closely resemble modern groups (Cunningham and Jantz, 2001). It is possible that the Archaic Indians, and not the Paleoamericans, were the first group to regularly transverse the Bering land bridge. In this scenario, larger Archaic groups would have completely replaced or partially replaced the earlier Paleoamerican groups that migrated to the New World via a coastal route.

Plains Woodland Period

The Archaic Period ends around AD 500-1000 in most subareas with the beginning of the Plains Woodland Period. This period is characterized archaeologically by the first use of pottery. In later Woodland sites, there is evidence of domestic plant use and burial mounds. As the name implies, the Woodland people were highly adapted to a woodland environment. In the Plains, Woodland campsites are generally found along river and stream margins, where a woodland environment could be exploited. The Plains Woodland people hunted, fished and gathered wild plants, and also started to experiment with cultigens. In order to tend crops during the growing season, Woodland populations probably became less nomadic.

Archaeologists divide the Plains Woodland Period into Early, Middle, Late and Late Late subperiods, each with multiple phases (Table 4.1). However, most archaeological sites can be dated to the Middle and Late Woodland periods (Blakeslee, 1994). Furthermore, not all the subperiods appear in all cultural/geographical regions.

For example, Blakeslee (1994:11) states that there are "no clear equivalents of the Late Late Woodland complexes found in Iowa, Nebraska, and South Dakota."

The Woodland Period begins earlier in eastern North America than it does on the Plains, making some suggest that the Plains Woodland represents a migration of groups from the east (Key, 1994; Wilmeth, 1972). Then again, Wood (1998) argues that archaeologically there is a smooth transformation from Archaic to Woodland in most areas. Craniometric data from the Northern Plains seem to support biological continuity, but the picture is not as clear in the Central Plains (Key, 1994).

Plains Village Period

The Plains Village period is characterized by an increasingly sedentary lifestyle, with permanent houses in small villages and a dependence on domesticated plants. However, like earlier groups, the Plains Villagers used bison for food, clothing, bedding, containers, and a variety of other necessities. Bison dominate the faunal refuse in most village sites, especially in the north, with deer and other animals being of only secondary importance. Lehmer and Wood (1977:87) characterized the subsistence practices of the Plains Villagers as resembling "the mixed horticultural and pastoral economies of the Old World more closely than they do other cultures of native America." This basic economic pattern of farming and hunting bison lasted from around AD 950 well into the European contact period, and all Plains Village groups during the historic period (post AD 1780) made annual long-distance bison hunts. Because of the abundance of archaeological and

biological data available for the Plains Village period, the following sections discuss the Plains Village Period in depth by geographical region.

Northern and Central Plains

In the Northern and Central Plains, the Plains Village period encompasses four cultural traditions: Oneota, Middle Missouri, Central Plains, and Coalescent (Table 4.1). The Oneota tradition (c.a. AD 1000 - 1800) represents cultures living in the Prairie Peninsula, while the Middle Missouri tradition (c.a. AD 900 - 1600) accounts for groups distributed along the Missouri River in North and South Dakota. The Central Plains tradition (c.a. AD 1000 -1400) represents populations living south of the Nebraska-South Dakota border prior to the protohistoric period, and the Coalescent tradition (c.a. AD 1300 – 1800) corresponds to protohistoric groups from the Central Plains moving into the Middle Missouri area. Specific phases and source references for each Plains Village period tradition are listed in Table 4.1.

Oneota Tradition

Oneota tradition (AD 1000 – AD 1800) is related to Upper Mississippian cultures with sites scattered across the Prairie Peninsula of present-day Missouri, Iowa, Minnesota, Wisconsin, and Illinois (Blakeslee, 1994; Henning, 1998). According to Henning (1998:353), the Oneota is best viewed as a culture that "links the Plains to the eastern Woodlands". The Oneota peoples appear to have interacted with Mississippian, Caddoan, Central Plains, Middle Missouri, and Coalescent cultures (Henning, 1998), and

are assumed ancestral to the historic Chiwere Siouan-speaking Iowa, Missouri, Oto and Winnebago tribes and the Dhegiha Siouan-speaking Osage, Omaha, and Kansa tribes (Blakeslee, 1994; Henning, 1998; Straffin, 1971).

The Oneota peoples were primarily horticulturalists, but they also exploited the vast local faunal and floral resources (Henning, 1998; Straffin, 1971). Historical records also suggest that the Oneota peoples hunted bison at least once a year (Henning, 1998). The seasonal bison hunts involved large groups of people who often traveled hundreds of miles on foot. Once the bison were located and killed, they were processed on-site and carried back to the village (Henning, 1998).

Middle Missouri Tradition

Populations of the Middle Missouri tradition were most likely the Siouan-speaking ancestors of the historic Mandan and Hidatsa tribes of North Dakota. Generally, archaeologists divide the Middle Missouri tradition into the Initial (AD 900 – 1350/1400), Extended (AD 1100 – 1500) and Terminal (AD 1500-1675) variants (Table 4.1; Figure 4.3). The Initial Middle Missouri variant represents the first appearance of Plains Village period peoples in the Northern Plains. The first Initial Middle Missouri populations probably moved onto the Plains from Minnesota and Iowa during the Neo-Atlantic episode—a period when climatic conditions in the Northern and Central Plains river valleys would have been ideal for growing maize (Blakeslee, 1994). However, some archaeological evidence suggests the Initial Middle Missouri may have developed *in situ* through cultural diffusion (Tiffany, 1983). This latter hypothesis is also supported by Key

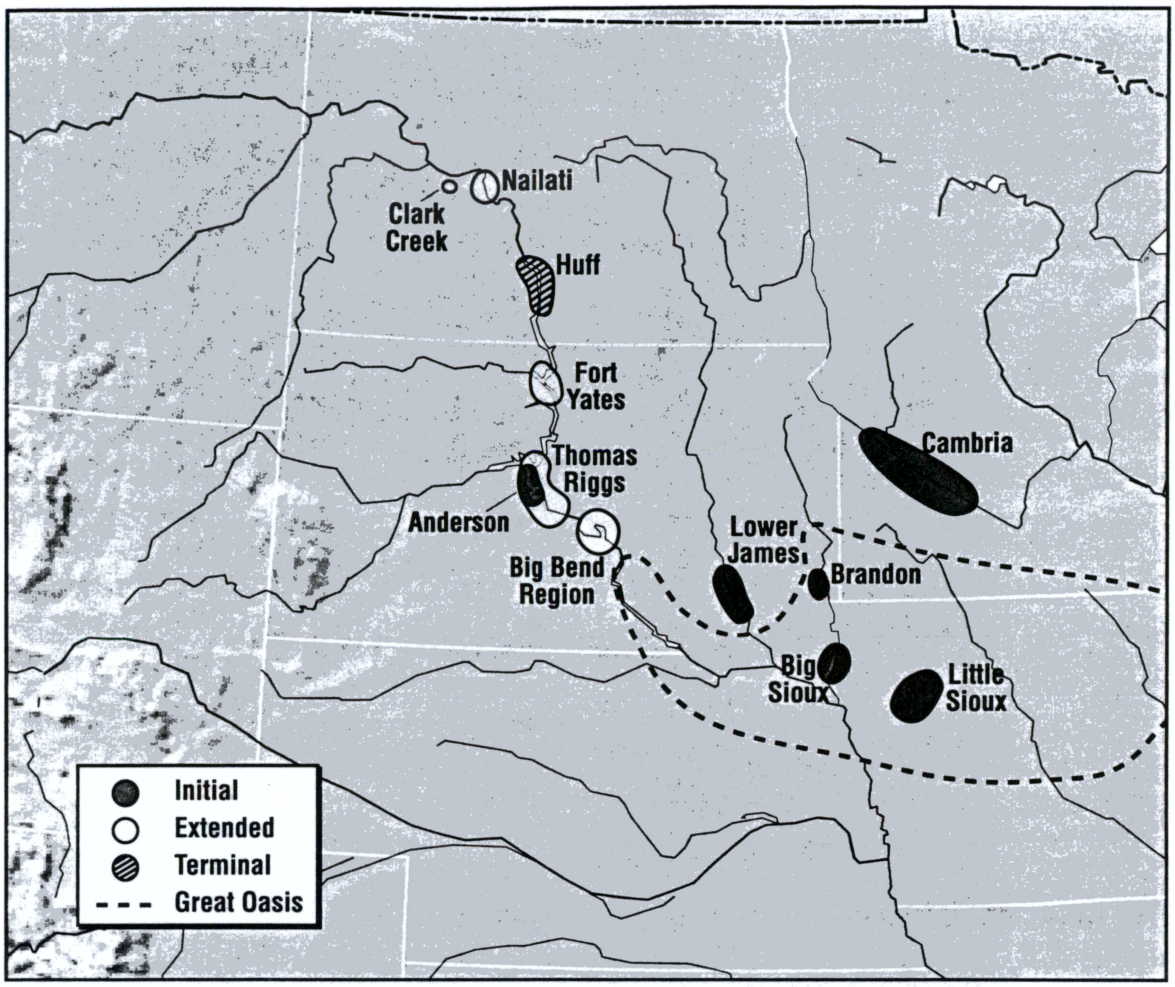


Figure 4.3. Middle Missouri tradition cultural complexes. The Big Bend Region contains both Initial and Extended Middle Missouri sites. Adapted from RP Winham and FA Calabrese (1998: Figure 9.2). The Middle Missouri. In WR Wood (editor): Archaeology of the Great Plains. Lawrence, KS: University Press of Kansas, pp. 269-307.

(1994) using craniometric evidence. Either way, by AD 1100, the Initial Middle Missouri peoples were spread along the James and Big Sioux river valleys of southeastern South Dakota and northwestern Iowa, and in the Bad-Cheyenne and Big Bend regions of the Middle Missouri subarea. Initial Middle Missouri villages were generally compact and frequently fortified with a ditch and palisade. Houses were long, rectangular, and semi subterranean and appear to have been occupied for long periods (Blakeslee, 1994). The Initial Middle Missouri people made plain or cord-roughened globular jars with rim and neck designs that were distinct from Central Plains Tradition pottery (Winham and Calabrese, 1998).

The Extended Middle Missouri variant sites overlap in time with Initial Middle Missouri by several hundred years, and they are found in two clusters along the Missouri River Valley. The largest cluster extends from central North Dakota to northern South Dakota. The second cluster, approximately 90 miles away, is located between the Bad and Cheyenne rivers in South Dakota (Blakeslee, 1994; Lehmer, 1971; Winham and Calabrese, 1998). The more northern location of Extended Middle Missouri sites compared to Initial Middle Missouri sites is probably associated with the northern migration of Initial Coalescent populations. The general village layout of the Extended Middle Missouri is similar to that of the Initial Middle Missouri but the fortification system often includes bastions along the palisade (Blakeslee, 1994). The Extended Middle Missouri sites are distinguished from Initial Middle Missouri and Central Plains sites primarily by pottery and projectile point styles.

Sites of the Terminal Middle Missouri are found primarily in North Dakota, suggesting a northward shrinkage of the Middle Missouri territory (Winham and Calabrese, 1998). Terminal Middle Missouri sites are usually very large with extensive fortification, and there seems to be a decline in the number of villages during the Terminal Middle Missouri compared to the Initial and Extended Middle Missouri. Following the Terminal variant, Middle Missouri Tradition sites are generally indistinguishable from southern sites and are therefore taxonomically absorbed into the Coalescent Tradition.

Central Plains Tradition

Archaeologists generally divide the Central Plains tradition (AD 1000 – 1400) into six geographically distinct phases: Nebraska, Smoky Hill, Solomon River, Classic Republican, Itskari (formerly the Loup River), and St. Helena (Table 4.1; Figure 4.4). Even though actual cultural, biological, and linguistic differences may have existed between these phases, in general, they only represent geographical variations in ceramic style (Billeck and Urcid, 1995). Two other related units, the Steed-Kisker phase and the Pomona variant, are also important to Central Plains tradition history but are not included in the Central Plains tradition (Blakeslee, 1994).

The Nebraska and St. Helena phases are concentrated along the Missouri River, with Nebraska phase sites located in eastern Nebraska and western Iowa and St. Helena sites positioned in northeastern Nebraska. Smoky Hill phase sites, on the other hand, are concentrated in northeastern Kansas and southeastern Nebraska along the tributaries of

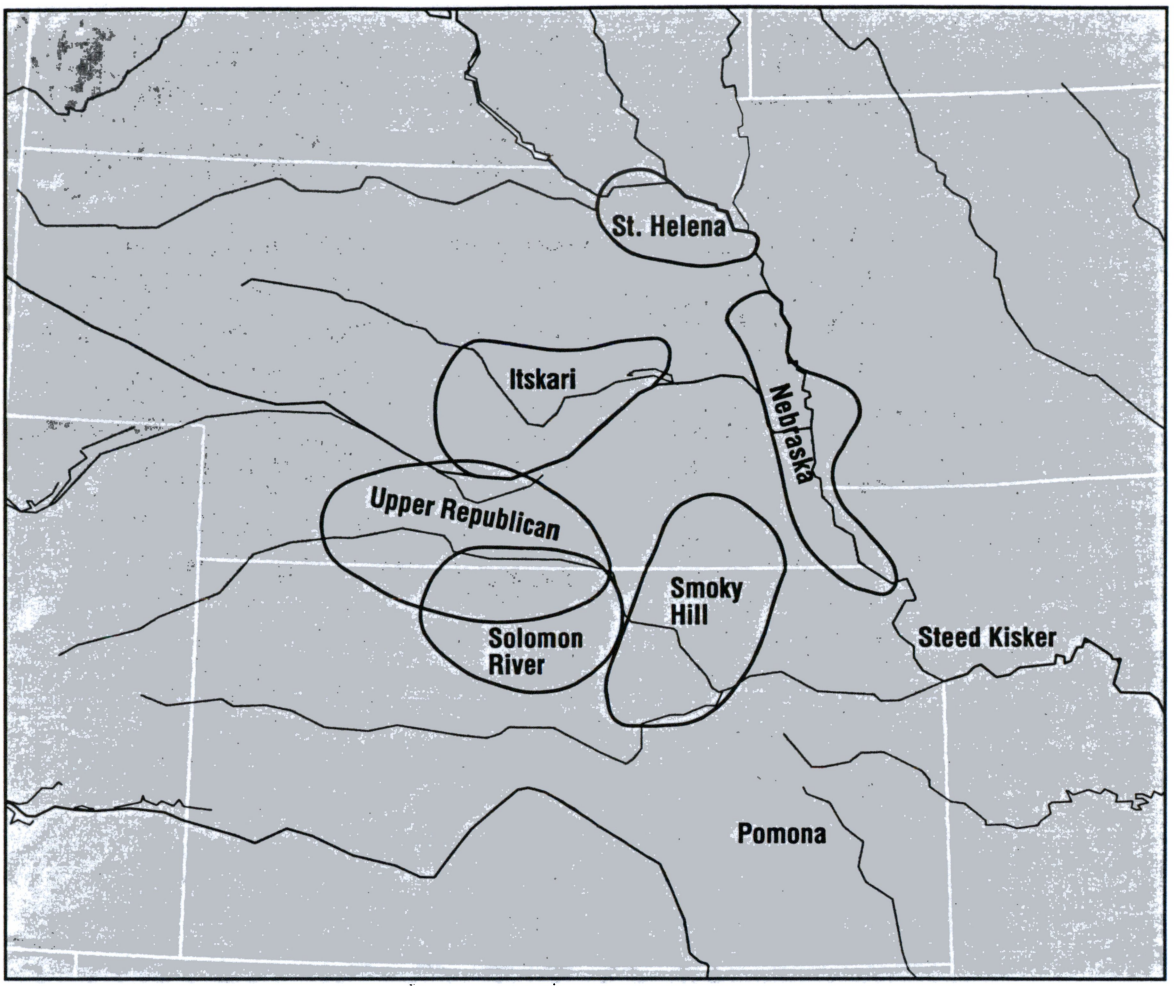


Figure 4.4. Central Plains tradition phases and contemporary units. Adapted from Steinarcher and Carlson (1998: Figure 8.1). The Central Plains Tradition. In WR Wood (editor): Archaeology of the Great Plains. Lawrence, KS: University of Kansas, pp. 235-268.

the Kansas River. The geographical range of the Classic Republican and Solomon River phases overlap slightly. The Classic Republican area is centered in south-central Nebraska around the Republican River, and the Solomon River area is centered in north-central Kansas along the Solomon and Saline rivers. Itskari phase sites can be found north of the North Platte River in central Nebraska. The two related units, Steed-Kisker phase and Pomona variant are concentrated in the Kansas City area and in southeastern Kansas, respectively.

The origins of the Central Plains tradition peoples are still not completely clear (Steinacher and Carlson, 1998). The Central Plains tradition may have originally developed along the Missouri River near present-day Kansas City. In this case, the Steed-Kisker phase would most likely have given rise to the Nebraska phase. Another possibility is that the Central Plains tradition developed in the Smoky Hill and Solomon River phases from an earlier indigenous Plains Woodland groups. Finally, Wedel (1959) has suggested that the Smoky Hill phase is culturally tied to the Caddo groups of eastern Oklahoma.

While the Steed-Kisker phase (AD 1000 – 1250) is on the periphery of the Plains, it is generally considered part of the Middle Mississippian tradition. Most likely, it represents a western migration of Mississippian peoples from Cahokia (Blakeslee, 1994; O'Brien, 1984). O'Brien (1984) states that Steed-Kisker may represent rural Cahokian farmers that helped supply the city with food.

The Pomona Complex (AD 980 – 1560) encompasses sites in eastern Kansas that are contemporaneous with the Central Plains tradition but have no earthlodges, a trait that

is used to help define the Central Plains tradition (O'Brien, 1984). Some archaeologists suggest that Pomona may be part of the Smoky Hill phase because Pomona pottery becomes similar to Smoky Hill pottery as one moves closer to the heart of the Smoky Hills. Lithic tools associated with Pomona sites are also identical to Smoky Hill stone tools.

Coalescent Tradition

The Coalescent tradition follows the Central Plains tradition, but they are closely related. In fact, it has even been proposed that the Central Plains and Coalescent traditions should be combined (Blakeslee, 1994). Originally, the Coalescent tradition, as its name implies, was thought to represent a blending of the Central Plains and Middle Missouri traditions, and was divided into Initial (c.a. AD 1400 – 1550), Extended (c.a. AD 1550 – 1675), Post-contact (c.a. AD 1675 – 1780), and Disorganized (c.a. AD 1780 – 1862) variants (Lehmer, 1954). However, recent studies suggest that the Initial Coalescent variant is probably an extension of the Central Plains tradition, specifically the St. Helena phase, into the Middle Missouri area (Johnson, 1998). The movement of Central Plains tradition populations into the Middle Missouri subarea is associated with an extended drought in the Central Plains (Ahler and Tooms, 1995; Lehmer, 1971).

The sequential order of the Coalescent tradition variants envisioned by Lehmer (1971) has also been questioned (Billeck, personal communication; Johnson, 1998). Recent work suggests that the Initial and Extended Coalescent variants overlap by approximately 100 years. The Inital Coalescent dates have been modified by some

archaeologists to extend from approximately AD 1300 to 1600, and the Extended Coalescent dates have been modified to AD 1500 to 1650 (Johnson, 1998). It has also been suggested that the beginning of the Post-Contact Coalescent should be pushed back to AD 1600/1650 (Ahler and Toom, 1995; Johnson, 1998).

Coalescent tradition sites consist primarily of circular earthlodges organized into permanent or semipermanent villages, and extend along the Missouri River from the Niobrara and Knife rivers. The Chapelle Creek, Cheyenne River, Indian Creek, and Cattle Oilers sites represent Coalescent villages superimposed on earlier Middle Missouri Tradition occupations (Johnson, 1998).

Initial Coalescent sites are distributed along the Missouri River south of the Bad River, primarily in the Big Bend region (Figure 4.5). Villages range in size from about 10 to 45 houses surrounded by a fortification ditch and interior palisade. The heavy fortification of most Initial Coalescent sites suggests that the movement of Central Plains tradition populations into the Middle Missouri subarea was not a peaceful event. The Crow Creek site, which contains the remains of approximately 500 massacred individuals, is a prime example of this conflict (Willey, 1990). It is still unclear if the fortification of Initial Coalescent villages was to provide protection against Middle Missouri groups (Johnson, 1994, 1998; Lehmer, 1971) or against other Initial Coalescent groups competing for horticultural land (Zimmermand and Bradley, 1993). Unfortunately, with the exception of the Crow Creek skeletons, which have been reburied, there are few skeletal remains from the Initial Coalescent.

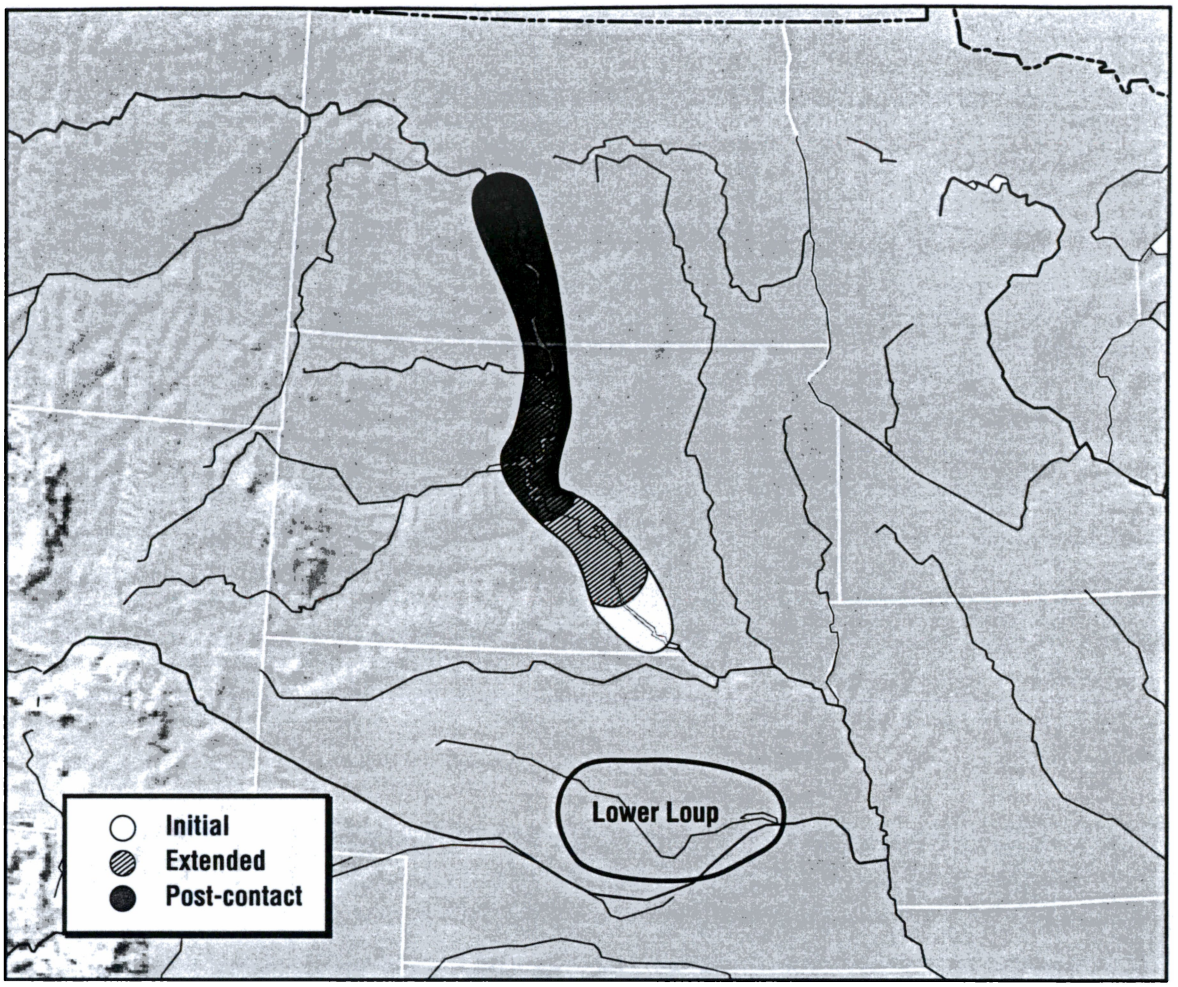


Figure 4.5. Distribution of the Coalescent Tradition.

Extended Coalescent sites are dispersed along the Missouri River between the White and the Grand rivers in South Dakota (Figure 4.5). This represents a significant northern expansion compared to the Initial Coalescent. Communities were typically small with a high degree of geographic mobility (Lehmer, 1970), and villages range in size from only a few scattered houses to as many as 200 at the Sully site (Johnson, 1998). Unlike Initial Coalescent villages, those of the Extended Coalescent are generally unfortified. Even when fortifications are present, frequently there are houses outside the central fortification (Blakeslee, 1994; Johnson, 1998). This relaxation in defense suggests that intra- and inter-group friction may have been reduced in the Middle Missouri subarea during the Extended Coalescent.

Archaeologists recognize four Extended Coalescent phases: Shannon, Le Compte, La Roche, and Akaska (Lehmer, 1971; Johnson, 1998). Most Extended Coalescent sites with human burials are attributed to the La Roche phase, and all four phases are associated with the historic Arikara tribe. Sites attributed to the Shannon phase are located south of the Bad River and represents the southern extent of the Extended Coalescent. The Le Compte and Akaska phases represent the northern extent of the Extended Coalescent with sites located in the Grand-Moreau region.

The Post-Contact Coalescent variant is marked by the presence of European trade goods, especially with burials (Billeck et al., 1995). However these groups probably had little contact with Europeans (Billeck et al., 1995; Rogers, 1990). Villages associated with the Post-Contact Coalescent are located at the mouth of the Knife, Heart, Grand, Cheyenne, and Bad rivers in the Middle Missouri subarea and along the Platte and Loup

rivers in the Central Plains (Figure 4.5). There have been numerous phases or complexes defined for the Post-Contact Coalescent (Table 4.1). Blakeslee (1994) subdivides the Post-Contact Coalescent into four phases (Felicia, Bad River, Le Beau, and Heart River) and two foci (Lower Loup and Redbird). The Felicia, Bad River and Le Beau phases are connected to the historic Arikara, while the Heart River phase, Lower Loup focus, and Redbird focus are associated with the Mandan, Pawnee, and Ponca, respectively. Johnson (1998), on the other hand, proposes that Post-Contact Coalescent should be subdivided into nine units: Felicia, Talking Crow, Bad River, Le Beau, Knife River, Willows, Minnetaree, Roadmaker, and Four Bears. In this scenario, the Willow and Minnetaree phases are connected with protohistoric Hidatsa and the Roadmaker and Four Bears phases represent the consolidation of the historic Hidatsa, Mandan, and Arikara.

Southern Plains

In the Southern Plains, the major archaeological units of the Plains Village period are the Upper Canark variant (AD940/1100 – 1500), Redbed Plains Variant (AD 900 – 1600), Henrietta Complex (AD 1100 – 1600) and Great Bend Aspect (AD 1450 – 1700) (Table 4.1; Figure 4.6). The people of the Plains Village period in the Southern Plains shared a general way of life with groups from the Northern and Central Plains. Southern Plains Village people lived in permanent houses and small villages along major rivers, and they supplemented their garden produce with bison and edible wild plants (Drass, 1998). However, Southern Plains groups on the western margins may have relied as much on hunting as they did on garden products.

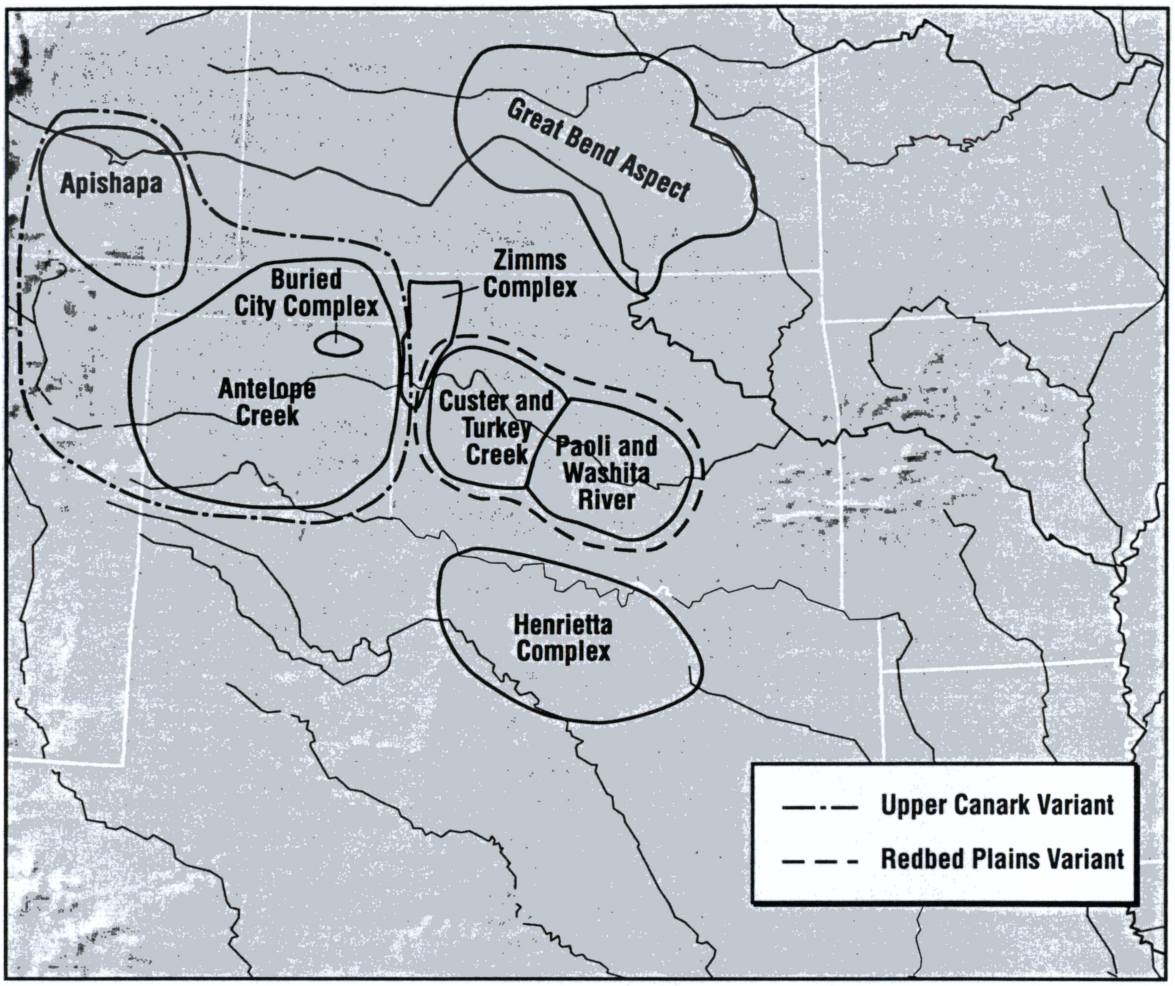


Figure 4.6. Southern Plains Village cultural complexes. Adapted from RR Drass (1998: Figure 12.1). The Southern Plains Villagers. In WR Wood (editor): Archaeology of the Great Plains. Lawrence, KS: University Press of Kansas, pp. 415-455.

The Upper Canark Variant represents a distinct cultural pattern in the Oklahoma and Texas panhandle area, southeastern Colorado, and northeastern New Mexico. Archaeologists divide the Upper Canark Variant into four geographically and temporally distinct units: Antelope Creek Phase, Apishapa Phase, Buried City Complex, and Zimms Complex (Drass, 1998). Stone-slab foundation houses, cordmarked globular pots, small triangular side-notched points, manos and grinding stones, and bison-bone tools are common features of Upper Canark sites (Brook, 1994; Drass, 1998). Common Upper Canark archaeological sites include villages, isolated hamlets, and temporary bison kill and processing stations (Drass, 1998).

The Antelope Creek Phase is the best known and dated phase in the Southern Plains. The people of the Antelope Creek probably originated *in situ* from indigenous Plains Woodland groups (Brook, 1994; Drass, 1998; Lintz. 1986). Archaeologists generally associate the Antelope Creek Phase with Plains Caddoans, but the Antelope Creek inhabitants were also in close contact with the Puebloan peoples to the west. Many aspects of Puebloan culture appear to have been incorporated by Antelope Creek people. Hunting seems to have been as important or even more important than horticulture in their economy (Brook, 1994; Drass, 1998). The drier conditions of the short-grass-prairie found in the western Plains margins may have been more suitable for bison herds than gardening because of frequent droughts (Brook, 1994; Drass, 1998). It is unclear if the Antelope Creek Phase people changed subsistence patterns or abandoned the Texas and Oklahoma panhandle region, but only nomadic groups were present by the time of Coronado's expedition (AD 1541). Drier climatic conditions and the migration of the

Apache into the Southern Plains around AD 1500 may have caused them to change subsistence or move to other locations (Drass, 1998).

The Apishapa Phase, Buried City Complex, and Zimms Complex are culturally similar to the Antelope Creek Phase but are distinguished by variations in house architecture and artifact assemblages. Apishapa groups also appear to have either abandoned their homelands or shifted to a nomadic lifestyle by AD 1400. Hughes (1991) suggests that the Buried City groups interacted with Great Bend Aspect groups based on numerous similarities in pottery.

The Redbed Plains Variant encompasses Plains Village sites along the Washita and Canadian rivers in Oklahoma (Figure 4.6). Sites from central Oklahoma are grouped into the Paoli and Washita River phases. The Paoli phase sites are early in time (AD 900-1250), while Washita River Phase sites are late (AD 1250-1450). In west-central Oklahoma, early sites are grouped in the Custer Phase and later sites are grouped in the Turkey Creek Phase. The two early phases appear to have evolved from local Plains Woodland groups, and the Washita River and Turkey Creek phases developed out of the earlier phases in the corresponding geographical regions. Culturally, all four Redbed Plains Variant phases are similar and only distinguished from one another by slight variations in artifacts, settlement patterns, and subsistence strategies.

Archaeologically, Washita River is the best understood of the Redbed phases. Washita River sites consist primarily of villages composed of 5 to 20 wattle and daub houses. Interestingly, archaeologists have recognized diversity in subsistence activities when comparing Washita River sites from the east to the west. Eastern groups appear to

have been more agriculturally oriented, while western groups had a much greater reliance on bison hunting (Brook, 1994). However, isotopic analysis of human skeletal material from the McLemore site in western Oklahoma suggests that even western groups were heavily dependent on horticultural products (Brook, 1994). Eastern groups were also likely to be in contact with the Caddo and other groups, as exotic trade items are common at Washita River sites (Drass, 1998).

The Henrietta Complex encompasses Plains Village sites located in the valleys of the Red and upper Brazos rivers in north-central Texas. Researchers have discovered Henrietta Complex sites as far west as the Wichita River and as far east as Trinity River (Figure 4.6) (Drass, 1994). The primary identifying characteristic of Henrietta Complex sites is the presence of Nocona Plain shell-tempered pottery, but the complex is not well defined. Research in this area of Texas is lacking, and therefore little is known about Henrietta Complex culture. Dates for the Henrietta are also not well established, but Drass (1998) suggests that sites associated with this complex extend from about AD 1100 to AD 1600. Because of the lack of research in this area, it is nearly impossible to speculate about the origins of this complex or its tie to historic groups.

Sites associated with the Great Bend aspect are located near the Arkansas River in south-central Kansas. The origin of this cultural aspect remains unclear, but archaeologists generally agree that it is associated with protohistoric Wichita. The earliest Great Bend sites date to around AD 1450. The presence of iron, copper, and brass artifacts suggests that some of the sites were occupied when Coronado's expedition passed through the area sometime between AD 1541 and AD 1601 (Drass, 1998). Great

Bend sites are generally very large and contain a tremendous amount of debris. Most of the artifacts are typical of Central and Southern Plains Village assemblages, but many exotic artifacts (e.g., Southwestern pottery, obsidian, turquoise, *Olivella* shell, red pipestone pipes, and Ozark cherts) and European items (e.g., chain mail, iron ax heads, and glass beads) are also common.

Historic Period

The Historic Period begins with the historical documentation of Plains groups by European traders and travelers during the late-18th century and ends when the Indian tribes are placed on reservations in the mid-19th century. During this period, more than 30 tribes made the Great Plains their home (Figure 4.7). These tribes include semi-sedentary horticulturalists along the eastern prairies and nomadic hunters in the western high plains.

The horticulturalists, like their ancestors, lived in semi-permanent villages, cultivated a variety of crops, and hunted bison annually or semi-annually. The sedentary lifestyle of these horticultural tribes has provided a substantial archaeological record (Hanson, 1998), as discussed above. Their sedentary lifestyles and village locations also put many of the horticulturalists in a position as "middlemen" in the intertribal and European-Indian trade networks. Arikara, Mandan, and Hidatsa villages in the north and Wichita villages in the south served as trade centers with nomadic groups coming to exchange bison hides, furs, eagle feathers, horses, slaves, and garden utensils, rifles, ammunition, and a variety of European trade goods (Carlson, 1998).

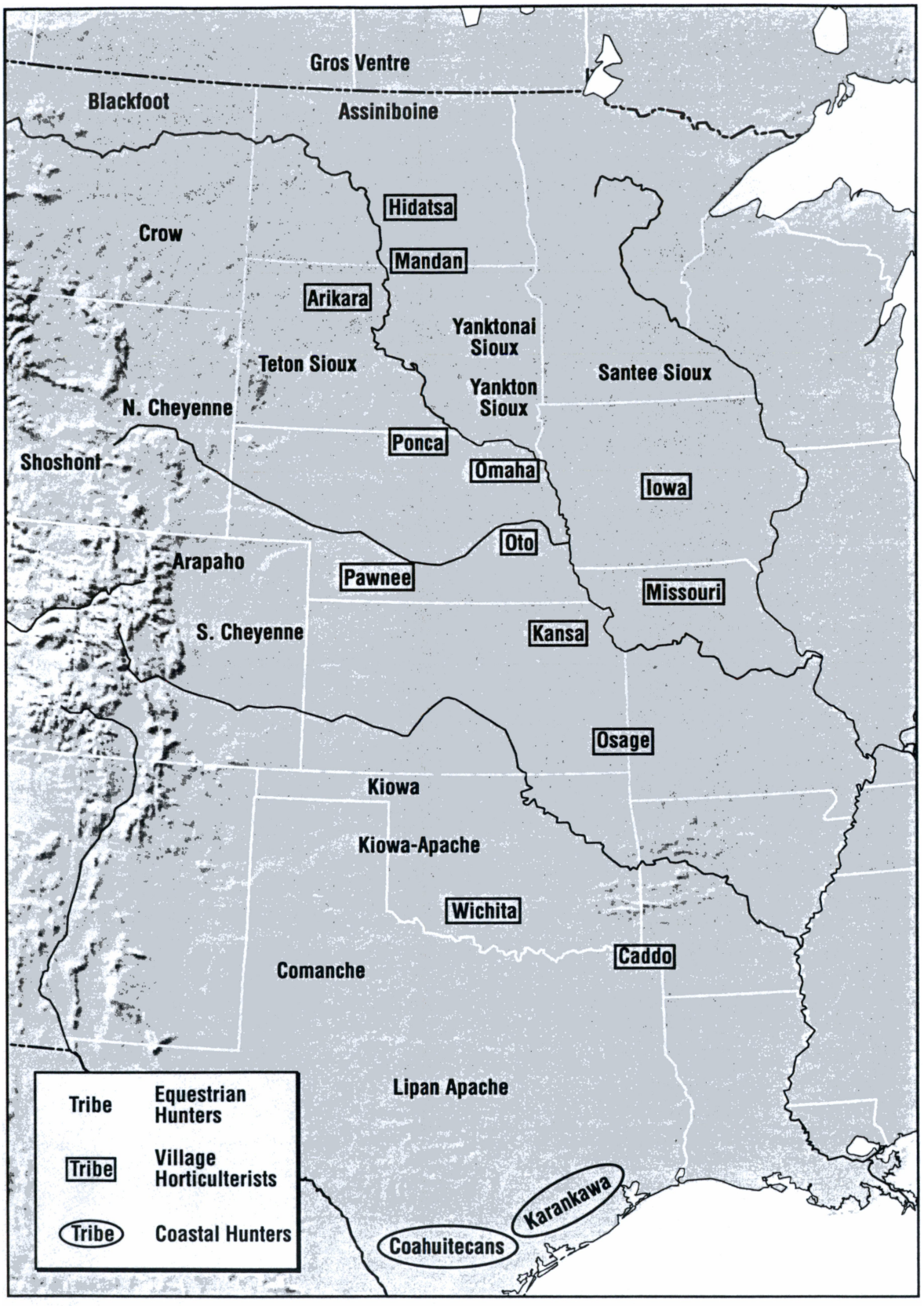


Figure 4.7. Historic tribes of the Central United States.

The nomadic tribes, on the other hand, lived in tipis, hunted on horseback, and exploited the abundant supply of bison on the Plains. Bison was a crucial part of almost every facet of life including art, religion, and economy, and was used for food, housing, clothing, fuel, and a variety of other items. While bison were extremely important, members of the nomadic tribes also hunted elk, pronghorn, deer, and numerous small game animals. They traded with horticultural groups for maize and other vegetable foods, and collected wild plants and tubers. Unfortunately, the equestrian nomads of the Plains are not well defined archaeologically, as their "portable and highly mobile lifestyle rarely left much in the way of accumulated archaeological deposits" (Hanson, 1998: 456).

Semi-sedentary Horticulturalists

The semi-sedentary groups include the Arikara, Hidatsa, Kansa, Mandan, Omaha, Oto, Pawnee, Ponca and Wichita (Table 4.1; Figure 4.7). The Kansa, Omaha, Oto, and Ponca occupied the tall-grass prairie country of the lower Missouri River basin, and the Arikara, Hidatsa, and Mandan lived in the rich Middle Missouri River valley. The Pawnee inhabited the Central Plains, and the Wichita lived further south in Kansas, Oklahoma, and northern Texas. A few other semi-sedentary groups such as the Iowa, Missouri, Quapaw, Osage, and Caddo lived on the eastern border of the Plains and probably ventured out onto the Plains to hunt bison.

The typical village of a Plains horticulture group may have only been occupied for five or six months a year. For instance, according to O'Shea and Ludwickson (1992), the Omaha tribe would reside in a village from April through early July until the

cornfields were well established, then abandon the village for several months while they hunted bison. In late September, the Omaha would return to the village to harvest corn, but would again leave from December until late March, returning to the village for short visits to restock on corn from the caches.

Tall-Grass Prairie

The Kansa, Omaha, Ponca, Osage and Quapaw are all Dhegiha Sioux speakers and share a common heritage. Linguistically, the Omaha-Ponca language is much more closely related to the Kansa and Osage languages than it is to the Quapaw, a temporal separation that is also supported by oral tradition (Billeck, 1997; Henning, 1993; Vehik, 1993). Oral tradition holds that the five Dhegihan groups were once a single nation living east of the Mississippi, possibly in the Ohio Valley (Blakeslee, 1994; Henning, 1993; Vehik, 1993). Sometime before AD 950, the Dhegihan speakers began a westward migration towards the mouth of the Ohio River. Once there, a small group moved south on the Mississippi River toward the Arkansas River to become the Quapaw, while the rest of the Dhegihan speakers followed the Mississippi upstream to the confluence with the Missouri. At some point, the main Dhegiha Sioux group then started migrating up the Missouri River. The Osage split from the main group and ascended the Osage River, and the Kansa separated from the Omaha-Ponca once they reached the Kansas River. The Omaha-Ponca crossed the Missouri and continued to move northward to present-day northeast Nebraska, where they remained a single group until as late as the early part of

the 18th century (Billeck, 1997; Henning, 1993; O'Shea and Ludwickson, 1992; Wood, 1993).

Archaeologically, the Dhegihan speakers have been clearly associated with the Oneota complex at the Blood Run, Fanning, and King Hill sites (Henning, 1993). The Blood Run site was inhabited by the Omaha-Ponca, while the Fanning and King Hill sites have been tied to the Kansa (Billeck, 1997; Henning, 1993, 1998). Other archaeological complexes have also been suggested to be associated with the Dhegihan. Chapman (1959) has argues for a connection between the Osage and Neosho focus, and Johnson (1991) suggests the Pomona variant is ancestral Kansa. However, both the Pomona variant and the Neosho focus are generally connected to Caddoan speakers (Vehik, 1993). In addition, if Pomona variant or Neosho focus were Dhegihan, this would suggest an indigenous development along the eastern border of the Plains. This scenario is not consistent with Dhegihan oral tradition or other archaeological data (Henning, 1993; Vehik, 1993). Additionally, Wood (1965) thought sites of the Redbird focus were affiliated with the Ponca, but this association is no longer accepted by other archaeologists (Billeck, 1997; O'Shea and Ludwickson, 1992).

The Chiwere Siouan speakers include the Iowa, Missouri, Oto, and the nomadic Winnebago. Migration traditions (e.g., O'Brien and Wood, 1998; Ludwickson et al. 1987) suggest the Chiwere Sioux began to move south from their homeland north of the Great Lakes. Near present-day Green Bay, Wisconsin, the group split with the Winnebago and settled on Lake Winnebago. The main group continued south. At the Upper Iowa River, the Iowa separated from the main Chiwere group. The combined Oto

and Missouri continued moving south until they reached the Missouri River where they then divided.

Middle Missouri River Valley

Blakeslee (1994) believes that the antecedents of the Arikara (i.e., Initial Coalescent tradition groups) diverged from the Pawnee in prehistoric times and moved north into the southern portions of the Missouri River trench (Blakeslee, 1994). However, this area was already occupied by the antecedents of the Mandan and Hidatsa (i.e., Middle Missouri Tradition groups). Heavily fortified villages and evidence of a massacre at the Crow Creek site (39BF11) may indicate that the first contact between Middle Missouri Tradition and Initial Coalescent groups was not a peaceful endeavor (Willey, 1990; Willey and Emerson, 1993).

Although European-made items were present (though still rare) in the Missouri River Valley by the mid-17th century, direct contact between the Europeans and the Upper Missouri tribes probably did not occur until the mid-18th century because of remote location of the Upper Missouri tribes (Rogers, 1990). After this time the Arikara and other tribes acted as middlemen in the fur trade, exchanging furs received from equestrian tribes for European items obtained by eastern tribes.

The Arikara, Mandan, and Hidatsa were primarily dependent on garden products but hunting was always important. The Upper Missouri tribes hunted bison and other game throughout the year, but a winter bison hunt was especially important (Rogers, 1990). During the 19th century, the Arikara were often forced to abandon their villages

due to pressure from the Sioux, and consequently, the Arikara became less dependent on horticulture and more dependent on hunting (Rogers, 1990).

Central Plains

The Pawnee are a loose confederacy of four bands: Chawi (or Grand), Kitkahahki (or Republican), Pitwerehawirata (or Tappage), and the Skiri (or Loup). The first three bands are frequently grouped together as the Southern Bands. It has been hypothesized that the historic Pawnee are direct descendants of the Central Plains tradition people, especially the Itskari phase. However, there is no concrete archaeological or biological evidence to support this hypothesis (Billeck et al., 1995; Steinarcher et al., 1991; Steinarcher and Carlson, 1998). If the Itskari phase people are ancestral to the Pawnee, then there is an approximately 200 year gap in the archaeological record (Billeck et al., 1995). Furthermore, Jantz (1993) found that morphological differences between Itskari phase and Pawnee crania are too distinct to be explained by a direct ancestor/descentant model.

Another possible model for the origins of the Pawnee is that they developed out of the Coalescent Tradition and later moved back into the Central Plains. This hypothesis is supported by the biological data that suggests the Lower Loup phase crania from the Coalescent Tradition are intermediate between Central Plains Tradition and Pawnee crania. This model also explains the 200 year gap in the Central Plains archaeological record.

Most archaeologists still accept the ancestral/descendant relationship between the Central Plains Tradition and Pawnee, but only because there are no other likely ancestors of the Pawnee or any other historical tribes in which the Central Plains Tradition is likely ancestral to (Billeck et al., 1995). Most likely, the Central Plains Tradition people are the ancestors of the historic Pawnee, Arikara, and Wichita, but this is not a direct relationship.

During the historic period, the Pawnee economy was based on growing crops, hunting bison, and trading furs with European traders. Corn, beans, squash and other garden products were grown in small plots near the village. Bison was hunted twice a year—once in June and again in late October (O'Brien, 1984). The Pawnee also hunted elk, deer, beaver, otter, raccoon, badger, and other animals for their pelts and meat.

Southern Plains

The Wichita were the first Plains group to encounter Europeans when Coronado and his men entered southwestern and central Kansas (O'Brien, 1984). Around this time, the Wichita migrated south from Kansas into Oklahoma and Texas. By 1719, Wichita villages were located on the Arkansas River near Tulsa, Oklahoma (Drass, 1998). The Wichita continued to be sedentary horticulturalists, but bison hunting may have become more important once horses and firearms were obtained. Drass (1998) suggests that the abundance of large-end and side scrappers in some Wichita archaeological sites reflects an importance on processing bison hides for trade.

Nomadic Equestrian Hunters

The Arapaho, Assiniboine, Blackfoot, Cheyenne, Comanche, Crow, Gros Ventre, Kiowa, Plains Apache, and Sioux were the equestrian bison-hunting nomads of the Great Plains. Most of these groups, however, did not move onto the Plains until after the introduction of the horse. The only non-horticulture groups on the Plains prior to European contact were the Blackfoot in the north and the Comanche in the south (Carlson, 1998). The other nomadic groups, faced with droughts in other regions and the expanding European populations, entered the Plains to take advantage of the buffalo hunting style made possible by the horse.

Northwestern Plains

The Blackfoot occupied the northwestern plains from the North Fork of the Saskatchewan River in Alberta and Saskatchewan to as far south as the Yellowstone River in central Montana (Hanson, 1998). The Blackfoot tribe is formed by four politically and economically autonomous confederations: Siksika (Blackfeet-proper), Pikuni (Piegan), Kainai (Blood), and Small Robes (Carlson, 1998; Kipp, 1996), but little is known about these groups prior to the historic period. The Blackfoot may be descendants of groups that occupied this area earlier in history or moved into the Plains during a southern migration (Hanson, 1998).

High Plains

Four nomadic tribes inhabited the western High Plains: Arapaho, Cheyenne, Crow, and Gros Ventre. All four of these tribes are believed to have originally been horticulturalists in the northeastern plains before becoming equestrian hunters. There is some archaeological evidence that the Cheyenne practiced a horticultural lifestyle prior to the 18th century near the Red River in eastern North Dakota (Hanson, 1998). By 1795, however, Jean-Baptiste Trudeau noted the presence of the Algonquian-speaking Cheyenne along the Cheyenne River in South Dakota, and by 1805 they were living near the Black Hills (Hanson, 1998). Soon after, the Cheyenne split into northern and southern divisions. The Northern Cheyenne occupied the areas west of the Black Hills near the North Platte and Powder rivers, while the Southern Cheyenne migrated south and made their home in the short-grass plains between the Platte and Arkansas rivers.

The Gros Ventre and Arapaho also practiced a semi-sedentary horticultural lifestyle near the Red River prior to 1650 (Hanson, 1998). These two groups may have once been a single tribe, but they were distinct, geographically separate tribes by the historic period. The Gros Ventre roamed the area between the Saskatchewan River in Alberta and the Missouri River in Montana and allied themselves with the Blackfeet (Carlson, 1998; Hanson, 1998). Anthony Hendry, the first European to encounter the Gros Ventre, found them living in present-day Alberta near the confluence of the forks of the Saskatchewan River in 1754 (Hanson, 1998). The Arapaho probably moved into present-day Montana and Wyoming in the early 18th century. Later they migrated south

and divided into a northern and southern group. The Southern Arapaho allied themselves with the Cheyenne and settled between the Arkansas and North Platte Rivers.

The Siouan-speaking Crow, after branching off the Hidatsa, moved to the foot of the Rocky Mountains at the headwaters of the Yellowstone River. There are two main subdivisions of the Crow. The River Crow probably split from the Awatixa Hidatsa and migrated into Montana near the Yellowstone River, while the Mountain Crow separated from the Hidatsa-proper and lived in the valleys of the Bighorn Mountains (Carlson, 1998).

Northeastern Plains

The Sioux and the Assiniboine were the primary northeastern Plains groups, although the Algonquian-speaking Plains Ojibway and Plains Cree also adopted a Plains cultural lifestyle. The Sioux moved onto the Plains from the Great Lakes region as the Ojibwa and other groups, supplied with firearms from the French, pushed them from their homelands (Carlson, 1998). The Teton Sioux (Lakota division) occupied the area west of the Missouri River and north of the Platte River, while the Santee (Dakota division) and the Yanktonai and Yankton (Nakota division) lived east of the Missouri River (Figure 4.7). The Assiniboine first moved onto the plains from the forests of Minnesota, where they lived along tributaries of the Mississippi River (Denig, 1939). It has long been thought that the Assiniboine separated from the Yanktonai Sioux during17th century, but linguistic, archaeological, and biological data demonstrates that the split probably occurred centuries before (Wescott and Jantz, 1999). After moving onto the Plains, the

Assiniboine allied themselves with the Cree and Chippewa and inhabited the area north of the Missouri River from eastern Alberta to the confluence of the Assiniboine and Red rivers in Manitoba.

Southern Plains

The nomads of the southern plains were the Comanche, Kiowa, and Kiowa-Apache tribes. The Kiowa and Kiowa-Apache occupied the territory between the Arkansas and Canadian rivers, and the Comanche roamed southern Oklahoma and northwestern Texas (Figure 4.7). The Kiowa have a distant linguistic tie to the Tanoan speaking Pueblo Indians of the Southwest (Hanson, 1998). Kiowa oral tradition suggests they lived near the Yellowstone River in western Montana during the late 17th century, but migrated south until they reached western Kansas, Oklahoma and Texas around 1820 (Hanson, 1998). During the southern migration, a small band of Apaches joined the Kiowa. These Apaches, known as the Kiowa-Apaches, adopted the Kiowa cultural and political structure. Linguistic evidence suggests the Kiowa-Apaches split from the Jicarillas and Lipans prior to 1750 (Hanson, 1998). The Comanche share a language with Great Basin tribes, especially the Wind River Shoshone. The Comanche and Wind River Shoshone probably did not split until the late prehistoric or protohistoric period. Archaeologically, the Comanche, Kiowa, and Kiowa-Apache are difficult to differentiate because they shared overlapping territories and similar material culture (Hanson, 1998).

Other Relevant Cultural Groups

Great Basin Cultural Area

The desert basin of Nevada, Utah, and parts of Colorado, Wyoming, Oregon, and California form the Great Basin cultural area (Figure 4.8). The Great Basin, as its name implies, is surrounded by uplands: Sierra Nevada to the west, Rocky mountains to the east, Colorado Plateau to the southwest, and Columbia Plateau to the north. While the Great Basin is a vast desert, it also contains a number of isolated wetlands that are supplied by rivers and streams from the uplands (Shimer, 1972). The major wetlands of the western Great Basin are Pyramid Lake, Walker Lake, Humboldt Sink, and Carson Sink. The Great Salt and Utah Lakes are in the eastern Great Basin.

Inhabitants of the Great Basin, primarily hunter-gatherers, have long exploited the resources of these wetland environments (Kelly, 1995; Larsen and Kelly, 1995). They foraged for seeds, nuts, roots, and insects, and hunted antelope, rabbit and other small game. The major historic Indian tribes of the Great Basin include the Northern and Southern Paiute, Ute, and Shoshone. By the 18th and 19th centuries, several bands of these three tribes became equestrian hunters on the eastern edge of the Great Plains.

Southwest Cultural Area

The American Southwest cultural region includes southern Utah and Colorado, Arizona, New Mexico, and southwestern Texas (Figure 4.9). The landscape is quite diverse with mountains, extensive mesas, and low-lying deserts, but overall the entire

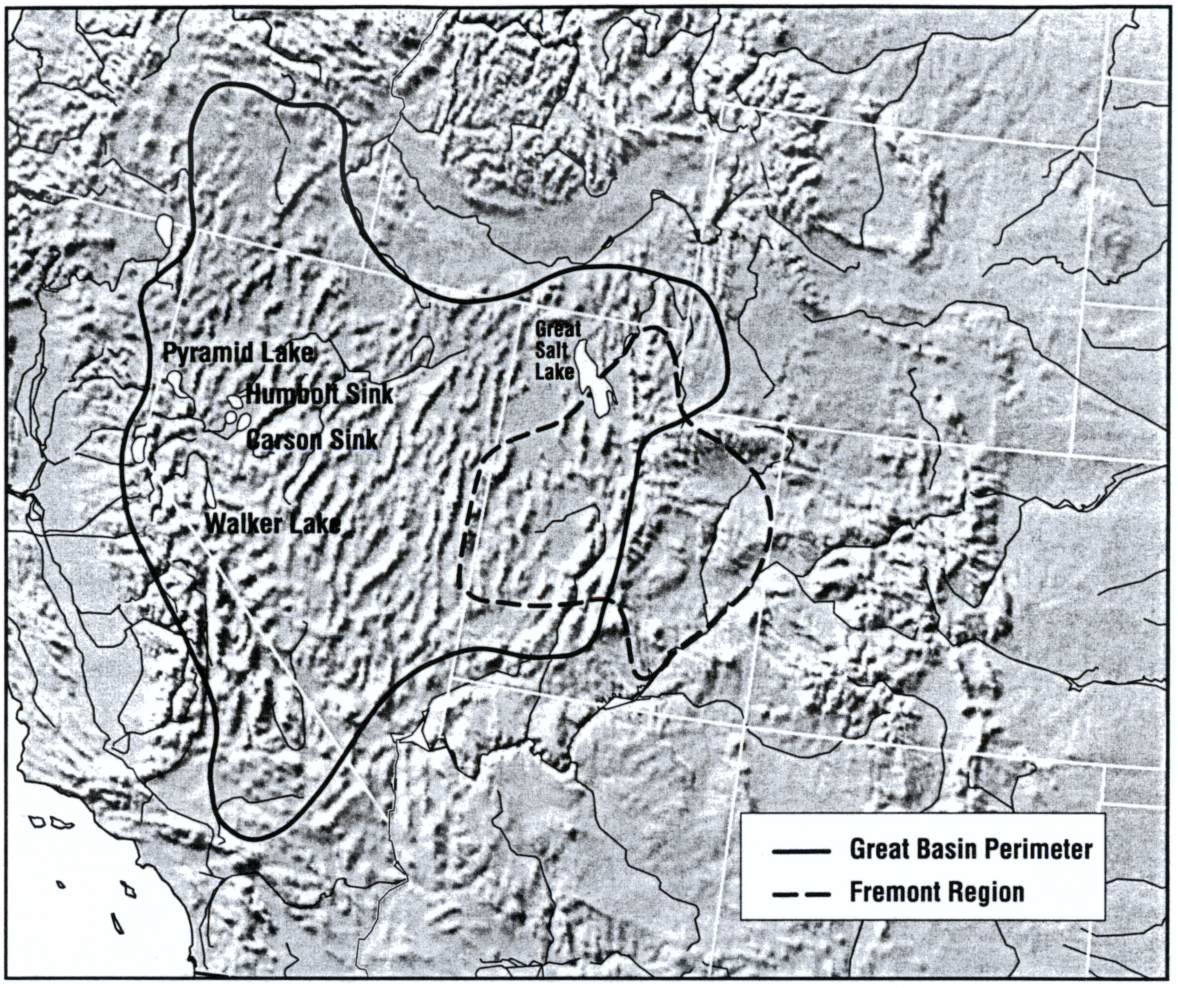


Figure 4.8. Great Basin and Fremont Cultural Area. Adapted from RL Kelly (1997: Figure 1). Late Holocene Great Basin prehistory. Journal of World Prehistory 11:1-49.

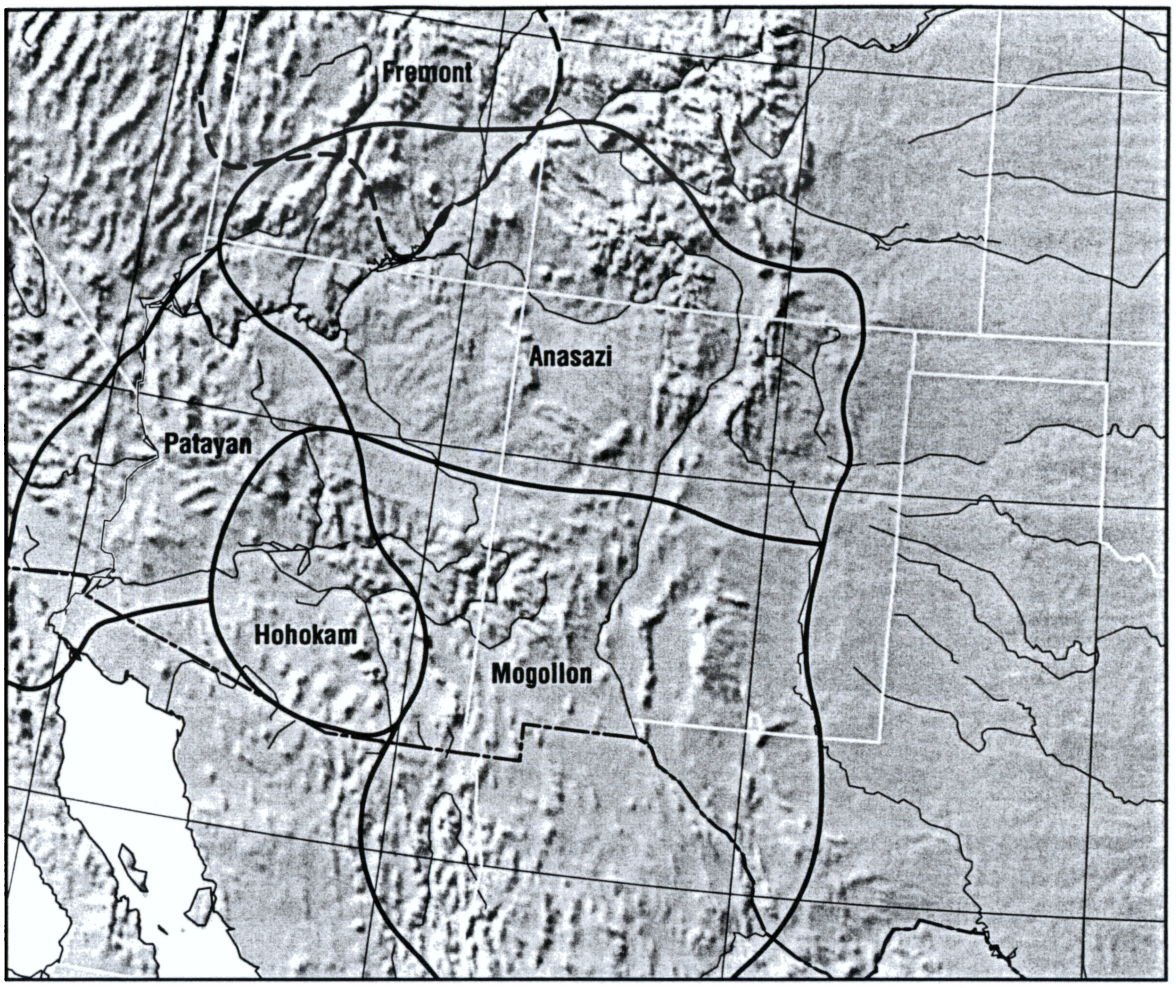


Figure 4.9. Prehistoric cultural areas of the Southwest. Adapted from Cordell (1984: Figure 1.5). Prehistory of the Southwest. Orlando: Academic Press.

Southwest is extremely arid. Culturally and linguistically, the Southwest is very heterogeneous, but all of the groups share an intensive agricultural adaptation that sets them apart from their Great Basin and Great Plains neighbors.

Like the Great Plains, the Southwest can be divided into distinct temporal periods and cultural areas. The Paleoamerican (< 5500 BC) and Archaic (5500 BC to AD 100) periods are very similar to the corresponding Plains periods, but the use of domestic cultigens begins during the late Archaic period (Cordell, 1984). Southwest archaeologists have divided the post-Archaic prehistoric Southwest into four major cultural traditions: Anasazi, Hohokam, Mogollon, and Patayan (Figure 4.9) (Caldwell, 1984; Woodbury, 1979). Several minor prehistoric traditions have also been defined, the most important being the Fremont tradition. Chronological frameworks have been developed by archaeologists for each cultural tradition (Rohn, 1979). However, prehistoric Southwest skeletal remains used in this study are primarily associated with the Anasazi and Fremont cultures, and therefore only these two regions will be discussed in more detail.

The Anasazi occupied the Four-Corners area of Arizona, Colorado, New Mexico, and Utah. Chronologically, the Anasazi cultural area has been divided into two Basket Maker and five Pueblo periods (Table 4.2). The Basket Maker II period is characterized by an abundant assortment of baskets, as the name implies, and a mixed horticulture and hunting-gathering economy. There is also abundant evidence for atlatl use during the Basket Maker II period (Cordell, 1984; Rohn1978). Basket Maker III period (AD 450 to 750) sites show a greater reliance on horticulture and the development of villages with semi-subterrainian pithouses. Pottery also appears during the Basket Maker III period, as

Table 4.2. Archaeological Framework for the Southwest Anasazi Cultural Area.

Period	Date Range[1]	Identifying Features
Basket Maker II	250 BC – AD 450	mixed hunting-gathering / horticulture economy; no pottery; abundant basketry; atlatl use
Basket Maker III	AD 450 – 750	reliance on horticulture; domestic turkey; semi-subterranean earth lodges; use of bow and arrow; appearance of pottery
Pueblo I	AD 750 – 900	agriculture; above ground dwellings; large villages; distinct pottery; elaborate ceremonial structures appear; cranial deformation
Pueblo II	AD 900 – 1100	agriculture; stone masonry pueblos; widespread villages; water storage reservoirs; corrugated cooking pottery
Pueblo III	AD 1100 – 1300	agriculture; large, multi-room, multistory pueblos; irrigation; local specializations
Pueblo IV	AD 1300 – 1540	agriculture; movement of Pueblo people from the region; diminished use of corrugated wares
Pueblo V	AD 1540 – 1850	Spanish influence

[1]Cordell, 1979; Rohn, 1978

does turkey domestication. During the Pueblo periods, Anasazi groups settled into large villages with masonry pueblos, and they built reservoirs to irrigate their fields. The Anasazi culture supported large populations and allowed for specialized occupations such as potters, weavers, and other artisans (Cordell, 1984).

The Fremont people occupied the area northwest of the Anasazi in present central Utah and western Nevada (Figures 4.8 and 4.9). This region overlaps the Southwest and Great Basin cultural regions, and the Fremont culture displays similarities with both regions. The origin of the Fremont is still not clear. They may have developed from local Desert Archaic groups or as an Anasazi expansion, but mitochondrial DNA analysis of Fremont skeletal remains suggest they share a distant ancestry with the Anasazi (Parr et al., 1996).

Like other Southwest groups, the Fremont cultivated corn, beans, and squash, but they may not have been as dependent on agriculture as other prehistoric Southwest groups (Cordell, 1984; Simms, 1999). Kelly (1997:21) argues "there was spatial and temporal variability in dependence on maize." In the Great Salt Lake wetlands, for example, during certain climatic shifts agriculture may have been less viable than foraging (Kelly, 1997; Simms, 1999). According to Coltrain and Stafford (1999), stable isotope analysis of human remains from the Great Salt Lake region indicates a wide range of diets among the Fremont, especially between AD 400 and 1150. However, in other areas, the Fremont diet appears to have had a very uniform with a reliance on maize.

During the historic period, the Southwest cultural region was occupied by agriculturalists (Hopi, Zuni, Rio Grande Pueblos, Yaman, Pima, and Papagos),

pastoralists (Navajo), and nomadic raiders (Apache). The historic agricultural groups of the Southwest are probably descended from earlier Southwest groups: Zini from the Mogollon, Hopi and Rio Grande from the Anasazi, Yuma from the Patayan, and the Pima and Papago from the Hohokam. The Athapascan Navaho and Apache did not move into the region until much later (ca. AD 800-1000).

Texas Gulf Region: Coahuiltecans and Karankawas

The Coahuiltecans and Karankawas were hunters and gatherers that occupied the coastal region of Texas between the Colorado River and the Rio Grande River during historic times (Newcomb, 1990) (Figure 4.7). Both tribes exploited the coastal region by fishing, hunting, and gathering wild fruits (Humphreys, 1971; Newcomb, 1990; Obertse, 1943). Since the Coahuiltecans resided more inland, they are thought to have exploited more inland animals compared to the Karankawans, but stable isotope analysis suggests the Coahuiltecans were heavily reliant on marine protein (Norr, 1999).

During the 18th century, members of each tribe periodically resided in Spanish missions. The Mission of Our Lady of Refuge in Refugio, Texas was built in 1793 for the Karankawa, and the Coahuiltecans inhabited the Mission San Juan Capistrano in San Antonio. When at the mission, they grew gardens and tended cattle. Most likely, the Coahuiltecans and Karankawans at the missions participated in both coastal hunting-gathering and farming. Historical records and isotope data indicate that the Indians frequently abandoned the missions and returned to their coastal homelands when food became scarce (Meadows Jantz et al., 2001).

The Coahuiltecan and Karankawan specimens used in this study were obtained from mission cemeteries. The Coahuiltecan sample was excavated in 1967 at the Spanish Mission San Juan Capistrano on the San Antonio River (Schuetz, 1969). The mission was established in 1731, but the burials date from approximately 1760 to 1785 (Humphreys, 1971). The Coahuiltecan and Spanish missionaries were the primary inhabitants of the mission, but other Indian groups may have been present as well (Humphreys, 1971). The Karakankawan sample consists of Indians buried in the Mission of Our Lady of Refuge cemetery. The cemetery was utilized from 1795 to 1830 (Meadows Jantz, personal communication). The Refugio mission cemetery contains the remains of Indians and Spaniards, but only skeletal remains classified as "Indian" were used in this study.

Southeastern Woodlands: The Caddo

The Caddo represent the westernmost manifestation of the Mississippian cultural tradition, and have continuously resided in present-day southwestern Arkansas, southeastern Oklahoma, eastern Texas, and northwestern Louisiana for at least the past 800 years (Wyckoff, 1971). Like other Mississippian groups, the Caddo groups practiced intensive horticulture, lived in large sedentary villages along fertile river valleys, practiced complex religious ceremonialism, and built earthen platform mounds as politico-religious structures (Wyckoff, 1971).

Traditionally, archaeologists have divided the Caddo into two distinct cultural aspects: Gibson and Fulton (Hughes, 1974; Krieger, 1946). The Fulton Aspect represents

late prehistoric and historic groups in the Caddo area, while the Gibson Aspect correspond to early prehistoric groups. A five-stage sequence of Caddo prehistory (Caddo I – V) with multiple foci has also been composed (Table 4.3) (Wyckoff, 1971). Caddo I and II correspond to the Gibson Aspect and Caddo III through V are associated with the Fulton Aspect (Wyckoff, 1974).

While linguistically affiliated with the Arikara, Pawnee, and Wichita, the Caddo are culturally distinct from the Plains Caddoans. The Caddo's dependence on crops is far greater than that of other Plains Caddoan speakers, and deer was much more important than bison as a source of protein (Hughes, 1974). Furthermore, the Caddo lived year round in their villages.

The two primary physiographic features in the Caddo cultural area are the Gulf Coastal Plains and the Quachita Mountains. The Coastal Plains compose the southern two-thirds of the area and the Quachita province the northern third. The Coast Plains landform is generally sloping with rolling hills and broad river valleys, while the Quachita province exhibits rolling hilly uplands, mesas, and mountains.

Historic African, Asian, and European Americans

The historic African, Asian, and European Americans represent a wide variety of occupations: early explorers and missionaries, slaves, laborers, and modern industrialists. Specimens were drawn from historic cemeteries, the Terry anatomical collection, and the Forensic Database.

Table 4.3. Archaeological chronology of the Caddo Indians.

Gibson Aspect	
Caddo I	AD 1000 – 1200
Alto Focus	
Harlen Complex	
Caddo II	AD 1200 – 1400
Haley Focus	
Sanders Focus	
Spiro Focus	
Fulton Aspect	
Caddo III	AD 1400 – 1500
Bossier Focus	
Whelan Complex	
McCurtain Focus	
Texarkana Focus	
Mid-Ouachita Focus	
Fort Coffee Focus	
Caddo IV	AD 1500 – 1700
Belcher Focus	
Titus Focus	
Mid-Ouachita Focus	
Fort Coffee Focus	
Neosho Focus	
Caddo V	AD 1700 – 1859

CHAPTER 5

MATERIALS AND METHODS

In order to examine postcranial variation within a biomechanical framework, two primary sources of data are used: humeral and femoral external measurements and computed tomographic (CT) cross-sectional scans. Previously, a large database of external dimensional data has been compiled, especially for the American Great Plains, and many of the skeletons in this database have been repatriated and are no longer available for scientific research. Humeri and femora from a subsample of these specimens were CT scanned.

Both types of data have advantages and disadvantages, and therefore used in conjunction. One advantage of using external dimensions is that they can be collected rather easily on a large number of individuals. The collection of external measurements is also inexpensive, requires minimal equipment, and many of the measurements can be performed on fragmentary and incomplete bones. Computed tomography scans, on the contrary, are expensive and time consuming, necessitate an available CT scanner, and require mostly complete bones.

External dimension data may be easier to collect than CT data, but Larsen (1998) argues they only have limited use in a biomechanical study. However, while external dimensions may only provide a general picture of robusticity and cross-sectional shape, total area, torsional strength (J) and the I_{AP}/I_{ML} ratio can be reliably estimated from external dimensions of long bone diaphyses. An advantage of using CT data is that cross-

sectional scans provide a different type of information, about not only bone size and shape, but how the bone is distributed in cross-section.

Specimens used in this study were selected based on accessibility, completeness, absence of pathology, availability of sex indicators, the complete or nearly complete closure of epiphyses. The age and sex of the individual was estimated using standard osteological techniques (Bass, 1995; Phenice, 1969; Krogman and Iscan, 1986; Owsley and Jantz 1999; Stewart, 1979; Ubelaker, 1989). Each specimen was assigned an age code (Table 5.1). When possible, sex was estimated using pelvic morphology, and age was estimated using auricular surface and pubic symphysis morphology.

External Measurements

University of Tennessee / Smithsonian Institution Database

The long bone external dimension data come primarily from the University of Tennessee / Smithsonian Institution (UT/SI) Postcranial database. This database presently consists of 70 external measurements taken on 11 bones (Appendix A, Table A.1). In most cases, only the left side is measured for bilateral bones. In this study, only selected measurements of the humerus and femur are employed (Table 5.2). A full description of the measurements can be found in Zobeck (1983).

The database was first assembled by Zobeck (1983) during analysis of the William H. Over collection, but has received regular additions, especially from Dr. Owsley and coworkers at the Smithsonian Institution and Dr. Jantz and coworkers at the University of Tennessee. In addition, data from the Crow Creek site, collected by Dr.

Table 5.1. Age Codes Used in Study

Code	***Age Range (years)***
18	16.5 – 17.5
19	17.5 – 18.5
20	18.5 – 19.9
21	20 - 24
22	25 - 29
23	30 - 34
24	35 - 39
25	40 - 44
26	45 - 49
27	50 - 54
28	55 - 59
29	60+

Table 5.2. Selected Long Bone Dimensions Used in this Study.

Measurement	*Instrument*	*Source*
Humerus		
1. Maximum length (HML)	osteometric board	Bass (1987)
2. Proximal epiphysel breadth (BUE)	osteometric board	McHenry and Corrucini (1978)
3. Maximum diameter at midshaft (MDS)	sliding calipers	Bass (1987)
4. Minimum diameter at midshaft (MDM)	sliding calipers	Bass (1987)
5. Maximum vertical diameter of the head (MDH)	sliding calipers	Bass (1987)
6. Epicondylar breadth (EBR)	osteometric board	McHenry and Corrucini (1978)
Femur		
1. Maximum length (FML)	osteometric board	Bass (1987)
2. Trochanteric length (FTL)	osteometric board	Martin and Saller (1957)
3. Subtrochanteric anteroposterior diameter (APD)	sliding calipers	Bass (1987)
4. Subtrochanteric mediolateral diameter (MLD)	sliding calipers	Bass (1987)
5. Anteroposterior diameter at midshaft (APS)	sliding calipers	Bass (1987)
6. Mediolateral diameter at midshaft (MLS)	sliding calipers	Bass (1987)
7. Maximum vertical diameter of the head (VHD)	sliding calipers	Martin and Saller (1957)
9. Maximum horizontal diameter of the head (HHD)	sliding calipers	Martin and Saller (1957)
10. Epiconylar breadth (FEB)	osteometric board	Martin and Saller (1957)
11. Bicondylar breadth (BCB)	spreading calipers	Hrdlička (1939)

Willey (Willey, 1990), data from a variety of Plains groups collected by the Repatriation Office of the Smithsonian Institution, and measurements collected by the author have been added. The database presently consists of more than 2500 individuals from over 350 archaeological and historical sites in Iowa, Kansas, Louisiana, Maine, Maryland, Minnesota, Missouri, Montana, Nebraska, Nevada, North Dakota, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, Utah, Virginia, and Wyoming. Specimens in the database range in time from the Paleoamerican period to the historic period. At least eight language families, ten different subsistence strategies, and five varied physical terrains are also represented in the UT/SI database.

Smithsonian site designations, site name, geographical region, cultural affiliation, mean date, and subsistence are given in Table B.1, Appendix B. Cultural affiliation and mean date for each archaeological site were gathered from archaeological literature, state historical societies, and archaeologists.

External measurements of recent white and black Americans from the Terry collection and the Forensic Data Base (FDB) are also used in this study. The Terry collection, housed at the Smithsonian Institution, consists of nearly 1600 19th and 20th century blacks and whites with known biographic information. A sub-sample of 200 individuals is used in this study. Skeletons in the Terry collection were collected from 1898 until the mid 1960s from cadavers dissected at the Medical Department of Washington University (Trotter, 1981). While most of the individuals resided, at least temporarily, in the St. Louis, Missouri area, the geographical origin is unknown for most of the specimens. The FDB, developed under the direction of Dr. Jantz in 1989, receives

regular additions from forensic anthropologist around the United States. At present, there are nearly 2000 positively identified individuals in the FDB.

Diaphyseal Robusticity and Shape

Long bone external dimensions were used to calculate diaphyseal shape and robusticity at the subtrochanter and midshaft of the femur. The formulae are as shown in Table 5.3. In addition, the subperiosteal area (TA) and torsional strength (J) were estimated for the femur at each level and TA was calculated for the mid-distal humerus. These variables roughly reflect the cross-sectional properties of the bone and provide a measure of the average resistance to bending (Cole, 1994).

Diaphyseal shape is defined as the ratio of the anteroposterior diameter to the mediolateral diameter at each level (Larsen, 1997). For example, femur midshaft shape (FMS) is APS divided by MLS (Table 5.3). A ratio greater than 1.0 indicates that the cross-section is elongated along the sagittal or anteroposterior plane, while a ratio of less than 1.0 shows the diaphysis is wider in the coronal or mediolateral plane than in the anteroposterior plane (Larsen, 1997). The diaphyseal shape ratio provides an excellent estimate of the Ix/Iy ratio or "mobility index" obtained from cross-sectional analysis (Rockhold, 1998).

Diaphyseal robusticity offers a measure of the bones average resistance to bending. The term "robusticity" is commonly used in the anthropological literature, but as Pearson (2000) has pointed out, there are numerous definitions. Traditionally, robusticity is defined as diaphyseal thickness relative to bone length (Martin and Saller,

Table 5.3. Formulae used to calculate diaphyseal robusticity, shape and area.

Bone	***Property***	***Abbreviation***	***Formula***
Humerus	Midshaft Shape	HMS	MDS / MDM
	Midshaft Robusticity	HMR	100(√MDS*MDM) / HML
	Midshaft Area	HMTA	π(MDS / 2)(MDM / 2)
	Distal Shape	HDS	DAP / DML
	Distal Robusticity	HDR	100(DAP + DML) / BLH
	Distal Area	HDTA	π(DAP / 2)(DML / 2)
Femur	Subtrochanter Shape	FSS	APD / MLD
	Subtrochanter Robusticity	FSR	100(√APD*MLD) / FML
	Subtrochanter Area	FSTA	π(APD / 2)(MLD / 2)
	Midshaft Shape	FMS	APS / MLS
	Midshaft Robusticity	FMR	100(√APS*MLS) / FML
	Midshaft Area	FMTA	π(APs / 2)(MLs / 2)

1956), but it has also been applied to joint surface size, bending strength, torsional strength, and cortical area relative to length. In most biomechanical studies, robusticity is defined as bone strength relative to length. In this study, robusticity is examined by using standardized torsional strength ($J/FML^{5.33}$) and the traditional definition using external dimensions.

An elliptical cross-sectional shape of both the humerus and femur will be assumed in order to estimate subperiosteal area, and therefore only two dimensions (i.e., anteroposterior and mediolateral) are needed. This assumption is followed for radiographic analyses of the femur and humerus (Fresia et al., 1990; Ruff and Jones, 1981). While the femur and midshaft of the humerus are roughly elliptical, the distal end of the humerus is more triangular. Fresia et al. (1990) addressed this problem by testing the accuracy of using an elliptical formula to calculate cross-sectional area in the distal end of the humerus. They compared the estimated total diaphyseal area at 35% from the distal end with areas calculated from actual cross-sections of the same bone. Fresia et al. (1990) found that the area estimate was highly correlated with actual area values obtained from the cross-sections, but the area was slightly overestimated in a relatively constant manner.

Computed Tomography Cross-Sections

Computed tomographic (CT) cross-sectional images were collected on paired humeri and femora from available Plains Archaic, Plains Woodland, Coalescent and Middle Missouri Variant groups, prehistoric Texas Caddo, protohistoric and historic

Arikara, and historic Sioux and Karankawa samples housed at the Smithsonian Institution NMNH and the University of Tennessee (Table B.2, Appendix B). In addition, Dr. Ruff kindly provided me permission to utilize his raw Plains data (Ruff, 1994).

External Dimensions of Scanned Bones

Prior to scanning, all of the bones first measured externally. Nine measurements were collected for the humerus and eleven for the femur (see Table 5.4 and Figures 5.1 and 5.2). The external dimensions include a sub-sample of those collected for the UT/SI Postcranial database and several additional measurements. For the humerus, anteroposterior and mediolateral dimensions at 35% from the proximal end (DAP and DML, respectively) were collected in addition to maximum length, biomechanical length, breadth of the distal epiphyses and diameters of the shaft. For the femur, maximum length (FML), trochanteric length (FTL), diameters of the shaft at subtrochanteric and midshaft, and dimensions of the epiphyses were collected.

Cross-sectional Computed Tomography Scans

Cross-sectional images of the humeri and femora were collected using three scanners. Specimens housed at the Smithsonian Institution were scanned with a Siemans Samaton AR, SP scanner. A General Electric scanner at the University of Tennessee Medical Center was used for Arikara long bones housed at the University of Tennessee, while the Refugio and Broken Kettle material were scanned at Abercrombie Radiological using a Picker MxTwin. All bones were scanned in air with a 1 mm slice thickness for 1-

Table 5.4. External Measurements Taken on CT Scanned Bones

Humerus

1. Maximum length (HML): The length of the humerus from the most proximal point on the head to the most distal point on the trochlea. Measure to the nearest millimeter using an osteometric board. Source: Moore-Jansen and Jantz (1989: 72 #40).
2. Biomechanical length (BLH): "The length of the humerus from the most proximal point on the head to the most distal point on the lateral lip of the trochlea." The bone is placed on the osteometric board with the head against the vertical headboard so that the bones long axis parallels the instrument. Length is determined by visual inspection. Measure to the nearest millimeter. Source: Equivalent to the measurement taken on radiographs by Fresia et al. (1990: 122).
3. Epicondylar breadth (EBR): The maximum distance, measured with an osteometric board, across the distal epicondyles of the humerus. Measure to the nearest millimeter. Source: Moore-Jansen and Jantz (1989, 72 #41).
4. Maximum vertical diameter of the head (MVD): The vertical distance, measured with sliding calipers to the nearest millimeter, from the most proximal and distal points on the border of the articular surface of the humeral head. Source: Moore-Jansen and Jantz (1989: 72 #42).
5. Maximum diameter at midshaft (MDS): The maximum diameter of the shaft at the HML midpoint. Measurement is taken with sliding calipers to the nearest millimeter. Source: Moore-Jansen and Jantz (1989: 73 #43).
6. Minimum diameter at midshaft (MDM): The least diameter of the shaft at the HML midpoint. Measurement is taken with sliding calipers to the nearest millimeter. Source: Moore-Jansen and Jantz (1989: 73 #44).
7. Anteroposterior diameter at 65% (DAP): The diameter of the shaft at 65% of BLH from the proximal end in the anteroposterior plane. Take the measurement with sliding calipers to the nearest millimeter.
8. Mediolateral diameter at 65% (DML): The diameter of the shaft at 65% of BLH from the proximal end in the mediolateral plane. Measure to the nearest millimeter with sliding calipers.
9. Least circumference of the shaft (LCS): The least circumference of the humeral shaft. Measure to the nearest millimeter using a steel tape. Source: Zobeck (1983).

Table 5.4. Continued

Femur

1. Maximum length (FML): The direct distance from the most proximal point on the head of the femur and the most distal point on the distal condyles. Measure to the nearest millimeter using an osteometric board. Source: Moore-Jansen and Jantz (1989: 78 #60).
2. Trochanteric length (FTL): The distance from the most proximal point on the greater trochanter and most distal point on the distal condyles. Measure to the nearest millimeter using an osteometrc board. Source: Martin and Saller (1957) and Zobeck (1983: 130 # 7).
3. Epiconylar breadth (FEB): The maximum distance from the two most lateral point on the lateral epicondyle and most medial point on the medial epicondyle parallel to the infracondylar angle. This measurement is taken to the nearest millimeter with an osteometric board or spreading calipers. Source: Martin and Saller (1957:565 #21), Moore-Jansen and Jantz (1989: 79 #62) and Zobeck 1983: 133 #43).
4. Maximum diameter of the head (MFH): The maximum diameter of the articular surface of the femur head. Measure to the nearest millimeter with sliding calipers. Source: Bass (1987:168), Montagu (1960: 70) and Moore-Jansen and Jantz (1989: 79 #63).
5. Subtrochanteric anteroposterior diameter (APD): The anteroposterior diameter of the proximal end of the diaphysis perpendicular to greatest expansion below the base of the lesser trochanter. Measure with sliding calipers to the nearest millimeter. Source: Bass (1987:169), Martin and Saller (1957:564 #10), Moore-Jansen and Jantz (1989: 79 # 64), and Zobeck (1983:131 #23).
6. Subtrochanteric mediolateral diameter (MLD): The mediolateral diameter of the proximal end of the diaphysis below the lesser trochanter at the point of greatest lateral expansion. The measurement is taken parallel to the anterior surface of the femur neck. Measure to the nearest millimeter with sliding calipers. Source: Moore-Jansen and Jantz (1989:80 #65) and Zobeck (1983:131 #24).
7. Anteroposterior diameter at midshaft (APS): The anterioposterior diameter of the FTL midpoint of the shaft. Measure to the nearest millimeter using sliding calipers. Source: Moore-Jansen and Jantz (1989: 80 #66), and Zobeck (1983: 131 #25).
8. Mediolateral diameter at midshaft (MLS): The mediolateral diameter of the FTL midpoint of the shaft perpendicular to APS. Measure to the nearest millimeter using sliding calipers. Source: Moore-Jansen and Jantz (1989: 80 #67) and Zobeck (1983: 131 #26).

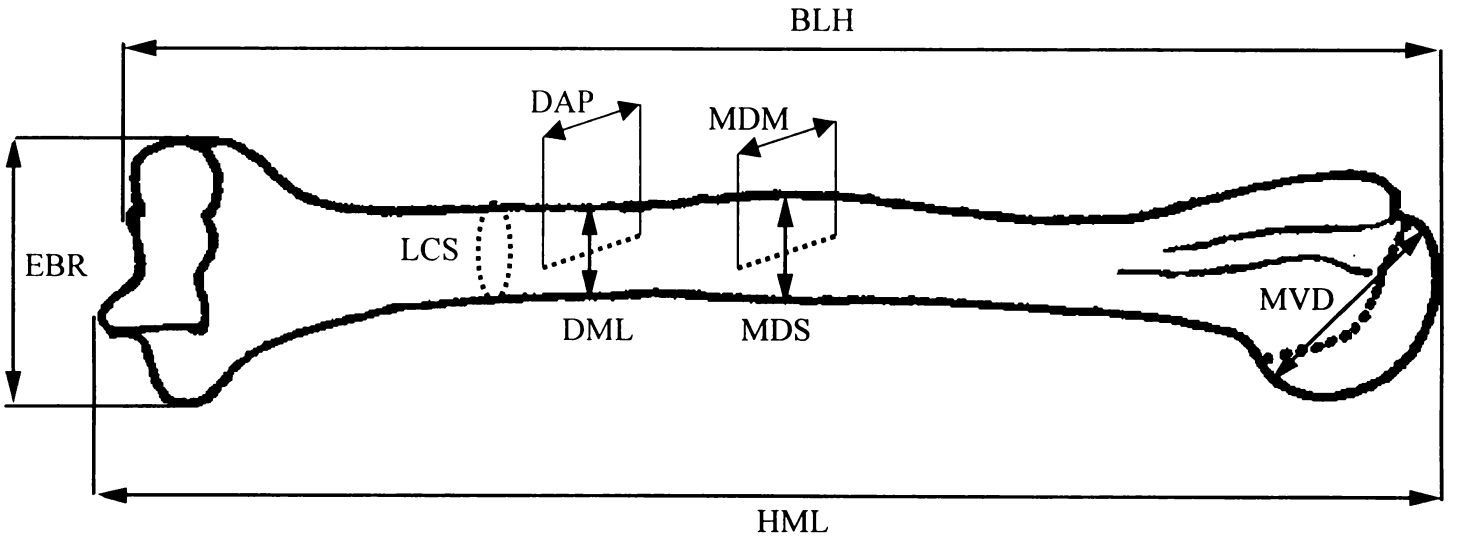


Figure 5.1. External measurements of the humerus

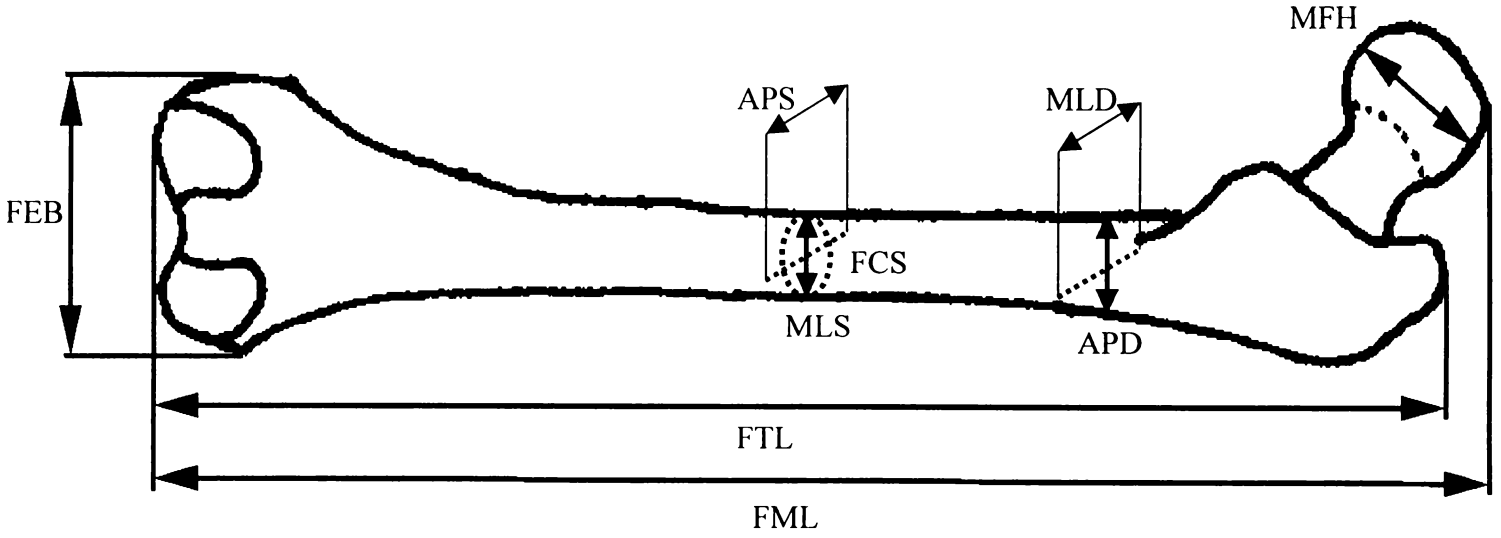


Figure 5.2. External measurements of the femur.

3 seconds. Bone equivalent phantoms (i.e., aluminum and PVC tubes) and a broken femur of known dimensions were scanned to establish proper display settings and bone boundary thresholds (Ohman, 1993; Ruff and Leo, 1986).

Prior to computed tomographic scanning, the bones were positioned with respect to a sagittal plane and a coronal plane, and the appropriate location of the cross-section marked. The cross-sectional images were taken perpendicular to both the sagittal and coronal planes (Figures 5.3 and 5.4).

The sagittal plane of the humerus passes longitudinally through the midpoint of the proximal diaphysis mediolateral breadth and the crest of lateral lip of the trochlea (Ruff and Larsen, 1990) (Figure 5.3). The coronal plane passes at a right angle to the sagittal plane through the centers of the trochlea and capitulum and the anteroposterior midpoint of the diaphysis at the surgical neck (Ruff and Larsen, 1990). In order to insure that the coronal plane was level with the tabletop, the distal end of the humerus was raised using modeling clay until it was at the same level (distance from the tabletop) as the proximal end. A level sagittal plane was assured by adjusting the bone so that the marks on both the medial and the lateral sides were at equal heights from the tabletop.

The sagittal plane of the femur is defined as the plane passing through the midpoint of the mediolateral breadth of the diaphysis just distal to the lesser trochanter (subtrochanteric) and the deepest point in the patellar groove (Ruff, 1983; Ruff, 2000) (Figure 5.4). The coronal plane passes through the AP midpoints of the diaphysis at subtrochanteric and just proximal to the condyles (Ruff, 1983; Ruff, 2000). The anteroposterior midpoints of the diaphysis were located with the femur resting dorsal side

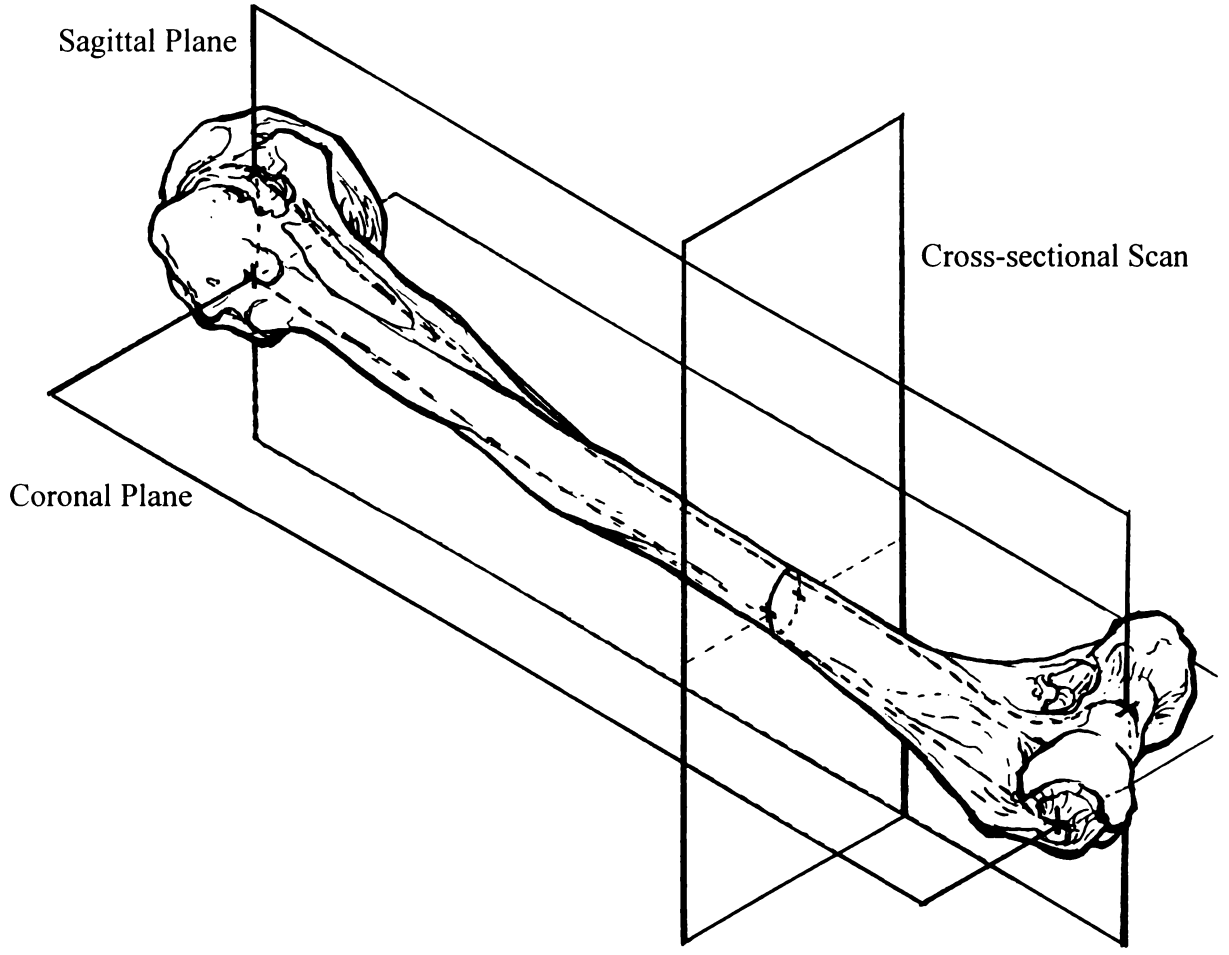


Figure 5.3. Anatomical planes of the humerus

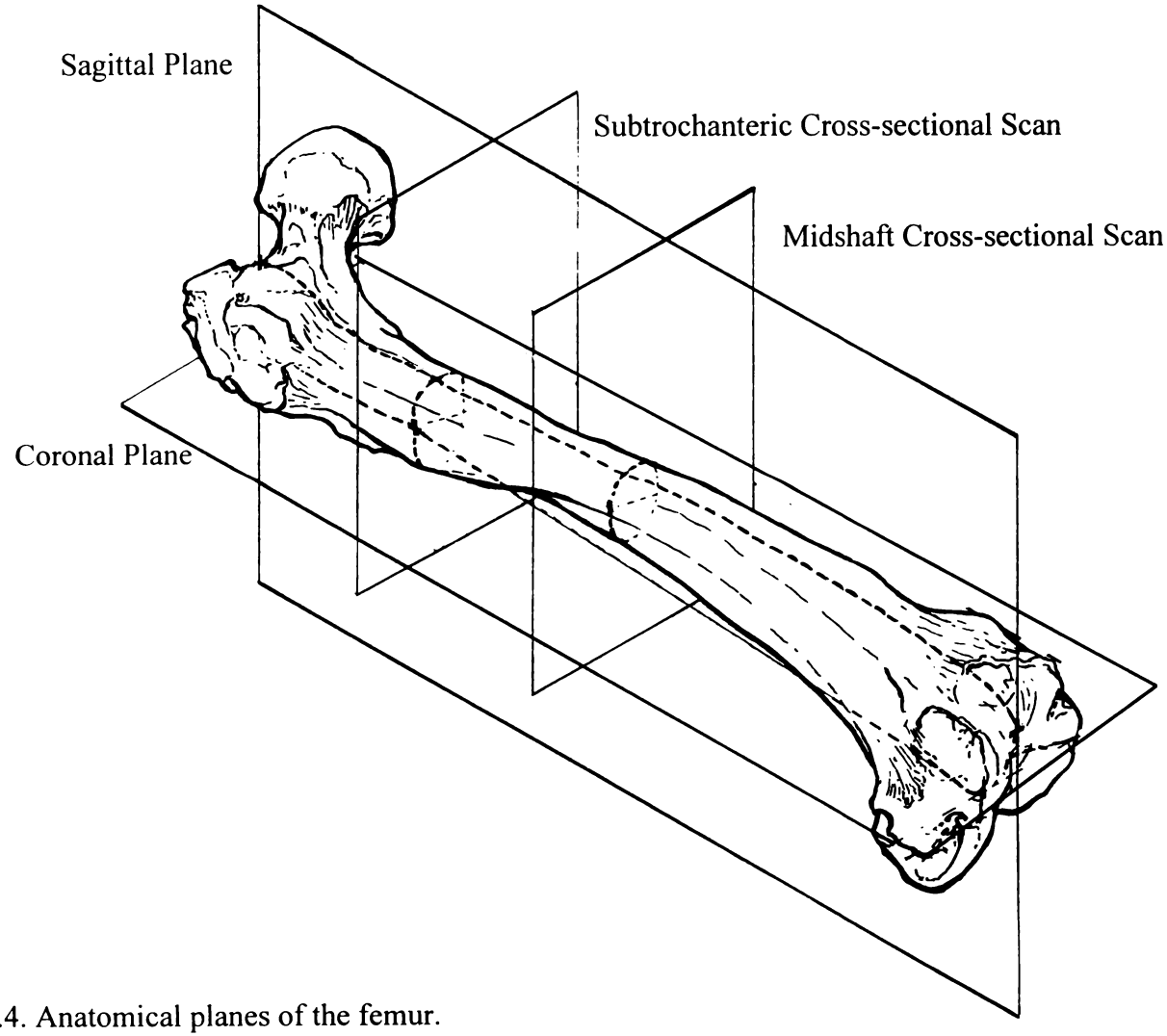


Figure 5.4. Anatomical planes of the femur.

down on a tabletop. The bone was resting on the posterior surface of the condyles distally and the greater trochanter proximally. To determine the proximal midpoint, a point was located on the anterior surface of the diaphysis defined by the intersection of a line drawn at the greatest lateral expansion of the diaphysis just distal to the lesser trochanter (subtrochanteric) and the mediolateral breadth midpoint used for the sagittal plane. Next, the height of this point from the tabletop surface and the anteroposterior breadth of the diaphysis was measured. Half of the anteroposterior breadth of the diaphysis was subtracted from the height of the anterior surface. This distance was then measured from the tabletop and marked on the bone. The distal midpoint is determined in a similar fashion. The deepest point on the distal end near the center was found and the height of this point from the tabletop measured. The anteroposterior diameter was measured and the midpoint of the shaft determined by subtracting half of the diameter from the height. The midpoint on the bone was marked. To level the coronal plane, the proximal end of the bone was raised using modeling clay under the greater trochanter until the proximal and distal midpoints were at equal heights above the tabletop.

The humeri were scanned at 35% of BLH from the distal end perpendicular to the sagittal and coronal planes. The purpose of scanning the humeri at this location is to avoid the deltoid tuberosity, which often extends beyond midshaft (Ruff and Larsen, 1990). This location is also consistent with studies of the humerus in other geographical regions (e.g., Fresia et al., 1990; Ruff and Jones, 1981; Ruff and Larsen, 1990). The femora were scanned at midshaft (based on trochanteric length) and at subtrochanteric. In most biomechanical studies (e.g., Ruff, 1999; Ruff and Hayes, 1983; Ruff and Jones,

1981; Ruff and Larsen, 1990), the femur is scanned at 80% from the distal end instead of subtrochanteric, but subtrochanteric is more appropriate because it is a definable anatomical landmark and because it is consistent with most studies using external measurements. The midshaft CT scan is consistent with other cross-sectional studies of the femur (e.g., Bridges, 1989; Ohman, 1993; Ruff, 1983, 1999; Ruff and Jones, 1981; Ruff and Larsen, 1990).

The computed tomography images were converted to TIFF files, and the cross-sectional properties were calculated in Scion Image (Scion Corporation, 2000) using "Momentmacro" (Warfel, 1997). The cross-sectional properties calculated include: total subperiosteal area (TA), cortical area (CA), second moments of inertia (I_{max}, I_{min}, I_x, I_y), and theta (θ). The polar second moment of area (J) was derived by adding I_{max} and I_{min}, and percent cortical area (%CA) was calculated as CA/TA*100. Cross sectional properties of the humerus and femur were standardized for body size by dividing TA and CA by bone length^3 and moments of inertia (I and J) by bone length$^{5.33}$.

Ruff's (1994) Great Plains Data

Chris Ruff graciously allowed me access to his Great Plains raw data. Ruff's data, collected during osteological investigations of the William Over skeletal collection (Owsley and Jantz, 1994a, 1994b), consists of femoral midshaft cross-sectional properties representing 129 individuals from 34 prehistoric and protohistoric archaeological sites (32 from South Dakota and 2 from Oklahoma). External dimensions for these specimens were collected by Zobeck (1983) and are part of the UT/SI postcranial database. One

femur from each individual was selected and prepared for biomechanical analysis. The femur was orientated with respect to anatomical planes (discussed above) and sectioned transversely at midshaft (Ruff, 1994). The cut bone surfaces were then photographed, projected onto a digitizer, and the subperiosteal and endosteal surfaces were manually traced. Cartesian coordinates of the traced boundaries were used to calculate the cross-sectional properties (i.e., I_x, I_y, I_{max}, I_{min}, and theta) with the program SLICE (Nagurka and Hayes, 1980).

Activity, Mobility, and Terrain Scores

Activity levels, mobility, and the type of terrain all appear to have an affect on long bone cross-sectional properties (Ruff, 1999, 2000a). In order to test hypotheses regarding the effect of these factors on diaphyseal morphology, each specimen is given a numeric score for activity level, mobility, and terrain. The activity level and mobility scores are based on subsistence strategy, while the terrain score is based on the dominant landform in the region from which the skeleton was found.

It is important to note that the subdivisions of subsistence economy discussed below, while based on archaeological and historical information, are only arbitrary markers established for convenience. In addition, there are several problems with generalizing about mobility and activity level based on subsistence economy. First, there is considerable variability in how much groups of any subsistence strategy work and move, and it is probably not possible to precisely know the mobility patterns or level of activity in groups from the past. Some hunter-gatherer groups, for example, are

extremely mobile while others are sedentary (Kelly, 1995). Second, the term "mobility" is often confusing because a group can be residentially and/or logistically mobile (Binford, 1980; Kelly, 1995). Residential mobility is the frequent moving of a group from one residence to another, while logistic mobility is the movement of individuals away from and back to the resident. It is likely that logistic mobility would have a greater affect on lower limb cross-sectional morphology than residential mobility. Finally, logistic mobility is an individual phenomenon (Hemphill, 1999). Certain members of any group are more mobile then others and males may be far more mobile than females from the same population (Ruff, 1999, 2000a).

The subdivisions of terrain are also arbitrary, and how these different terrains were used by the prehistoric inhabitants is completely speculative. Case in point, while there is obviously greater physical relief in mountainous regions compared to the Coastal Plains, groups from the Great Basin (considered mountainous) may have primarily occupied the relatively flat basin areas, infrequently traversing the mountainous areas. (Heizer, 1967; Heizer and Napton, 1970; Hemphill, 1999).

Mobility and Activity Level

In this study, subsistence strategy is divided into nine adaptation types: (1) broad-spectrum hunter-gatherers (BSHG), (2) coastal hunter-gatherers (CHG), (3) woodland hunter-gatherers (WDHG), (4) equestrian hunter-gatherers (EHG), (5) incipient horticulturalist, (6) village horticulturalists and hunters (VHH), (7) agriculturalists (AGR), (8) early modern industrialists (EMI), and (9) late modern industrialists (LMI).

Each adaptation type has a numeric score for mobility and activity level (Table 5.5). Mobility ranges from extremely low (score of 0) to high (score of 4), while activity level ranges from very low (score of 0) to high (score of 3).

The BSHG adaptation type is typified by the Paleoamerican and Archaic traditions and Great Basin hunter-gatherers. A BSHG adaptation generally requires a very highly mobile lifestyle, probably both logistic and residentially. However, this adaptation type probably only requires a moderate level of activity compared to other groups. While some researchers have suggested that the hunter-gatherers of the Great Basin were relatively sedentary (Heizer, 1967; Heizer and Napton, 1970), most recent research suggests that the Great Basin hunter-gatherers were very mobile (Hemphill, 1999; Kelly, 1990; Larsen and Kelly, 1995; Larsen et al., 1995; Ruff, 1999).

The Karankawa and Coahuiltecans of the Texas Gulf Coast are used to represent the CHG adaptation type. Coastal hunter-gatherers fished, hunted marine mammals and gathered wild flora. As a result, the Karankawa and Coahuiltecans were probably highly mobile but not as mobile as the BSHG. Unfortunately, because the CHG sample used in this study was drawn from mission cemeteries, it may represent a relatively sedentary sample. However, mission records suggest that the Karankawas and Coahuiltecans frequently abandoned the missions and returned to a hunting and gathering lifestyle (Meadows Jantz et al., 2001).

The WDHG are best represented by Early and Middle variants of the Woodland tradition, which focused primarily on local woodland resources. During this time in the Plains, bison hunting continued to be extremely important but a focus on smaller game

Table 5.5. Mobility and Activity Levels by Subsistence Pattern.

ADAPTATION	ABBREVIATION	MOBILITY	NUMERIC CODE	ACTIVITY LEVEL	NUMERIC CODE
Broad-Spectrum Hunter-Gatherer	BSHG	Very High	5	Moderate	2
Woodland Hunter-Gatherer	WDHG	High	4	Moderate	2
Coastal Hunter-Gatherer	CHG	High	4	High	3
Equestrian Hunter-Gatherer	EHG	Low	2	Moderate	2
Incipient Horticulturalist	IH	Moderate	3	Moderate	2
Village Horticulturalist / Hunters	VHH	Moderate	3	High	3
Agriculturalist	AGR	Low	2	High	3
Early Modern Industrialist	EMI	Very Low	1	Low	1
Late Modern Industrialist	LMI	Extremely Low	0	Very Low	0

animals is also apparent (Johnson and Johnson, 1998), especially in the Central and Southern Plains where bison were not as numerous (Blakeslee, 1994). Based on the presence of pottery and the type of faunal and floral foods found in Early and Middle Woodland sites, the WDHG appear to have been less mobile than BSHG.

The Late Plains Woodland tradition and Fremont culture characterize the IH adaptation type. The Late Plains Woodland groups practiced a dual economy of hunting and gathering and horticulture, and through time cultigens became an increasingly important part of the Woodland diet (Adair, 1996; Johnson and Johnson, 1998). The greater reliance on cultigens and the abundance of pottery in Late Woodland sites suggest that IH were more sedentary, at least residentially, than earlier Woodland hunter-gatherers (WDHG). The Fremont are generally considered horticulturalists that subsisted on a uniform diet high in maize (Coltrain and Stafford, 1999), but were probably much less dependent on domestic cultigens than the Anasazi and other Southwestern groups. Stable isotope analysis of Fremont skeletons from the Salt Lake region even suggest that some groups subsisted on diets primarily comprised of wild plants (Cultrain and Stafford, 1999). The IH were relatively sedentary compared to hunter-gatherer groups with only moderate mobility.

The VHH adaptation is best represented by the historic Plains horticultural tribes and the prehistoric Plains Village and Middle Missouri traditions (see Table 4.1). These groups were primarily horticulturalists, but they also hunted bison at least once a year. The bison hunts generally involved the entire village and long distances, frequently

hundreds of miles (Blakeslee, 1994). During the bison hunts, the village would be virtually abandoned as men, women, and children traveled long distances during the hunt.

Agriculturalists are represented by the Pueblo groups, Caddo, and others who depended almost entirely on maize agriculture. These groups exhibit relatively low mobility compared to the BSHG, WDHG, IH, and VHH. Residential mobility was probably especially low, as indicated by the continuous occupation of Pecos and other Pueblo towns for hundreds of years.

The EHG adaptation was practiced by the protohistoric and historic equestrian groups of the Plains (see Table 4.1). These groups were extremely nomadic, but they relied primarily on the horse for both residential and logistical mobility. As a result, they receive a low mobility score. Some tribes had much greater access to horses than others, but the Sioux, Comanche, Blackfoot, and Crow that make up most of the EHG sample used in this study had abundant horses (Carlson, 1998).

The early African, Chinese, and European immigrants to American represent the EMI adaptation type. These groups were moderately mobile and participated in high activity levels. The Chinese sample represent railroad workers, the African American sample represent slaves and laborers, while the European sample is composed of explorers, missionaries, laborers, soldiers, and other occupations.

The late modern industrial (LMI) adaptation pattern is typified by 20th century groups. The LMI exhibit extremely low mobility due to modern forms of transportation.

Terrain

The United States can be divided into major and minor terrain types. The major divisions include the mountain terrain of the east and west and the low plains in between (Shimer, 1972). The minor terrain types consist of the Great Plains, the Gulf Coast Plains, Central Lowlands, and Mountainous regions of the Great Basin and Southwest.

Each region was scored from 0 to 4 based on the ruggedness of the terrain (Table 5.6). The Karankawa, Coahultecans, and Southern Texas Caddo groups occupied the Texas Gulf Coast region, which is characterized by a relatively flat, gently sloping landform, and shallow river valleys (Shimer, 1972). The Gulf Coast region was given the score of zero. The Central Lowlands or Prairie area (scored as 1), including present day Minnesota, Wisconsin, Iowa, Illinois, and Missouri, is generally typified by rolling hills and rivers with a gentle gradient (Shimer, 1972). In contrast to the Central Lowlands, the Great Plains have a higher elevation, exhibit greater relief, and have less rainfall and tree cover (Shimer, 1972). The Great Plains are also extremely diverse, with very flat terrain in parts of the Central and Southern Plains and rugged badlands and hills in the Northern Plains. For this reason, the Southern and Central Plains were given a terrain score of 2, while the Northern Plains was assigned a terrain score of 3. The Great Basin and Southwestern cultural areas are generally very mountainous. The primary landform of the Great Basin is the desert basin surrounded by mountains. The Southwest includes the Rocky Mountains and Colorado Plateau. Mountainous regions were assigned a terrain score of 4.

Table 5.6. Terrain Types.

LANDFORM	ABBREVIATION	BASIC FEATURES	NUMERIC CODE
Gulf Coastal Plains	GC	low relief; shallow valleys; near sea level	0
Central Lowlands (Prairie)	PR	gentle rolling hills; some flat areas; rivers have gentle gradient	1
Great Plain			
Central Plains	CP	flat with some rolling hills and river trenches	2
Southern Plains	SP	flat with some rolling hills and river trenches	2
Northern Plains	NP	rugged areas and deep river trenches	3
Great Basin	GB	desert basin; isolated mountains which rise abruptly	4
Southwest	SW	mountains, flat-toped mesas and steep-walled canyons	4

Statistical Analyses

Assumptions of the Data

The use of parametric statistical methods requires homogeneity of variance and that the data are sampled from a normal distribution. If either assumption is not reasonably met, parametric methods are inappropriate and nonparametric methods must be employed. The uses of indices in statistical analyses have been especially criticized because they frequently display non-normal distributions. Prior to the performance of other statistical tests, all of the variables and indices used in this study were tested for normality using the NORMAL option in PROC UNIVARIATE. Equal variance of groups was checked by examining standard deviations of each variable for each group.

Another criticism of ratio data is that they can provide false correlations between the ratio and the variable used in the denominator (Jungers et al., 1995). The problem of false correlations does not present a dilemma here either because false correlations only occur when the numerator and denominator of the ratio are independent (Pearson, 2000). For the ratios used in this study, the numerator and the denominator are highly correlated.

Prediction of J, TA, and Shape Ratio

To examine the relationship between polar moment of area (J), total subperiosteal area (TA) and shape ratios (Ix/Iy and Imax/Imin) and anteroposterior and mediolateral diaphyseal dimensions, least squared regression analysis (LSR) was conducted using the PROC REG procedure in SAS (SAS Institute, 1994). Regression analysis provides

information about the relationship between two variables by expressing one variable in terms of a linear function of the other variable (Schlotzhauer and Littell, 1987; Sokal and Rohlf, 2000). Hence, regression analysis can be used to predict one variable using another. In this study, anteroposterior and mediolateral dimensions (DAP and DML for the humerus, APS and MLS for the femur subtrochanter, and APD and MLD for the femur midshaft) were used to predict J at each point on the diaphysis. Estimation of total subperiosteal area and shape ratio was calculated for the mid-distal humerus, femur subtrochanteric, and femur midshaft using the formulae in Table 5.3.

Group Comparisons

The data were used to compare sexual dimorphism within and among groups, and for sex-specific comparisons among groups with different mobility, activity levels, and terrain. Sexual dimorphism within each archaeological population is investigated to reveal any effects of sex specific activity patterns. Comparisons of sexual dimorphism between subsistence groups have been used by researchers to sort out differences in the sexual division of labor within each group, while sex-specific comparisons among subsistence groups have been used for the comparison of groups without the potential effects of sexual dimorphism.

Group comparisons were performed using three methods: least squared regression, analysis of variance, and canonical analysis. Regression analysis (PROC REG procedure) was used to look at the relationship between long bone variables and the ordinal codes for mobility level, activity level, and terrain type. Analysis of variance, on

the other hand, was used to examine differences between groups without regard to the ordinal order of the mobility level, activity level, and terrain codes. The PROC GLM procedure in SAS was used to perform ANOVA procedures (SAS, 1990). Canonical analysis, which weights and combines variables in such a way as that the ratio of between-group variance to within-group variance best reflects the variation present between the groups under investigation, was performed so that group differences could be visualized in multidimensional space (Pietrusewsky, 2000).

When comparing more than two groups using ANOVA, it is necessary to control for the experimentwise error rate—the chance of making an error in the decision of overall experimental significance. In addition, the performance of an analysis of variance provides information on the overall significance of group differences but no information on which groups differ. In an ANOVA with x means there are $x(x\text{-}1)/2$ possible comparisons (Schlotzhauer and Littell, 1987; Sokal and Rohlf, 2000). To discover which groups differ, it is necessary to perform a multiple comparison test. In this study, analysis of variance procedures were followed by Tukey's multiple comparison tests, which conservatively compare all possible pairs of means (SAS, 1990; Sokal and Rohlf, 2000). The use of Tukey's multiple comparison tests also helps eliminate experimentwise error in ANOVA procedures with unequal sample sizes.

CHAPTER 6

RESULTS

Normality Test

Each variable was tested by group for normality using the NORMAL procedure of PROC UNIVARIATE (SAS Institute, 1999). The results indicate that none of the variables greatly deviates from normality. Table 6.1 provides the test statistic, skewness, and kurtosis values. The test statistic ranges from zero to one. Values close to zero indicate the data are not from a normal distribution (Schlotzhauer and Littell, 1987).

Prediction of Cross-Sectional Properties

Polar second moment of area (J), total subperiosteal area (TA), and the shape ratio (Ix/Iy) were predicted from anteroposterior and mediolateral external dimensions for individuals with computed tomography data using the PROC REG procedure in SAS. Table 6.2 presents the results of the least squared regression of the J, TA, and Ix/Iy on the predicted polar moment of area (J_{est}), total subperiosteal area (TA_{est}), and the shape ratio (R_{est}). The external diaphyseal dimensions are closely related to J, TA, and shape ratio derived from CT diaphyseal cross-sections. Figures 6.1 – 6.3 illustrate the relationship of external measurements to cross-sectional properties for the humerus. The relationship between external dimensions and cross-sectional properties of the femur is shown in Figures 6.4 – 6.9.

Table 6.1. Test for normality.

Variable	W statistic	Skewness	Kurtosis
HML	0.991	0.066	0.957
BUE	0.983	0.159	-0.263
MDS	0.975	0.261	-0.158
MDM	0.952	0.646	0.397
MDH	0.983	0.145	-0.500
EBR	0.993	0.115	-0.309
LCS	0.991	0.263	0.425
HMTA	0.963	0.745	0.412
HMS	0.973	0.667	2.370
HMR	0.979	0.649	1.638
FML	0.996	-0.088	0.083
FTL	0.994	0.159	0.116
APD	0.970	0.587	0.962
MLD	0.986	-0.174	0.494
APS	0.986	0.266	-0.007
MLS	0.979	0.223	0.495
VHD	0.986	0.036	-0.392
HHD	0.985	0.104	-0.422
FEB	0.986	-0.050	-0.630
BCB	0.988	-0.133	-0.312
FSJ*	0.998	0.089	-0.079
FSJstd*	0.970	0.788	1.538
FSTA	0.991	0.343	0.207
FSS	0.973	-0.631	1.210
FSR	0.998	0.162	0.308
FMJ*	0.994	0.046	-0.310
FMJstd*	0.982	0.573	0.663
FMTA	0.992	0.249	-0.196
FMS	0.973	0.613	1.588
FMR	0.997	0.116	0.292

*Predicted value of J.

Table 6.2. Relationship between actual and predicted properties.

Variable	*N*	*F-statistic*	*Pr > F*	*Adj. R2*
HJ	300	837.47	<0.0001	0.85
HTA	301	4049.96	<0.0001	0.93
HS	301	695.37	<0.0001	0.71
FMJ	436	2033.87	<0.0001	0.83
FMTA	436	2733.14	<0.0001	0.86
FMS	426	958.99	<0.0001	0.69
FSJ	365	854.36	<0.0001	0.82
FSTA	365	2342.23	<0.0001	0.86
FSS	365	322.68	<0.0001	0.47

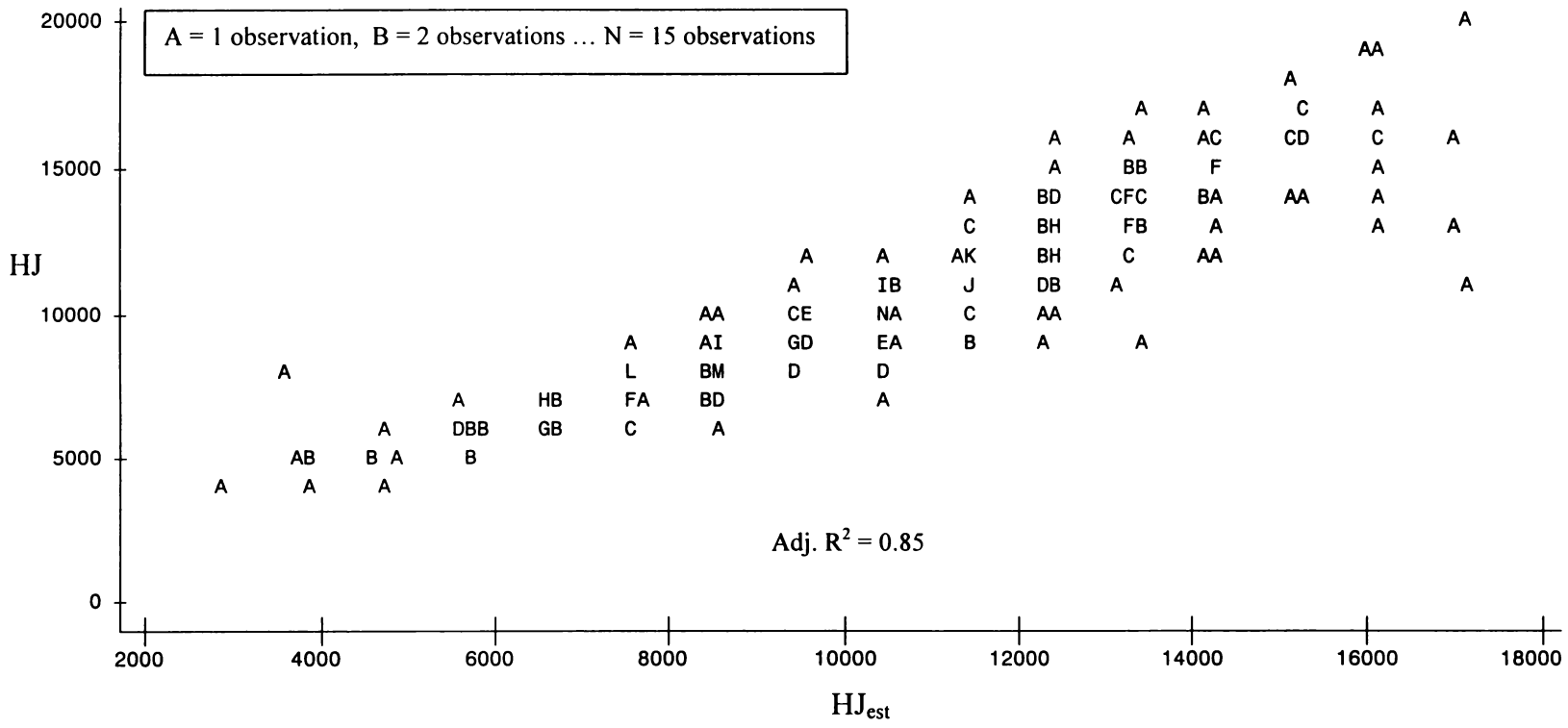


Figure 6.1. Relationship between actual (J) and predicted (J_{est}) polar second moment of area of the humerus. Regression formula: HJ_{est} = -25011 + 998 (DAP) + 917 (DML).

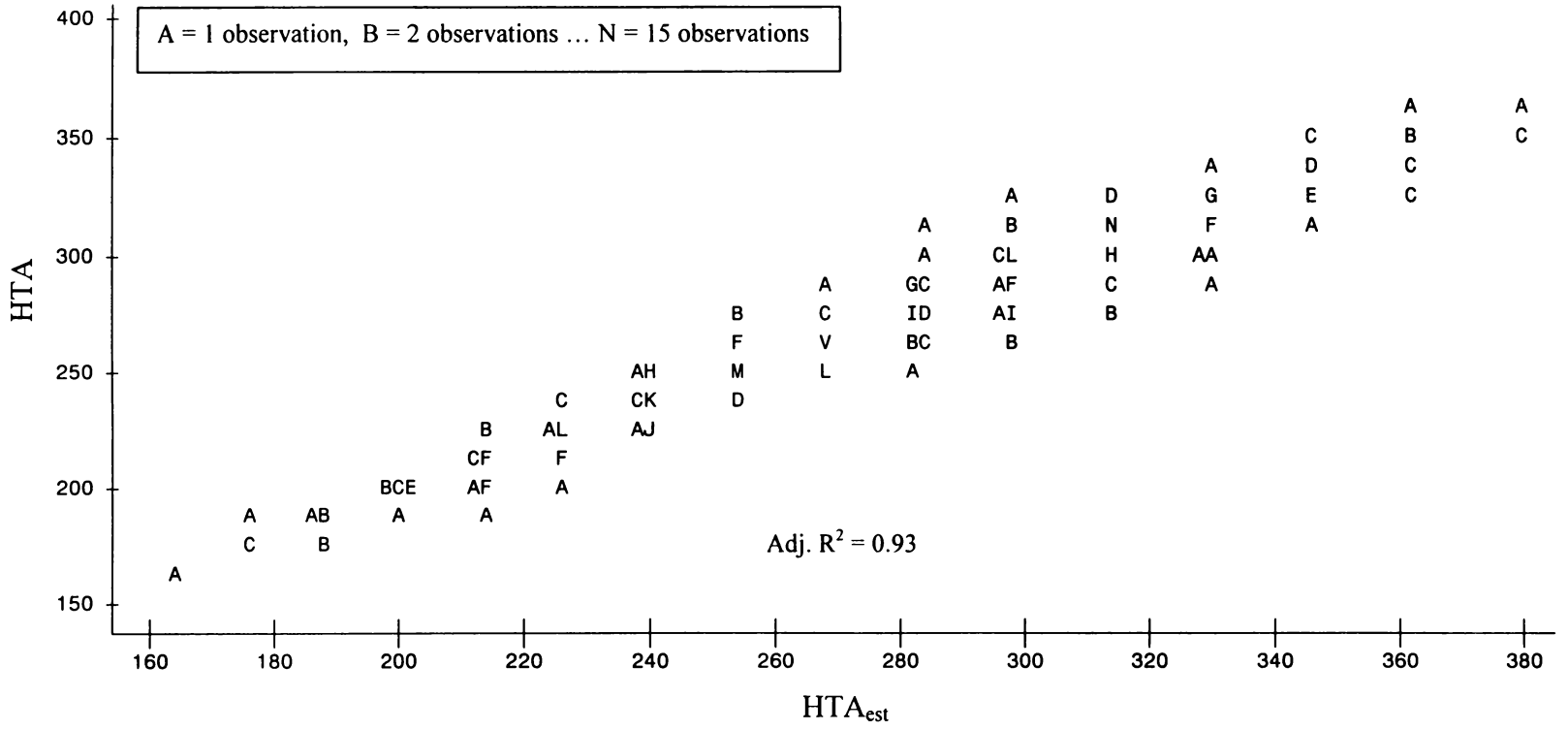


Figure 6.2. Regression results for relationship between total subperiosteal area (HTA) and predicted total subperiosteal (HTA_{est}) area of the humerus. $HTA_{est} = \pi(APS/2)(MLS/2)$.

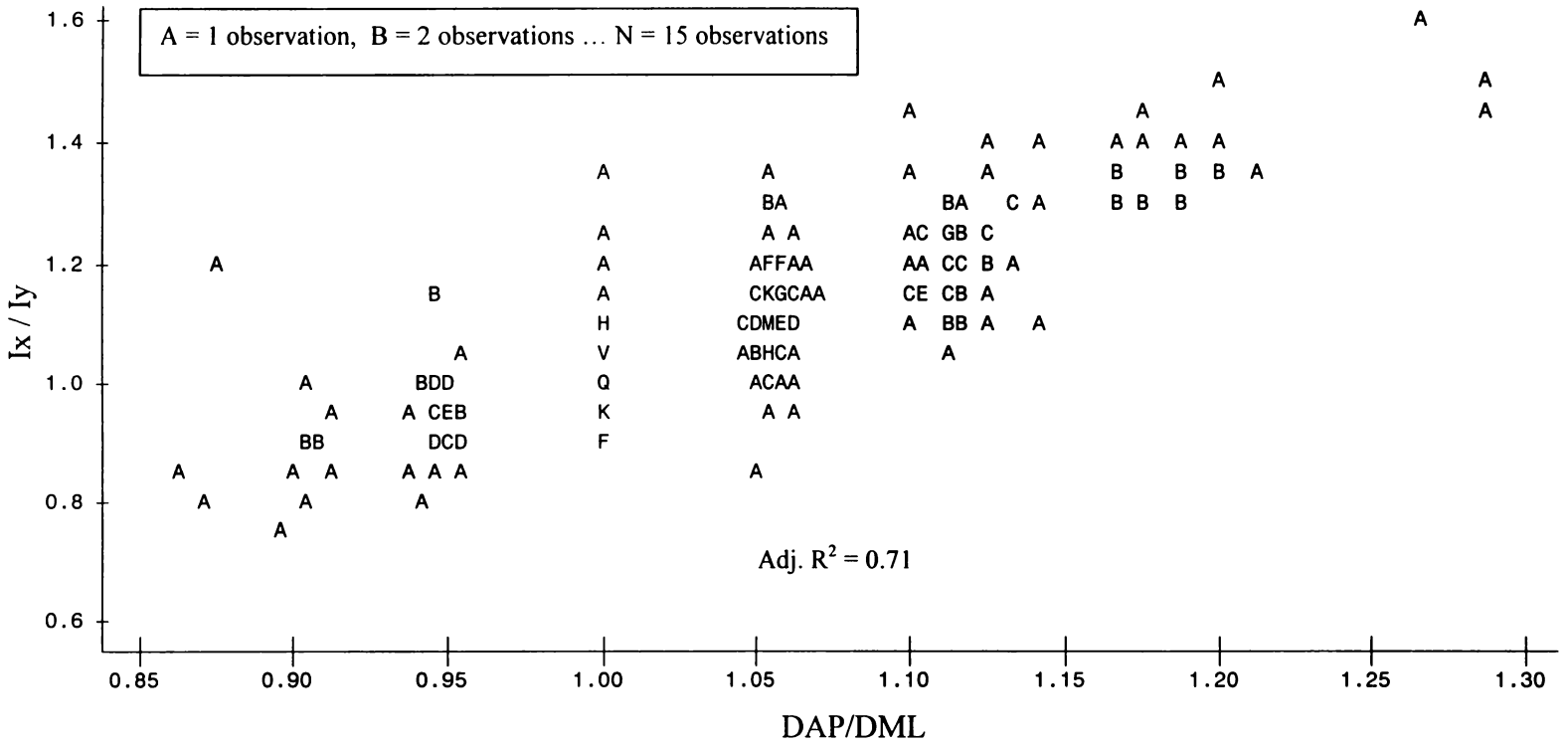


Figure 6.3. Relationship between Ix/Iy and DAP/DML.

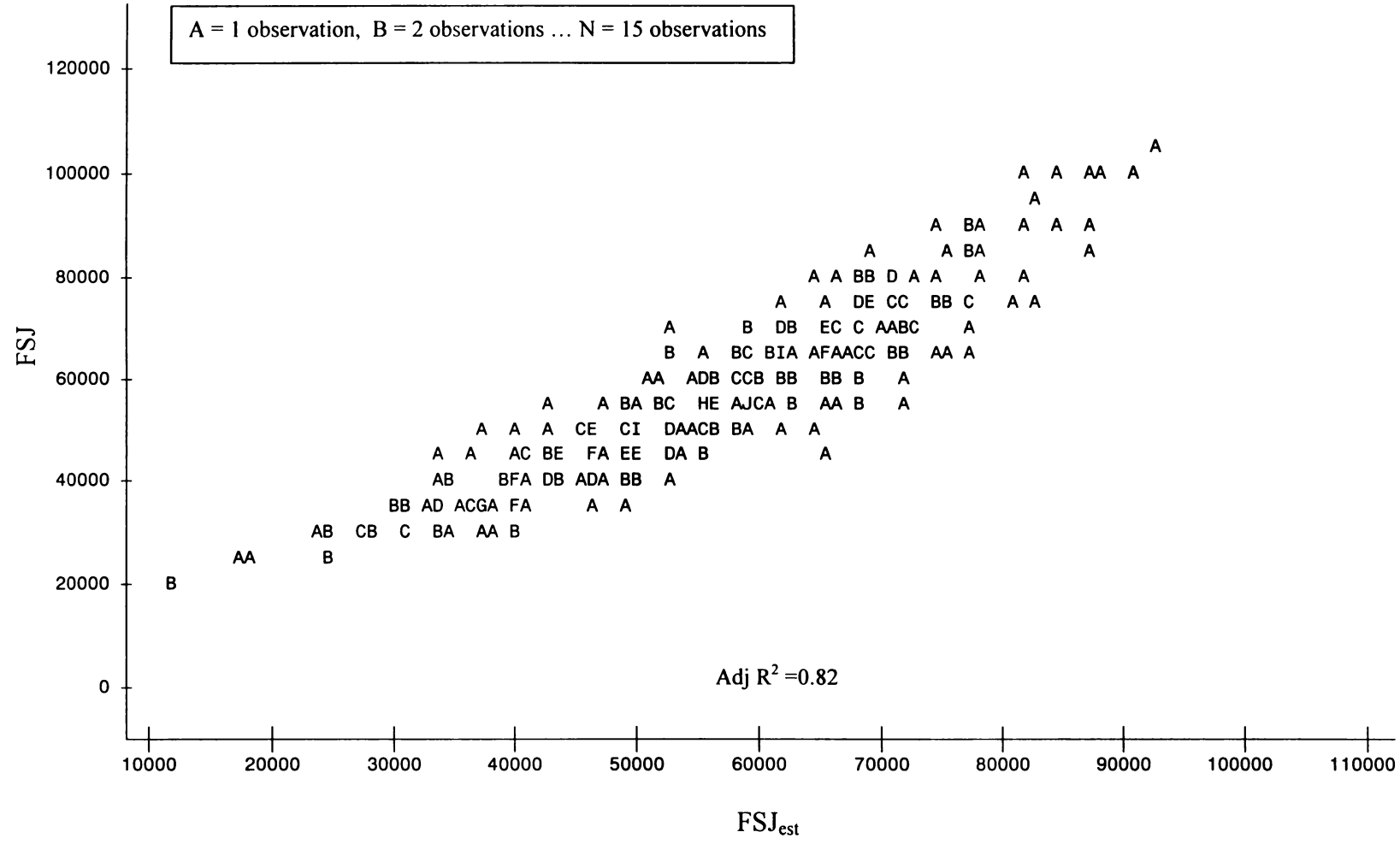


Figure 6.4. Relationship between femur subtrocanteric polar second moment of area (FSJ) and prediction (FSJ_{est}) based on external dimensions. Regression formula: FSJ_{est} = -124812 + 2925(APD) + 3360 (MLD).

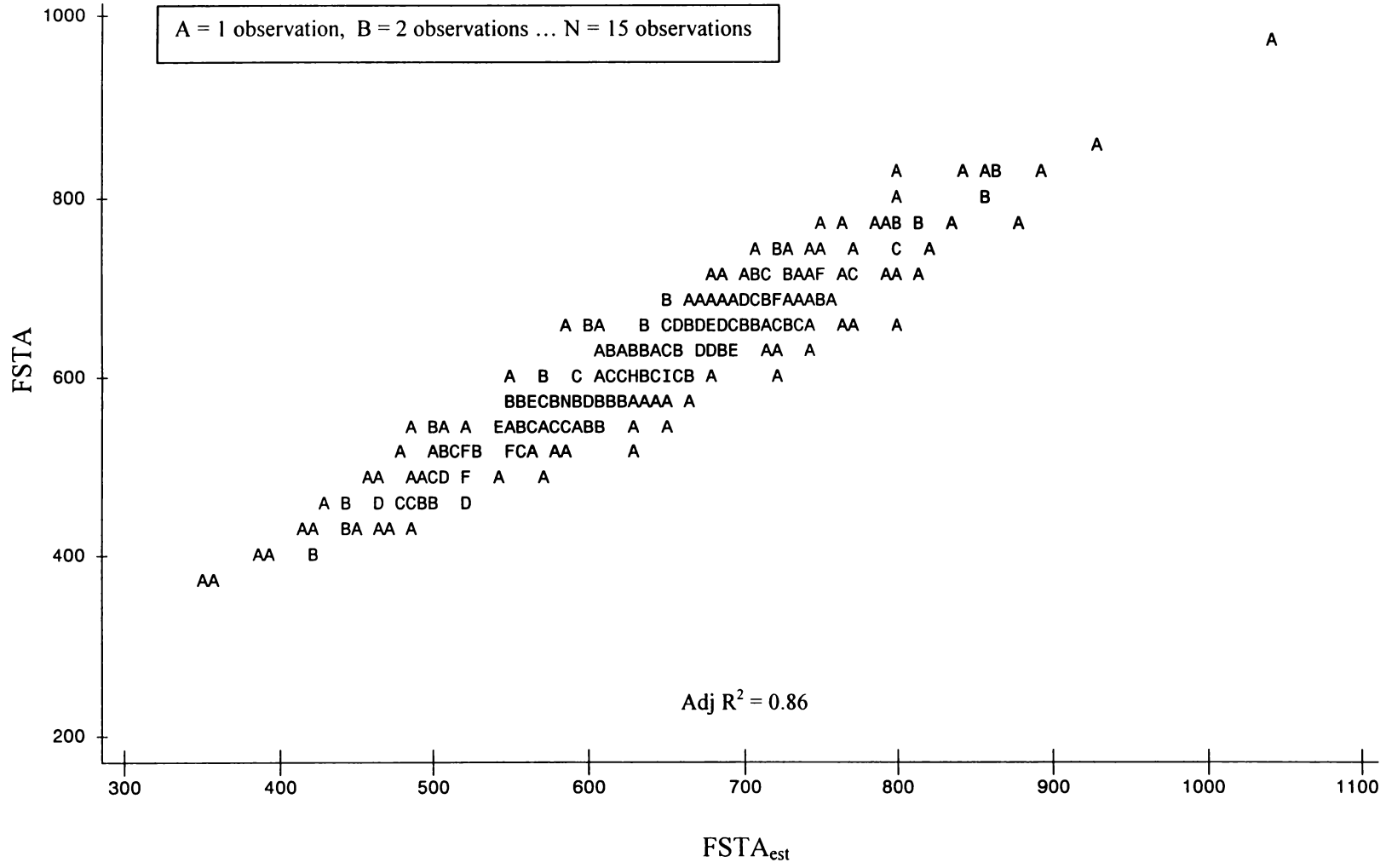


Figure 6.5. Relationship between femur subtrochanteric total area (FSTA) and predicted femur subtrochanteric total subperiosteal area ($FSTA_{est}$). $FSTA_{est} = \pi(APD/2)(MLD/2)$.

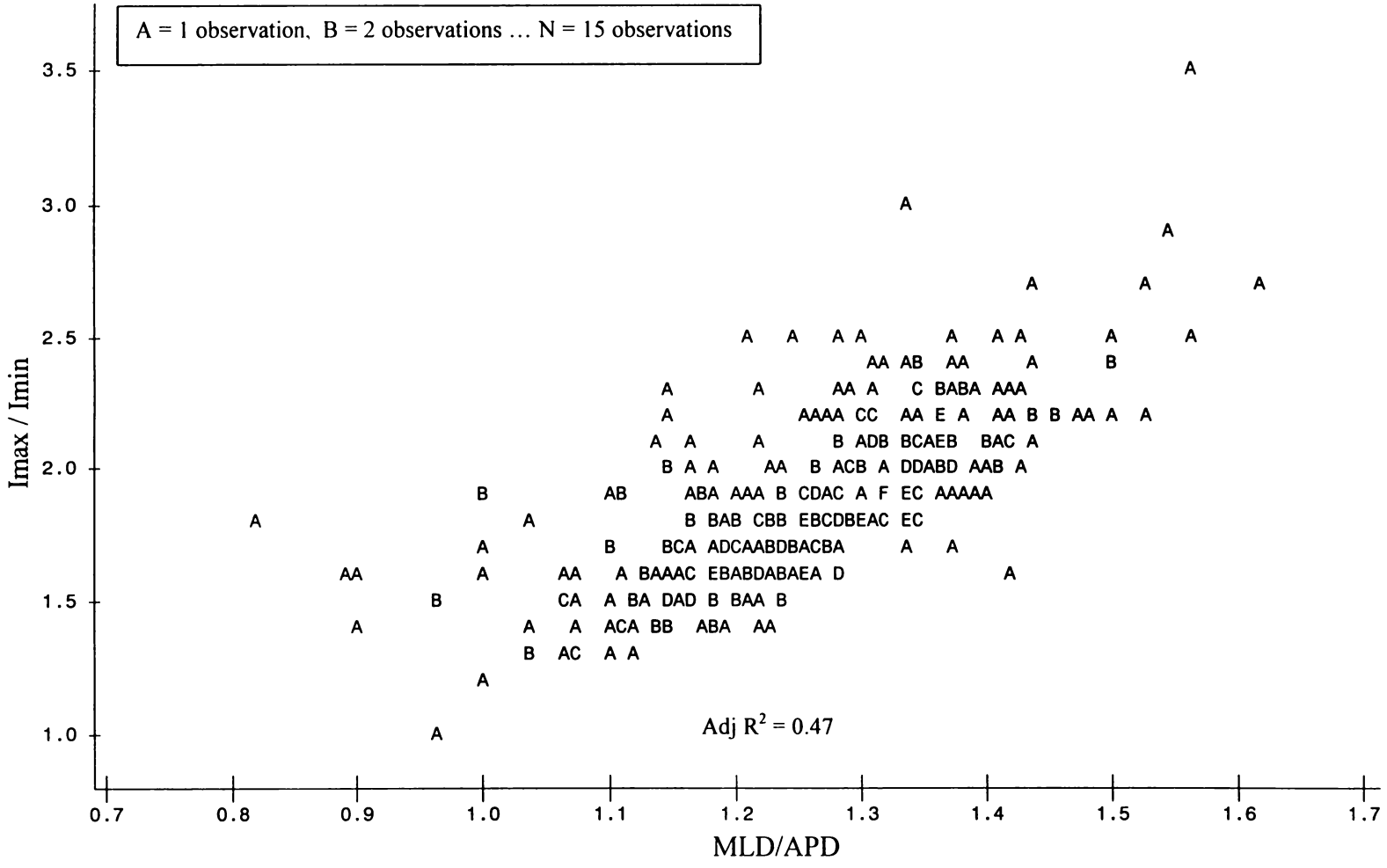


Figure 6.6. Relationship between femur subtrochanteric Imax/Imin and MLD/APD.

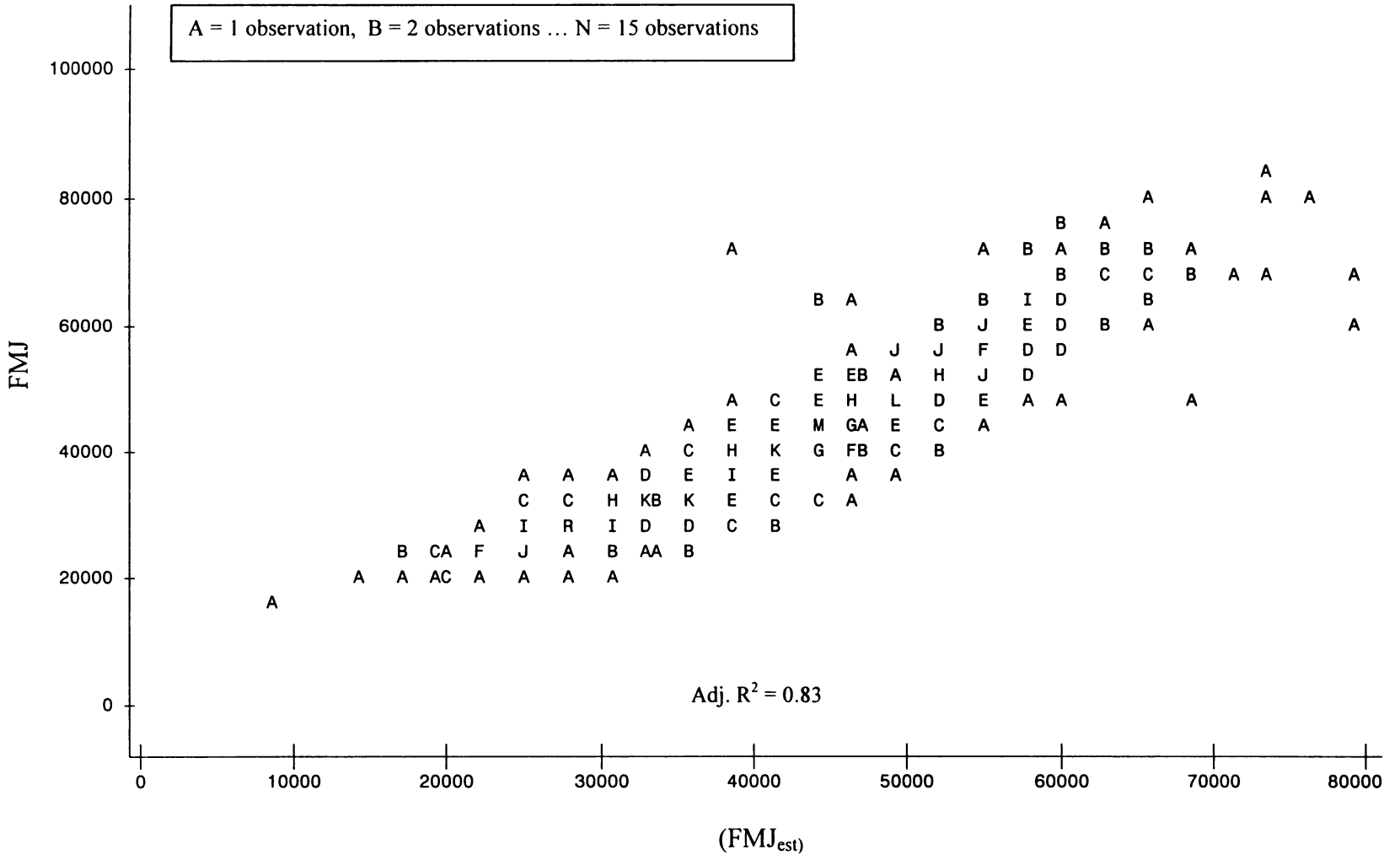


Figure 6.7. Relationship between femur midshaft polar moment of area (FMJ) and predicted femur midshaft polar moment of area (FMJ_{est}). Regression formula: FMJ_{est} = -102286 + 2721(APS) + 2697 (MLS).

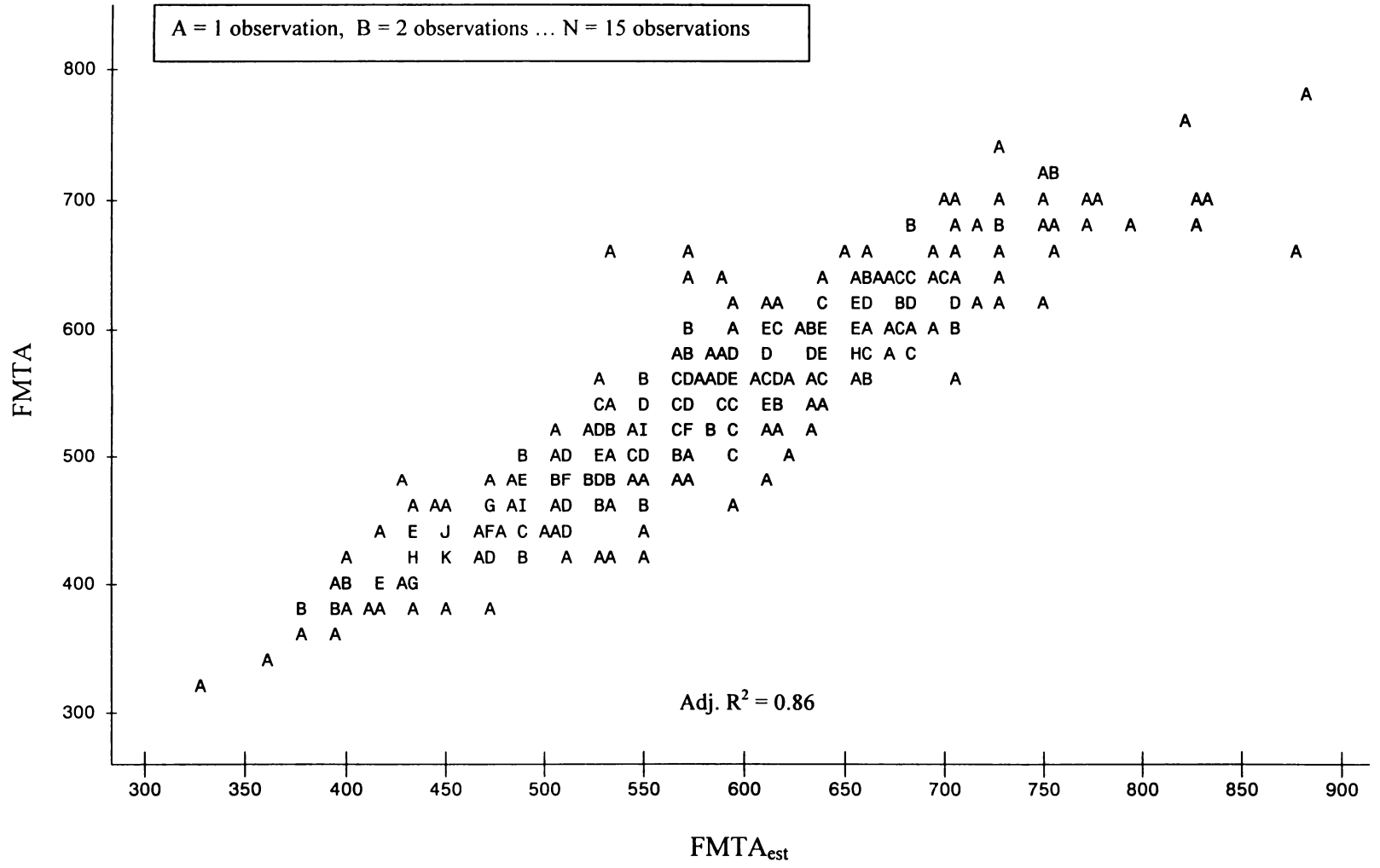


Figure 6.8. Relationship between femoral midshaft subperiosteal area (FMTA) and predicted femoral subperiosteal area FMTA. $FMTA_{est} = \pi(APS/2)(MLS/2)$.

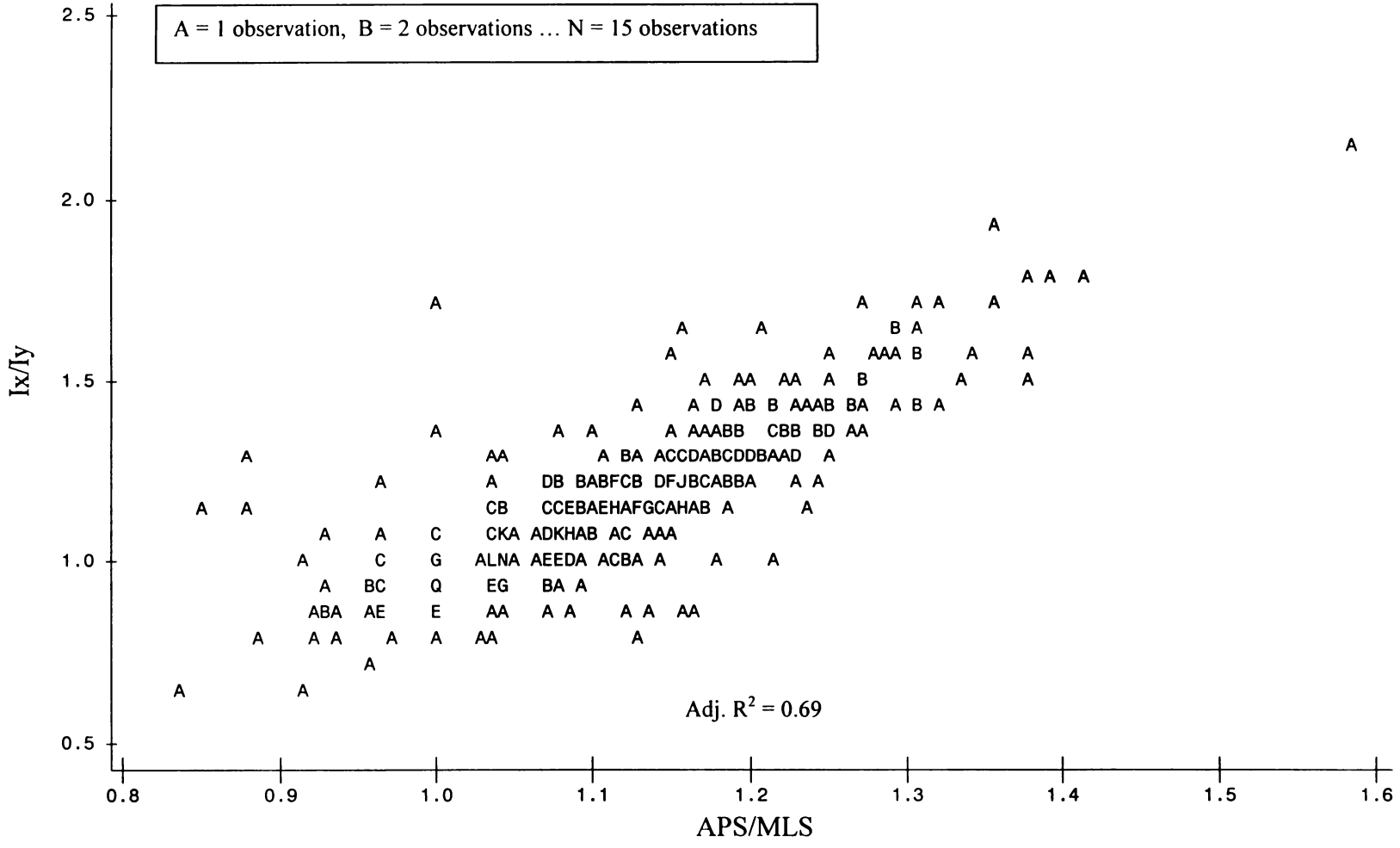


Figure 6.9. Relationship between femoral midshaft Ix/Iy and APS/MLS.

Diaphyseal anteroposterior and mediolateral external dimensions of the humerus, femur subtrochanteric, and femur midshaft can be used to predict 85%, 82%, and 83%, respectively, of the variance in polar moment of area (Table 6.2). In other words, diaphyseal cross-sections provide only a slightly better (approximately 15 to 18%) reflection of J than external dimensions alone.

Subperiosteal total area and diaphyseal shape can also be reliably predicted using external dimensions. Approximately 93% of the variance in humerus mid-distal subperiosteal area and 86% of the femur subtrochanteric and midshaft subperiosteal area variance can be predicted with external dimensions (Table 6.2; Figures 6.2, 6.5, and 6.8). Shape ratios derived from external dimensions generally underestimate those derived from moments of area (Table 6.2; Figures 6.3, 6.6, and 6.9), but still provide a reliable predictor. For the humerus and femur midshaft, external dimensions best predict Ix/Iy (i.e., I_{AP}/I_{ML}). However, because of the shape of the femoral subtrochanteric region, anteroposterior and mediolateral diaphyseal dimensions at subtrochanteric predict Imax/Imin better than Ix/Iy.

The close relationship between external dimensions and cross-sectional properties shows that both types of data provide very similar depictions of long bone biomechanical strength. Therefore, the use of external measurements can be reliably used to conduct biomechanical analyses on long bones.

Summary Statistics

Summary statistics for each variable, including sample size, mean, standard deviation, and minimum and maximum values of the humerus and femur are presented by sex, subsistence strategy, and geographical region in Appendix C. Table C.1 provides summary statistics for the computed tomography data by sex, while Table C.2 presents summary statistics for the external dimension data by sex. Summary statistics for external dimension data by subsistence strategy and geographical region are presented in Tables C.3 and C.4, respectively.

Group Comparisons: Subsistence Strategy

Level of Mobility

Table 6.3 describes ANOVA results (sample size, F-statistic, and p-values) for comparisons of males and females by mobility level. Males exhibit significantly greater means for all size variables of the humerus and femur (HML, MDS, MDM, MDH, BUE, EBR, HMTA, FSTA, FMTA, FML, VHD, FEB, APS, MLS, APD, and MLD) in all mobility level groups. Femur subtrochanter and midshaft polar moments of area only exhibit significant sexual dimorphism in terrain 3 (Northern Plains), but there is significant sexual dimorphism in robusticity at the femur midshaft (FMR) and subtrochanteric (FSR) in most mobility levels. Femur subtrochanter and midshaft diaphyseal shape only differs significantly between males and females in 3 of the 6

Table 6.3. Sex comparison of size and shape variables by mobility level (n, F-statistic, p-value).

		Variable								
		HML	***MDS'***	***MDM'***	***MDH***	***BUE***	***EBR'***	***HMTA***	***HMS***	***HMR'***
	Male	232	219	219	213	---	216	219	219	216
0	Female	123	115	115	111	---	116	115	115	111
	F	193.9	286.0	283.1	327.5	---	457.4	332.9	14.3	105.8
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	---	0.0001*	0.0001*	0.0002*	0.0001*
	Male	69	88	88	69	64	69	88	88	69
1	Female	24	37	37	20	17	24	37	37	24
	F	32.5	39.6	66.5	54.5	46.2	64.8	63.6	11.4	13.8
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0010*	0.0004*
	Male	83	90	90	82	52	83	90	90	83
2	Female	107	105	105	104	73	99	105	105	102
	F	70.2	12.2	52.1	167.3	82.5	130.8	38.6	18.4	0.73
	p-value	0.0001*	0.0002*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.3936
	Male	54	62	62	56	53	59	62	62	51
3	Female	32	42	42	39	35	33	42	42	32
	F	48.3	35.0	31.3	107.8	117.0	73.1	42.9	0.09	6.0
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.7707	0.0165
	Male	39	51	51	44	36	49	51	51	39
4	Female	24	35	35	26	20	27	35	35	24
	F	41.8	42.3	35.4	62.1	48.9	56.8	46.8	2.65	8.87
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.1073	0.0041*
	Male	49	65	65	52	52	52	65	65	49
5	Female	31	37	37	32	27	34	37	37	30
	F	35.9	31.6	21.0	108.2	74.4	89.2	30.7	0.06	1.17
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.8004	0.2818

Table 6.3. Continued.

		Variable								
		FML	***APS***	***MLS***	***APD***	***MLD***	***VHD***	***FEB***	***FSTA***	***FMTA***
	Male	265	249	249	251	251	247	235	250	249
0	Female	165	159	159	161	161	152	147	161	159
	F	189.3	214.0	273.8	192.8	179.5	454.9	407.9	260.3	332.0
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	98	109	109	109	108	102	75	108	109
1	Female	52	58	58	60	60	49	37	60	58
	F	52.0	54.6	58.1	34.9	71.3	166.1	87.1	81.2	82.6
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	98	101	101	102	102	97	85	102	101
2	Female	115	115	115	116	116	108	93	116	115
	F	79.7	77.6	26.6	89.6	33.1	153.9	152.6	87.0	64.4
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	593	649	649	640	641	590	436	640	648
3	Female	513	581	581	581	579	504	340	579	580
	F	845.8	779.1	457.5	394.1	349.6	1250.1	1032.1	701.1	933.7
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	43	52	52	53	54	48	35	53	52
4	Female	22	33	33	34	34	28	13	34	33
	F	24.1	46.3	28.8	41.0	19.1	141.0	32.0	58.4	56.2
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	41	56	56	58	58	49	33	58	56
5	Female	25	33	33	34	34	29	18	34	33
	F	51.1	96.5	11.6	29.9	21.6	91.9	83.4	67.7	59.3
	p-value	0.0001*	0.0001*	0.0010*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*

Table 6.3. Continued.

		Variable					
		FSJ	***FMJ***	***FSR***	***FMR***	***FSS'***	***FMS***
	Male	237	243	237	243	250	249
0	Female	150	151	150	151	161	159
	F	0.7	0.5	27.2	61.6	0.6	3.3
	p-value	0.3944	0.4705	0.0001*	0.0001*	0.4248	0.0681
	Male	97	98	97	98	108	109
1	Female	52	52	52	52	60	58
	F	0.02	0.05	8.2	11.4	1.3	0.23
	p-value	0.8949	0.8204	0.0048*	0.0009*	0.2489	0.6344
	Male	98	98	98	98	102	101
2	Female	112	112	112	112	116	115
	F	0.06	1.2	11.8	4.2	17.5	15.8
	p-value	0.8107	0.2772	0.0007*	0.0427	0.0001*	0.0001*
	Male	584	590	584	590	640	648
3	Female	505	510	505	510	579	580
	F	37.1	0.3	39.2	109.5	9.6	76.3
	p-value	0.0001*	0.5814	0.0001*	0.0001*	0.0020*	0.0001*
	Male	42	42	42	42	53	52
4	Female	19	21	19	21	34	33
	F	0.6	1.6	14.7	13.1	5.7	2.7
	p-value	0.4242	0.2156	0.0005*	0.0006*	0.0194	0.1057
	Male	41	41	41	41	58	56
5	Female	25	25	25	25	34	33
	F	1.0	0.1	8.3	10.9	1.4	24.7
	p-value	0.3304	0.8062	0.0053	0.0015*	0.2488	0.0001*

[1] Significant mobility*sex interaction.

* Statistically significant sexual dimorphism.

activity levels. Females generally exhibit greater mean values for FSS, while male have greater mean values for FMS. In other words, males in all groups are more robust and eurymeric at subtrochanteric, and they exhibit more robust and anteroposterior elongated femoral midshafts than females.

As would be expected, there are no overall significant differences between mobility levels observed in the humerus for either males or females, with the exception of HMS in males (Tables 6.4 and 6.5). The R^2 values indicate that less than 6% of the variation in humerus variables can be explained by the level of mobility.

Significant differences between mobility groups were found in both sexes for most of the variables of the femur, but the R^2 values are extremely low (Table 6.4 and 6.5). This suggests that only a small amount of the variation in femur size and shape variables is due to differences associated with mobility levels. Examination of Tukey multiple case results also suggests that the significant differences are due to only a few paired differences, and these differences do not seem to be related to mobility. For example, there is an overall significant difference in male mobility groups for the standardized midshaft polar moment of area (FMJ_{std}), but only the "extremely low" level mobility group (0) significantly differs from the other groups (See Table 6.4).

Level of Activity

Within each activity level group, significant sexual dimorphism is present for all size variables of the humerus and femur (Table 6.6). Males normally exhibit larger, more robust, and broader (flatter) humeral midshafts. Females have significantly greater

Table 6.4. Mobility level regression analysis and Tukey multiple comparison results for males.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences**
HML	0.32	0.5705	-0.0031	0>4>1>5>3>2 (0:1, 0:5, 0:3, 0:2)
BUE	0.46	0.4993	-0.0025	4>2>5>3>1 (none)
MDS	0.58	0.4481	-0.0019	4>0>1>5>3>2 (4:2, 0:3, 0:2)
MDM	9.5	0.0023	0.0374	0>1>4>5>2>3 (0:4, 0:5, 0:2, 0:3, 1:5, 1:2, 1:3, 4:5, 4:2, 4:3)
MDH	0.08	0.7817	-0.0042	0>4>1>5>2>3 (0:1, 0:5, 0:2, 0:3)
EBR	0.64	0.4234	-0.0016	0>4>1>5>2>3 (0:4, 0:1, 0:5, 0:2, 0:3, 4:2, 4:3)
HMTA	2.26	0.134	0.0057	0>1>4>5>3>2 (0:5, 0:3, 0:2, 1:5, 1:3, 1:2, 4:5, 4:3, 4:2)
HMR	4	0.0473	0.0134	1>0>4>5>2>3 (1:5, 1:2, 1:3, 0:2, 0:3, 4:2, 4:3)
HMS	16.6	<0.0001	0.0667	3>5>2>4>0>1 (3:4, 3:0, 3:1, 5:0, 5:1, 2:0, 2:1, 4:0, 4:1)
FML	127.59	<0.0001	0.1318	0>1>4>5>3>2 (0:1, 0:4, 0:5, 0:3, 0:2, 1:2)
APS	6.9	0.0085	0.0071	0>3>5>4>2>1 (0:3, 0:2, 0:1)
MLS	26.9	<0.0001	0.0301	0>4>1>5>3>2 (0:3, 0:2, 4:2, 1:3, 1:2)
APD	96.1	<0.0001	0.1023	0>5>4>1>2>3 (0:1, 0:2, 0:3, 5:3)
MLD	37.1	<0.0001	0.0415	3>2>0>4>5 (3:2, 3:0, 3:4, 3:5)
VHD	16.5	<0.0001	0.0183	0>1>3>5>4>2 (0:3, 0:2, 1:2)
FEB	6.2	0.013	0.0062	0>3>5>4>1>2 (0:1, 0:2, 3:1, 3:2)
FSTA	11.1	0.0009	0.012	0>3>5>4>1>2 (1:3, 0:1, 0:2)
FMTA	22.7	<0.0001	0.0253	0>4>5>1>3>2 (0:1, 0:3, 0:2)
FSJstd	92.8	<0.0001	0.0992	3>2>5>4>1>0 (3:1, 3:0, 2:0, 5:0)
FMJstd	52.8	<0.0001	0.0585	3>2>5>4>1>0 (3:0, 2:0, 5:0, 4:0, 1:0)
FSR	33.8	<0.0001	0.0378	3>5>2>4>1>0 (2:0, 3:1, 3:0)
FMR	18.3	<0.0001	0.0203	4>5>3>2>1>0 (3:0)
FSS	150.4	<0.0001	0.1519	3>2>4>5>1>0 (3:2, 3:4, 3:5, 3:1, 3:0, 2:0)
FMS	3.8	0.051	0.0034	3>5>2>0>4>1 (3:1, 2:1, 0:1)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.5 Mobility level regression anaylsis and Tukey multiple group comparison results for females.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences**
HML	0.03	0.8654	-0.0066	0>4>5>1>2>3 (0:2, 0:3)
BUE	0.41	0.5214	-0.0040	2>4>3>5>1 (none
MDS	0.75	0.3874	-0.0017	4>2>5>1>3>0 (0:4, 0:2)
MDM	0.44	0.5097	-0.0038	1>0>4>5>2>3 (1:2, 1:3, 0:2, 0:3, 4:3)
MDH	0.26	0.6128	-0.0050	0>4>1>5>2>3 (0:5, 0:2, 0:3, 4:2, 4:30
EBR	0.35	0.5523	-0.0043	4>0>5>3>2>1 (0:2)
HMTA	0.01	0.9123	-0.0067	4>1>0>5>2>3 (4:3, 1:3)
HMR	0.0	0.9465	-0.0067	1>5>2>4>3>0 (1:0, 2:0)
HMS	2.5	0.1175	0.0098	2>3>5>4>1>0 (2:4, 2:1, 2:0, 3:1, 3:0, 5:0, 4:0)
FML	84.9	<0.0001	0.1207	0>4>1>5>2>3 (0:1, 0:5, 0:2, 0:3)
APS	23	<0.0001	0.0347	0>2>3>4>1>5 (0:2, 0:3, 0:1)
MLS	1.9	0.1716	0.0014	1>5>4>2>3>0 (1:0)
APD	72.1	<0.0001	0.1042	0>1>4>5>3>2 (0:3, 0:2, 1:3, 1:2)
MLD	63.7	<0.0001	0.0930	3>2>5>0>4>1 (3:3, 3:2, 3:5, 3:0, 3:4, 3:1, 2:0, 2:1)
VHD	0.0	0.9462	-0.0016	3>0>1>5>4>2 (3:2, 0:2)
FEB	0.52	0.4703	-0.0008	4>0>3>1>2>5 (0:1, 3:2)
FSTA	2.2	0.1385	0.0020	0>3>1>5>2>4 (none)
FMTA	4.9	0.0274	0.0063	0>1>4>2>5>3 (none)
FSJstd	69.9	<0.0001	0.1013	3>5>2>1>4>0 (3:2, 3:1, 3:0, 2:0)
FMJstd	33.0	<0.0001	0.0497	2>3>5>1>4>0 (2:0, 3:0)
FSR	29.0	<0.0001	0.0438	3>5>1>2>0>4 (3:0)
FMR	22.8	<0.0001	0.0344	2>3>5>1>4>0 (2:0, 3:0)
FSS	172.1	<0.0001	0.2188	3>2>5>4>1>0 (3:2, 3:5, 3:1, 3:0, 2:1, 2:0, 5:3)
FMS	33	<0.0001	0.0497	0>2>3>4>5>1 (0:2, 0:3, 0:5, 0:1)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.6. Sex comparison of size and shape variables by activity level (n, F-statistic, p-value).

		Variable								
		HML	***MDS***	***MDM***	***MDH***	***BUE***	***EBR***	***HMTA***	***HMS***	***HMR***
	Male	232	219	219	213	---	216	219	219	216
0	Female	123	115	115	111	---	116	115	115	111
	F	193.9	286	283.1	327.5	---	457.4	332.9	14.3	105.8
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	---	0.0001*	0.0001*	0.0002*	0.0001*
	Male	69	88	69	69	64	69	88	88	89
1	Female	24	37	20	20	17	24	37	37	36
	F	32.5	39.6	54.5	54.5	46.2	64.8	63.6	11.4	52.4
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0010*	0.0001*
	Male	153	185	185	164	142	164	185	126	150
2	Female	112	126	126	115	98	110	126	185	106
	F	89.7	36.7	36.7	228.6	155.1	168.3	45.6	2.3	6.5
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0985	0.0113
	Male	72	83	83	71	52	79	83	83	72
3	Female	85	96	96	88	59	86	96	96	85
	F	122.5	28.9	61.6	234.6	151.9	213.3	56.21	20.3	4.3
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0389	0.0389

Table 6.6. Continued.

		Variable								
		FML	***APS***	***MLS*** [1]	***APD***	***MLD*** [1]	***VHD*** [1]	***FEB***	***FSTA*** [1]	***FMTA*** [1]
	Male	265	249	249	251	250	247	235	250	249
0	Female	165	159	159	161	161	152	147	161	159
	F	189.3	214.0	273.8	192.8	179.5	454.9	407.9	260.3	332.0
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	98	109	109	109	108	102	75	108	109
1	Female	52	58	58	60	60	49	37	60	58
	F	52.1	54.6	58.1	34.9	71.3	166.1	87.1	81.2	82.6
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	141	179	179	177	179	151	114	177	179
2	Female	117	145	145	148	148	122	83	148	145
	F	124.8	168.3	66.1	100.2	41.4	255.1	196.9	125.3	149.3
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Male	634	679	679	676	676	633	475	676	678
3	Female	558	617	617	617	615	547	381	615	616
	F	871.6	818.9	448.1	472.3	362	1328.4	1081.42	782.1	954.7
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*

Table 6.6. Continued.

		Variable					
		FSJ [1]	***FMJ***	***FSR***	***FMR***	***FSS*** [1]	***FMS*** [1]
	Male	243	243	237	243	250	249
0	Female	151	151	150	151	161	159
	F	0.7	0.5	27.2	61.6	0.6	3.3
	p-value	0.3944	0.4705	0.0001*	0.0001*	0.4248	0.0681
	Male	97	98	97	98	108	109
1	Female	52	52	52	52	60	58
	F	0.02	0.05	8.2	11.4	1.3	0.23
	p-value	0.8949	0.8204	0.0001*	0.0009*	0.2489	0.6344
	Male	139	140	139	140	177	179
2	Female	113	114	113	114	148	145
	F	9.5	0.03	9.7	19.9	14.1	24.8
	p-value	0.0023*	0.8562	0.002	0.0001*	0.0002*	0.0001*
	Male	626	631	631	631	676	678
3	Female	548	554	554	554	615	616
	F	21.8	0.45	54.5	108.7	14.21	84.9
	p-value	0.0001*	0.5002	0.0001*	0.0001*	0.0002*	0.0001*

[1] Significant activity*sex interaction.

* Statistically significant sexual dimorphism.

means for FSJ and FMJ in activity levels 2 and 3, but males exhibit greater robusticity at subtrochanter and midshaft. In general, females in all activity level groups have more platymeric femora than males, and males have more anteroposterior elongated femoral midshafts. However, statistical significance in femur subtrochater and mishaft shape (FSS and FMS, respectively) was only reached in activity level groups 2 and 3.

Tables 6.7 and 6.8 show regression analysis and Tukey multiple comparison test results of activity level for males and females, respectively. Similar to mobility level, very little of the variation in the humerus is explained by levels of activity (Tables 6.7 and 6.8). For males, significant differences between activity levels were found in the humerus variables MDM, HMTA, HMR, and HMS. Groups with very low (0) and low (1) levels of activity differ from those with moderate (3) and high (4) activity levels, but paired comparisons do not show significant differences between very low and low levels or between moderate and high levels of activity (Table 6.7). Humerus variables MDM, MDH, and HMS demonstrate overall significance in females, but again, significant differences only exist between lower-level activity groups and higher-level activity groups. In both sexes, higher-level activity groups tend to have more robust and flattened humeral midshafts than groups with low levels of activity.

Overall, statistically significant differences between activity level groups were observed in all of the male femur variables and in most of those of the female. For the femur, paired comparisons suggest that only very low (0) activity level groups significantly differ from the other groups. Groups with higher levels of activity generally

Table 6.7.Activity level regression analysis and Tukey multiple comparison results for males.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences**
HML	0.12	0.7345	-0.0041	0>2>1>3 (0:2, 0:1, 0:3)
BUE	0.43	0.5131	-0.0026	2>3>1 (none)
MDS	0.68	0.4117	-0.0015	0>2>1>3 (0:2, 0:3)
MDM	25.4	<0.0001	0.1004	0>1>3>2 (0:3, 0:2, 1:3, 1:2)
MDH	3.9	0.0508	0.0129	0>1>2>3 (0:1, 0:2, 0:3, 2:3)
EBR	1.8	0.1793	0.0037	0>1>2>3 (0:1, 0:2, 0:3, 1:3)
HMTA	10.8	0.0012	0.0428	0>1>2>3 (0:2, 0:3, 1:2, 1:3)
HMR	13.2	0.0004	0.0527	1>0>2>3 (1:2, 1:3, 0:2, 0:3)
HMS	22.9	<0.0001	0.0908	2>3>0>1 (2:3, 2:0, 2:1, 3:0, 3:1)
FML	161.11	<0.0001	0.1611	0>1>2>3 (0:1, 0:2, 0:3)
APS	8.9	0.003	0.0093	0>3>2>1 (0:3, 0:2, 0:1)
MLS	40.4	<0.0001	0.0451	0>1>2>3 (0:2, 0:3)
APD	156.6	<0.0001	0.1582	0>1>2>3 (0:1, 0:2, 0:3, 1:3, 2:3)
MLD	55.2	<0.0001	0.0610	3>2>0>1 (none)
VHD	24.3	<0.0001		0>1>2>3 (0:2, 0:3)
FEB	8.0	0.0048	0.0083	0>3>2>1 (0:3, 0:2, 0:1)
FSTA	17.04	<0.0001	0.0189	0>2>3>1 (0:3, 0:1)
FMTA	32.2	<0.0001	0.0361	0>1>3>2 (0:1, 0:3, 0:2)
FSJstd	119.6	<0.0001	0.1245	3>2>1>0 (3:1, 3:0, 2:0)
FMJstd	64.5	<0.0001	0.0707	3>1>2>0 (3:0, 1:0, 2:0)
FSR	36.2	<0.0001	0.0405	2>3>1>0 (2:1, 2:0, 3:1, 3:0)
FMR	19.0	<0.0001	0.0212	3>2>1>0 (3:0)
FSS	240.9	<0.0001	0.2243	3>2>1>0 (3:2, 3:1, 3:0)
FMS	6.8	0.0092	0.0069	3>0>2>1 (3:1, 0:1, 2:1)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.8.Activity level regression analysis and Tukey multiple comparison results for females.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences**
HML	8.03	0.0052	0.0451	0>2>1>3 (0:2, 0:1, 0:3, 2:3)
BUE	1.6	0.2109	0.0039	2>3>1 (2:3)
MDS	0.05	0.8278	-0.0064	2>3>1>0 (2:0)
MDM	15.8	<0.0001	0.0903	1>0>2>3 (1:2, 1:3, 0:2, 0:3)
MDH	15.2	<0.0001	0.0872	0>1>2>3 (0:3, 1:3, 2:3)
EBR	2.5	0.116	0.01	2>0>1>3 (2:3, 0:3)
HMTA	6.4	0.0124	0.035	1>2>0>3 (none)
HMR	0.25	0.6189	-0.0051	1>2>3>0 (1:0, 2:0)
HMS	14.89	0.0002	0.0853	3>2>1>0 (3:1, 3:0, 2:1, 2:0)
FML	108.9	<0.0001	0.1501	0>1>2>3 (0:1, 0:2, 0:3)
APS	21.4	<0.0001	0.0323	0>3>2>1 (0:3, 0:2, 0:1)
MLS	0.66	0.416	-0.0006	1>2>3>0 (0:1, 0:2, 0:3)
APD	113.3	<0.0001	0.1553	0>1>2>3 (0:2, 0:3, 1:2, 1:3, 2:3)
MLD	69.4	<0.0001	0.1007	2>3>0>1 (2:0, 2:1, 3:0, 3:1)
VHD	0.59	0.4412	-0.0007	0>3>2>1 (none)
FEB	0.93	0.3354	-0.0001	0>3>2>1 (none)
FSTA	6.4	0.0115	0.0088	2>0>1>3 (none)
FMTA	4	0.0147	0.0081	0>1>2>3 (none)
FSJstd	71.7	<0.0001	0.1037	3>2>1>0 (3:0, 2:0)
FMJstd	45.8	<0.0001	0.0683	3>2>1>0 (3:0, 2:0)
FSR	25	<0.0001	0.0378	2>3>1>0 (2:0, 3:0)
FMR	29.8	<0.0001	0.045	3>2>1>0 (3:0, 2:0)
FSS	233.8	<0.0001	0.2759	3>2>1>0 (3:2, 3:1, 3:0, 2:1, 2:0)
FMS	27.2	<0.0001	0.0411	0>3>2>1 (0:3, 0:2, 0:1)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses spearated by a colon are significantly (alpha=0.05) different.

have greater polar moments of area at the femoral subtrochanter and midshaft, more anteroposterior elongation of the femur midshaft, and a more platymeric subtrochanter region.

Multivariate Analysis of Subsistence Strategy

Canonical analyses were conducted by subsistence strategy to examine the pattern of relationship among groups in multidimensional space. Multivariate analyses tend to reveal a clearer pattern of subsistence than univariate analyses, at least in males. Figures 6.10 and 6.11 illustrate the relationship among males and females, respectively, based on the femur. Figures 6.12 and 6.13 represent relationships based on humeral measurements. In Figures 6.10 and 6.12, canonical axis 1 primarily separates the males into three groups: modern industrialists, hunter-gatherers, and farmers. Farmers are robust at the femur subtrochanter but gracile at midshaft, while modern industrialists are very robust at midshaft but gracile at subtrochanter (Figure 6.10). Farmers also possess large humeral heads but small proximal epiphyseal breadths (Figure 6.12). Hunter-gatherer groups are intermediate between modern industrialists and village horticulturalists. Canonical axis 2 in both plots (Figures 6.10 and 6.12) primarily separates large robust groups from smaller and more gracile groups.

As can be seen in Figures 6.11 and 6.13, the relationship among females with different subsistence strategies does not show any clear patterns. Female humeral and femoral morphology appears to be less effected by subsistence than in males.

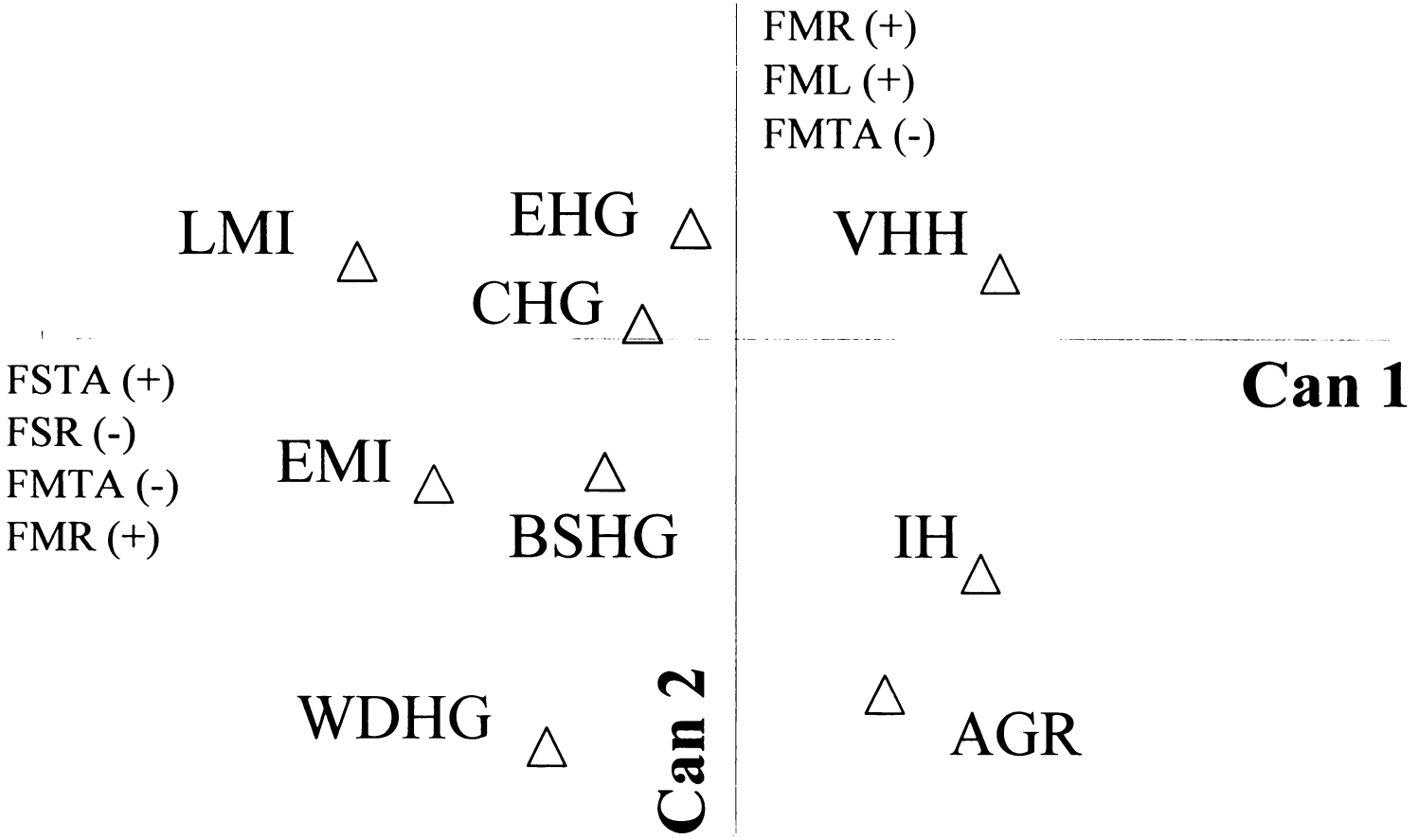


Figure 6.10. Canonical plot based on femur variables showing the relationship among males with different subsistence strategies.

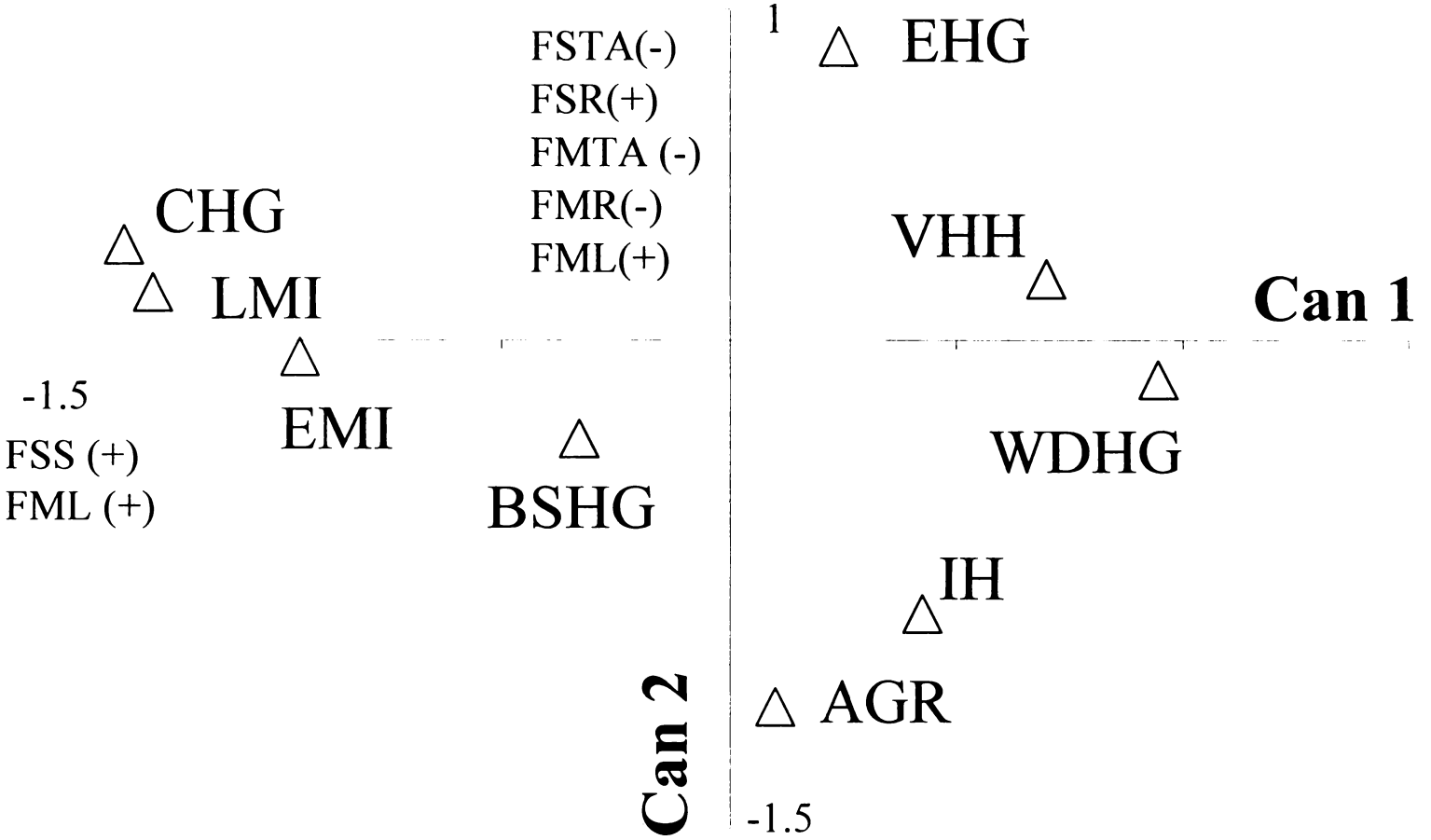


Figure 6.11. Canonical plot based on femur variables showing the relationship among females with different subsistence strategies.

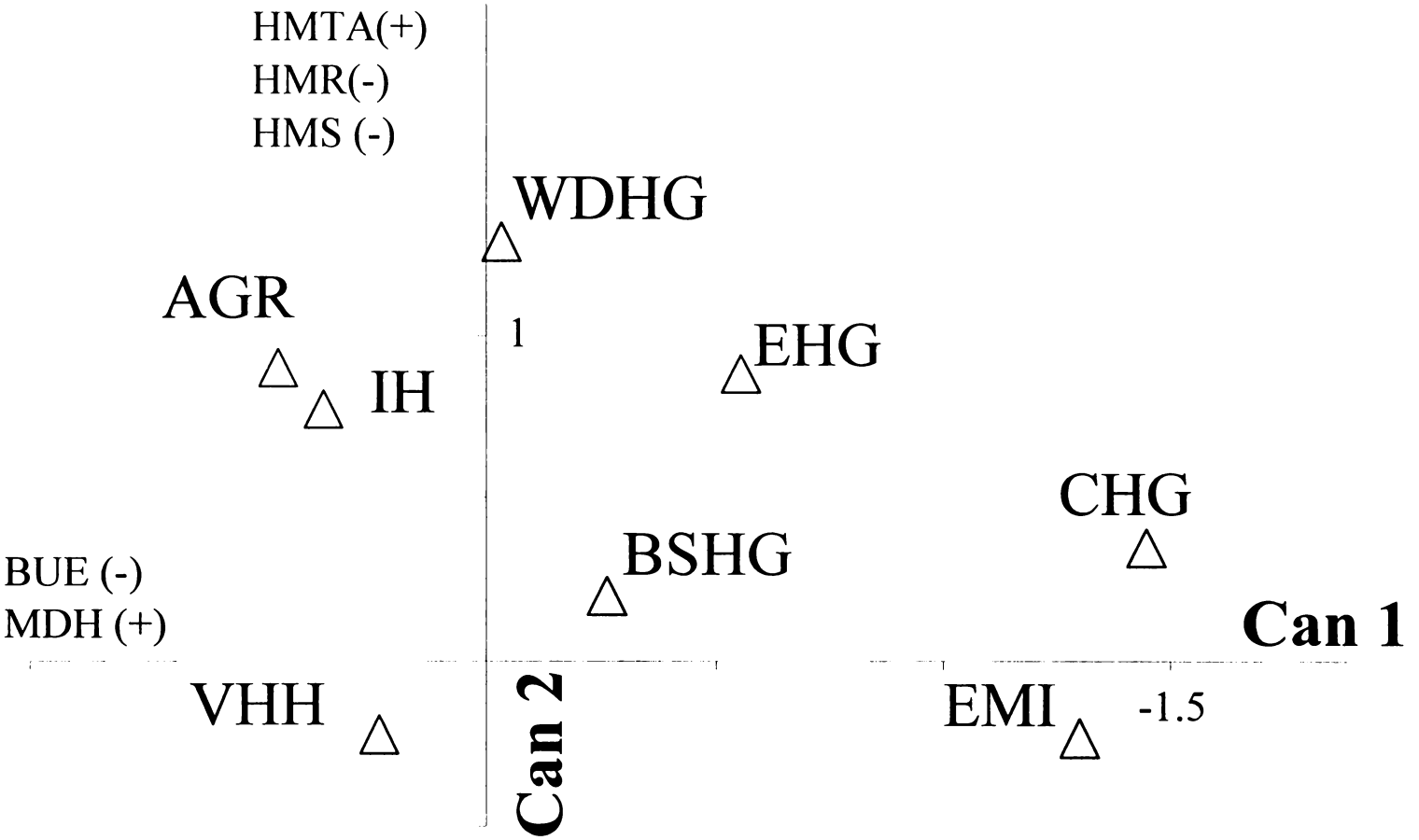


Figure 6.12. Canonical plot based on humerus variables showing the relationship among males with different subsistence strategies.

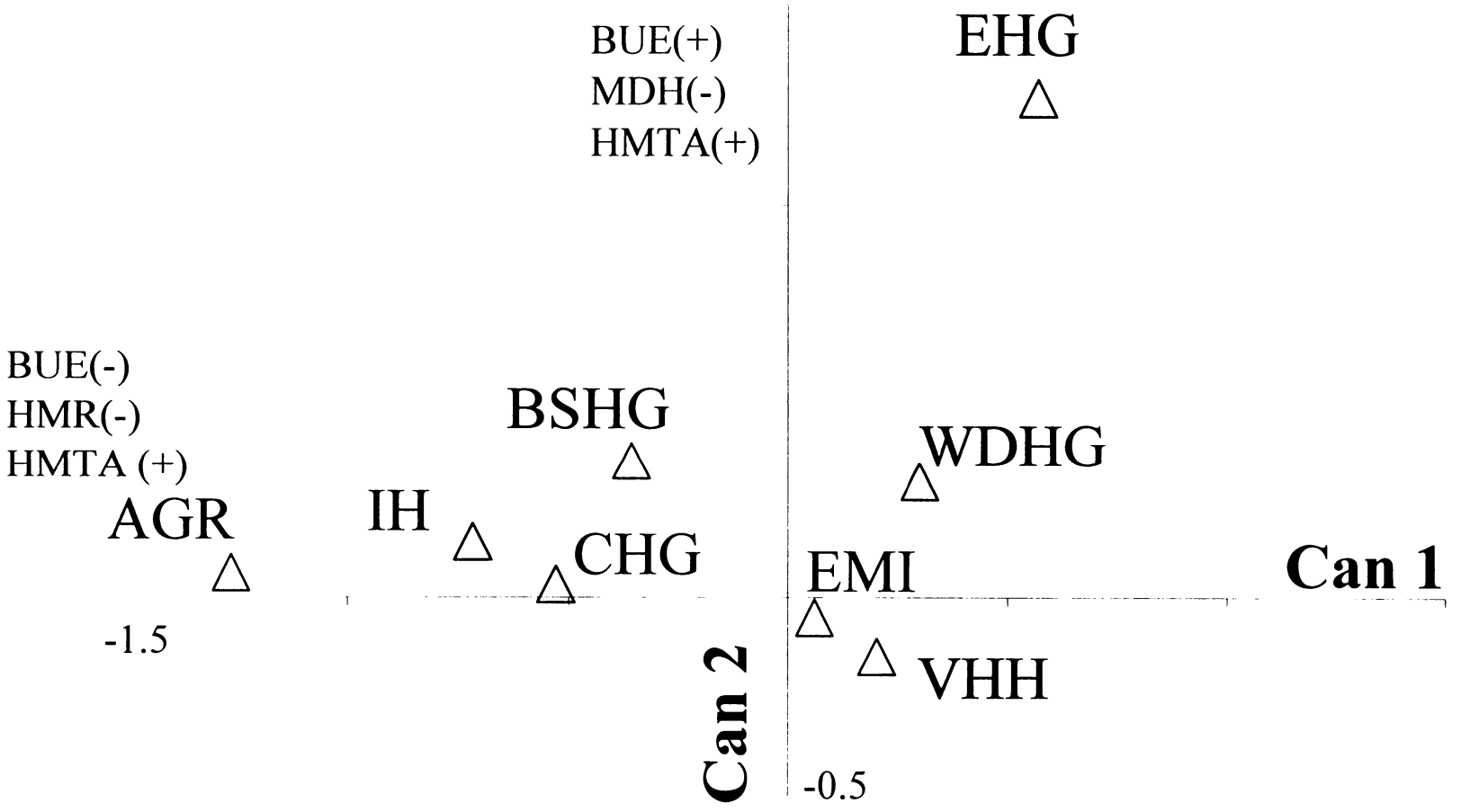


Figure 6.13. Canonical plot based on humerus variables showing the relationship among females with different subsistence strategies.

Sexual Dimorphism and Subsistence Strategy

Sexual dimorphism in bone length and epiphyseal size is relatively similar for all subsistence groups (Table 6.9; Figure 6.14), but marked differences in sexual dimorphism are observed in femoral and humeral midshaft shape (Figures 6.15 and 6.16). Hunter-gatherers, with the exception of EHG, have significantly greater sexual dimorphism in femoral midshaft shape than farmers or modern industrialists (Figure 6.15). Modern industrialists exhibit less sexual dimorphism than farmers. Nearly the opposite pattern occurs in the humerus midshaft (Figure 6.16). Early modern industrialists and agriculturalists exhibit the greatest sexual dimorphism, followed by late modern industrialists, coastal hunter-gatherers, and village horticulturalists.

Group Comparisons: Physical Terrain

Analysis of variance tests comparing males and females from each terrain type show that there is significant sexual dimorphism in all humerus and femur size variables, except for MLD in terrain 1 (Table 6.10). Males exhibit greater mean values than females in all size variables. At the humerus midshaft, females generally display less robusticity and a rounder diaphysis, however, statistical significance was only reached for HMR and HMS in some groups. For the shape of the femur, significant sexual dimorphism was observed at the subtrochanter (FSS) only for terrains 0, 2, and 3, and at midshaft (FMS) for terrains 2 – 4. Females have a greater mean for FSS, while males have a greater mean for FMS. That is, females exhibit a more platymeric femur. With regard to femur robusticity, there is no significant sexual dimorphism in standardized FMJ for any of the

Table 6.9. Percent sex difference [(male-female)/mean)*100] by subsistence strategy.

Group	*AGR*			*VHH*			*IH*		
Variable	*Male Mean*	*Female Mean*	*% Diff*	*Male Mean*	*Female Mean*	*% Diff*	*Male Mean*	*Female Mean*	*% Diff*
HML	315	291	7.92	321	299	7.10	319	294	8.16
MDH	44	39	12.05	46	41	11.49	45	39	14.29
EBR	59	53	10.71	61	55	10.34	60	54	10.53
HMS	1.36	1.45	-6.41	1.36	1.4	-2.90	1.4	1.41	-0.71
HMR	5.8	5.83	-0.52	5.89	5.86	0.51	5.96	5.71	4.28
FML	438	407	7.34	450	416	7.85	446	407	2.29
VHD	45	40	11.76	47	42	11.24	46	40	3.49
FEB	79	71	10.67	83	75	10.13	81	71	13.16
FSJstd	456	456	0.00	488	534	-9.00	473	538	-12.86
FSS	1.22	1.3	-6.35	1.3	1.3	0.00	1.27	1.3	-2.33
FSR	6.39	6.19	3.18	6.64	6.5	2.13	6.57	6.5	1.07
FSR2	6.24	6.35	-1.75	6.34	6.38	-0.63	6.4	6.6	-3.08
FMJstd	363	382	-5.10	387	391	-0.26	353	350	0.85
FMS	1.12	1.06	5.50	1.12	1.07	4.57	1.09	1.06	2.79
FMR	6.1	6.03	1.15	6.34	6.1	3.86	6.16	5.93	3.80
FMR2	5.97	6.18	-3.46	6.05	6.01	0.66	6.03	6.06	-0.50

Table 6.9. Continued.

Group	*BSHG*			*WDHG*			*EHG*		
	Male	*Female*		*Male*	*Female*		*Male*	*Female*	
Variable	*Mean*	*Mean*	*% Diff*	*Mean*	*Mean*	*% Diff*	*Mean*	*Mean*	*% Diff*
HML	320	299	6.79	---	---	---	325	309	5.05
MDH	46	40	13.95	---	---	---	48	43	10.99
EBR	62	55	11.97	---	---	---	62	58	6.67
HMS	1.37	1.38	-0.73	---	---	---	1.37	1.4	-2.17
HMR	6.11	5.98	2.15	---	---	---	6.23	6.1	2.11
FML	450	417	7.61	451	421	6.88	459	435	5.37
VHD	46	41	11.49	47	42	11.24	48	44	8.70
FEB	82	72	12.99	82	76	7.59	85	77	9.88
FSJstd	443	465	-4.85	421	458	-8.42	471	487	-3.34
FSS	1.22	1.22	-0.18	1.20	1.32	-9.52	1.2	1.3	-8.00
FSR	6.39	6.31	1.24	6.42	6.22	3.16	6.7	6.5	3.03
FSR2	6.3	6.3	0.00	6.09	6.44	-5.59	6.46	6.47	-0.15
FMJstd	370	366	1.09	324	325	-0.31	377	384	-1.84
FMS	1.12	1.02	9.35	1.1	1.02	7.55	1.09	1.05	3.74
FMR	6.27	6.01	4.23	6.04	5.84	3.37	6.41	6.19	3.49
FMR2	6.1	6.08	0.33	5.78	6.01	-3.90	6.14	6.18	-0.65

Table 6.9. Continued.

Group	*CHG*			*EMI*			*LMI*		
Variable	*Male Mean*	*Female Mean*	*% Diff*	*Male Mean*	*Female Mean*	*% Diff*	*Male Mean*	*Female Mean*	*% Diff*
HML	327	296	9.95	321	297	7.77	334	307	8.42
MDH	46	40	13.95	46	41	11.49	48	42	13.33
EBR	63	54	15.38	62	53	15.65	64	56	13.33
HMS	1.3	1.35	-3.77	1.22	1.3	-6.35	1.24	1.29	-3.95
HMR	6.5	5.87	10.19	6.41	6	6.61	6.31	5.71	9.98
FML	451	427	5.47	454	425	6.60	474	438	7.89
VHD	47	41	13.64	47	42	11.24	48	42	13.33
FEB	83	75	10.13	82	73	11.61	84	75	11.32
FSJstd	465	386	18.57	438	441	-0.68	373	384	-2.91
FSS	1.2	1.26	-4.88	1.16	1.14	1.74	1.12	1.13	-0.89
FSR	6.65	6.1	8.63	6.5	6.29	3.28	6.38	6.14	3.83
FSR2	6.45	6.34	1.72	6.22	6.4	-2.85	6.32	6.38	-0.94
FMJstd	401	338	17.05	368	364	1.09	319	312	2.22
FMS	1.07	1.06	0.94	1.05	1.05	0.00	1.11	1.13	-1.79
FMR	6.52	5.93	9.48	6.26	6.04	3.58	6.18	5.85	5.49
FMR2	6.34	6.17	2.72	6	6.17	-2.79	6.12	6.09	0.49

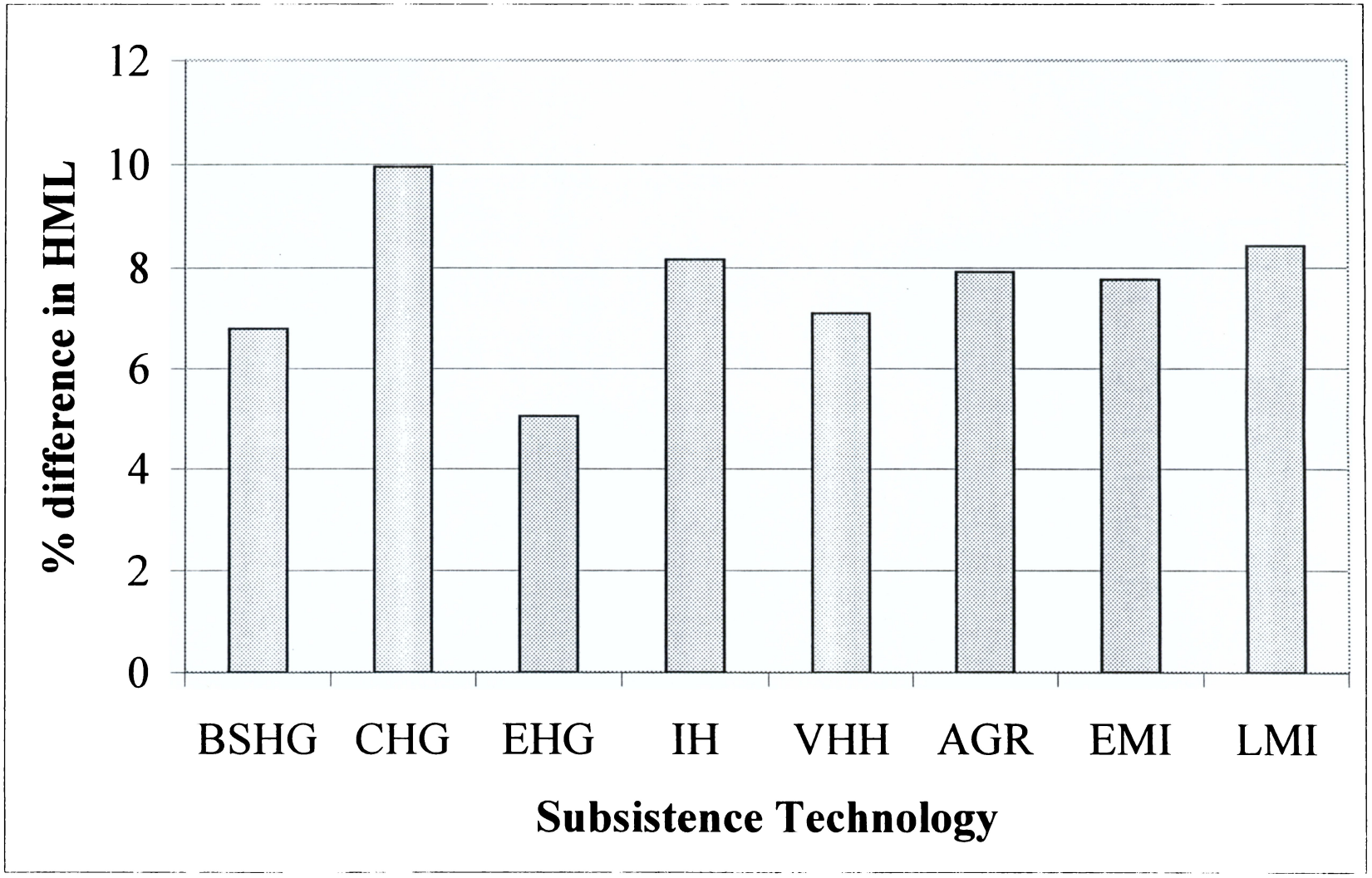


Figure 6.14. Sexual dimorphism in humeral length.

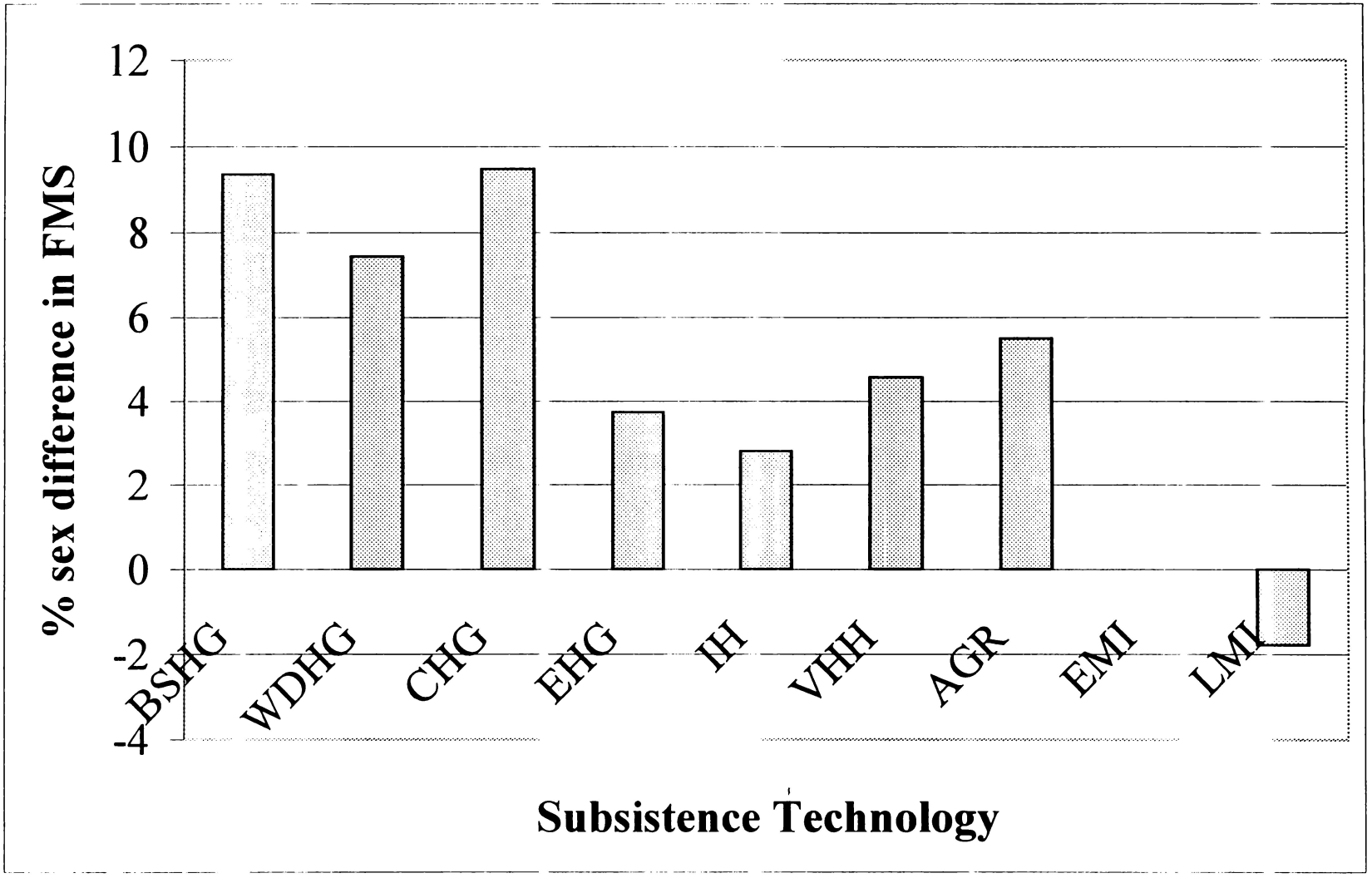


Figure 6.15 Sexual dimorphism in femur midshaft shape.

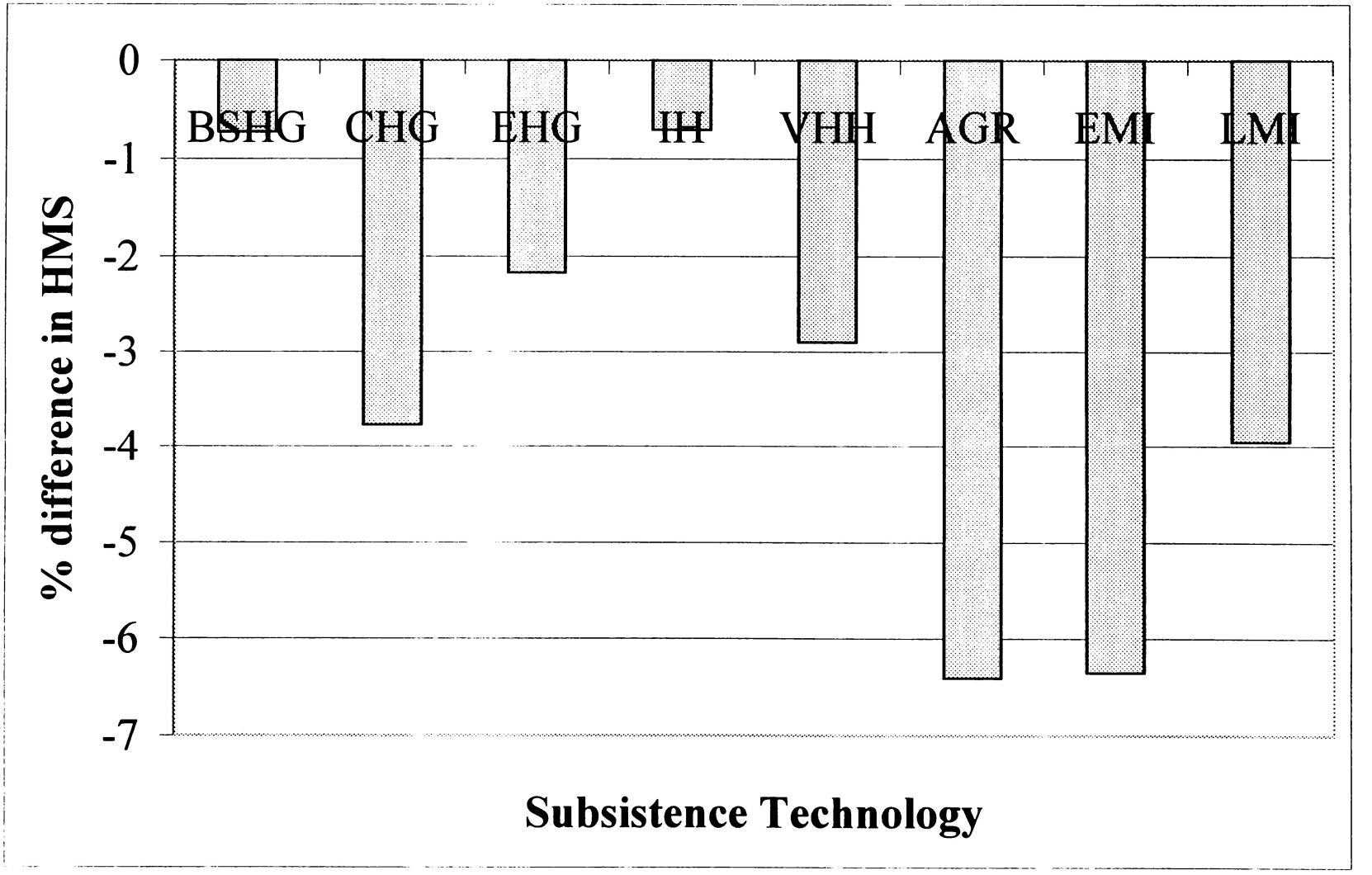


Figure 6.16. Sexual dimorphism in humerus midshaft shape.

Table 6.10. Sex comparison of size and shape variables by terrain (n, F-statistic, p-value).

		Variable								
		HML	***MDS***	***MDM***	***MDH***	***BUE***	***EBR***	***HMTA***	***HMS***	***HMR***
	Male	47	52	52	45	27	51	52	45	47
0	Female	34	45	45	38	13	37	45	52	34
	F	63.8	29.8	41.8	164.8	50.2	127.6	43.8	8.2	8.8
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0052*	0.004*
	Male	13	19	19	15	14	16	19	19	13
1	Female	19	21	21	21	18	19	21	21	19
	F	6.3	30	6.1	29.4	26.1	45.3	16.8	3.3	1.3
	p-value	0.0176	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0002*	0.0786	0.2621
	Male	155	204	204	156	141	160	204	204	152
2	Female	138	178	178	130	116	130	178	178	131
	F	135.5	110.6	110.2	309.3	253.4	219.3	148.9	3.7	12.9
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0536	0.0004*
	Male	374	385	385	377	335	362	385	385	374
3	Female	338	341	341	336	304	314	341	341	334
	F	391	92.2	125.1	843.2	627.7	522.1	137	10.5	0.05
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0012	0.8203
	Male	95	106	106	96	97	104	106	106	92
4	Female	87	95	92	85	89	95	95	86	93
	F	119.4	12.7	28.2	222.7	221.7	183.6	24.9	10.8	0.49
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.4862

Table 6.10. Continued.

		Variable								
		FML	***APS***	***MLS***	***APD***	***MLD***	***VHD***	***FEB***	***FSTA***	***FMTA***
	Male	51	56	56	60	60	58	43	60	56
0	Female	38	45	45	46	46	43	32	46	45
	F	56.7	71.6	36.3	89.4	37.0	174.7	92.7	97.8	79.0
	p-value	.0001*	.0001*	.0001*	.0001*	0.0001	.0001*	.0001*	0.0001	0.0001
	Male	24	29	29	28	29	27	20	28	29
1	Female	25	33	33	35	35	29	14	35	33
	F	41.5	49.2	38.4	22.1	5.0	59.9	22.4	32.7	67.1
	p-value	.0001*	.0001*	.0001*	.0001*	0.0284	.0001*	.0001*	.0001*	0.0001
	Male	174	222	222	223	222	168	118	222	221
2	Female	151	210	210	214	212	142	91	212	209
	F	239.6	199.3	135.9	177.0	61.8	332.4	196.0	220.9	277.3
	p-value	.0001*	.0001*	0.0001	.0001*	0.0001	.0001*	.0001*	.0001*	.0001*
	Male	448	468	468	457	457	446	344	457	468
3	Female	389	403	403	400	400	385	276	400	403
	F	571.8	591.3	313.4	274.7	337.5	945.6	975.9	508..86	647.6
	p-value	.0001*	.0001*	0.0001	.0001*	0.0001	.0001*	0.0001	.0001*	.0001*
	Male	103	112	112	113	113	106	87	133	112
4	Female	96	104	104	105	105	94	72	105	104
	F	128.2	142.0	37.7	85.9	83.1	240.7	240.2	172.3	120.4
	p-value	.0001*	.0001*	0.0001	.0001*	0.0001	.0001*	.0001*	.0001*	.0001*

Table 6.10. Continued.

		Variable					
		FSJ	***FMJ***	***FSR***	***FMR***	***FSS***	***FMS***
	Male	51	50	51	50	60	56
0	Female	35	37	35	37	46	48
	F	2.5	0.2	18.8	12.0	10.6	5.1
	p-value	0.1145	0.6296	.0001*	.0008*	0.0015	0.0264
	Male	23	24	23	24	28	29
1	Female	24	25	24	25	35	33
	F	4.3	0.0	0.7	7.2	2.9	0.7
	p-value	0.0451	0.9466	0.4033	.0100*	0.0953	0.4016
	Male	172	172	172	172	222	221
2	Female	148	147	148	147	212	209
	F	6.0	0.1	14.5	26.5	15.0	11.3
	p-value	0.015	0.7806	.0002*	.0001*	.0001*	.0008*
	Male	448	448	442	448	457	468
3	Female	386	386	382	386	400	403
	F	26.9	0.3	33.5	84.1	7.1	81.1
	p-value	.0001*	0.561	0.0001	.0001*	0.0079*	.0001*
	Male	102	102	102	102	113	112
4	Female	96	96	96	96	105	104
	F	0.9	0.2	15.0	7.7	4.2	30.3
	p-value	0.3504	0.6402	.0001*	.0061*	0.0414	.0001*

terrain groups, and significant sexual dimorphism was discovered only for terrains 2 and 3 for standardized FSJ. Females show greater means for FSJ in both groups. Significant sexual dimorphism in FSR and FMR was observed for all terrains with the exception of FSR in terrain 1. In all cases, males display greater robusticity.

Size and shape variables were regressed on terrain codes followed by a 1-way ANAOVA and Tukey's range test. Tables 6.11 and 6.12 present the regression and Tukey multiple comparisons results for males and females, respectively. Statistically significant differences were found among groups of contrasting terrains for humerus variables HML, MDS, MDM, EBR, HMTA, and HMR in males and for variables HML, MDH, and EBR in females. Nevertheless, no clear patterns were observed in paired comparison tests (Table 6.11 and 6.12), and the extremely low R^2 values associated with humerus variables show that terrain differences can explain very little of the variation seen in the humerus.

For the femur, no statistically significant differences were found for variables FSTA, FMJstd, FSR, or FMR among groups in disparate terrains. Statistically significant differences were discovered between terrain groups for variables FSJstd, FSS, FMTA, FMS, and FML. However, the pattern of significance based on Tukey multiple comparison tests and R^2 values for all variables suggests there is no equivocal effect of terrain on femur shape or robusticity (Tables 6.11 and 6.12). Figure 6.17 illustrates the pattern of the standardized femoral midshaft polar moment of area, which Ruff (1999) has shown to be significantly greater in mountainous groups. No significant distinctions were found between any of the groups for FMJ in this study. Femur maximum length

Table 6.11. Terrain regression anaylsis and Tukey multiple group comparison results for males.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences* *
HML	10.2	0.0012	0.0169	0>3>1>2>4 (3:4)
BUE	2.2	0.1346	0.0022	0>1>3>2>4 (none)
MDS	54.6	<0.0001	0.087	1>2>0>3>4 (1:2, 1:0, 1:3, 1:4, 2:3, 2:4, 0:3, 0:4)
MDM	41.5	<0.0001	0.0671	0>2>1>4>3 (0:2, 0:4, 0:3, 2:4, 2:3)
MDH	3.0	0.0815	0.0036	1>3>2>0>4 (1:0, 1:4, 3:4, 2:4)
EBR	7.6	0.0058	0.0117	1>3>0>2>4 (3:4)
HMTA	61.3	<0.0001	0.0968	1>0>2>4>3 (1:4, 1:3, 0:4, 0:3, 2:4, 2:3, 4:1)
HMR	37.8	<0.0001	0.0554	1>2>0>4>3 (1:3, 2:3, 0:3)
HMS	0.0	0.9851	-0.0018	1>3>2>4>0 (1:3, 1:2, 1:4, 1:0, 3:0, 2:0)
FML	5.9	0.0151	0.0087	1>3>0>2>4 (3:4, 2:4)
APS	8.9	0.0029	0.014	1>2>0>3>4 (1:4)
MLS	7.7	0.0055	0.0119	1>2>3>0>4 (1:4. 2:4, 3:4, 0:4)
APD	17.9	0.0001	0.0293	1>2>0>4>3 (1:0, 1:4, 1:3, 2:4, 2:3)
MLD	8.2	0.0043	0.0127	3>2>1>4>0 (3:2, 3:4, 3:0, 2:0)
VHD	0.7	0.4079	-0.0006	3>2>1>0>4 (3:0, 3:4, 2:0, 2:4)
FEB	2.3	0.1269	0.0024	3>2>0>4>1 (3:2, 3:0, 3:4, 3:1, 2:4)
FSTA	1.7	0.1973	0.0012	1>2>3>0>4 (1:0, 1:4, 2:0, 2:4, 3:0, 3:4)
FMTA	12.5	0.0004	0.0201	1>2>3>0>4 (1:4, 2:4, 3:4, 0:4)
FSJstd	4.6	0.0325	0.0064	1>2>4>3>0 (2:0)
FMJstd	0.4	0.5282	-0.0011	1>2>0>3>4 (none)
FSR	0.3	0.0691	-0.0013	1>2>3>4>0 (1:0)
FMR	3.9	0.0484	0.0052	1>2>0>3>4 (2:4)
FSS	27.2	0.0001	0.0446	3>4>2>0>1 (3:4, 3:2, 3:0, 3:1)
FMS	0.4	0.4981	-0.001	1>2>0>4>3 (none)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.12. Terrain type regression analysis and Tukey multiple group comparisons for females.

Variable	*F-statistic*	*p-value*	*Adj R^2*	*Paired Group Differences**
HML	5.5	0.0196	0.0093	3>1>2>0>4 (3:0, 3:4, 2:4)
BUE	1.3	0.2521	0.0007	1>3>2>4>0 (none)
MDS	2.5	0.1107	0.0033	1>2>3>4>0 (none)
MDM	3.4	0.0663	0.005	1>2>0>3>4 (none)
MDH	13.1	0.0003	0.0248	1>3>2>0>4 (1:0, 1:4, 3:0, 3:4, 2:0, 2:4)
EBR	6.0	0.0151	0.0103	1>3>2>4>0 (1:4, 1:0, 3:4, 3:0, 2:4, 2:0)
HMTA	3.9	0.0475	0.0062	1>2>3>0>4 (none)
HMR	0.4	0.5353	-0.0013	1>4>2>3>0 (none)
HMS	0.3	0.5843	-0.0015	4>1>2>3>0 (none)
FML	8.4	0.004	0.0161	1>3>2>0>4 (1:4, 3:4, 2:4, 0:4)
APS	8.7	0.0034	0.0168	2>0>1>3>4 (2:4, 3:4)
MLS	0.8	0.3642	-0.0004	3>2>1>0>4 (3:4, 2:4)
APD	5.5	0.0200	0.0098	1>2>3>0>4 (1:3, 1:0, 1:4, 2:3, 2:4)
MLD	4.6	0.0326	0.0079	3>1>2>4>0 (3:2, 3:4, 3:0, 1:0, 2:4, 2:0)
VHD	1.9	0.1638	0.00021	1>3>2>0>4 (1:0, 1:4, 3:0, 3:4, 2:0, 2:4)
FEB	0.2	0.6731	-0.0018	3>2>1>0>4 (3:0, 3:4, 2:4)
FSTA	0.1	0.7066	-0.0019	1>2>3>4>0 (1:4, 1:0, 2:4, 2:0, 3:4, 3:0)
FMTA	5.3	0.0215	0.0095	2>3>1>0>4 (2:4, 3:4)
FSJstd	7.1	0.0081	0.0133	1>2>3>4>0 (1:0, 2:0, 3:0)
FMJstd	0.0	0.874	-0.0022	2>3>4>0>1 (none)
FSR	3.4	0.0663	0.0075	1>2>3>4>0 (1:0, 2:0, 3:0, 4:0)
FMR	0.3	0.6046	-0.0016	2>3>0>4>1 (none)
FSS	12.6	0.0004	0.0252	3>4>2>0>1 (3:3, 3:4, 3:2, 3:0, 3:1)
FMS	4.2	0.0408	0.0071	1>2>1>4>3 (none)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

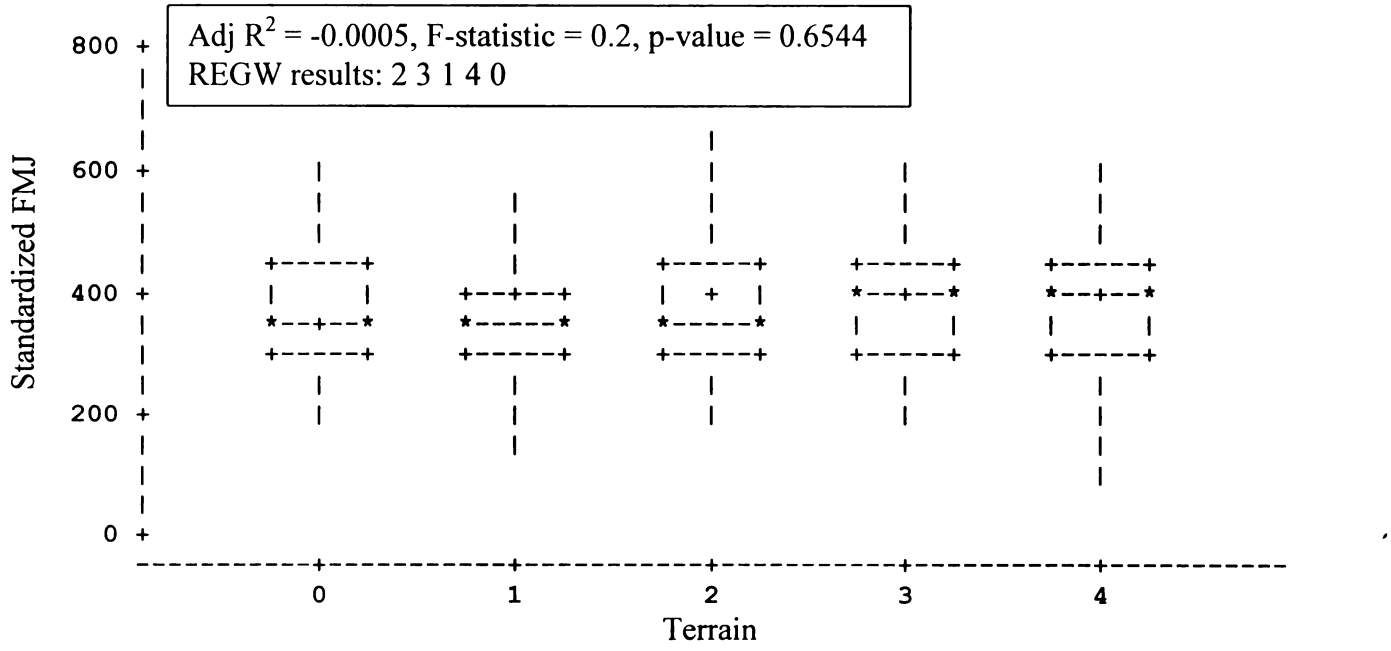


Figure 6.17. Box plot of standardized femur midshaft polar second moment of area for combined sexes. The box equals one inter-quartile distance and the "+" indicates the mean.

does appear to generally decrease in length from the Gulf Coast to the mountainous regions, but only mountain groups are significantly different. As seen in Figure 6.18, samples from the Gulf Coast exhibit the longest femora, followed in descending order by the prairie samples (terrain = 1), Northern Plains (terrain = 3), Southern Plains and Central Plains (terrain = 2) and Southwest and Great Basin (terrain = 4).

Canonical plots illustrating the relationship among different cultural regions are presented in Figures 6.19 – 6.22. Neither femoral or humeral morphology follows a clear terrain pattern in males, but in females, a relatively clear geographical pattern is seen for both the humerus and femur along axis 2 of Figures 6.21 and 6.22.

Comparisons within the Great Plains

Sexual Dimorphism

Significant sexual dimorphism is observed for all size variables of the humerus and femur, but only in some of the shape and robusticity variables. For example, males exhibit significantly more robust humeral midshafts than females in the Central Plains but not in the other Plains regions. Humerus midshaft shape significantly differs between the sexes in the Northern and Southern Plains with females exhibiting more rounds humeral midshafts. At the femur subtrochanter, females are significantly more platymeric, while males are more robust. The femoral midshaft is significantly more robust and anteroposteriorly elongated in males of all cultural regions.

Sexual dimorphism was also analyzed by Plains subsistence technology. Broad-spectrum hunter-gathers of the Plains exhibit significant sexual dimorphism in all

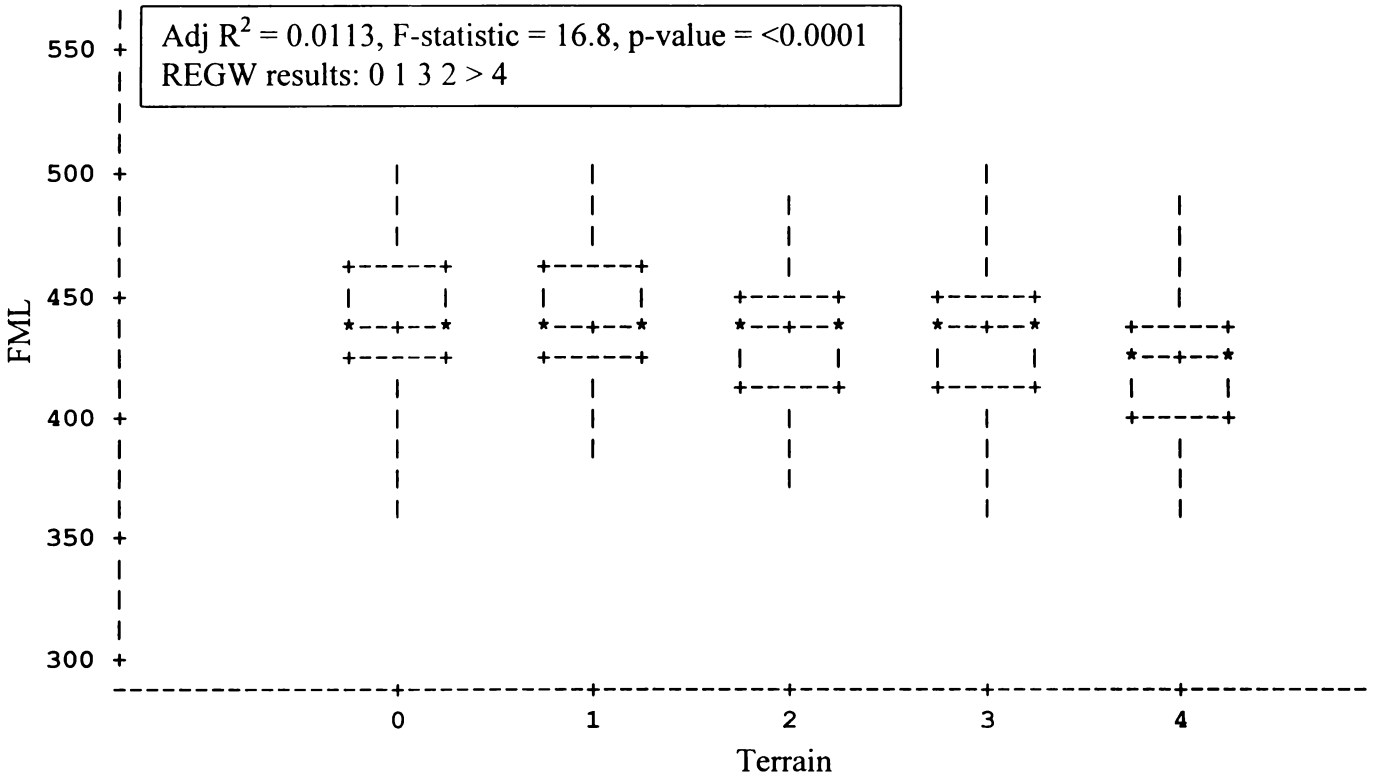


Figure 6.18. Box plots of femur maximum length by terrain for combined sexes. The box equals one inter-quartile distance and the "+" indicates the mean.

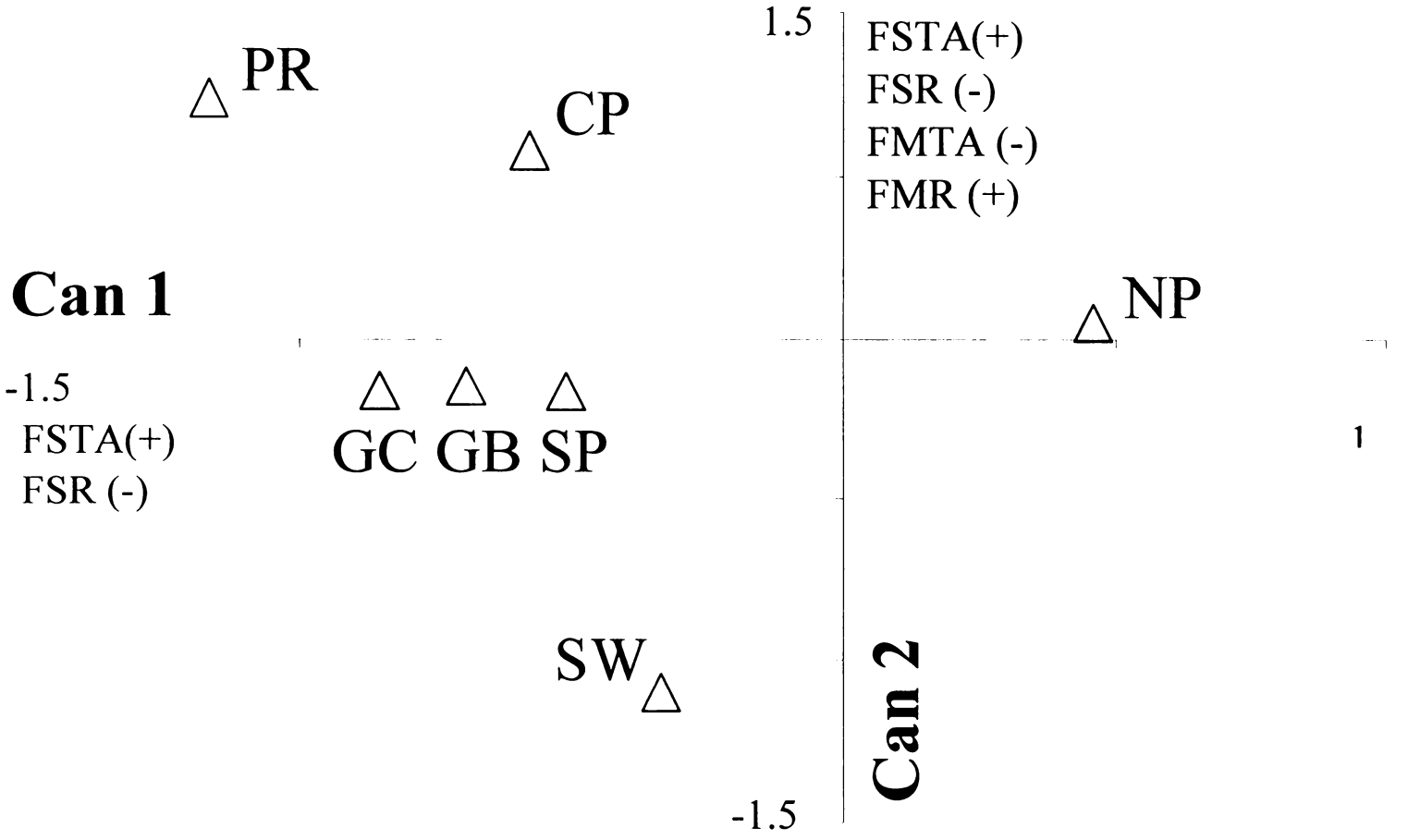


Figure 6.19. Canonical plot based on femur variables showing the relationship among males in different cultural areas.

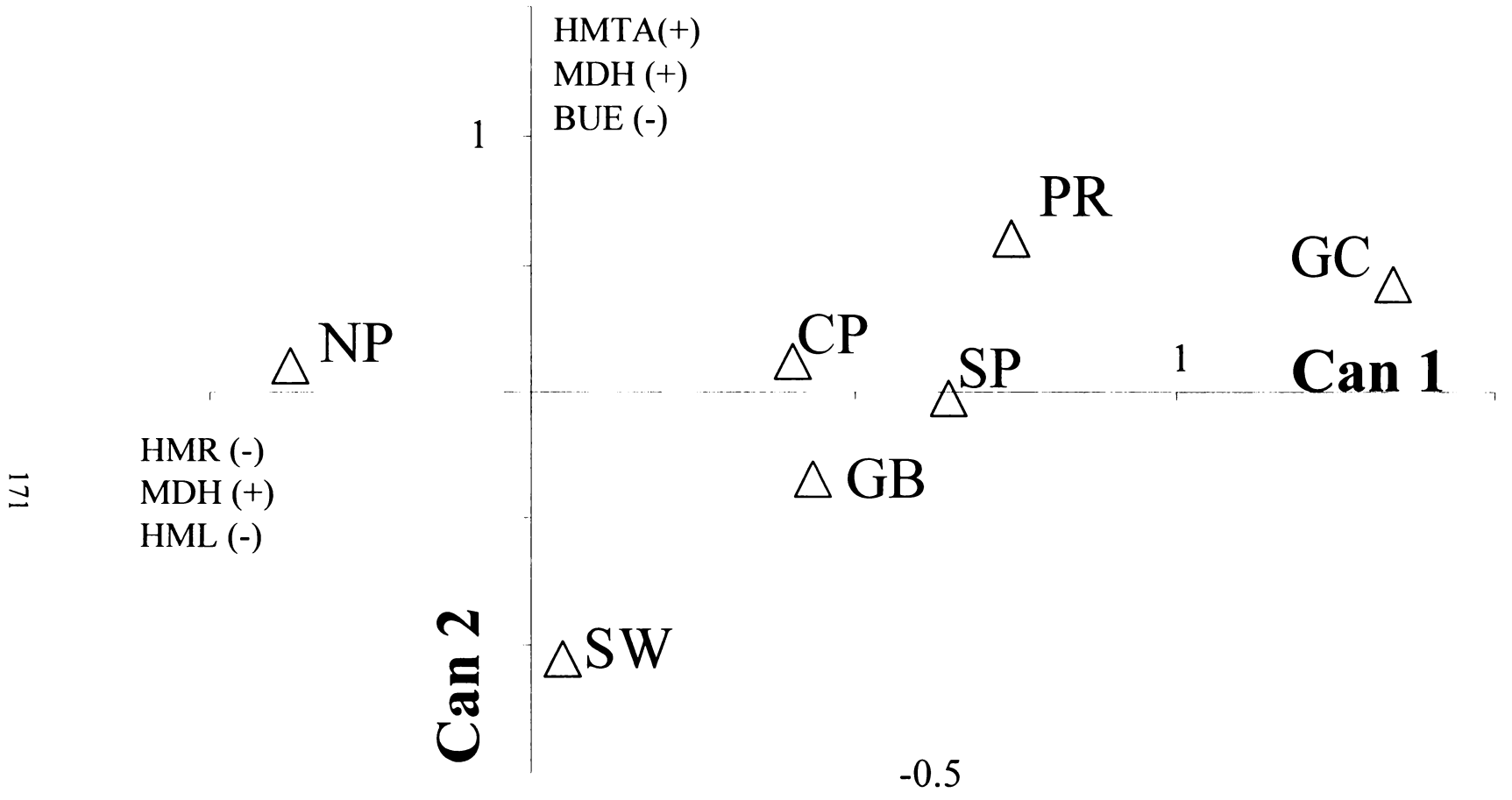


Figure 6.20. Canonical plot showing relationships among males in different cultural regions based on humerus variables.

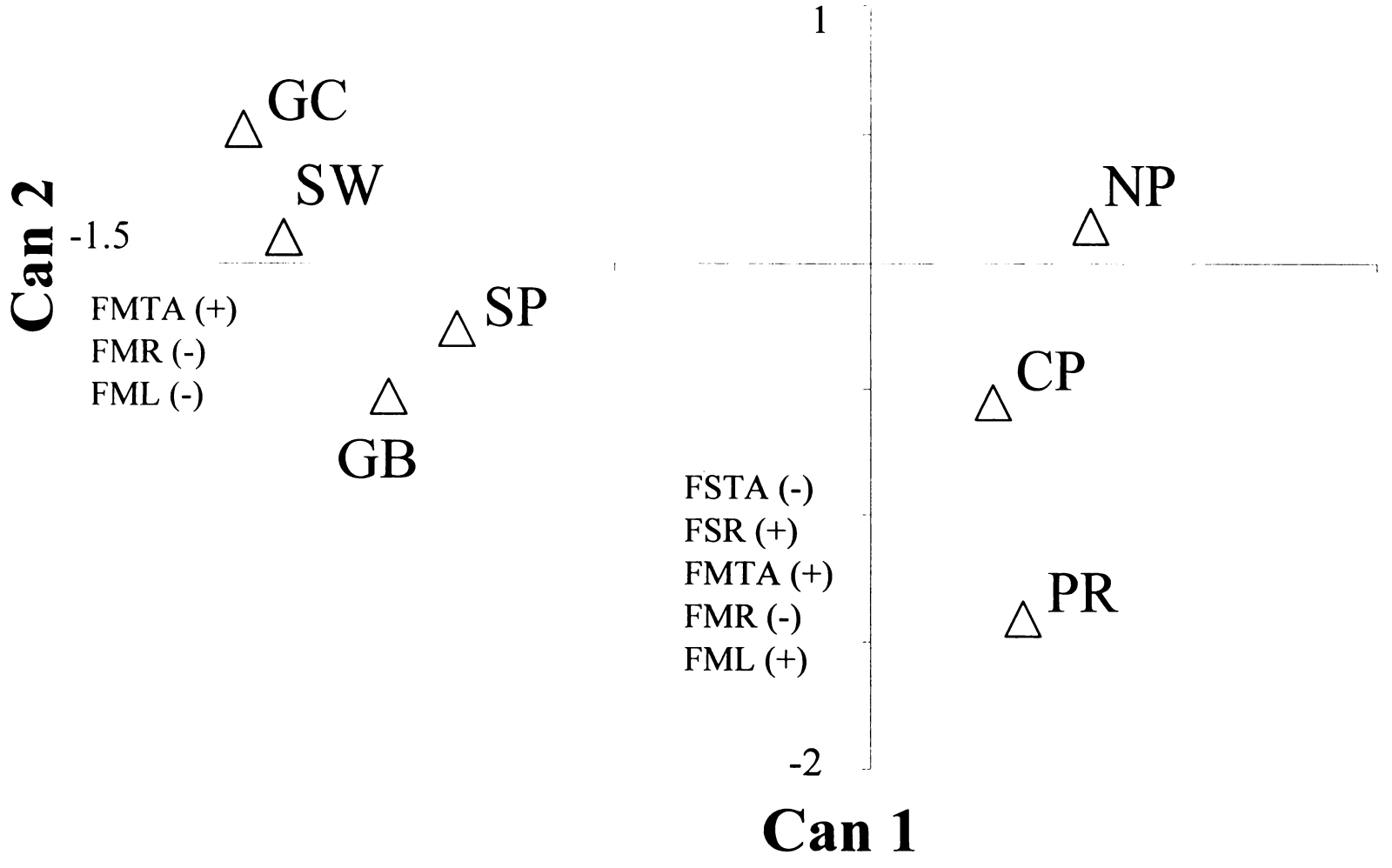


Figure 6.21. Canonical plot showing relationships among female in different cultural regions based on femur variables.

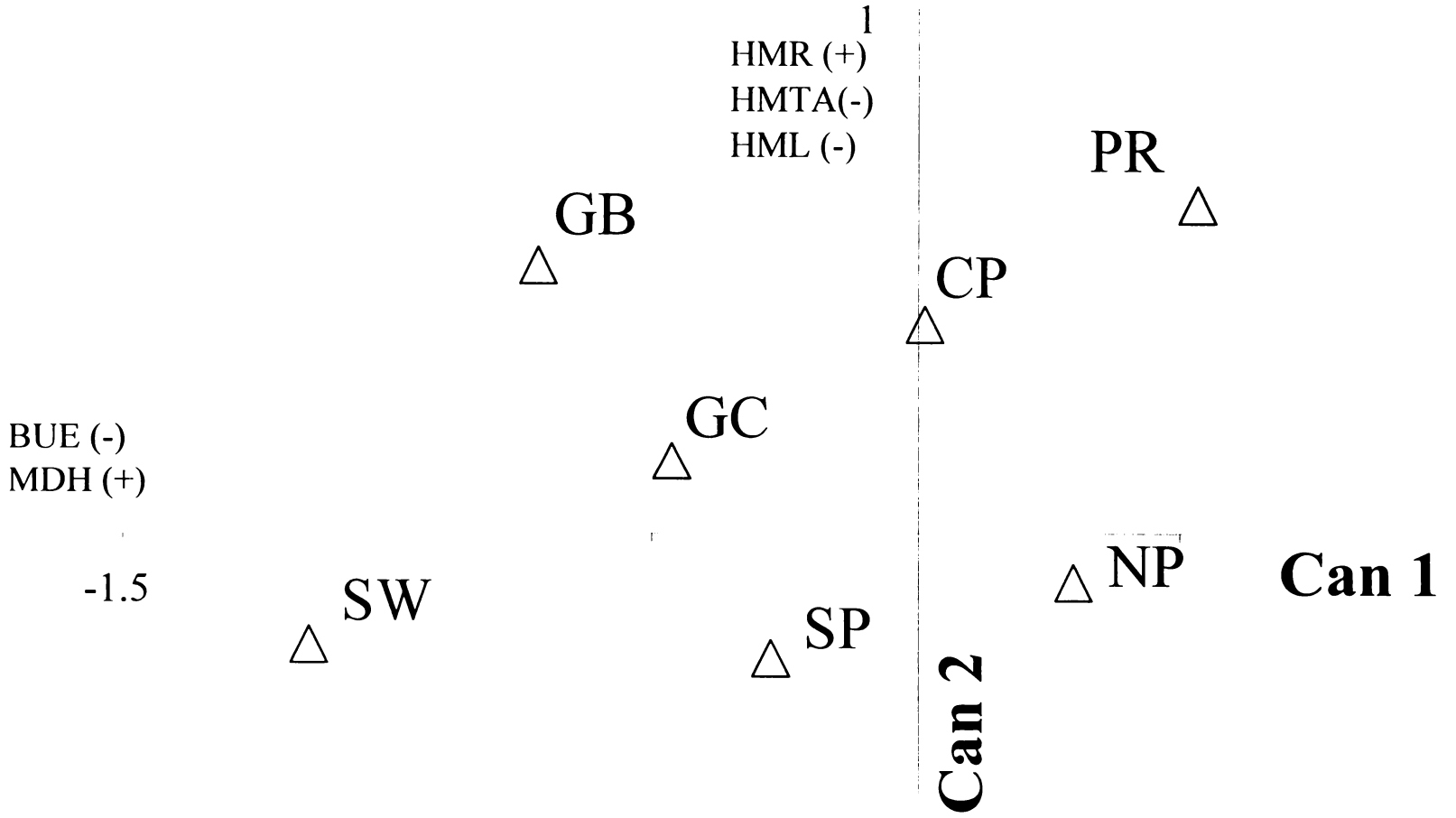


Figure 6.22. Canonical plot showing relationships among female in different cultural regions based on humerus variables.

variables except HMS, FMR, FMS, and FSJ. Equestrian hunter-gatherers, on the other hand, are not significantly sexually dimorphic in subtrochanteric or midshaft shape. They also do not exhibit significant sexual dimorphism in humeral midshaft robusticity. Incipient horticulturalists show significant sexual dimorphism in all variables except HMS, FSR, and FMS. Village horticulturalists are sexually dimorphic for all variables in femur size and shape, but not in humeral midshaft robusticity.

Culture Area

Table 6.13 presents regression results for males by geographical or cultural region (NP, PR, CP, and SP). Plains groups are generally homogeneous in humeral size and shape, with only HMS in males exhibiting any significant differences by cultural region. The prairie sample has a significantly flatter humeral diaphysis than the other Plains groups. Regarding the femur, robusticity at the femoral subtrochanter (FSR), subtrochanteric total area (FSTA), subtrochanteric shape (FSS), femur midshaft shape (FMS), and femoral head diameter (VHD) are significant overall. At the femur subtrochanter, Southern Plains groups are significantly smaller, rounder, and less gracile than the Northern Plains, Central Plains, or Prairie groups. Northern Plains males exhibit the most platymeria but are less robust at the subtrochanter than Southern Plains groups. At the femur midshaft, Southern Plains groups display the greatest amount of anteroposterior elongation in both sexes (Figure 6.23), while Central Plains groups are the most robust.

Table 6.13. Regression and Tukey multiple comparison test results of Plains males by cultural area.

Variable	*F-statistic*	*p-value*	*Paired Group Differences**
HML	0.41	0.7442	SP>NP>PR>CP (none)
BUE	0.93	0.4922	PR>CP>NP>SP (none)
MDH	1.7	0.1736	PR>CP>NP>SP (PR:SP, CP:SP, NP:SP)
EBR	1.4	0.2429	PR>NP>CP>SP (none)
HMTA	1.7	0.1698	PR>CP>SP>NP (PR:NP, CP:NP)
HMR	2.3	0.0814	PR>CP>SP>NP (PR:NP, CP:NP)
HMS	4.0	0.0076	PR>CP>NP>SP (PR:CP, PR:NP, PR:SP)
FML	0.8	0.4746	PR>CP>SP>NP (none)
VHD	7.7	<0.0001	NP>CP>PR>SP (NP:SP, CP:SP, PR:SP)
FSTA	8.9	<0.0001	PR>CP>NP>SP (PR:SP, CP:SP, NP:SP)
FMTA	3.6	0.0143	PR>CP>NP>SP (PR:SP)
FSJstd	3.2	0.0229	CP>NP>PR>SP (CP:SP, NP:SP)
FMJstd	1.1	0.3370	CP>NP>PR>SP (none)
FSR	4.7	0.0030	CP>PR>NP>SP (CP:SP, NP:SP)
FMR	2.6	0.0519	CP>PR>NP>SP (CP:SP)
FSS	40.6	<0.0001	NP>CP>PR>SP (NP:CP, NP:PR, NP:SP)
FMS	11.8	<0.0001	SP>PR>NP>CP (SP:PR, SP:NP, SP:CP)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

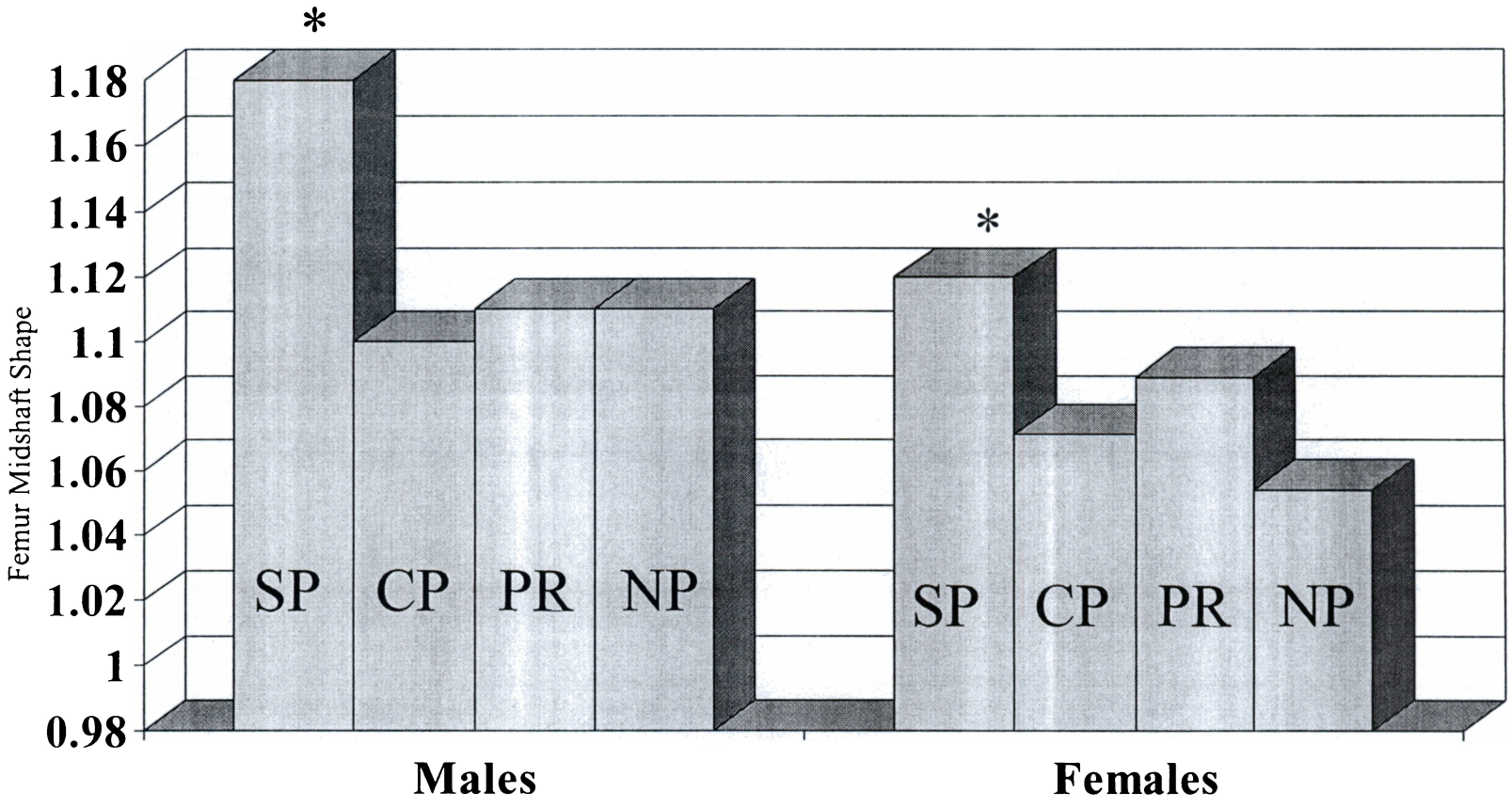


Figure 6.23. Comparison of femur midshaft shape by Plains geographical area. * Statistically significant.

Females exhibit a similar pattern as males with Southern Plains groups exhibiting significantly smaller femoral and humeral head sizes and significantly greater anteroposterior elongation of the femoral midshaft (Table 6.14). Northern Plains females are significantly more platymeric than the other three groups. The subtrochanteric total area (FSTA) is significantly greater in Prairie groups.

Subsistence Strategy

Regression results by subsistence strategy are presented in Tables 6.15 and 6.16 for males and females, respectively. Equestrian hunter-gatherers exhibit significantly longer femora and humeri than other groups. They are also more robust at the humerus midshaft than VHH and exhibit a larger humerus head size than VHH or BSHG. In general, village horticulturalists have robust femoral midshafts and relatively gracile femoral subtrochanteric areas, while Woodland and broad-spectrum hunter-gatherers exhibit gracile femoral midshafts and robust subtrochanter. Equestrian hunters have very round femoral midshafts and are robust at both the femoral midshaft and subtrochanter.

Table 6.14. Comparison of Plains females by cultural area.

Variable	*F-statistic*	*p-value*	*Paired Group Differences**
HML	1.7	0.1693	CP>PR>NP>SP (none)
BUE	3.0	0.0292	PR>NP>CP>SP (none)
MDH	2.7	0.0486	PR>NP>CP>SP (PR:SP, NP:SP, CP:SP)
EBR	2.2	0.0921	PR>NP>SP>CP (NP:CP)
HMTA	0.8	0.5134	PR>CP>SP>NP (none)
HMR	0.7	0.5691	PR>CP>SP>NP (none)
HMS	0.3	0.8585	SP>NP>PR>CP (none)
FML	0.6	0.6314	PR>SP>NP>CP (none)
VHD	4.6	0.0033	NP>PR>CP>SP (NP:SP)
FSTA	5.5	0.001	PR>NP>CP>SP (PR:NP, PR:CP, PR:SP, NP:SP)
FMTA	0.1	0.9411	PR>SP>NP>CP (none)
FSJstd	1.5	0.2163	PR>NP>CP>SP (none)
FMJstd	0.3	0.8391	SP>NP>CP>PR (none)
FSR	1.2	0.3205	PR>NP>CP>SP (none)
FMR	0.3	0.8582	SP>NP>LP>PR (none)
FSS	27.3	<0.0001	NP>CP>PR>SP (NP:CP, NP:PR, NP:SP)
FMS	10.8	<0.0001	SP>PR>CP>NP (SP:CP, SP:NP)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.15. Comparison of Plains males by subsistence strategy.

Variable	*F*	*p-value*	*Paired Group Differences**	
HML	1.97	0.0972	WDHG>IH>EHG>VHH>BSHG	(none)
BUE	3.31	0.0108	EHG>WDHG>IH>VHH>BSHG	(EHG:IH, EHG:VHH:EHG:BSHG, WDHG:VHH, WDHG:BSHG)
MDH	1.62	0.1666	EHG>WDHG>VHH>IHH>BSHG	(EHG:VHH, EHG:BSHG)
EBR	1.08	0.3637	EHG>WDHG>IH>VHH>BSHG	(none)
HMTA	2.11	0.0781	EHG>WDHG>IH>BSHG>VHH	(EHG:IH, EHG:VHH)
HMR	1.05	0.3826	EHG>WDHG>BSHG>VHH>IH	(EHG:VHH)
HMS	1.88	0.1126	IH>BSHG>EHG>WDHG>VHH	(IH:VHH)
FML	1.84	0.12	EHG>IH>WDHG>VH>BSHG	(none)
FSTA	4.56	0.0012	EHG>IH>VHH>BSHG>WDHG	(EHG:VH, EHG:WDHG)
FMTA	5.29	0.0003	EHG>VHH>IH>BSHG>WDHG	(EHG:VHH, EHG:IH, EHG:BSHG, EHG:WDHG)
FSJstd	1.81	0.1246	VHH>IH>EHG>BSHG>WDHG	(none)
FMJstd	2.88	0.022	VHH>EHG>IH>BSHG>WDHG	(VHH:WDHG)
FSR	1.92	0.1062	EHG>IH>VHH>BSHG>WDHG	(none)
FMR	4.14	0.0026	EHG>VHH>IH>BSHG>WDHG	(WHG:WDHG, VHH:WDHG)
FSS	6.77	<0.0001	VHH>IH>EHG>BSHG>WDHG	(VH:EGH, VH:WDGH)
FMS	4.64	0.0011	VHH>WDHG>BSHG>EHG>IH	(VHH:IH)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

Table 6.16. Comparison of Plains females by subsistence strategy.

Variable	*F-statistic*	*p-value*	*Paired Group Differences**	
HML	0.98	0.4174	EHG>IH>WDHG>BSHG>VHH	(EHG:VHH)
BUE	0.61	0.6538	EHG>WDHG>IH>VHH>BSHG	(EHG:IH, EHG:VHH, EHG:BSHG, WDHG:BSHG)
MDH	4.48	0.0015	EHG>WDHG>VHH>IH>BSHG	(EHG:VHH, EHG:IH, EHG:BSHG, WDHG:VHH, WDHG:IH, WDHG:BSHG)
EBR	2.69	0.031	EHG>WDHG>VHH>IH>BSHG	(EHG:IH, EHG:BSHG, EHG:VHH, WDHG:BSHG)
HMTA	5.57	0.0002	EHG>VHH>WDHG>IH>BSHG	(EHG:VHH, EHG:WDHG, EHG:IH, EHG:BSHG, VHH:BSHG)
HMR	4.65	0.0011	EHG>VHH>WDHG>IH>BSHG	(EHG:1H, EHG:BSHG)
HMS	0.54	0.7076	BSHG>IH>EHG>WDHG>VHH	(none)
FML	8.23	<0.0001	EHG>WDHG>IH>VHH>BSHG	(EHG:IH, EHG:VHH)
FSTA	8.5	<0.0001	EHG>IH>VHH>WDHG>BSHG	(EHG:VHH, EHG:WDHG, EHG:BSHG, BSHG:IH, BSHG:VHH)
FMTA	8.81	<0.0001	EHG>VHH>IH>WDHG>BSHG	(EHG:VHH, EHG:IH, VHH:WDHG, VHH:BSHG)
FSJstd	2.55	0.0386	VHH>IH>EHG>WDHG>BSHG	(none)
FMJstd	3.4	0.0093	VHH>EHG>IH>WDHG>BSHG	(VH>IH)
FSR	2.71	0.0295	IH>VHH>EHG>WDHG>BSHG	(none)
FMR	4.73	0.0009	EHG>VHH>IH>WDHG>BSHG	(EHG:IH, VHH:IH)
FSS	1.65	0.1606	BSHG>EHD>WDHG>VHH>EHG	(none)
FMS	1.32	0.2598	IH>VHH>EHG>BSHG>WDHG	(none)

*Numbers separated by a ">" signify order of group mean size. Pairs in parentheses separated by a colon are significantly (alpha=0.05) different.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

The interdependence between long bone morphology and physical activity has been known since at least the late 19th century (Wolff, 1870), but the use of biomechanical analyses to help interpret physical activity patterns from long bone morphology has only been extensively used for about two decades. During this time, great insight has been gained regarding behavior associated with various subsistence strategies and physical terrains. While skeletal remains from several of the major geographical regions of North America (e.g., Georgia coast, Southwest, Great Basin, and Southeast) have been extensively analyzed using a biomechanical approach, few studies have examined the American Great Plains. Furthermore, only a small number of studies have investigated the potential of external measurements in biomechanical studies or attempted to examine the effects of subsistence strategy and terrain on a geographically and temporally diverse sample. Therefore, the purpose of this study is three fold. The first goal of this study is to examine the correlation between long bone cross-sectional properties and those predicted using external dimensions alone. A second purpose is to test if physical terrain and subsistence adaptation consistently affects long bone morphology in the same manner when a large number of populations are examined. The final purpose of this study is to examine the pattern of long bone structural variation within the American Great Plains.

Prediction of Cross-sectional Properties

The investigation of long bone structural variation associated with subsistence strategy and physical terrain, a large database with considerable time-depth and geographical distribution is needed. Ruff and colleagues argue that the most appropriate database for a biomechanical analysis would consist of cross-sectional geometric properties derived from computed tomography scans or physically sectioned long bones. However, the collection of long bone cross-sectional data is extremely time-consuming, expensive, and often requires specialized machinery (e.g., CT scanner). In addition, recent laws regarding the reburial of Native American skeletons further complicate the development of this type of database. External dimensions of long bones, on the other hand, can be easily collected in a short period with minimal equipment and cost. Furthermore, a great deal of external dimensional data is readily available in the literature. As a result, researchers can often accumulate large data sets of external dimensions.

Larsen (1997) states that anteroposterior and mediolateral dimensions of long bones can provide a general picture of long bone strength, but that they are extremely limited because they do not take into account the distribution of bone in a cross-section. Ruff (2000a) concurs, arguing that long bone external dimensions alone are not sufficient to conduct biomechanical analyses, and stresses the importance of obtaining cross-sectional properties such as cortical area and moments of area. However, the results of this study show that this insistence on cross-sectional data is not warranted. External dimensions of long bones can be used to reliably predict cross-sectional

properties. Nearly 90% of the variation in long bone shape and strength is obtained by using external dimensions alone. The only limiting factor to external dimensions appears to be that cortical area cannot be predicted.

The strong relationship between diaphyseal external dimensions and cross-sectional properties suggest that both types of data will provide similar interpretations in biomechanical investigations of long bones. Considering that the collection of cross-sectional data is both time consuming and expensive, many researchers may find it more practical to use external bone dimensions in studies of long bone structural variation.

Structural Variation Associated with Subsistence Strategy and Terrain

A recurrent theme in most biomechanical studies is that hunter-gatherers exhibit greater robusticity in their long bones, greater sexual dimorphism in diaphyseal shape, and an anteroposteriorly elongated femoral midshaft, especially in males. Ruff and colleagues have argued that this pattern of morphology suggests hunter-gatherers led a more active lifestyle, were more mobile, and engaged in significantly more sex-specific activities than farmers. They argue that the greater anteroposterior elongation of the femur midshaft indicates that hunter-gatherers, especially males, were involved in activities that caused plane-specific diaphyseal bending. That is, the activities of hunter-gatherers result in greater anteroposterior bending loads on their femora. Ruff (1987, 2000a) has argued that because hunter-gatherer males frequently had to travel long-distances during hunts, the greater mobility of hunter-gatherers is key to understanding the morphological differences between hunter-gatherers and agriculturalists.

If long bones architecture reflects the mechanical loads placed on it during daily activities, both the type of activity and the level of activity should play an important role. In order to test hypotheses regarding the affect of both activity level and mobility on diaphyseal morphology, each specimen was assigned a numeric score for activity level and mobility (Table 5.5) based on subsistence technology. While there is a stronger relationship between femoral morphology and mobility than between humeral morphology and mobility, the current study demonstrates that femoral shape and robusticity are not clearly associated with mobility in either males or females, as has been hypothesized by Ruff (2000a). Regression analysis shows that less than 15% of the total variation in femur size and shape variables is explained by level of mobility. Furthermore, post-hoc paired comparisons demonstrate that significant group differences do not correspond to mobility scores. Hunter-gatherer males do not appear to exhibit significantly greater anteroposterior elongation of the femoral midshaft than horticulturalists, agriculturalists, or modern industrialists. For example, the femur midshaft shape (FMS) mean is 1.12 for BSHG (very high mobility) and 1.11 for LMI (very low mobility). Male agriculturalists (low mobility) also have a mean FMS of 1.12. Interestingly, the mean anteroposterior dimension (APD) is identical in all three groups, but BSHG have a narrower mediolateral dimension. For males, femur midshaft robusticity (FMR and FMJstd) is greatest in CHG, followed by EHG, VHH, BSHG, EMI, LMI, AGR, and WDHG.

Both humeral and femoral size and shape variables show significant differences among activity level groups, but again regression analysis demonstrates that very little of

the total variation in the humerus or femur is explained by activity level. Nevertheless, there are significant differences between lower-level activity groups (very low and low) and higher-level activity groups (moderate and high). Furthermore, examination of paired comparisons show that femoral torsional strength increases significantly with increased levels of activity due to an increase in the diaphysis' mediolateral breadth.

Multivariate analysis by subsistence strategy provides the most interesting results. As can be seen in Figures 6.10 – 6.13, in multidimensional space, males tend to cluster by subsistence technology but females do not. Larsen et al. (1995) found similar results when comparing Stillwater Marsh, Georgia coast, and Pecos Pueblo samples. They observed that in males midshaft torsional strength closely parrellelled subsistence strategy, but in females torsional strength more clearly aligned with geographical region (physical terrain). The results of this study also suggest that females are more closely patterned with geographical region (Figures 6.21 and 6.22). However, while Larsen (1997) argues that the geographical patterning of femoral midshaft torsional strength in females is associated with the ruggedness of the terrain, the results in this study do not support this hypothesis. Females cluster nearly identically whether femoral or humeral dimensions are used (Figures 6.21 and 6.22), and there is probably no reason to believe that humeral shape would be greatly affected by terrain type.

Sex differences in long bone cross-sectional shape are generally greatest in hunter-gatherers, less in agriculturalists, and least in modern industrialists. A similar pattern of sexual dimorphism was found in the current study. Long bone length and articular surface measurements do not show any clear patterns in sexual dimorphism, but

broad-spectrum hunter-gatherers exhibit the greatest amount of femoral midshaft sexual dimorphism and LMI display the least amount. Of the hunter-gatherer groups used in this study, only the equestrian hunter-gatherers show lower levels of sexual dimorphism, which may be associated with their unique form of subsistence. Interestingly, the Texas Gulf coast hunter-gathers, which are drawn from missionary samples that also participated in farming and animal husbandry at the missions, show the greatest amount of sexual dimorphism in femur length, humeral length, and femur midshaft shape.

The opposite pattern of sexual dimorphism is seen in humeral midshaft shape. Agriculturalists and early modern industrialists exhibit the greatest amount of humeral midshaft sexual dimorphism (Figure 6.15). Both male and female hunter-gatherers tend to have relatively flat (greater difference between minimum and maximum values) humeral midshafts, while late modern industrialists generally exhibit round midshafts.

Ruff (1999, 2000a) has recently argued that the physical terrain in which a population subsists may have a greater effect on their lower limb bone robusticity than the type of subsistence technology they employ. Ruff (1999) found that populations from mountainous areas exhibit significantly greater femoral robusticity than groups from the Great Plains or coastal regions. Ruff (1999, 2000a) argues that terrain does not appear to have any effect on upper limb bone morphology, as would be expected. However, it is unclear if he tested the relationship between humerus strength and terrain. Ruff's (1999) Great Basin sample display significantly greater femoral midshaft robusticity than other American Indian groups, but he provided no data on humerus robusticity.

Larsen (1997:205), however, states that Stillwater adults exhibit extremely strong femora but relatively weak humeri, and that femoral midshaft robusticity especially corresponds to the "degree of ruggedness of terrain" in females. The results of this study do not support the strong relationship between geographical terrain and femur robusticity observed by Ruff (1999) and Larsen et al (1995). Regression analysis suggests that less than 3% of the variation in femoral size and shape variables are explained by terrain type. As with mobility and activity, groups were assigned numeric values from 0 (coastal plains) to 4 (mountainous) based on the location of the archaeological site. For females, femoral midshaft robusticity is greatest in groups from the Central and Southern Plains (terrain score = 2), followed by the Northern Plains (terrain score = 3), Texas Gulf coast (terrain score = 0), mountains (terrain score = 4), and prairie (terrain score = 1). Canonical plots show that females are generally patterned by geographical region, but since they pattern this way with both humerus and femur measurements, it suggests that the degree of terrain ruggedness is not the driving factor. Further study might show that residency patterns have more to do with the distribution of females in multidimensional space than either subsistence strategy or geographical terrain.

The present study demonstrates that humeral and femoral structural morphology are not clearly linked with either mobility or terrain, especially in females, when a diverse sample is examined. There does appear, however, to be a slight correlation between long bone structural morphology and the level of activity. Groups with high activity levels have significantly stronger bones than groups with lower activity levels.

Sexual dimorphism, on the other hand, does appear to be associated with subsistence strategy. Hunter-gather groups clearly exhibit greater sexual dimorphism than farming or modern industrial groups. However, the degree to which this can be explained by sexual division of labor remains to be tested.

Since there is a significant body of clinical research showing the relationship between bone modeling and biomechanical stress, the question as to why subsistence technology and terrain does not have a consistent effect on long bone morphology when examined over a wide geographical and temporal span must be addressed. Part of the problem may be derived from the difficulty of lumping groups into broad categories of subsistence economy. While the assignment of specimens to a particular subsistence strategy and terrain are based on archaeological and historical data, there is and probably always has been considerable variability in the degree of mobility and activity in any subsistence economy. Jurmain (1999) argues that it is impossible to assign levels of mobility and activity to the broad categories of subsistence strategy. Jurmain (1999) points out that Eskimos show evidence of extreme logistic mobility, while hunter-gatherers of Central California are semi-sedentary.

Bridges et al. (2000) argue that considerable regional variation in the activities associated with subsistence strategies is apparent in the archaeological record. They point out that while most researchers examining changes in long bone strength associated with the introduction of agriculture observe marked modifications in long bone morphology with the introduction of agriculture, the pattern of change is not consistent from one region to the next. On the Georgia coast, Ruff and Larsen (1990) found

significant decreases in humeral strength with the introduction of agriculture, but Bridges (1989) observed a significant increase in humeral strength with the introduction of agriculture in Alabama. More recently, Bridges et al. (2000) report that among horticulturalists in west-central Illinois, humeral strength increases at the very early stages of agriculture (Late Woodland) but then declines again in the Mississippian period. Bridges et al. (2000) suggest that there is considerable regional diversity in the activities associated with the introduction of agriculture.

In addition to the problems of having diverse activity patterns within subsistence groups, other factors such as genetics, climate, health, diet, individual's age, the age at which individuals begin a specific activity, and numerous other systemic and local factors all effect the shape and robusticity of the final adult skeleton. Unfortunately, these factors vary considerably from group to group and over time.

For example, Ohman and Lovejoy (2000) argue that adult bone morphology may be a constrained by developmental factors. In a study of African ape femora, Ohman and Lovejoy (20001) observed that while great apes place large anteroposterior loads on their femora, they show their maximum second moment of area (I_{max}) along the mediolateral plane. Ohman and Lovejoy (2000) hypothesize that shape of the growth plate places developmental constraints on the shape of the diaphysis, and since great apes have very mediolaterally broad proximal and distal epiphyses, they have mediolaterally expanded femoral midshafts.

Human data from this study appears to support the developmental constraint model proposed by Ohman and Lovejoy (2000), but results do not reach statistical

significance. In general, groups with wide femur epicondylar breadths (FEB) also exhibit extreme platymeria and round femoral midshafts due to mediolateral expansion. Contrary to this, groups with narrow epicondylar breadths have a relatively round subtrochanter and anteroposterior elongated femoral midshafts (Figure 7.1 and 7.2). However, females appear to follow this pattern better than males. This could be because males place a large enough mechanical load on their long bones to alter the genetic pattern, while females do not.

Structural Variation in the Great Plains

Two previous biomechanical studies of the femur have been conducted on Plains groups. Cole (1994) employed external measurements to examine structural changes associated with the transition from hunting and gathering to agriculture in the northern Plains. Ruff (1994), on the other hand, used femoral midshaft cross-sections to make comparisons among temporal periods, between Northern and Southern Plains groups, and between prehorse and posthorse Arikara. Ruff (1994) also compared cross-sectional properties of Plains groups to archaeological samples from the Georgia coast and Pecos Pueblo. The current study expands on both of these studies by utilizing a much larger database, employing femur subtrochanteric and humeral measurements, and including Archaic period broad-spectrum hunter-gatherers, central Plains horticulturalists and equestrian hunter-gatherers.

Similar to the current study, Cole (1994) found relatively little alteration in bone size or shape with changes within sex-specific groups and little to no change in sexual

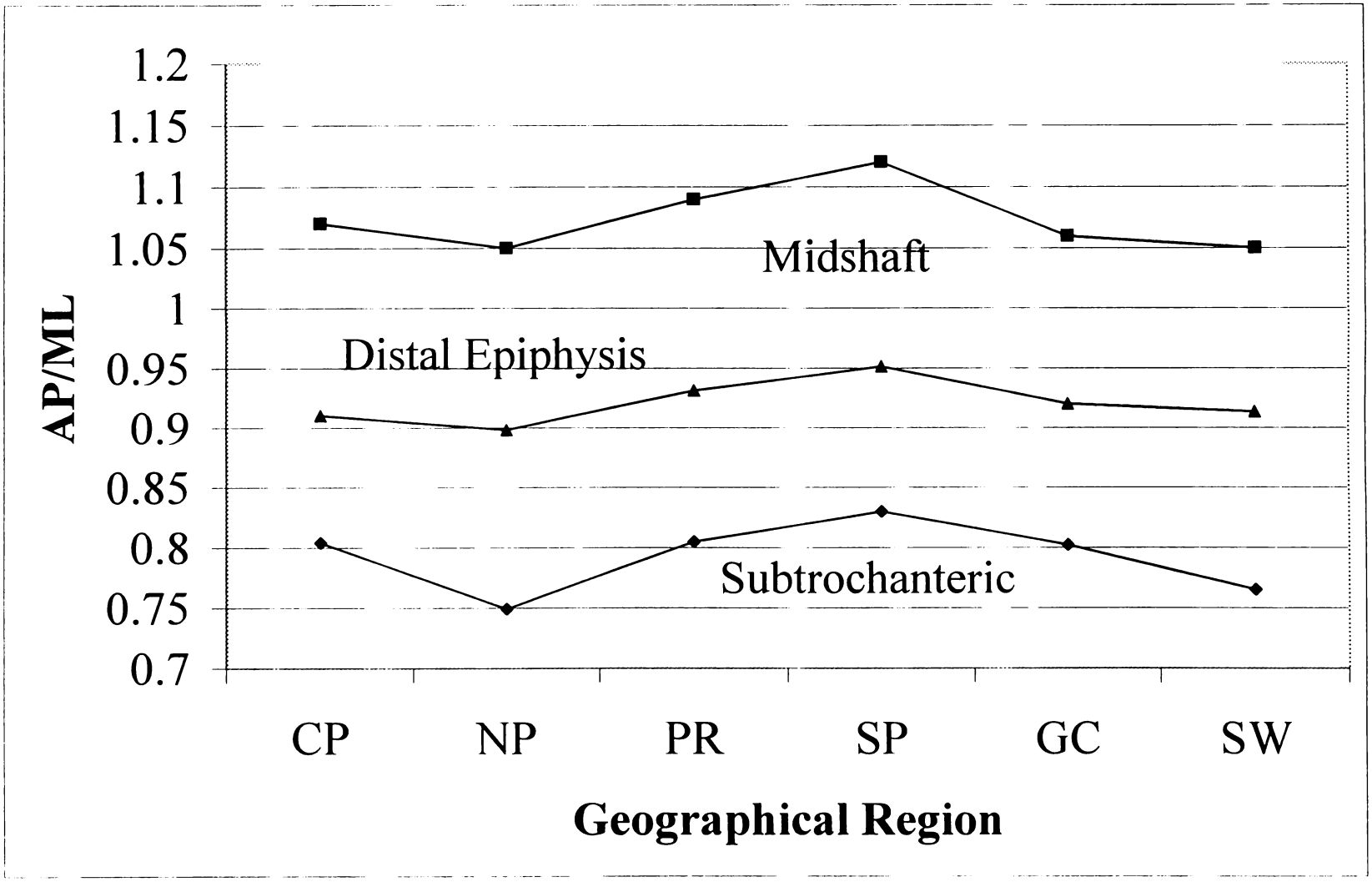


Figure 7.1. Relationship between femur subtrochanteric, midshaft, and distal epiphysis shape in females.

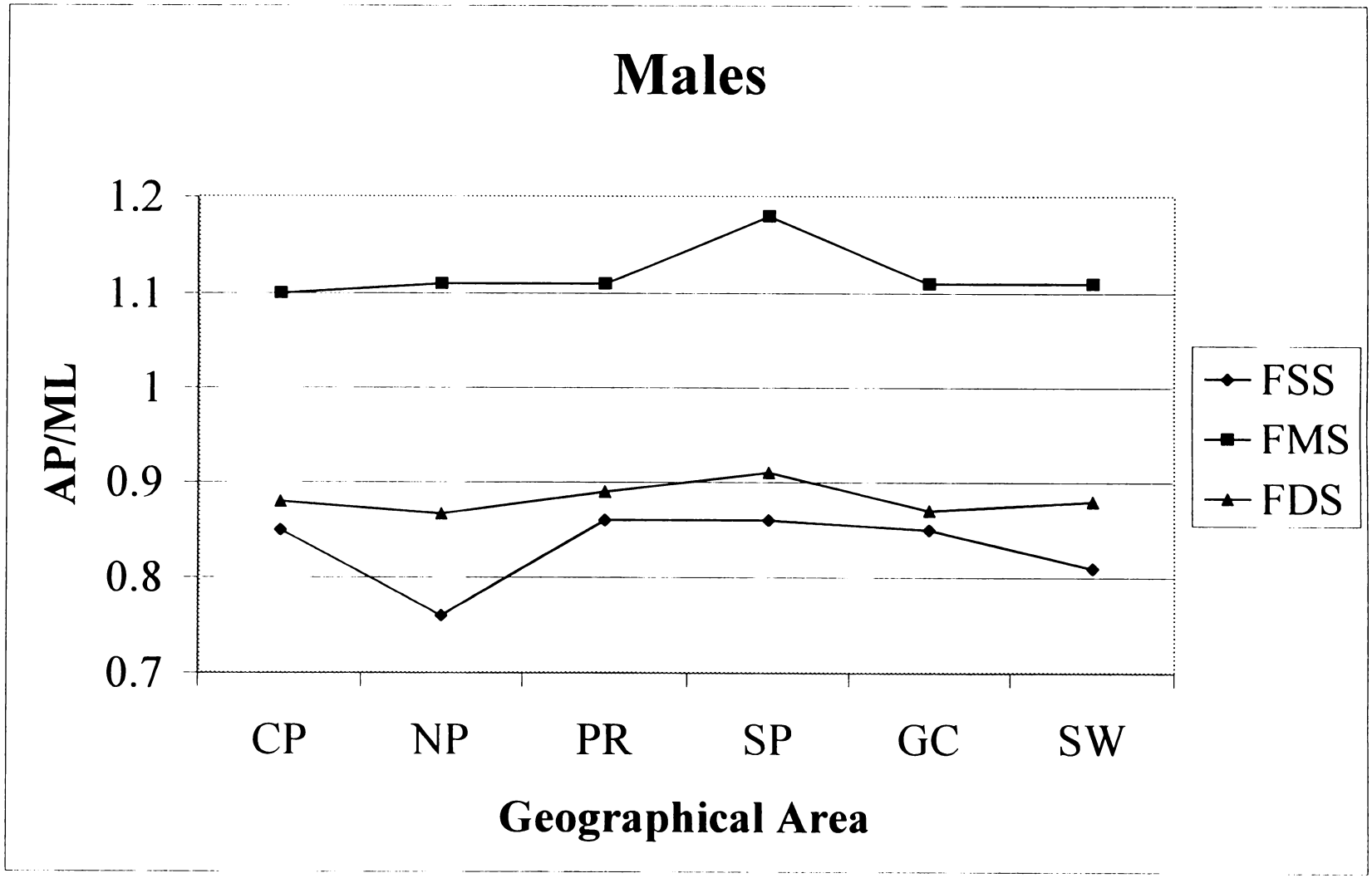


Figure 7.2. Relationship between femur subtrochanteric, midshaft, and distal epiphysis shape in males.

dimorphism with changes in subsistence on the Plains. Contrary to other geographical regions, the transition from hunting and gathering to agriculture in the Plains appears to be associated with an increase, although not a significant increase, in femoral midshaft robusticity and anteroposterior bending stress among males. Male village horticulturalists exhibit significantly more robusticity at the femoral midshaft and a slightly greater APD/MLD ratio. While different from other geographical regions, the increase in femoral robusticity is not surprising. The Arikara and other Plains horticulturalists are known to have traveled over long distances twice a year in pursuit of bison, and as Cole (1994) points out, VHH may have actually been more mobile than Woodland hunter-gatherers. In addition, Lehmer and Wood (1977) argue that Plain Villagers were more like the mixed horticultural and pastoral societies of the Old World than they are like other Native American groups.

On average, Woodland males have larger and more robust humeri than village horticulturalists, but statistical significance between these two groups was only reached for proximal epiphyseal breadth. Comparison between Woodland and VHH females shows no significant differences in size or shape of the femur or humerus. Again, this may not be too surprising since females do not appear to be as greatly affected by subsistence strategy as males.

The most notable finding in Ruff's (1994) study was a marked difference in femoral midshaft shape between northern and southern Plains groups. However, Ruff's (1994) Southern Plains only consisted of 5 males and 13 females. With a greatly increased sample size and the inclusion of subtrochanter measurements the differences

between Northern and Southern Plains femora is even more apparent. Southern Plains groups of both sexes are relatively gracile and round at the femoral subtrochanter but exhibit a very anteroposterior elongated femoral midshaft. Northern Plains, on the other hand, exhibit extreme platymeria but have relatively round femoral midshafts. Northern Plains groups also flaunt a relatively short and gracile humerus, while the Southern Plains groups have long and robust humeri.

In his comparison of pre- and post-horse Arikara, Ruff (1994) observed only a nonsignificant increase in femoral midshaft circularity. However, Ruff predicted that increased horse riding might lead to increased mediolateral bending stress and therefore a decline in the Ix/Iy ratio. Interestingly, the Sioux, Crow, Cheyenne, and other equestrians groups exhibit this pattern and stand out as unique among subsistence groups on the Plains. Equestrian hunter-gatherers have significantly larger and more robust long bones and a slightly more circular femoral midshaft and subtrochanter shape. In addition, the equestrian hunter-gatherers are also much less sexually dimorphic than other hunter-gatherer groups.

Compared to populations from the Georgia coast and Pecos Pueblo, New Mexico, Ruff (1994) found the Plains horticulturalists to be similar in robusticity to preagricultural groups than to agricultural populations, a conclusion also reached in this study. In general, the Plains horticulturalists are relatively robust for farmers. Of course, this is not surprising since they were also active hunters.

Conclusions

The current study had three primary objectives. The first objective was to investigate the relationship between cross-sectional properties and external dimensions of the diaphysis. The second objective was to examine the general effects of subsistence strategy and terrain on femoral and humeral structural variation, while the third objective was to investigate the range and pattern of long bone shape variation in prehistoric, protohistoric, and historic populations from the American Great Plains. Results suggest that many of the long bone cross-sectional properties can be reliably predicted using external dimensions alone. Only cortical area cannot be predicted. In addition, long bone size and shape is probably a reflection of multiple determinants, including biomechanical load, genetics, diet, and health factors. Within a tightly controlled geographical region, patterns of behavior can probably be reliably interpreted from long bone structural morphology, but variation in mobility within subsistence groups, cultural practices, diet, health and other factors probably preclude the broad generalizations about the type of activity based on long bone morphology. It does appear, however, that the level of activity might be predictable from long bone architecture.

Within the Great Plains, long bone size and shape is relatively homogeneous, but significant differences do exist between equestrian groups and non-equestrian groups. Unlike many other geographical regions, Plains hunter-gatherers do not appear to place greater anteroposterior bending stress on their femora than farmers. On the contrary, Plains horticulturalists generally have larger and stronger humeri and femora than earlier hunter-gatherers.

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APPENDICIES

APPENDIX A

UT/SI POSTCRANIAL DATA BASE MEASUREME NTS

Table A1. Postcranial measurements in UT / SI database.

#	*Measurement*	*Abbreviation*
1	Clavicle maximum length	CML
2	Clavicle anteroposterior diameter at midshaft	CSD
3	Clavicle superoinferior diameter at midshaft	CVD
4	Scapula maximum height	SML
5	Scapula maximum breadth	SMB
6	Scapula spine length	SLS
7	Scapula supraspinous length	SSL
8	Scapula infraspinous length	LSL
9	Scapula glenoid cavity breadth	GCB
10	Scapula glenoid cavity height	GCH
11	Scapula glenoid to inferior angle	GIL
12	Manubrium length	MML
13	Mesosternum length	MSL
14	Stenebra 1 width	S1W
15	Stenebra 3 width	S3W
16	Humerus maximum length	HML
17	Humerus proximal epiphysis breadth	BUE
18	Humerus maximum diameter at midshaft	MDS
19	Humerus minimum diameter at midshaft	MDM
20	Humerus max vertical diameter of head	MDH
21	Humerus epicondylar breadth	EBR
22	Humerus least circumference of shaft	LCS
23	Radius maximum length	RML
24	Radius maximum diameter of head	RDH
25	Radius anteroposterior diameter of shaft	RSD
26	Radius mediolateral diameter of shaft	RTD
27	Radius neck shaft circumference	MCS
28	Ulna maximum length	UML
29	Ulna physiological length	UPL
30	Ulna maximum breadth of olecranon	BOP
31	Ulna minimum breadth of olecranon	MBO
32	Ulna maximum width of olecranon	WOP
33	Ulna olecranon-radial notch length	ORL
34	Ulna olecranon-coronoid length	OCL
35	Ulna anteroposterior diameter at maximum crest	UAD

Table A1. Continued

#	*Measurement*	*Abbreviation*
36	Ulna mediolateral diameter at maximum crest	UMD
37	Ulna least circumference of shaft	ULC
38	Sacrum anterior length	SAL
39	Sacrum anterosuperior breadth	SAB
40	Sacrum maximum breadth at S1	SXB
41	Innominate height	INH
42	Iliac breadth	ILB
43	Pubic length	PUL
44	Ischium length	ICL
45	Femur maximum length	FML
46	Femur bicondylar length	FOL
47	Femur trochanteric length	FTL
48	Femur subtrochanteric anteroposterior diameter	APD
49	Femur subtrochanteric mediolateral diameter	MLD
50	Femur anteroposterior diameter at midshaft	APS
51	Femur mediolateral diameter at midshaft	MLS
52	Femur maximum vertical diameter of head	VHD
53	Femur maximum horizontal diameter of head	HHD
54	Femur anteroposterior diameter of lateral condyle	APL
55	Femur anteroposterior diameter of medial condyle	APM
56	Femur epicondylar breadth	FEB
57	Femur bicondylar breadth	BCB
58	Femur minimum vertical diameter of neck	VDN
59	Femur circumference at midshaft	FCS
60	Tibia condylo-malleolar length	TML
61	Tibia maximum breadth of proximal epiphysis	BPE
62	Tibia maximum breadth of distal epiphysis	BDE
63	Tibia anteroposterior diameter at nutrient foramen	APN
64	Tibia mediolateral diameter at nutrient foramen	MLM
65	Tibia position of nutrient foramen	CFL
66	Tibia circumference at nutrient foramen	TCN
67	Fibula maximum length	BML
68	Fibula maximum diameter at midshaft	FMD
69	Calcaneous maximum length	CLL
70	Calcaneous middle breadth	CMB

APPENDIX B

SITE DATA

Table B.1. Sites with external dimensional data.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
Arizona						
	Awatovi	SW	HOP	HIST	AD1680	AGR
Idaho						
10AM193	Demoss	NW	NWAR	AR		BSHG
10OE128	Larson	NW				
10WN117	Braden	NW	NWAR	AR		BSHG
Iowa						
13AM43	Flynn Burial	PR	ON	ON		VHH
13AM59	Elephant Terrace	PR				
13AM103	Hartley Fort	PR	PRLW	WD		IH
13AM105	Hill Mound Group	PR	PRLW	WD		IH
13CT166	Frenchtown Mound Group	PR	PRMW	WD		WDHG
13JK11	Deppe Mound Group	PR	PRWD	WD		WDHG
13LO2	Blood Run Mound	PR	ON	ON	AD1725	VHH
13PK38	West Des Moines Burial	PR	PRLW	WD	AD1030	IH
13PM1	Broken Kettle	PR	IMM	MM	AD1063	VHH
13PM4	Kimball Mounds	PR	IMM	MM	AD1063	VHH
13WD6	Correctionville	PR	ON	ON		VHH
Kansas						
	Dinsmore Mound	CP	NEB?	CP		VHH
14DP2	Doniphan	CP	KAN	HIST	AD1724	VHH
14PH4	Woodruff	CP	PMW	WD	AD 634	WDHG
14SA1	Whiteford	CP	SHL	CP	AD1100	VHH
14SC2	Young	CP	PAR	AR		BSHG
14WY7	Calovich	CP	STDK	CP	AD1125	VHH
Louisiana						
16OR95	St. Louis II		WHT	HIST		EMI
Maine						
17HAN421		EW		AR		BSHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
Maryland						
18AG119	Cresaptown	EW	EWAR	WD	AD1447	IH
18CA89			WHT	HIST		EMI
18CE141	Keith's House		WHT	HIST		EMI
18CH79	Chapel Point		BLK	HIST		EMI
18FR14	Briggs Ford	EW	EWLW	WD		IH
18FR17	Nolan's Ferry	EW	EWLW	WD		IH
	Hogan		BLK	HIST		EMI
18QU20	Crouse Mill		BLK	HIST		EMI
18QU28	Bennett's Point		BLK	HIST	AD1700	EMI
18WC70	Twin Oaks		BLK	HIST		EMI
	Duvall		WHT	HIST		EMI
Minnesota						
21TO1	Sauk Valley	PR	PRAR	AR	4270BC	BSHG
21TR5	Brown's Valley	PR	PA	PA	7099BC	BSHG
Missouri						
23SL733	Second Catholic Graveyard		BLK	HIST	AD1837	EMI
23SL733	Second Catholic Graveyard		WHT	HIST	AD1837	EMI
23SL733	Second Catholic Graveyard		?	HIST	AD1837	EMI
Montana						
24LN9001	Gateway	NP				
Nebraska						
25AP29	Oakdale Burial	CP				
25AP32		CP	PON		AD1750	VHH
25BF26		CP				
25BF179		CP	PMW	WD	AD 100	WDHG
25BF229		CP	PMW	WD	AD 100	WDHG
25BO8		CP	PAR	AR		BSHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
25BU1	Linwood	CP	PAW	CO	AD1793	VHH
25BU2	Bellwood	CP	PAW	CO	AD1793	VHH
25BU4	Barcal	CP	PAW	CO	AD1725	VHH
25BU35	T.Davis?	CP		HIST		VHH
25CC1	Ashland	CP	NEB	CP	AD1187	VHH
25CC29	Kunkle Ossuary	CP				
25CC131	King Hill	CP	OTO?	CO	AD1825	VHH
25CD21	Burney	CP	PLW	WD	AD 800	BSHG
25CN55		CP	PAR	AR	1960BC	BSHG
25CX1	Gray	CP	PAW	CO	AD1675	VHH
25DD11	Scribner	CP	PAR	AR		BSHG
25DK2A	Ryan	CP	OMA	HIST	AD1797	VHH
25DK10	Large Village	CP	OMA	HIST	AD1810	VHH
25DO4	Havlicek Farm	CP	NEB	CP	AD1225	VHH
25DO9002	DKD	CP	PAR	AR	1820BC	BSHG
25DW211		CP	SIU	HIST	AD1870	EHG
25FN22	Wilsonville	CP	PMW	WD		WDHG
25FR9	Schnuerle	CP	PMW	WD		WDHG
25FR9001		CP				
25FT13	Medicine Creek	CP	URP	CP	AD1023	VHH
25FT16	Aiken	CP	URP	CP	AD1020	VHH
25HK16	Swanson Reservoir	CP		AR		BSHG
25HL2	Cairo Burial	CP		HIST	AD1870	VHH
25HM2	Burial Ridge	CP	PAW	HIST	AD1822	VHH
25HN2	Stevenson	CP	URP	CP	AD1200	VHH
25HW2	Lehn	CP	ITSK	CP	AD1350	VHH
25HW3	Sondergaard	CP	ITSK	CP	AD1350	VHH
25HW5	Gyderson	CP	ITSK	CP	AD1350	VHH
25HW8	Christensen	CP	ITSK	CP	AD1350	VHH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
25JF4	Washington	CP	SHL	CP	AD1175	VHH
25KN4			WHT	HIST		EMI
25KX1	Ponca Fort	CP	PON	HIST	AD1785	VHH
25MK14		CP	PAW	HIST	AD1820	VHH
25MP2	Huffman / Dry Lake	CP	PAR	AR	AD 150	BSHG
25NC1	Burkett	CP	PAW	CO	AD1630	VHH
25NC3	Wright	CP	PAW	CO	AD1680	VHH
25NC7	Fullerton Burial	CP	PAW	HIST	AD1845	VHH
25NC11	Vogel	CP	ITSK	CP	AD1250	VHH
25NC13	Wozney	CP	ITSK	CP	AD1250	VHH
25NC20	Genoa	CP	PAW	HIST	AD1865	VHH
25NC23	Swantek	CP	PAW	CO	AD1820	VHH
25NH4	Whitten	CP	PLW	WD	AD 850	IH
25PK1	Clarks	CP	PAW	CO	AD1832	VHH
25PT9	Feye	CP	ITSK	CP		VHH
25PT13	Hill-Rupp	CP	PAW	CP	AD1675	VHH
25PT30	Gillett	CP				
25PT31	Christman	CP	PAW	HIST	AD1675	VHH
25RH1	Leary	CP	ON	ON	AD1300	VHH
25RW2	Red Willow / Indianola	CP	PAR	AR		BSHG
25SD31	Woodcliff Burials	CP	PAW	HIST	AD1854	VHH
25SF10	Gering	CP	PAR	AR	50BC	BSHG
25SF9002		CP				
25ST12	Stanton Burial	CP				
25SX25		CP	PAR	AR		BSHG
25SY8	Wescott	CP	PLW	WD		IH
25SY11	Sieh	CP	NEB	CP	AD1187	VHH
25SY16	Fish Hatchery	CP	PAR	AR		BSHG
25SY67	Wallace Mound	CP	NEB	CP		VHH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
25SY114??		CP				
25VY3	Schultz Burial	CP	PMW	WD		WDHG
25WH2	Olson		WHT	HIST		EMI
25WH3	Kelly Ossuary	CP	NEB	CP	AD1225	VHH
25WN6	O'Hanlon	CP	NEB	CP	AD1187	VHH
25WT1	Pike Village	CP	PAW	HIST	AD1795	VHH
	Camp Sheridan	CP	SIU	HIST	AD1878	EHG
	Old Red Cloud Agency	CP	SIU	HIST	AD1878	EHG
	Ft. Robinson	CP	SIU	HIST	AD1880	EHG
Nevada						
26CH1E	Fish Cave	GB			557BC	BSHG
26CH1F	Spirit Cave	GB	PA	PA	7465BC	BSHG
26CH180	Jessup, White Plains	GB			90BC	BSHG
26CH224		GB				BSHG
26CH1065		GB				BSHG
26CH1069		GB				BSHG
26CH1159		GB			315BC	BSHG
26CH?	L72	GB			AD1130	BSHG
26DO300		GB				BSHG
26LA2681			WHT	HIST		EMI
26PE3A	Crypt Cave	GB	GBAR	AR	2400BC	BSHG
26PE3B	Chimney Cave	GB				BSHG
26PE3B	Chimney Cave	GB	GBAR	AR	1200BC	BSHG
26PE3B	Chimney Cave	GB	GBAR	AR	583BC	BSHG
26PE3E	Fishbone Cave	GB	PA	PA	6065BC	BSHG
26PE10	Brinkerhoff Ranch	GB		HIST	AD1760	BSHG
26WA291	Disiccation Cave	GB			AD 0	BSHG
	4-2145A	GB				
	4-759	GB	PAI	HIST		BSHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
6-2029		GB	WAS	HIST		BSHG
6-2061		GB		HIST		BSHG
6-822		GB				BSHG
6-916		GB	WAS		30 BC	BSHG
6-2144		GB				BSHG
7-2047		GB	PAI	HIST		BSHG
7-2067		GB				BSHG
7-755		GB				BSHG
7-839		GB				BSHG
8-910		GB		HIST	AD1640	BSHG
9A-129394		GB				BSHG
9A-129395		GB				BSHG
9A-2007	Pyrimid Lake Delta	GB			AD 590	BSHG
9A-2011	Pancho House Area	GB			AD 430	BSHG
9A-2022	Needles Area	GB			3955BC	BSHG
9A-2023	Wizard's Beach	GB	PA	PA	7275BC	BSHG
9A-2087	Cowbone Cave	GB	GNAR	AR	4020BC	BSHG
9A-2100		GB				BSHG
9A-830	Marble Bluff Dam	GB	GBAR	AR	985 BC	BSHG
9A-847		GB				BSHG
9A-862	Pyrimid Lake	GB			AD 130	BSHG
9A-871		GB	GBAR	AR	485 BC	BSHG
9A-912		GB				BSHG
9A-920		GB				BSHG
9A-129396		GB				BSHG
9B-2016		GB	GBAR	AR	1775BC	BSHG
9C-2266		GB	PAI	HIST		BSHG
9C-1215		GB		HIST	AD1710	BSHG
9C-1216		GB				BSHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
	9C-1217	GB			AD 640	BSHG
	9C-1221	GB			AD 930	BSHG
	9C-1235	GB	SHO	HIST		BSHG
	9C-1268	GB			10 BC	BSHG
	9C-2100	GB				BSHG
	9C-122617	GB				BSHG
	9C-122618	GB				BSHG
	9C-128252	GB				BSHG
	9C-129368	GB				BSHG
	9C-129369	GB				BSHG
	9C-129370	GB				BSHG
	9F-1268	GB			10 BC	BSHG
	9F-1783	GB				BSHG
	9F-2019	GB				BSHG
	9F-2020	GB				BSHG
	9F-2071A	GB				BSHG
	9F-2071B	GB				BSHG
	9F-2109	GB	SHO	HIST		BSHG
	9F-NSM-300	GB				BSHG
	9F-NSM-301	GB				BSHG
	9F-NSM-735	GB			AD1120	BSHG
	9F-NSM-747	GB				BSHG
	9F-NSM-843	GB			AD1240	BSHG
New Mexico						
	Pecos Pueblo	SW	PB	HIST		AGR
	Pecos Pueblo		WHT	HIST		EMI
	Gran Quivira	SW	PB	PB		AGR

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
North Dakota						
32BL8	Double Ditch	NP	MAN	CO	AD1736	VHH
32BL9	Larson	NP	MAN	CO	AD1637	VHH
32EM1	Havens	NP	EMM	MM	AD1217	VHH
32EM28		NP				
32ML2	Like A Fishhook	NP	ARK	CO	AD1840	VHH
32MO11	Huff	NP	MAN	MM	AD1610	VHH
32MO29	Motsiff	NP	MAN	CO	AD1698	VHH
32MO141		NP				
32OL17	Greenshield	NP	ARK	HIST	AD1815	VHH
32SI1	Boundry Mound	NP	PMW	WD	AD 610	WDHG
32SI200	Alkire Mound	NP	PMW	WD	AD 610	WDHG
32SN8	Krop Mound	NP	ARK	CO		VHH
32SN31	Jamestown Dam Area	NP				
32WI17	Fort Union Iches??	NP		HIST	AD1883	VHH
	Benson	NP				
	Sanger	NP				
Oklahoma						
34BK1	Sandstone Creek #1	SP		LP		VHH
34BK6	Fowler	SP		LP		VHH
34CL210		SP	SHAW	HIST		AGR
34CM131	Gore Pit	SP	PAR	AR	4672BC	BSHG
34CM221	Cared	SP		HIST		VHH
34CM324	Jenkins Pit	SP	PAR	AR		BSHG
34CT17	Henry	SP		LP		VHH
34CU11	Phillips	SP	RBP	LP	AD 950	VHH
34CU25	Mouse 1	SP	RBP	LP	AD 950	VHH
34CU27	Heerwald	SP	RBP	LP	AD1300	VHH
34GD24	Jones	SP	RBP	LP	AD1350	VHH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
34GD78	Horn	SP	RBP	LP	AD1350	VHH
34GD95		SP	RBP	LP	AD1350	VHH
34GR4	Rattlesnake Slough	SP		LP		VHH
34GR5		SP	PLW	WD	AD1150	IH
34GR6		SP		LP		VHH
34GV2	Grant	SP	RBP	LP	AD1350	VHH
34JF1	Longest	SP	WIC	HIST	AD1750	VHH
34KI2	Lone Wolf	SP		LP		VHH
34KI3		SP		LP		VHH
34MA2	Buncombe Creek	SP	PAR	AR	525BC	BSHG
34MA23	Wheeler	SP		HIST		
34OK4	Nagle	SP	CAD	LP	AD1200	AGR
34OS97	Craddock Shelter	SP				
34PT29	Trice	SP	SHAW	HIST		AGR
34RM29	Wickham # 3	SP	CAD	LP	AD1345	
34RM400	New Smith	SP	CAD	LP	AD1345	
34RM668	Sullivan-Carpenter	SP	PEW	WD	AD 350	WDHG
34WA5	McLemore	SP	RBP	LP	AD1300	VHH
34WD47		SP				
Oregon						
35SJ9001		NW				
	Prospect	NW	NWAR	EA	5050BC	BSHG
Pennsylvania						
36AD176			WHT	HIST		EMI
South Dakota						
39BF2A	Medicine Crow	NP	ARK	CO		VHH
39BF11	Crow Creek	NP	IC	CO	AD1325	VHH
39BF?	Fort Thompson Area	NP	SIU	HIST		EHG
39BN124		NP	PWD	WD		WDHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
39CA4	Rygh	NP	EC	CO	AD1625	VHH
39CA102		NP	EC	CO	AD1625	VHH
39CH7	Oldham	NP	PLW	WD	AD 850	IH
39CH54	Platte-Winner Ridge	NP	PLW	WD	AD1030	IH
39CL2	Ufford Mounds	NP	PLW	WD	AD1030	IH
39CO9	Leavenworth	NP	ARK	HIST	AD1817	VHH
39CO11	Ashley Island	NP	ARK	HIST	AD1807	VHH
39CO31	Norvold 1	NP	ARK	CO	AD1727	VHH
39CO32/3	Norvold 2&3 (Oak Creek Village)	NP	ARK	CO	AD1727	VHH
39CO32/3	Norvold 2&3 (Oak Creek Village)	NP	EC	CO	AD1612	VHH
39DA3	Enemy Swim Lake	NP	PWD	WD		WDHG
39DV1-2	Mitchell Mound	NP	IMM	MM	AD1069	VHH
39DW2	Four Bear	NP	ARK	CO	AD1766	VHH
39DW252	Arpan	NP	PMW	WD	AD 100	WDHG
39GR1	Scalp Creek	NP	PLW	WD	AD 775	IH
39HS1	Bloom Creek	NP	IMM	MM	AD1150	VHH
39HT1	Twelve Mile Creek	NP	IMM	MM	AD1088	VHH
39HT2	Hofer Mound	NP	PLW	WD	AD 775	IH
39HU1	Thomas Riggs	NP	EMM	MM	AD1451	VHH
39HU2	Oahe Village	NP	ARK	CO	AD1727	VHH
39HU6	Arzberger	NP	IC	CO	AD1450	VHH
39LK2	Madison Pass Mounds	NP	PLW	WD		IH
39LM2A	Medicine Creek	NP	IMM	MM	AD1150	VHH
39LM26	Oacoma	NP	ARK	CO	AD1725	VHH
39LM33	Dinehart's Village	NP	IMM	MM	AD1150	VHH
39LN10	Newton Hills	NP	PWD	WD		WDHG
39MC1	Montrose Mound	NP				
39MD9001		NP		HIST		VHH
39MH1	Brandon	NP	IMM	MM	AD1100	VHH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
39MH6	Split Rock Creek Mounds	NP	PLW	WD		IH
39PO7	Hosterman	NP	EC	CO	AD1612	VHH
39RO2	Madsen Mound	NP	PLW	WD	AD 700	IH
39RO4	Hartford Beach Mound	NP	PLW	WD	AD 700	IH
39RO7	Hunter's Mound	NP	PLW	WD		IH
39RO10	Daughtery Mounds	NP	PLW	WD	AD 700	IH
39RO9001		NP		HIST		VHH
39SL2	Fairbanks Village	NP	EC	CO	AD1662	VHH
39SL4A	Sully A	NP	EC	CO	AD1662	VHH
39SL4D	Sully D	NP	EC	CO	AD1662	VHH
39SL4E	Sully E	NP	ARK	CO	AD1687	VHH
39SL29	CB Smith	NP	EMM	MM	AD1325	VHH
39ST1	Cheyenne River	NP	ARK	CO	AD1767	VHH
39ST15	Indian Creek	NP	ARK	CO	AD1707	VHH
39ST16	Breeden	NP	IMM	MM	AD1030	VHH
39ST203	Black Widow Ridge	NP	EMM	MM	AD1325	VHH
39ST215	Leavitt	NP	ARK	CO	AD1766	VHH
39ST216	Buffalo Pasture	NP	ARK	CO	AD1778	VHH
39ST224	Cattle Oiler	NP	IMM	MM	AD1032	VHH
39ST235	Stony Point Village	NP	ARK	CO	AD1767	VHH
39UN1	Arbor Hill	NP	PLW	WD	AD 850	IH
39WW1A	Mobridge A	NP	EC	CO	AD1624	VHH
39WW1B	Mobridge B	NP	ARK	CO	AD1687	VHH
39WW1B	Mobridge B	NP	EC	CO	AD	VHH
39WW2	Larson	NP	ARK	CO	AD1706	VHH
39WW3	Spiry Eklo	NP	ARK	CO	AD1706	VHH
39WW7	Swan Creek	NP	ARK	CO	AD1700	VHH
39WW203	Walth Bay	NP	EC	CO	AD1450	VHH
39WW303	White Tail	NP	EC	CO	AD1612	VHH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
39YK1	Yankton Mounds	NP	PMW	WD		WDHG
Texas						
41AD2	Salt Cedar	GC		LP		VHH
41AD180		GC				
41BI?	Taylor Ranch Burial (A1063)	GC	PAR	AR		BSHG
41BW3	Hatchel	GC	CAD	LP		AGR
41BW4	Paul Mitchell	GC	CAD	LP		AGR
41BX5	Mission San Juan Capistrano	GC	COA	HIST	AD1772	CHG
41BX5	Mission San Juan Capistrano		WHT	HIST	AD1772	EMI
41CI9001		SP				
41CI?	(W19)	SP				
41CS10	Fannie Snipel	GC	CAD	HIST		AGR
41CS14	Knight's Bluff	GC	CAD	LP	AD1400	AGR
41DF?	(A156)	SP				
41DS14		SP				
41DY?	(A616)	SP		LP		VHH
41DY?	(A714)	SP				
41FL45	Bruce McFall Burial	SP	COM	HIST		EHG
41FL?	(W06)	SP				
41FS1	W.H. Watson	SP	COM	HIST		EHG
41HC23	Antelope Creek 22	SP	UC	LP	AD1350	VHH
41HC24	Antelope Creek 22A	SP	UC	LP	AD1350	VHH
41HC?	(A61)	SP				
41HC?	(A473)	SP		LP		VHH
41HC?	(A490)	SP		LP		VHH
41HC?	(A546)	SP				
41HC?	(A588)	SP		LP		VHH
41HC?	(A765)	SP				
41HH9001		SP				

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
41HH?	(A1184)	SP				
41HL?	(A568)	SP				
41HQ120		SP				
41LR2	T.M. Sanders	SP	CAD	LP	AD1300	AGR
41LU113	Ampitheater	SP				
41MH112		SP				
41MO184		SP				
	A2121	SP				
41MO?	(A175)	SP	CAD	LP		AGR
41OC27	Courson B	SP	UC	LP	AD1250	VHH
41OL9001		SP				
41OL?	Gun Sight Shelter (A1203)	SP	PAR	AR		BSHG
41OL?	Tasocsa Creek (A2060)	SP	PWD	WD		WDHG
41OL?	(A481)	SP				
41OL?	(A533)	SP	PWD	WD		WDHG
41PT11	Alibates Ruin 28	SP	UC	LP	AD1350	VHH
41RB106	Dykema Canyon Burial	SP	PWD	WD		WDHG
41RB9001		SP				
41RD?	(A227)	SP				
41RD?	(A180)	SP		LP		VHH
41RE1	Mission San Lorenzo	GC	APA	HIST		EHG
41RF1	Refugio	GC	KAR	HIST	AD1814	CHG
41RR16	Kaufman-Williams	GC	CAD	HIST	AD1720	AGR
41RR16	Kaufman-Williams	GC	CAD	LP	AD1625	AGR
41SA89	41-42D5-9	SP	CAD	LP		AGR
41SW23	Deadman's Shelter	SP	PMW	WD	AD 165	WDHG
Utah						
42BO73		GB	FRE	FRE	AD 926	IH
42BO98		GB	FRE	FRE	AD 595	IH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
42BO579		GB	FRE	FRE	AD 427	IH
42BO599		GB	FRE	FRE	AD1062	IH
42CB561		SW	FRE	FRE		IH
42CB9005		SW				IH
42DC55		SW	FRE	FRE		IH
42DM9001		GB				
43EM3		SW	FRE	FRE		IH
42EM9001		SW	FRE	FRE		IH
42GA540		SW	PAI	HIST		BSHG
42GR314	Turner Look	SW	FRE	FRE		IH
42KA2574		SW	ANA	BMK		IH
42MD9001		GB				
42RI13		GB				
42SA2096		SW	ANA	PB		AGR
42SA3786		SW				
42SA681		SW	ANA	PB		AGR
42SA8875		SW	ANA	PB		AGR
42SA8880		SW	ANA	PB		AGR
42SA9002		SW	ANA	PB		AGR
42SL1		GB	FRE	FRE		IH
42SL8		GB	GBAR	AR		BSHG
42SL197		GB	FRE	FRE	AD 684	IH
42SL9001		GB				
42SV5		GB	FRE	FRE		IH
42SV211		GB	FRE	FRE		IH
42SV633	Nawthis Village	GB	FRE	FRE		IH
42SV662	Backhoe Village	GB	FRE	FRE		IH
42SV2175		GB	FRE	FRE		IH
42SV9001		GB	FRE	FRE		IH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
42TO?		GB	FRE	FRE		IH
42UN95	Caldwell Village	SW	FRE	FRE		IH
42UT111		GB	FRE	FRE		IH
42UT225		GB	UTE	HIST		BSHG
42UT808		GB	GBAR	AR		BSHG
42WB34		GB	FRE	FRE	AD1550	IH
42WB48		GB	FRE	FRE	AD1077	IH
42WB57		GB	FRE	FRE		IH
42WB269		GB	FRE	FRE	AD 899	IH
42WB269		GB	FRE	FRE	AD1017	IH
42WB269		GB	FRE	FRE	AD1148	IH
42WB286		GB	FRE	FRE	AD1148	IH
42WB324		GB	FRE	FRE	AD 776	IH
42WB324		GB	FRE	FRE	AD1021	IH
42WB324		GB	FRE	FRE	AD1081	IH
42WB324		GB	FRE	FRE	AD1093	IH
42WB324		GB	FRE	FRE	AD 776	IH
Virginia						
44AX132		EW				
44GL394	County Landfill		BLK	HIST	AD1830	EMI
44GL394	County Landfill		WHT	HIST	AD1830	EMI
44HE778		EW				
44WB3			BLK	HIST		EMI
44WB3			BLK	HIST		EMI
Wyoming						
	Riverton	NP				
48AB6	City Springs	NP				
48AB7	Flag Ranch	NP				
48AB571	Benick Ranch	NP	PLW	WD	AD 450	IH

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
48CO15	Douglas	NP				
48CO1829	Nunn	NP				
48FR63	Boysen 1	NP				
48GO7	Huntley	NP				
48GO54	Korell-Bordeaux	NP		HIST	AD1845	EHG
48GO54	Korell-Bordeaux	NP	WHT	HIST	AD1845	EMI
48GO9002	Spring Canyon	NP				
48GO9004	Dicken	NP	PLW	WD	AD 380	WDHG
48JO46		NP				
48NA67	Dunlap-McMurry	NP	PAR	AR	AD3350	BSHG
48PA42	Pitchfork	NP	CRW	HIST	AD1810	EHG
48PA9002	Mount Peak	NP				
48PL56	Glendo	NP	WHT	HIST		EMI
48UT920	Bridger Gap	NP		HIST		EHG
Miscellaneous						
	Snake Hill		WHT	HIST	AD1814	EMI
		NP	BFT	HIST		EHG
		SW	ANA	BMK		IH
			EAN	HIST		EMI
		NP	CHY	HIST		EHG
		NP	CRW	HIST		EHG
		NP	MAN	HIST		VHH
		NP	SIU	HIST		EHG
		CP	PAW	HIST		VHH
	Jemez	SW	HOP			AGR
	Mesa Verde	SW	ANA	PB		AGR
		GB	SHO	HIST		BSHG
		GB	UTE	HIST		BSHG

Table B.1. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
	Terry Collection		BLK	HIST		EMI
	Terry Collection		BLK	HIST		LMI
	Terry Collection		WHT	HIST		EMI
	Terry Collection		WHT	HIST		LMI
	Forensic Data Base		BLK	HIST		LMI
	Forensic Data Base		WHT	HIST		LMI
	Forensic Data Base		HISP	HIST		LMI
	Forensic Data Base		POLY	HIST		LMI
	Forensic Data Base		AMIN	HIST		LMI

Table B.2. Sites with cross-sectional data.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
Iowa						
13AM43	Flynn Burial	PR	ON	ON		VHH
13AM103	Hartley Fort	PR	PRLW	WD		IH
13PK38	West Des Moines Burial	PR	PRLW	WD	AD1030	IH
13PM1	Broken Kettle	PR	IMM	MM	AD1063	VHH
13WD6	Correctionville	PR	ON	ON		VHH
Kansas						
14DP2	Doniphan	CP	KAN	HIST	AD1724	VHH
14PH4	Woodruff	CP	PMW	WD	AD 634	WDHG
14SC2	Young	CP	PAR	AR		BSHG
Nebraska						
25DO4	Havlicek Farm	CP	NEB	CP	AD1225	VHH
25NH4	Whitten	CP	PLW	WD	AD 850	IH
	Camp Sheridan	CP	SIU	HIST	AD1879	EHG
	Fort Robinson	CP	SIU	HIST	AD1879	EHG
	Old Red Cloud	CP	SIU	HIST	AD1880	EHG
North Dakota						
32SN8	Krop Mound	NP	ARK	CO		VHH
32SN31	Jamestown Dam Area	NP				
	Benson	NP				
Oklahoma						
34GV2	Grant	SP	RBP	LP	AD1350	VHH
34WA5	McLemore	SP	RBP	LP	AD1300	VHH
South Dakota						
39BF2A	Medicine Crow	NP	ARK	CO		VHH
39BF11	Crow Creek	NP	IC	CO	AD1325	VHH
39BF?	Fort Thompson Area	NP	SIU	HIST		EHG
39CA4	Rygh	NP	EC	CO	AD1625	VHH
39CH4	Wheeler Ridge	NP	PMW	WD	AD 150	WDHG

Table B.2. Continued

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
39CH7	Oldham	NP	PLW	WD	AD 850	IH
39CH54	Platte-Winner Ridge	NP	PLW	WD	AD1030	IH
39CL2	Ufford Mounds	NP	PLW	WD	AD1030	IH
39CO9	Leavenworth	NP	ARK	HIST	AD1817	VHH
39CO11	Ashley Island	NP	ARK	HIST	AD1807	VHH
39CO31	Norvold 1	NP	ARK	CO	AD1727	VHH
39CO32/3	Norvold 2&3 (Oak Creek Village)	NP	ARK	CO	AD1727	VHH
39CO32/3	Norvold 2&3 (Oak Creek Village)	NP	EC	CO	AD1612	VHH
39DA3	Enemy Swim Lake	NP	PWD	WD		WDHG
39DV1-2	Mitchell Mound	NP	IMM	MM	AD1069	VHH
39DW2	Four Bear	NP	ARK	CO	AD1766	VHH
39GR1	Scalp Creek	NP	PLW	WD	AD 775	IH
39HS1	Bloom Creek	NP	IMM	MM	AD1150	VHH
39HT1	Twelve Mile Creek	NP	IMM	MM	AD1088	VHH
39HT2	Hofer Mound	NP	PLW	WD	AD 775	IH
39HU1	Thomas Riggs	NP	EMM	MM	AD1451	VHH
39HU2	Oahe Village	NP	ARK	CO	AD1727	VHH
39LK2	Madison Pass Mounds	NP	PLW	WD		IH
39LM2A	Medicine Creek	NP	IMM	MM	AD1150	VHH
39LM26	Oacoma	NP	ARK	CO	AD1725	VHH
39LM33	Dinehart's Village	NP	IMM	MM	AD1150	VHH
39LN10	Newton Hills	NP	PWD	WD		WDHG
39MC1	Montrose Mound	NP				
39MH1	Brandon	NP	IMM	MM	AD1100	VHH
39MH6	Split Rock Creek Mounds	NP	PLW	WD		IH
39RO2	Madsen Mound	NP	PLW	WD	AD 700	IH
39RO7	Hunter's Mound	NP	PLW	WD		IH
39RO10	Daughtery Mounds	NP	PLW	WD	AD 700	IH
39SL2	Fairbanks Village	NP	EC	CO	AD1662	VHH

Table B.2. Continued.

Site Number	*Site Name*	*Area*	*Tribe*	*Period*	*Mean Date*	*Adaptation*
39SL4A	Sully A	NP	EC	CO	AD1662	VHH
39SL4D	Sully D	NP	EC	CO	AD1662	VHH
39SL4E	Sully E	NP	ARK	CO	AD1687	VHH
39SL29	CB Smith	NP	EMM	MM	AD1325	VHH
39ST1	Cheyenne River	NP	ARK	CO	AD1767	VHH
39ST15	Indian Creek	NP	ARK	CO	AD1707	VHH
39ST16	Breeden	NP	IMM	MM	AD1030	VHH
39ST203	Black Widow Ridge	NP	EMM	MM	AD1325	VHH
39ST215	Leavitt	NP	ARK	CO	AD1766	VHH
39ST216	Buffalo Pasture	NP	ARK	CO	AD1778	VHH
39ST235	Stony Point Village	NP	ARK	CO	AD1767	VHH
39UN1	Arbor Hill	NP	PLW	WD	AD 850	IH
39WW1A	Mobridge A	NP	EC	CO	AD1624	VHH
39WW1B	Mobridge B	NP	ARK	CO	AD1687	VHH
39WW2	Larson	NP	ARK	CO	AD1706	VHH
39WW7	Swan Creek	NP	ARK	CO	AD1700	VHH
39WW303	White Tail	NP	EC	CO	AD1612	VHH
39YK1	Yankton Mounds	NP	PMW	WD		WDHG
Texas						
41RF1	Refugio	GC	KAR	HIST	AD1814	CHG
41RR16	Kaufman-Williams	GC	CAD	HIST	AD1720	AGR
41RR16	Kaufman-Williams	GC	CAD	LP	AD1625	AGR
Wyoming						
48FR63	Boysen 1	NP				
	Riverton Area	NP				

APPENDIX C

SUMMARY STATISTICS

Table C.1. Summary statistics for computed tomography data by sex.

		Right					Left				
Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Female	HML	133	301	14	274	338	135	294	14	267	327
	BLH	133	298	14	272	353	134	291	13	266	323
	EBR	127	54	3	48	62	126	54	3	47	61
	MVD	130	40	2	36	47	134	40	2	35	48
	DAP	134	18	1	14	22	134	18	1	15	22
	DML	134	17	2	14	22	134	17	1	14	22
	LCS	136	55	4	35	67	135	55	4	45	65
	HTA	135	234	31	167	333	137	228	32	161	334
	HTAest	134	241	36	165	363	134	235	35	165	346
	HCA	135	158	22	104	207	137	156	23	86	209
	HIx	135	4257	1040	2114	7633	137	4072	1054	1671	7842
	HIy	135	3797	1012	1840	6697	137	3607	1022	1623	7581
	HImax	135	4531	1119	2194	7947	137	4266	1124	1976	8307
	HImin	135	3523	932	1760	6188	137	3413	942	1318	7116
	Htheta	135	-52	35	-89	90	137	41	52	-89	90
	HZx	135	445	78	275	659	137	432	81	213	687
	HZy	135	388	76	229	577	137	398	80	211	669
	HDJ	135	8054	1999	3954	14093	137	7679	2020	3294	15423
	HDJest	134	8474	2444	2792	16194	135	7957	2077	3464	14125
	HJstd	133	502	121	208	892	134	541	146	176	1060
	H%CA	135	68	8	41	88	129	68	8	44	89
	HCAstd	133	587	91	356	829	135	619	105	291	946
	HDS	135	1.14	0.14	0.84	1.59	137	1.14	0.14	0.77	1.56
	HDSest	134	1.06	0.08	0.86	1.29	134	1.06	0.07	0.82	1.24
	FML	156	415	17	358	464	159	415	19	296	460

Table C.1. Continued

		Right					Left				
Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Female	MFH	152	42	2	36	49	154	42	2	36	49
	FEB	144	74	3	65	83	142	74	3	66	83
	APD	161	23	2	18	30	161	23	2	18	29
	MLD	161	30	2	22	36	161	30	2	22	35
	APS	195	26	2	21	32	195	26	2	20	34
	MLS	195	24	2	20	28	198	25	2	21	37
	FSTA	155	528	65	362	677	155	540	68	365	729
	FSTAest	161	550	73	353	742	161	555	74	353	742
	FSCA	155	363	49	242	514	156	373	55	203	550
	FSCAstd	151	510	78	333	718	152	567	123	290	1650
	FS%CA	155	69	7	41	88	155	69	8	45	89
	FSIx	155	21669	5373	10772	45204	156	20608	5404	9325	40888
	FSIy	155	20903	5449	10201	39391	156	23943	6369	10764	43438
	Fstheta	155	46	10	18	78	156	-37	11	-72	5
	FSZx	155	1540	276	883	2462	156	1505	293	833	2493
	FSZy	155	1551	287	893	2381	156	1649	317	883	2550
	FSJ	155	42572	9643	21235	70533	156	44401	10419	21483	68640
	FSJest	161	44077	11127	11838	72198	161	44704	11248	11838	71763
	FSJstd	151	477	109	222	766	153	511	241	210	3074
	FSRlength	158	6.52	0.35	5.41	7.44	158	6.54	0.42	5.41	8.66
	FSRhead	152	62.45	3.38	53.65	70.46	154	63.03	3.49	54.43	72.16
	FSIx/Iy	155	1.95	0.30	1.31	3.04	156	1.92	0.28	1.27	2.71
	FSS	161	1.29	0.12	0.73	1.60	161	1.28	0.11	0.81	1.62
	FMTA	191	458	49	324	608	192	465	56	330	651
	FMTAest	195	491	60	330	679	195	509	78	346	959

Table C.1. Continued

		Right					Left			
Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Female	FMCA	191	333	46	213	456	193	339	49	200	469
	FMCAstd	184	465	75	282	684	187	517	78	286	752
	FM%CA	191	73	7	49	87	192	73	7	53	88
	FMIx	191	16590	3926	7812	30489	193	16917	4642	7020	35328
	FMIy	191	15207	3531	8100	25199	193	15883	3738	7501	27026
	Fmtheta	191	-20	60	-89	90	192	33	48	-89	89
	FMZx	156	1174	190	697	1674	156	1202	218	699	1896
	FMZy	156	1226	207	764	1768	156	1236	202	750	1782
	FMJ	191	31777	7068	15912	55029	193	32766	7997	16793	62353
	FMJest	195	33149	8273	8795	57605	195	116969	9269	95458	166226
	FMJstd	183	352	83	187	593	180	367	88	178	716
	FMRlength	188	6.01	0.34	5.14	6.90	184	6.10	0.38	5.24	7.60
	FMRhead	160	58.92	3.55	48.61	72.11	155	60.01	3.49	51.06	79.42
	FMIx/Iy	191	1.10	0.18	0.67	1.58	193	1.07	0.18	0.69	1.68
	FMS	195	1.10	0.09	0.88	1.38	195	1.07	0.10	0.85	1.45
Male	HML	175	323	13	288	361	175	319	14	280	351
	BLH	171	320	13	285	356	171	316	14	278	349
	EBR	171	60	3	52	68	161	60	3	51	68
	MVD	174	46	3	40	53	173	46	3	22	52
	DAP	171	20	1	16	22	171	19	1	14	22
	DML	171	19	1	14	23	171	19	1	14	24
	LCS	174	62	3	52	69	175	59	4	49	71
	HTA	171	292	32	201	368	175	268	30	166	341
	HTAest	171	298	36	198	380	171	275	34	176	396
	HCA	171	205	27	111	261	175	190	24	110	257

Table C.1. Continued

		Right					Left				
Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Male	HIx	171	6518	1364	2881	10043	175	5308	1134	1836	8638
	HIy	171	6108	1376	2543	10503	175	5371	1218	2129	8939
	HImax	171	7053	1466	3814	10848	175	5911	1280	2617	10167
	HImin	171	5573	1239	2453	9335	175	4790	1048	1708	8201
	Htheta	171	-42	38	-88	88	175	29	41	-89	89
	HZx	171	627	100	341	895	175	537	87	260	786
	HZy	171	569	99	289	861	175	536	88	285	765
	HJ	171	12625	2611	6341	19508	175	10702	2244	4325	16839
	HJest	171	12261	2277	5786	17111	173	10379	1926	4589	16875
	HJstd	171	537	132	270	935	171	495	132	212	917
	H%CA	171	70	8	31	86	166	65	8	31	85
	HCAstd	171	609	97	257	841	173	593	95	275	845
	HDS	171	1.08	0.14	0.75	1.49	175	1.00	0.14	0.68	1.48
	HDSest	171	1.04	0.07	0.87	1.29	171	1.00	0.07	0.79	1.24
	FML	226	448	19	391	502	225	449	20	390	504
	MFH	216	47	2	39	54	219	47	2	40	53
	FEB	205	83	4	71	93	207	83	4	72	95
	APD	228	27	2	19	39	229	27	2	20	38
	MLD	228	33	3	24	40	228	33	3	24	40
	APS	259	30	2	22	38	257	30	3	23	39
	MLS	259	27	2	21	33	259	27	2	20	34
	FSTA	215	657	82	209	968	216	676	82	350	960
	FSTAest	228	693	87	358	1045	228	705	93	377	1068
	FSCA	215	444	62	167	622	216	461	67	237	639
	FSCAstd	210	499	81	190	700	211	555	87	243	821

Table C.1. Continued

		Right					Left				
Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Male	FS%CA	215	68	8	27	85	216	69	8	25	86
	FSIx	215	32164	7670	3367	61211	216	33431	8365	9605	65108
	FSIy	215	32888	7819	3345	53765	216	35480	8456	9818	58551
	Fstheta	215	43	12	-41	75	216	-41	13	-71	39
	FSZx	215	2052	370	405	3259	216	2127	395	824	3234
	FSZy	215	2132	360	408	3055	216	2193	372	841	3213
	FSJ	215	65051	13991	6713	104592	216	68911	15314	19423	111322
	FSJest	228	64357	11908	11403	105243	228	65730	12670	14328	109038
	FSJstd	210	492	120	51	938	208	509	124	216	1116
	FSRlength	216	6.79	0.37	5.39	8.03	226	6.84	0.38	5.50	8.30
	FSRhead	215	63.33	3.34	53.39	77.69	218	64.06	3.48	54.55	74.88
	FSIx/Iy	215	1.89	0.35	1.11	3.49	216	1.85	0.34	1.01	3.54
	FSS	228	1.26	0.13	0.72	1.65	228	1.24	0.12	0.74	1.57
	FMTA	251	585	63	349	770	253	593	66	343	799
	FMTAest	259	632	77	363	881	257	643	82	361	908
	FMCA	251	432	54	256	568	254	436	60	246	600
	FMCAstd	237	484	69	306	652	251	522	79	276	839
	FM%CA	251	74	6	37	86	253	74	7	34	89
	FMIx	251	28459	6637	9508	49918	254	28765	6979	9831	56706
	FMIy	251	24076	5343	9046	45719	254	25072	5627	7938	44680
	Fmtheta	251	-35	55	-90	90	254	45	44	-88	90
	FMZx	214	1747	281	790	2561	218	1761	302	803	2479
	FMZy	214	1731	276	818	2675	218	1726	281	746	2643
	FMJ	251	52535	10868	18553	82483	254	53747	11600	17769	85288
	FMJest	259	51570	9452	14213	79253	257	132536	9007	97107	160133

Table C.1. Continued.

		Right					Left				
Sex	***Variable***	***N***	***Mean***	***Std Dev***	***Min***	***Max***	***N***	***Mean***	***Std Dev***	***Min***	***Max***
Male	FMJstd	237	391	87	192	635	248	390	91	144	719
	FMRlength	247	6.32	0.34	5.23	7.40	253	6.35	0.36	5.17	7.46
	FMRhead	217	60.66	3.47	52.21	70.50	213	61.14	3.31	52.08	69.43
	FMIx/Iy	251	1.20	0.23	0.66	2.17	254	1.16	0.21	0.63	2.31
	FMS	259	1.13	0.11	0.83	1.58	257	1.12	0.10	0.81	1.56

Table C.2. Summary statistics for external dimension data set by sex.

Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Female	HML	773	300	15	205	343
	BUE	563	44	3	37	60
	MDS	841	21	2	14	28
	MDM	841	15	2	10	22
	MDH	758	41	3	33	53
	EBR	736	55	3	44	66
	LCS	700	56	4	43	71
	HMTA*	841	243	40	132	393
	HMR	749	5.85	0.46	4.59	7.79
	HMS	841	1.38	0.14	0.86	2.09
	FML	980	421	23	358	525
	FTL	711	399	21		462
	APD	1088	24	3	17	34
	MLD	1986	30	3	20	39
	APS	1079	26	2	19	38
	MLS	1079	25	2	17	36
	VHD	961	42	2	34	50
	HHD	714	42	2	34	50
	FEB	729	74	4	56	87
	BCB	547	67	5	51	80
	FSJ*	1086	46469	11841	1758	85203
	FSJstd*	950	486	143	167	935
	FSTA*	1086	568	79	311	855
	FSS	1086	1.26	0.17	0.69	1.85
	FSR	953	6.38	0.43	5.18	9.50
	FMJ*	1075	35797	9756	6074	73859
	FMJstd*	957	370	106	95	703
	FMTA*	1075	511	72	314	829
	FMS	1075	1.07	0.10	0.64	1.46
	FMR	957	6.04	0.39	4.91	7.45
Male	HML	1006	324	18	218	391
	BUE	700	50	3	41	61
	MDS	1099	23	2	15	29
	MDM	1099	17	2	11	28
	MDH	993	46	3	39	59
	EBR	1000	62	4	46	75
	LCS	868	61	5	46	78
	HMTA	1099	305	58	153	594
	HMR	984	6.06	0.54	4.61	9.23

Table C.2. Continued.

Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Male	HMS	1099	1.33	0.14	0.76	2.17
	FML	1251	456	25	382	542
	FTL	881	432	22	352	540
	APD	1333	27	3	19	38
	MLD	1332	33	3	22	41
	APS	1337	30	3	21	40
	MLS	1337	27	2	18	36
	VHD	1244	47	3	39	58
	HHD	858	47	3	38	57
	FEB	1000	83	4	68	99
	BCB	719	76	5	50	92
	FSJ*	1330	64486	12676	10533	109473
	FSJstd*	1212	450	126	114	1152
	FSTA*	1330	697	93	358	1068
	FSS	1330	1.22	0.16	0.69	1.78
	FSR	1212	6.54	0.42	5.12	8.22
	FSR2	872	6.86	0.41	5.48	8.32
	FMJ*	1336	52518	10555	3401	92858
	FMJstd*	1225	364	97	36	841
	FMTA*	1336	641	87	270	1005
	FMS	1336	1.10	0.11	0.75	1.61
	FMR	1225	6.27	0.39	4.66	7.77
Unknown	HML	21	304	13	280	340
	BUE	1	47		47	47
	MDS	26	22	2	18	26
	MDM	26	16	2	13	21
	MDH	22	43	3	37	50
	EBR	5	58	6	50	68
	LCS	8	62	3	58	66
	HMTA*	26	278	44	212	396
	HMR	21	6.01	0.34	5.43	6.65
	HMS	26	1.38	0.15	1.14	1.73
	FML	19	432	54	315	515
	FTL	9	431	32	379	490
	APD	25	27	3	19	33
	MLD	24	33	4	26	40
	APS	26	29	4	21	37
	MLS	26	26	3	19	32
	VHD	17	47	5	39	55

Table C.2. Continued.

Sex	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Unknown	HHD	11	48	5	41	55
	FEB	10	81	7	70	91
	BCB	10	76	7	66	88
	FSJ	24	62754	20490	18123	106113
	FSJstd*	19	559	266	283	1179
	FSTA*	24	690	150	388	1037
	FSS	24	1.22	0.12	0.90	1.42
	FSR	18	6.72	0.55	6.05	7.95
	FMJ*	26	47468.00	17263.00	6098.00	71070.00
	FMJstd*	19	383	118	228	687
	FMTA*	26	605	131	313	804
	FMS	26	1.10	0.10	0.90	1.42
	FMR	19	6.29	0.34	5.50	6.82

*Predicted value.

Table C.3. Summary statistics for external dimension data set by subsistence strategy.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
AGR	Female	HML	73	291	14	267	319
		BUE	45	44	2	39	49
		MDS	75	20	2	18	28
		MDM	75	291	1	11	17
		MDH	74	39	2	34	46
		EBR	70	53	3	47	60
		LCS	75	54	4	48	65
		HMTA	75	227	32	156	308
		HMS	75	1.45	0.14	1.18	2.00
		HMR	73	5.83	0.39	5.10	7.23
		FML	81	407	18	370	445
		FTL	77	390	18	350	432
		APD	84	22	2	17	27
		MLD	84	29	2	22	34
		APS	83	25	2	19	31
		MLS	83	24	2	17	29
		VHD	79	40	2	35	46
		HHD	56	39	2	35	47
		FEB	66	71	3	59	79
		BCB	44	62	5	51	78
		FSJ*	84	36460	10402	1758	59628
		FSJstd*	79	456	129	169	848
		FSTA	84	501	63	311	641
		FSS	84	1.30	0.13	0.96	1.68
		FSR	81	6.19	0.37	5.18	7.10
		FMJ*	81				
		FMJstd*	79	382	113	132	703
		FMTA	81	479	63	328	661
		FMS	81	1.06	0.10	0.86	1.36
		FMR1**	79	6.04	0.38	5.12	7.18
		FMR2**	76	61.86	3.34	55.11	74.36
	Male	HML	52	315	15	287	363
		BUE	31	49	3	43	54
		MDS	58	21	2	18	25
		MDM	58	16	1	13	19
		MDH	51	44	3	39	51
		EBR	54	59	3	52	66
		LCS	58	59	4	49	68
		HMTA	58	262	36	184	358

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
AGR	Male	HMS	58	1.36	0.09	1.17	1.62
		HMR	52	5.80	0.40	5.13	6.80
		FML	68	438	23	382	489
		FTL	67	420	22	361	471
		APD	70	25	2	21	30
		MLD	70	31	3	25	37
		APS	70	28	2	23	34
		MLS	70	25	2	21	30
		VHD	66	45	2	39	50
		HHD	45	45	2	40	50
		FEB	58	79	4	70	86
		BCB	38	70	5	59	79
		FSJ*	70	53270	10799	20613	75123
		FSJstd*	68	456	143	208	799
		FSTA	70	617	72	412	763
		FSS	70	1.22	0.15	0.93	1.61
		FSR	68	6.39	0.44	5.47	7.20
		FMJ*					
		FMJstd*	68	363	102	192	640
		FMTA	70	564	70	379	721
		FMS	70	1.12	0.09	0.83	1.41
		FMR1**	68	6.10	0.39	5.28	6.98
		FMR2**	68	5.97	0.33	5.22	6.81
BSHG	Female	HML	31	299	13	265	325
		BUE	27	44	2	40	49
		MDS	37	20	2	16	26
		MDM	37	15	2	10	18
		MDH	32	40	2	36	43
		EBR	34	55	3	48	60
		LCS	35	55	4	46	65
		HMTA	37	241	45	134	368
		HMS	37	1.38	0.13	1.18	1.70
		HMR	30	5.98	0.58	4.78	7.38
		FML	25	417	14	382	447
		FTL	24	396	14	360	433
		APD	34	24	3	19	29
		MLD	34	29	2	25	33
		APS	33	25	2	22	29
		MLS	33	25	2	22	36

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
BSHG	Female	VHD	29	41	2	38	45
		HHD	26	41	2	37	45
		FEB	18	72	3	67	77
		BCB	15	65	3	59	70
		FSJ*	34	42037	9156	17688	62118
		FSJstd*	25	465	105	301	791
		FSTA	34	541	63	393	674
		FSS	34	1.22	0.19	0.89	1.63
		FSR	25	6.31	0.31	5.81	7.05
		FMJ*					
		FMJstd*	25	366	85	215	527
		FMTA	33	498	66	397	735
		FMS	33	1.02	0.09	0.72	1.17
		FMR1**	25	6.02	0.34	5.41	6.84
		FMR2**	28	6.08	0.42	5.35	6.95
	Male	HML	49	320	16	287	360
		BUE	52	50	3	41	56
		MDS	65	23	2	18	27
		MDM	65	17	2	11	21
		MDH	52	46	3	40	51
		EBR	52	62	4	54	69
		LCS	66	62	5	53	78
		HMTA	65	298	51	198	412
		HMS	65	1.37	0.17	1.11	2.17
		HMR	49	6.11	0.48	5.14	7.24
		FML	41	450	20	395	477
		FTL	37	429	18	385	460
		APD	58	27	3	22	33
		MLD	58	32	3	25	41
		APS	56	30	2	25	36
		MLS	56	27	2	23	32
		VHD	49	46	2	41	51
		HHD	44	47	3	41	52
		FEB	33	82	4	74	90
		BCB	35	74	4	65	81
		FSJ*	58	60948	11632	32313	91053
		FSJstd*	41	443	74	305	680
		FSTA	58	674	81	491	888
		FSS	58	1.17	0.17	0.88	1.58

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
BSHG	Male	FSR	41	6.51	0.26	5.97	7.05
		FMJ*					
		FMJstd*	41	370	67	238	558
		FMTA	56	623	78	488	829
		FMS	56	1.12	0.09	0.90	1.44
		FMR1**	41	6.27	0.27	5.67	6.91
		FMR2**	45	6.10	0.25	5.68	6.63
CHG	Female	HML	9	296	21	265	318
		BUE	12	44	3	40	49
		MDS	18	21	2	18	24
		MDM	18	16	2	13	19
		MDH	12	40	2	36	44
		EBR	13	54	4	47	63
		LCS	17	56	4	51	67
		HMTA	18	255	46	198	358
		HMS	18	1.35	0.13	1.05	1.64
		HMR	9	5.87	0.39	5.36	6.70
		FML	13	427	29	358	460
		FTL	9	405	35	349	436
		APD	19	24	3	20	32
		MLD	19	29	3	23	34
		APS	19	26	2	22	29
		MLS	19	25	2	21	29
		VHD	17	41	2	36	46
		HHD	17	41	3	36	45
		FEB	9	75	2	72	79
		BCB	9	66	4	60	70
		FSJ*	19	42635	13175	17688	62553
		FSJstd*	10	387	112	246	651
		FSTA	19	542	82	393	668
		FSS	19	1.26	0.20	0.72	1.57
		FSR	10	6.10	0.36	5.62	6.81
		FMJ*					
		FMJstd*	12	339	104	182	520
		FMTA	19	516	75	397	638
		FMS	19	1.06	0.01	0.83	1.29
		FMR1**	12	5.93	0.40	5.22	6.43
		FMR2**	16	6.17	0.32	5.60	6.82

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
CHG	Male	HML	20	327	18	280	364
		BUE	20	50	3	44	56
		MDS	25	24	2	19	28
		MDM	25	19	3	16	27
		MDH	19	46	2	42	50
		EBR	25	63	3	58	68
		LCS	26	67	4	59	73
		HMTA	25	365	72	280	594
		HMS	25	1.3	0.2	0.8	1.5
		HMR	20	6.5	0.8	5.8	8.7
		FML	24	457	24	401	503
		FTL	22	437	22	389	477
		APD	31	28	2	24	32
		MLD	31	33	2	27	38
		APS	28	31	3	24	35
		MLS	28	29	3	24	35
		VHD	31	47	2	43	51
		HHD	29	47	2	42	50
		FEB	20	83	4	76	89
		BCB	21	77	5	67	85
		FSJ*	31	68566	9117	48678	84768
		FSJstd*	24	465	108	279	716
		FSTA	31	728	67	592	855
		FSS	31	1.20	0.13	0.90	1.52
		FSR	24	6.65	0.29	5.84	7.17
		FSR2	30	64.50	1.90	60.40	68.26
		FMJ*					
		FMJstd*	23	401	102	243	624
		FMTA	28	704	84	452	829
		FMS	28	1.07	0.15	0.75	1.32
		FMR1**	23	6.52	0.40	5.53	7.24
		FMR2**	27	6.34	0.33	5.33	6.77
EHG	Female	HML	34	309	17	276	343
		BUE	28	47	4	41	60
		MDS	30	22	2	18	26
		MDM	30	16	2	13	19
		MDH	30	43	2	38	48
		EBR	29	58	3	51	64
		LCS	27	59	4	50	66

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EHG	Female	HMTA	30	277	47	184	368
		HMS	30	1.4	0.1	1.1	1.6
		HMR	29	6.1	0.6	5.0	7.1
		FML	36	435	23	395	475
		FTL	32	415	21	375	452
		APD	34	25	3	20	31
		MLD	34	32	3	25	37
		APS	34	28	2	23	32
		MLS	34	26	2	21	31
		VHD	31	44	3	40	49
		HHD	29	44	3	40	48
		FEB	29	77	4	69	85
		BCB	27	69	5	57	78
		FSJ*	34	55249	11658	35238	78048
		FSJstd*	33	487	131	232	792
		FSTA	34	626	82	495	792
		FSS	34	1.3	0.2	0.9	1.6
		FSR	33	6.5	0.4	5.6	7.2
		FSR2	32	6.8	0.4	5.8	7.5
		FMJ*					
		FMJstd*	33	384	109	210	594
		FMTA	34	572	79	397	683
		FMS	34	1.05	0.10	0.83	1.33
		FMR1**	33	6.19	0.43	5.34	6.95
		FMR2**	31	6.18	0.35	5.49	6.86
	Male	HML	31	325	24	218	359
		BUE	21	52	3	47	57
		MDS	32	24	2	20	27
		MDM	32	17	2	15	20
		MDH	31	48	2	42	53
		EBR	29	62	3	56	68
		LCS	30	64	5	58	74
		HMTA	32	320	48	236	424
		HMS	32	1.37	0.11	1.15	1.69
		HMR	31	6.23	0.73	5.22	9.27
		FML	30	459	17	430	499
		FTL	30	440	18	414	475
		APD	32	28	3	24	35
		MLD	32	34	2	30	40

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EHG	Male	APS	31	31	2	26	35
		MLS	31	28	2	25	34
		VHD	31	48	3	42	52
		HHD	22	48	2	44	53
		FEB	27	85	4	76	95
		BCB	18	77	4	68	81
		FSJ*	32	72306	12633	49548	109038
		FSJstd*	30	471	110	305	702
		FSTA	32	759	102	584	1068
		FSS	32	1.2	0.1	1.0	1.4
		FSR	30	6.7	0.5	6.0	8.0
		FSR2	31	64.6	5.1	56.3	76.1
		FMJ*					
		FMJstd*	30	377	84	228	557
		FMTA	31	687	88	530	908
		FMS	31	1.09	0.09	0.88	1.30
		FMR1**	30	6.41	0.40	5.79	7.39
		FMR2**	30	6.14	0.43	5.29	6.90
EMI	Female	HML	24	297	15	266	334
		BUE	17	44	4	37	51
		MDS	37	20	2	14	25
		MDM	37	16	2	12	19
		MDH	20	41	3	36	47
		EBR	24	53	5	44	61
		LCS	36	57	5	47	68
		HMTA	37	249	50	132	373
		HMS	37	1.30	0.12	1.13	1.54
		HMR	24	6.00	0.47	5.18	6.93
		FML	52	425	21	382	491
		FTL	51	401	27	263	462
		APD	60	25	2	19	30
		MLD	60	28	2	24	34
		APS	58	26	2	22	33
		MLS	58	25	2	20	31
		VHD	49	42	2	36	47
		HHD	47	41	2	36	47
		FEB	37	73	5	56	82
		BCB	35	67	5	58	78
		FSJ*	60	44113	10165	18123	71328

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EMI	Female	FSJstd*	52	442	131	211	819
		FSTA	60	561	69	388	748
		FSS	60	1.14	0.13	0.86	1.43
		FSR	52	6.29	0.41	5.36	7.32
		FSR2	49	64.00	3.29	58.08	71.75
		FMJ*					
		FMJstd*	52	364	108	152	642
		FMTA	58	517	75	346	660
		FMS	58	1.05	0.11	0.81	1.32
		FMR1**	52	6.04	0.41	5.07	6.99
		FMR2**	48	6.16	0.34	5.43	6.94
	Male	HML	69	321	19	266	365
		BUE	64	49	3	44	58
		MDS	88	23	2	20	29
		MDM	88	19	2	16	28
		MDH	69	46	3	40	53
		EBR	69	62	4	53	73
		LCS	89	64	5	52	78
		HMTA	88	339	60	264	569
		HMS	88	1.22	0.13	0.82	1.53
		HMR	69	6.41	0.47	5.67	8.21
		FML	98	454	27	377	524
		FTL	91	433	27	352	502
		APD	109	28	3	23	37
		MLD	108	32	3	25	39
		APS	109	29	3	24	37
		MLS	109	28	2	23	32
		VHD	102	47	3	40	54
		HHD	98	47	2	40	53
		FEB	75	82	4	71	90
		BCB	76	75	5	66	85
		FSJ*	108	62441	13028	33183	94293
		FSJstd*	97	439	133	218	1151
		FSTA	108	688	96	488	959
		FSS	108	1.16	0.12	0.83	1.44
		FSR	97	6.50	0.41	5.73	7.77
		FSR2	90	6.83	0.44	5.93	8.32
		FMJ*					
		FMJstd*	98	368	102	182	765

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EMI	Male	FMTA	109	637	84	452	872
		FMS	109	1.05	0.10	0.81	1.37
		FMR1**	98	6.26	0.37	5.41	7.01
		FMR2**	101	6.00	0.37	5.00	7.00
IH	Female	HML	32	294	16	268	337
		BUE	35	44	2	42	50
		MDS	42	20	2	17	25
		MDM	42	14	2	12	21
		MDH	39	39	2	36	44
		EBR	33	54	3	47	61
		LCS	39	53	4	43	61
		HMTA	42	226	39	160	363
		HMS	42	1.41	0.14	1.05	1.67
		HMR	32	5.71	0.39	4.94	6.97
		FML	47	407	25	361	465
		FTL	48	386	22	332	435
		APD	65	23	3	18	29
		MLD	65	31	3	24	35
		APS	64	25	2	19	30
		MLS	64	24	2	20	28
		VHD	51	40	2	35	47
		HHD	50	40	2	36	46
		FEB	32	71	3	65	77
		BCB	31	64	4	58	73
		FSJ*	65	46683	14214	18123	68838
		FSJstd*	46	538	126	250	813
		FSTA	65	566	94	382	721
		FSS	65	1.3	0.1	0.9	1.6
		FSR	46	6.5	0.4	5.5	7.1
		FSR2	48	6.8	0.4	6.0	7.5
		FMJ*					
		FMJstd*	47	350	112	117	628
		FMTA	64	472	74	314	616
		FMS	64	1.06	0.10	0.85	1.29
		FMR1**	47	5.93	0.37	5.18	6.90
		FMR2**	48	6.06	0.36	5.23	6.79
	Male	HML	54	319	16	276	352
		BUE	53	49	2	44	55
		MDS	62	22	2	17	29

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
IH	Male	MDM	62	16	2	13	22
		MDH	56	45	3	40	59
		EBR	59	60	3	52	65
		LCS	62	60	5	46	73
		HMTA	62	285	49	187	432
		HMS	62	1.40	0.15	1.05	1.92
		HMR	51	5.96	0.47	5.06	7.43
		FML	51	446	23	402	503
		FTL	52	427	27	382	540
		APD	65	26	3	21	31
		MLD	66	33	3	24	40
		APS	68	29	3	24	35
		MLS	68	27	2	20	33
		VHD	54	46	2	40	52
		HHD	52	45	2	38	51
		FEB	39	81	4	68	90
		BCB	42	72	4	66	80
		FSJ*	65	63006	12687	34803	94413
		FSJstd*	50	473	103	231	788
		FSTA	65	681	92	506	911
		FSS	65	1.27	0.18	0.87	1.71
		FSR	50	6.57	0.35	5.57	7.62
		FSR2	52	6.90	0.37	5.80	7.64
		FMJ*					
		FMJstd*	50	353	79	234	547
		FMTA	68	600	91	424	880
		FMS	68	1.09	0.10	0.83	1.35
		FMR1**	50	6.16	0.36	5.54	6.92
		FMR2**	52	6.03	0.39	5.22	6.83
LMI	Female	HML	23	307	15	264	341
		BUE	0	---	---	---	---
		MDS	15	20	2	17	24
		MDM	15	16	2	12	19
		MDH	11	42	2	35	49
		EBR	16	56	3	48	65
		LCS	0	---	---	---	---
		HMTA	15	244	38	174	358
		HMS	15	1.29	0.11	1.05	1.58
		HMR	11	5.71	0.46	4.72	6.78

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
LMI	Female	FML	165	438	22	386	525
		FTL	18	407	18	367	437
		APD	161	25	2	20	32
		MLD	161	28	2	23	36
		APS	159	27	2	20	32
		MLS	159	24	2	19	29
		VHD	152	42	2	35	47
		HHD	18	42	1	40	45
		FEB	147	75	4	66	85
		BCB	18	69	2	66	75
		FSJ*	161	45093	11386	20178	80973
		FSJstd*	150	384	123	166	785
		FSTA	161	569	77	415	820
		FSS	161	1.13	0.10	0.84	1.35
		FSR	150	6.14	0.43	5.19	7.39
		FSR2	150	64	4	57	72
		FMJ*					
		FMJstd*	151	312	90	95	599
		FMTA	159	519	65	330	682
		FMS	159	1.13	0.10	0.89	1.42
		FMR1**	151	5.85	0.37	4.91	6.88
		FMR2**	149	6.09	0.36	5.21	6.89
	Male	HML	32	334	19	286	391
		BUE	0	---	---	---	---
		MDS	19	23	2	18	28
		MDM	19	19	2	13	24
		MDH	13	48	3	39	57
		EBR	16	64	4	54	75
		LCS	0	---	---	---	---
		HMTA	19	350	56	198	488
		HMS	19	1.24	0.10	0.86	1.69
		HMR	16	6.31	0.52	4.96	8.28
		FML	265	474	28	398	542
		FTL	14	454	28	401	508
		APD	251	29	2	23	38
		MLD	250	32	3	24	39
		APS	249	31	3	25	40
		MLS	249	28	2	22	35
		VHD	247	48	3	40	55

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
LMI	Male	HHD	14	48	2	45	52
		FEB	235	84	5	69	99
		BCB	14	80	4	70	84
		FSJ*	250	66072	13419	29823	100578
		FSJstd*	237	374	114	181	905
		FSTA	250	719	101	470	1015
		FSS	250	1.12	0.11	0.81	1.48
		FSR	237	6.38	0.44	5.37	7.95
		FSR2	241	63	4	54	76
		FMJ*					
		FMJstd*	243	319	98	144	749
		FMTA	249	672	92	466	1005
		FMS	249	1.11	0.10	0.81	1.34
		FMR1	243	6.18	0.41	5.16	7.75
		FMR2**	237	6.12	0.37	5.17	7.23
VHH	Female	HML	93	299	14	205	340
		BUE	55	44	2	39	55
		MDS	26	21	2	16	26
		MDM	26	15	1	11	22
		MDH	86	41	2	35	49
		EBR	67	55	3	44	66
		LCS	12	56	4	44	71
		HMTA	26	243	39	151	393
		HMS	26	1.40	0.13	0.91	2.09
		HMR	87	5.86	0.45	4.59	7.79
		FML	464	416	19	263	480
		FTL	355	399	18	351	458
		APD	514	24	2	17	34
		MLD	512	31	2	20	39
		APS	515	26	2	20	38
		MLS	515	25	2	18	33
		VHD	450	42	2	36	49
		HHD	370	42	2	36	50
		FEB	305	75	4	62	87
		BCB	285	67	4	56	80
		FSJ*	512	48483	10805	12273	85203
		FSJstd*	459	534	136	191	935
		FSTA	512	576	74	347	827
		FSS	512	1.3	0.1	0.7	1.7

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
VHH	Female	FSR	457	6.49	0.42	5.30	9.50
		FSR2	445	63.80	3.69	51.20	74.75
		FMJ*					
		FMJstd*	463	391	103	136	674
		FMTA	516	510	67	330	776
		FMS	516	1.07	0.10	0.64	1.46
		FMR1	463	6.10	0.37	5.13	7.26
		FMR2**	443	6.01	0.36	4.75	70.71
	Male	HML	43	321	14	275	378
		BUE	10	49	2	42	56
		MDS	80	22	2	15	28
		MDM	80	16	2	12	23
		MDH	41	46	2	39	53
		EBR	31	61	3	53	74
		LCS	67	61	4	46	77
		HMTA	80	283	46	153	467
		HMS	80	1.36	0.12	1.05	2.00
		HMR	40	5.89	0.48	4.61	7.82
		FML	541	450	19	387	512
		FTL	442	431	18	378	486
		APD	574	26	2	19	37
		MLD	574	34	3	23	41
		APS	580	30	2	23	40
		MLS	580	27	2	20	36
		VHD	535	47	2	40	58
		HHD	424	47	2	40	54
		FEB	396	83	4	68	95
		BCB	362	76	5	50	92
		FSJ	574	65934	11400	11403	109473
		FSJstd*	534	489	120	123	1150
		FSTA	574	699	84	358	1063
		FSS	574	1.30	0.15	0.69	1.78
		FSR	533	6.64	0.40	5.12	8.22
		FSR2	525	63.00	3.44	48.76	84.10
		FMJ*	540				
		FMJstd*	540	387	93	149	842
		FMTA	580	640	76	361	901
		FMS	580	1.12	0.10	0.83	1.61
		FMR1	530	6.34	0.38	5.08	7.77

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
VHH	Male	FMR2**	530	6.05	0.33	5.29	7.37
WDHG	Female	HML	0	---	---	---	---
		BUE	0	---	---	---	---
		MDS	0	---	---	---	---
		MDM	0	---	---	---	---
		MDH	0	---	---	---	---
		EBR	0	---	---	---	---
		LCS	0	---	---	---	---
		HMTA	0	---	---	---	---
		HMS	0	---	---	---	---
		HMR	0	---	---	---	---
		FML	9	421	24	386	461
		FTL	9	403	22	370	442
		APD	15	23	3	18	27
		MLD	15	30	3	22	38
		APS	14	25	2	21	32
		MLS	14	25	2	22	28
		VHD	11	42	2	39	45
		HHD	10	42	2	39	45
		FEB	4	76	5	69	79
		BCB	4	69	4	63	72
		FSJ*	15	45192	14854	25278	81843
		FSJstd*	9	458	165	272	738
		FSTA	15	555	99	410	806
		FSS	15	1.32	0.18	0.81	1.61
		FSR	9	6.22	0.49	5.57	7.01
		FSR2	11	64.00	5.61	52.58	72.70
		FMJ*					
		FMJstd*	9	325	123	190	581
		FMTA	14	490	81	396	704
		FMS	14	1.02	0.07	0.88	1.14
		FMR1	9	5.84	0.44	5.26	6.67
		FMR2**	11	6.01	0.45	5.11	6.80
WDHG	Male	HML	19	329	14	303	350
		BUE	16	51	4	45	61
		MDS	26	23	2	20	26
		MDM	26	17	1	15	20
		MDH	25	47	3	41	54
		EBR	24	62	4	46	68

Table C.3. Continued.

Adapt	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
WDHG	Male	LCS	27	62	4	54	68
		HMTA	26	303	41	236	377
		HMS	26	1.37	0.11	1.20	1.63
		HMR	19	6.05	0.41	5.36	6.67
		FML	19	451	19	416	490
		FTL	19	430	22	390	477
		APD	22	27	4	21	36
		MLD	23	32	3	27	36
		APS	24	29	3	24	34
		MLS	24	26	2	23	31
		VHD	17	47	2	45	51
		HHD	16	48	3	44	57
		FEB	15	82	4	70	87
		BCB	11	75	5	69	82
		FSJ*	22	60195	15635	27333	98088
		FSJstd*	18	421	90	294	562
		FSTA	22	669	118	445	990
		FSS	22	1.20	0.17	0.83	1.40
		FSR	18	6.42	0.40	5.72	6.97
		FSR2	17	60.89	4.00	52.91	67.01
		FMJ*					
		FMJstd*	19	324	63	230	455
		FMTA	24	599	81	434	755
		FMS	24	1.10	0.11	0.93	1.36
		FMR1	19	6.04	0.31	5.46	6.50
		FMR2**	17	5.78	0.40	5.11	6.48

*Predicted value of J.

**1=standardized by length; 2 = standardized by head size.

Table C.4. Summary statistics for external dimension data set by cultural area.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
CP	Female	HML	89	301	13	250	332
		BUE	69	44	3	39	55
		MDS	114	21	2	17	26
		MDM	114	15	2	10	19
		MDH	81	41	2	37	48
		EBR	81	55	3	47	62
		LCS	110	56	4	47	68
		HMTA*	114	249	40	134	358
		HMS	114	1	0	1	2
		HMR	84	6	0	5	7
		FML	99	417	19	371	460
		FTL	83	397	18	351	441
		APD	139	24	2	19	30
		MLD	139	31	3	20	39
		APS	135	26	2	21	38
		MLS	135	25	2	20	33
		VHD	86	42	2	36	48
		HHD	89	42	2	36	47
		FEB	54	74	4	62	82
		BCB	45	66	4	56	75
		FSJ*	139	48441	10958	21048	85203
		FSJstd*	98	526	135	218	877
		FSTA*	139	579	73	408	827
		FSS	139	1.28	0.14	0.69	1.63
		FSR	98	6.49	0.39	5.50	7.38
		FMJ*	135	35612	9617	11516	71234
		FMJstd**	97	385	108	190	674
		FMTA*	135	509	71	346	776
		FMS	135	1	0	1	1
		FMR	97	6	0	5	7
	Male	HML	107	320	18	218	378
		BUE	90	50	3	44	61
		MDS	132	23	2	19	28
		MDM	132	17	2	11	22
		MDH	104	46	3	40	52
		EBR	105	61	4	46	69
		LCS	130	63	4	53	77
		HMTA*	132	306	48	199	467
		HMS	132	1	0	1	2

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
CP	Male	HMR	104	6	1	5	9
		FML	117	450	20	390	502
		FTL	106	430	20	382	477
		APD	144	28	3	20	37
		MLD	144	33	3	23	41
		APS	146	30	3	24	38
		MLS	146	27	2	21	34
		VHD	109	47	3	41	55
		HHD	94	47	2	41	53
		FEB	76	82	5	68	95
		BCB	63	75	4	63	86
		FSJ*	144	66529	14389	26463	109038
		FSJstd*	116	497	138	231	941
		FSTA*	144	713	107	452	1068
		FSS	144	1.21	0.17	0.69	1.75
		FSR	116	6.73	0.51	5.56	8.02
		FMJ*	146	52677	10926	22352	81998
		FMJstd*	116	395	105	203	757
		FMTA*	146	642	90	415	908
		FMS	146	1	0	1	2
		FMR	116	6	0	5	8
EW	Female	HML	5	296	10	280	308
		BUE	5	44	1	42	46
		MDS	5	20	2	18	22
		MDM	5	14	0	14	15
		MDH	5	40	1	38	41
		EBR	3	54	4	50	58
		LCS	5	52	3	47	54
		HMTA*	5	228	22	198	259
		HMS	5	1	0	1	2
		HMR	5	6	0	5	6
		FML	6	427	28	396	476
		FTL	5	396	18	366	414
		APD	6	26	2	23	28
		MLD	6	30	3	26	32
		APS	6	27	3	23	31
		MLS	6	25	2	21	28
		VHD	6	41	3	37	46
		HHD	6	41	3	37	46

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EW	Female	FEB	1	73		73	73
		BCB	4	69	3	65	72
		FSJ*	6	49943	13263	32748	61248
		FSJstd*	6	485	157	301	665
		FSTA*	6	600	88	488	682
		FSS	6	1.16	0.07	1.08	1.28
		FSR	6	6.47	0.48	5.78	7.01
		FMJ	6	38610	13604	16934	57581
		FMJstd*	6	356	84	242	440
		FMTA*	6	534	101	379	682
		FMS	6	1	0	1	1
		FMR	6	6	0	6	6
	Male	HML	12	324	16	300	352
		BUE	12	50	3	46	56
		MDS	14	23	3	18	29
		MDM	14	17	1	14	19
		MDH	13	46	3	41	50
		EBR	13	60	2	55	64
		LCS	13	61	6	52	71
		HMTA*	14	303	52	198	410
		HMS	14	1	0	1	2
		HMR	12	6	0	5	7
		FML	15	453	22	412	475
		FTL	11	423	23	386	446
		APD	15	27	3	22	31
		MLD	16	32	3	26	38
		APS	16	29	3	24	32
		MLS	16	26	3	21	33
		VHD	15	47	3	42	51
		HHD	15	46	3	42	52
		FEB	7	80	5	74	86
		BCB	9	74	5	69	81
		FSJ*	15	59891	12980	26898	78918
		FSJstd*	15	413	73	295	547
		FSTA*	15	666	88	449	776
		FSS	15	1.18	0.21	0.90	1.57
		FSR	15	6.41	0.28	5.75	6.75
		FMJ*	16	46232	12866	19655	65696
		FMJstd*	15	310	50	216	390

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
EW	Male	FMTA*	16	591	98	396	754
		FMS	16	1	0	1	1
		FMR	15	6	0	5	7
	Unknown	FML	7	465	43	398	515
		FTL	5	433	42	379	490
		APD	8	27	3	23	31
		MLD	8	33	4	28	36
		APS	8	30	4	26	37
		MLS	8	28	3	24	32
		VHD	7	49	6	41	55
		HHD	8	49	5	41	55
		FEB	4	80	11	70	91
		BCB	7	76	8	66	88
		FSJ*	8	63729	17416	36543	83898
		FSJstd*	7	384	92	283	507
		FSTA*	8	695	126	506	848
		FSS	8	1.21	0.14	0.90	1.42
		FSR	7	6.35	0.24	6.05	6.78
		FMJ*	8	54857	14489	33188	71090
		FMJstd*	7	330	81	228	461
		FMTA**	8	662	117	490	804
		FMS	8	1	0	1	1
		FMR	7	6	0	6	7
GB	Female	HML	35	294	15	265	324
		BUE	33	44	2	39	49
		MDS	38	21	2	16	26
		MDM	38	15	2	12	21
		MDH	36	40	3	33	46
		EBR	36	55	3	48	60
		LCS	36	54	4	43	61
		HMTA*	38	251	44	163	368
		HMS	38	1	0	1	2
		HMR	34	6	1	5	7
		FML	32	407	22	361	455
		FTL	31	385	22	332	433
		APD	37	24	3	20	29
		MLD	37	29	2	23	33
		APS	37	25	2	19	32
		MLS	37	24	3	20	36

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
GB	Female	VHD	32	41	2	34	45
		HHD	30	41	2	34	45
		FEB	25	72	4	61	79
		BCB	23	64	4	56	74
		FSJ*	37	40122	10951	10968	62118
		FSJstd*	32	495	133	242	813
		FSTA*	37	529	73	361	674
		FSS	37	1.23	0.16	0.89	1.55
		FSR	32	6.37	0.34	5.81	7.09
		FMJ*	37	31048	11547	8747	65552
		FMJstd*	32	373	94	194	527
		FMTA*	37	477	81	328	735
		FMS	37	1	0	1	1
		FMR	32	6	0	5	7
	Male	HML	52	317	18	276	356
		BUE	53	50	3	44	56
		MDS	58	22	2	17	27
		MDM	58	17	2	14	22
		MDH	53	45	3	39	51
		EBR	56	61	4	55	69
		LCS	58	61	5	53	78
		HMTA*	58	295	55	187	432
		HMS	58	1	0	1	2
		HMR	52	6	1	5	7
		FML	45	449	25	393	490
		FTL	45	425	24	366	471
		APD	54	26	3	21	33
		MLD	54	32	3	26	39
		APS	53	29	2	24	36
		MLS	53	26	2	23	32
		VHD	50	46	3	40	51
		HHD	51	46	3	40	52
		FEB	40	81	4	73	90
		BCB	43	73	4	62	81
		FSJ*	54	59336	11275	35673	91053
		FSJstd*	45	449	98	287	759
		FSTA*	54	660	83	511	888
		FSS	54	1.22	0.15	0.88	1.52
		FSR	45	6.50	0.28	5.88	7.11

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
GB	Male	FMJ*	53	48741	9421	30491	73811
		FMJstd*	45	369	86	227	633
		FMTA*	53	609	77	470	829
		FMS	53	1	0	1	1
		FMR	45	6	0	6	7
GC	Female	HML	34	293	15	265	319
		BUE	13	44	3	40	49
		MDS	45	20	2	18	28
		MDM	45	15	2	12	19
		MDH	38	39	2	35	44
		EBR	37	53	3	47	63
		LCS	44	54	4	46	67
		HMTA*	45	234	43	170	358
		HMS	45	1	0	1	2
		HMR	34	6	0	5	7
		FML	38	418	22	358	460
		FTL	34	401	21	349	436
		APD	46	23	2	19	32
		MLD	46	28	3	23	34
		APS	45	26	2	22	31
		MLS	45	24	2	21	29
		VHD	43	40	2	36	46
		HHD	19	41	3	36	45
		FEB	32	73	3	66	79
		BCB	10	65	4	57	70
		FSJ*	46	37060	12238	17253	62553
		FSJstd*	35	380	92	169	651
		FSTA*	46	507	76	388	668
		FSS	46	1.27	0.15	0.72	1.57
		FSR	35	6.03	0.31	5.18	6.81
		FMJ*	45	33905	9291	19607	52187
		FMJstd*	37	360	84	182	520
		FMTA*	45	497	68	397	638
		FMS	45	1	0	1	1
		FMR	37	6	0	5	7
	Male	HML	47	322	17	280	364
		BUE	27	50	3	44	56
		MDS	52	23	2	18	28
		MDM	52	18	3	13	27

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
GC	Male	MDH	45	45	2	40	51
		EBR	51	61	4	53	68
		LCS	53	64	6	49	74
		HMTA*	52	318	74	184	594
		HMS	52	1	0	1	2
		HMR	47	6	1	5	9
		FML	51	454	23	401	503
		FTL	49	434	21	389	477
		APD	60	27	2	21	32
		MLD	60	32	3	25	38
		APS	56	30	3	24	36
		MLS	56	27	3	21	35
		VHD	58	46	2	41	51
		HHD	36	47	2	42	50
		FEB	43	81	4	73	89
		BCB	25	76	6	67	86
		FSJ*	60	61011	13499	20613	84768
		FSJstd*	51	418	118	208	716
		FSTA*	60	676	95	412	855
		FSS	60	1.18	0.12	0.90	1.52
		FSR	51	6.40	0.44	5.47	7.17
		FMJ*	56	53807	12166	22376	73883
		FMJstd*	50	370	102	192	624
		FMTA*	56	651	99	412	829
		FMS	56	1	0	1	1
		FMR	50	6	0	5	7
	Unknown	FML	2	442	2	440	443
		FTL	1	428		428	428
		APD	5	26	1	24	28
		MLD	4	34	1	33	35
		APS	5	31	2	28	33
		MLS	5	27	2	24	28
		VHD	3	44	0	44	44
		HHD	2	44	1	43	44
		FEB	2	78	2	76	79
		BCB	2	73	2	71	74
		FSJ*	4	66318	7705	56268	74688
		FSJstd*	2	525	117	441	608
		FSTA*	4	700	61	622	770

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
GC	Unknown	FSS	4	1.32	0.05	1.25	1.38
		FSR	2	6.73	0.54	6.35	7.11
		FMJ*	5	53805	8697	38630	60326
		FMJstd*	2	450	27	431	468
		FMTA*	5	649	70	528	700
		FMS	5	1	0	1	1
		FMR	2	7	0	7	7
NP	Female	HML	338	300	15	254	343
		BUE	304	45	3	39	60
		MDS	341	21	2	16	26
		MDM	341	15	1	11	20
		MDH	336	41	2	35	53
		EBR	314	56	3	44	64
		LCS	324	56	4	44	67
		HMTA*	341	241	37	151	393
		HMS	341	1	0	1	2
		HMR	334	6	0	5	7
		FML	389	418	20	364	480
		FTL	306	401	19	362	458
		APD	400	23	2	17	32
		MLD	400	31	2	24	39
		APS	403	26	2	20	33
		MLS	403	25	2	20	32
		VHD	385	43	2	36	49
		HHD	292	42	2	36	50
		FEB	276	75	3	66	87
		BCB	253	68	4	60	80
		FSJ*	400	49436	11411	12273	83028
		FSJ*STD	382	534	136	191	928
		FSTA*	400	580	80	347	855
		FSS	400	1.35	0.13	0.86	1.72
		FSR	382	6.48	0.40	5.30	7.56
		FMJ*	403	35888	9503	8771	65672
		FMJstd*	386	386	101	136	657
		FMTA*	403	512	70	330	755
		FMS	403	1	0	1	1
		FMR	386	6	0	5	7
	Male	HML	374	322	14	275	365
		BUE	335	50	2	42	58

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
NP	Male	MDS	385	22	2	15	28
		MDM	385	16	2	12	23
		MDH	377	46	2	39	54
		EBR	362	61	3	53	74
		LCS	373	60	4	46	75
		HMTA*	385	277	45	153	452
		HMS	385	1	0	1	2
		HMR	374	6	0	5	7
		FML	448	450	20	387	512
		FTL	366	432	19	378	540
		APD	457	26	2	19	36
		MLD	457	34	2	24	41
		APS	468	30	2	23	40
		MLS	468	27	2	20	36
		VHD	446	47	2	40	58
		HHD	329	47	2	40	57
		FEB	344	84	3	75	95
		BCB	312	77	4	67	92
		FSJ*	457	67047	10954	11403	98088
		FSJstd*	442	489	114	124	1150
		FSTA*	457	705	82	358	990
		FSS	457	1.33	0.14	0.74	1.78
		FSR	442	6.64	0.37	5.12	8.22
		FMJ*	468	52417	9408	14237	81998
		FMJstd*	448	382	89	149	842
		FMTA*	468	639	76	361	901
		FMS	468	1	0	1	2
		FMR	448	6	0	5	8
	Unknown	HML	17	304	14	280	340
		BUE	0				
		MDS	17	22	2	18	26
		MDM	17	15	1	13	18
		MDH	17	44	3	38	50
		EBR	0				
		LCS	0				
		HMTA*	17	264	33	212	325
		HMS	17	1	0	1	2
		HMR	17	6	0	5	7
		FML	6	380	54	315	456

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
NP	Unkown	FTL	1	407	.	407	407
		APD	5	24	4	19	27
		MLD	5	30	4	26	36
		APS	6	26	4	21	32
		MLS	6	23	4	19	30
		VHD	2	46	2	44	47
		HHD	0				
		FEB	0				
		BCB	0				
		FSJ*	5	45018	23499	18123	75123
		FSJstd*	5	881	277	505	1179
		FSTA*	5	564	156	388	763
		FSS	5	1.28	0.11	1.11	1.37
		FSR	5	7.19	0.36	6.76	7.52
		FMJ	6	29584	20963	6098	65696
		FMJstd*	6	456	157	234	687
		FMTA*	6	473	156	313	754
		FMS	6	1	0	1	1
		FMR	6	6	0	6	7
NW	Female	HML	2	297	1	296	297
		BUE	2	41	1	40	41
		MDS	2	21	1	20	21
		MDM	2	14	0	14	14
		MDH	2	39	1	38	39
		EBR	1	56		56	56
		LCS	2	54	1	53	55
		HMTA*	2	225	8	220	231
		HMS	2	1	0	1	2
		HMR	2	6	0	6	6
		FML	1	414	.	414	414
		FTL	1	395	.	395	395
		APD	3	26	4	22	29
		MLD	3	26	1	25	26
		APS	2	27	1	26	27
		MLS	2	26	1	25	27
		VHD	3	40	2	37	41
		HHD	3	40	2	37	41
		FEB	0	.			
		BCB	0	.			
		FSJ*	3	38453	10489	26898	47373
		FSJstd*	1	462		462	462

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
NW	Female	FSTA*	3	530	73	449	592
		FSS	3	0.99	0.17	0.89	1.18
		FSR	1	6.39	.	6.39	6.39
		FMJ	2	39943	5738	35885	44000
		FMJstd*	1	404	.	404	404
		FMTA*	2	542	44	511	573
		FMS	2	1	0	1	1
		FMR	1	6	.	6	6
	Male	HML	6	309	15	299	337
		BUE	7	50	3	45	52
		MDS	9	22	2	19	25
		MDM	9	17	2	15	19
		MDH	6	45	3	40	48
		EBR	6	62	4	54	66
		LCS	10	62	5	55	69
		HMTA*	9	296	50	224	373
		HMS	9	1	0	1	2
		HMR	6	6	0	6	7
		FML	4	434	13	425	452
		FTL	3	411	14	398	426
		APD	8	28	3	24	31
		MLD	8	29	2	25	31
		APS	7	29	1	28	31
		MLS	7	25	2	24	28
		VHD	6	46	2	43	49
		HHD	5	46	2	43	48
		FEB	1	84	.	84	84
		BCB	1	78	.	78	78
		FSJ*	8	53688	11830	32313	67098
		FSJstd*	4	481	77	419	584
		FSTA*	8	633	84	491	730
		FSS	8	1.03	0.11	0.93	1.21
		FSR	4	6.59	0.34	6.21	7.03
		FMJ*	7	45599	7472	38630	57581
		FMJstd*	4	402	80	291	480
		FMTA*	7	582	61	528	682
		FMS	7	1	0	1	1
		FMR	4	6	0	6	7
PR	Female	HML	19	300	27	205	329
		BUE	18	45	2	42	49
		MDS	21	21	2	17	25

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
PR	Female	MDM	21	15	2	13	20
		MDH	21	42	2	39	46
		EBR	19	56	2	52	60
		LCS	21	57	5	49	70
		HMTA*	21	256	50	184	393
		HMS	21	1	0	1	2
		HMR	19	6	1	5	8
		FML	25	422	19	391	457
		FTL	22	398	18	373	435
		APD	35	25	2	21	34
		MLD	35	31	3	25	37
		APS	33	27	2	21	30
		MLS	33	25	2	21	29
		VHD	29	42	2	38	47
		HHD	27	42	2	38	46
		FEB	14	74	4	68	81
		BCB	16	65	5	58	74
		FSJ*	35	53959	9246	34053	75558
		FSJstd*	24	542	152	312	935
		FSTA*	35	617	63	478	756
		FSS	35	1.26	0.16	0.74	1.52
		FSR	24	6.57	0.42	5.84	7.47
		FMJ*	33	36801	9004	16886	52139
		FMJstd*	25	378	121	170	626
		FMTA*	33	517	67	379	638
		FMS	33	1	0	1	1
		FMR	25	6	0	5	7
	Male	HML	13	321	14	296	349
		BUE	14	50	3	43	55
		MDS	19	24	2	21	28
		MDM	19	17	2	13	20
		MDH	15	47	4	43	59
		EBR	16	62	3	57	67
		LCS	19	63	4	54	71
		HMTA*	19	320	48	231	403
		HMS	19	1	0	1	2
		HMR	13	6	0	5	7
		FML	24	456	18	411	503
		FTL	22	435	16	396	471
		APD	28	28	3	22	34
		MLD	29	33	3	24	41

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
PR	Male	APS	29	31	2	26	36
		MLS	29	28	2	24	33
		VHD	27	47	2	43	52
		HHD	26	47	2	43	51
		FEB	20	80	4	70	86
		BCB	18	74	4	66	82
		FSJ*	28	68908	12169	47058	109473
		FSJstd*	23	466	90	279	693
		FSTA*	28	731	96	553	1063
		FSS	28	1.18	0.20	0.71	1.52
		FSR	23	6.67	0.40	5.84	7.68
		FMJ*	29	56367	9710	35909	79277
		FMJstd*	24	376	73	235	547
		FMTA*	29	673	83	509	877
		FMS	29	1	0	1	1
		FMR	24	6	0	6	7
SP	Female	HML	49	297	15	265	326
		BUE	47	44	2	39	51
		MDS	64	21	2	17	26
		MDM	64	15	2	11	22
		MDH	49	40	2	35	46
		EBR	49	55	4	48	66
		LCS	64	56	5	44	71
		HMTA*	64	244	46	170	347
		HMS	64	1	0	1	2
		HMR	47	6	1	5	7
		FML	52	418	17	373	453
		FTL	43	396	18	355	433
		APD	75	24	2	20	30
		MLD	73	29	3	22	37
		APS	75	27	2	22	34
		MLS	75	24	2	20	28
		VHD	56	41	2	37	49
		HHD	62	41	2	38	49
		FEB	37	73	4	67	86
		BCB	39	65	4	56	76
		FSJ*	73	44311	9261	23973	64608
		FSJstd*	50	495	134	277	898
		FSTA*	73	554	60	429	704
		FSS	73	1.23	0.18	0.81	1.85
		FSR	50	6.40	0.37	5.68	7.13

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
SP	Female	FMJ*	74	36383	8685	16910	54956
		FMJstd*	50	399	114	202	618
		FMTA*	74	513	62	380	641
		FMS	74	1	0	1	1
		FMR	50	6	0	5	7
	Male	HML	48	322	14	290	360
		BUE	51	49	3	41	55
		MDS	72	23	2	19	27
		MDM	72	17	1	14	20
		MDH	52	45	2	41	50
		EBR	55	60	2	55	66
		LCS	70	61	5	50	74
		HMTA*	72	295	39	236	424
		HMS	72	1	0	1	2
		HMR	48	6	0	5	8
		FML	57	450	17	413	494
		FTL	47	429	17	394	472
		APD	79	27	2	23	33
		MLD	78	31	2	24	36
		APS	76	31	3	26	37
		MLS	76	26	2	23	29
		VHD	59	46	2	40	51
		HHD	64	46	2	39	50
		FEB	42	82	3	76	88
		BCB	40	73	7	50	82
		FSJ*	78	58494	9332	40653	80538
		FSJstd*	56	443	107	261	799
		FSTA*	78	656	68	542	825
		FSS	78	1.18	0.14	0.83	1.44
		FSR	56	6.48	0.38	5.77	7.49
		FMJ	75	50196	8649	30491	71186
		FMJstd*	56	369	89	237	616
		FMTA*	75	617	68	470	792
		FMS	75	1	0	1	2
		FMR	56	6	0	6	7
SW	Female	HML	52	288	13	267	317
		BUE	52	44	2	39	49
		MDS	57	20	2	17	24
		MDM	57	14	1	11	16
		MDH	56	38	2	34	46
		EBR	53	53	3	47	60

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
SW	Female	LCS	57	55	4	48	64
		HMTA*	57	225	30	156	302
		HMS	57	1	0	1	2
		HMR	52	6	0	5	7
		FML	64	404	18	363	443
		FTL	60	384	18	350	423
		APD	68	22	2	18	29
		MLD	68	29	2	24	34
		APS	67	25	2	19	30
		MLS	67	24	2	20	29
		VHD	62	39	2	36	46
		HHD	64	39	2	35	47
		FEB	47	71	3	63	77
		BCB	47	62	5	51	78
		FSJ*	68	37896	9391	17253	59628
		FSJstd*	64	491	126	272	848
		FSTA*	68	507	60	382	641
		FSS	68	1.33	0.14	0.96	1.68
		FSR	64	6.29	0.34	5.59	7.10
		FMJ*	67	29822	9555	6074	54836
		FMJstd*	64	383	129	118	703
		FMTA*	67	468	67	314	661
		FMS	67	1	0	1	1
		FMR	64	6	0	5	7
	Male	HML	43	314	14	287	363
		BUE	44	49	2	43	54
		MDS	48	21	2	18	25
		MDM	48	16	1	13	19
		MDH	43	44	3	39	50
		EBR	48	59	3	52	66
		LCS	50	58	4	46	68
		HMTA*	48	262	35	194	358
		HMS	48	1	0	1	2
		HMR	40	6	0	5	7
		FML	58	433	21	382	474
		FTL	57	415	19	361	451
		APD	59	25	2	21	31
		MLD	59	32	3	26	37
		APS	59	28	2	23	35
		MLS	59	25	2	20	29
		VHD	56	45	2	39	50

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
SW	Male	HHD	57	44	2	38	50
		FEB	47	79	4	70	85
		BCB	48	71	4	59	79
		FSJ*	59	55596	10305	27333	75123
		FSJstd*	57	497	129	259	799
		FSTA*	59	628	70	445	763
		FSS	59	1.27	0.16	0.93	1.71
		FSR	57	6.51	0.37	5.55	7.20
		FMJ*	59	42427	9199	16934	63071
		FMJstd*	57	375	101	194	640
		FMTA*	59	560	70	379	715
		FMS	59	1	0	1	1
		FMR	57	6	0	5	7
Not Assigned	Female	HML	150	305	15	264	341
		BUE	20	44	3	37	51
		MDS	154	20	2	14	25
		MDM	154	16	2	12	22
		MDH	134	42	3	35	49
		EBR	143	55	3	44	65
		LCS	37	57	5	47	68
		HMTA*	154	246	42	132	373
		HMS	154	1	0	1	2
		HMR	138	6	0	5	7
		FML	274	435	23	382	525
		FTL	124	407	24	263	462
		APD	276	26	2	19	32
		MLD	276	28	2	22	36
		APS	273	27	2	20	35
		MLS	273	25	2	19	33
		VHD	257	42	2	35	50
		HHD	120	42	2	36	50
		FEB	241	75	4	56	85
		BCB	108	69	4	58	80
		FSJ*	276	45689	11360	18123	80973
		FSJstd*	258	407	128	167	820
		FSTA*	276	574	77	388	828
		FSS	276	1.11	0.12	0.81	1.43
		FSR	258	6.22	0.44	5.19	7.45
		FMJ*	273	37803	9629	8771	73859
		FMJstd*	259	334	101	95	668
		FMTA*	273	525	72	330	829

Table C.4. Continued.

Area	*Sex*	*Variable*	*N*	*Mean*	*Std Dev*	*Min*	*Max*
Not		FMS	273	1	0	1	1
Assigned		FMR	259	6	0	5	7
	Male	HML	304	331	20	266	391
		BUE	67	49	3	44	58
		MDS	310	23	2	18	29
		MDM	310	19	2	13	28
		MDH	285	47	3	39	57
		EBR	288	64	4	53	75
		LCS	92	64	5	52	78
		HMTA*	310	347	57	198	569
		HMS	310	1	0	1	2
		HMR	288	6	1	5	8
		FML	432	468	28	394	542
		FTL	175	439	27	352	508
		APD	429	28	2	21	38
		MLD	427	32	3	22	39
		APS	427	30	3	21	40
		MLS	427	28	2	18	35
		VHD	418	48	3	40	55
		HHD	181	47	3	40	54
		FEB	380	83	5	69	99
		BCB	160	77	5	66	91
		FSJ*	427	64594	13401	10533	100578
		FSJstd*	403	392	120	114	1152
		FSTA*	427	708	100	363	1015
		FSS	427	1.12	0.11	0.81	1.48
		FSR	403	6.41	0.43	5.15	7.95
		FMJ*	427	54766	10901	3401	92858
		FMJstd*	410	333	100	37	765
		FMTA*	427	661	91	297	1005
		FMS	427	1	0	1	1
		FMR	410	6	0	5	8

VITA

In 1994, Danny received his Bachelors of Arts in anthropology with minors in chemistry and biology from Wichita State University. Two years later, he earned his Masters of Arts in anthropology at the same institution. Danny became a Ph.D. student at the University of Tennessee in 1996, and admitted to candidacy in 2000.

While a graduate student, Danny actively engaged in scientific research. He participated in archaeological research in Kansas, Oklahoma, Texas, and Nebraska, and served as a crew chief for Dr. Donald Blakeslee at Waconda Lake. Danny also assisted Dr. Peer Moore-Jansen in the inventory and analysis of human skeletal remains from a number of Plains archaeological sites. Danny has received several research grants and authored / co-authored several peer-reviewed journal articles and technical reports. In addition, he presented numerous research papers and posters at professional conferences.

Danny also actively engaged in teaching while a graduate student. At Wichita State University, he served as a gross anatomy laboratory instructor for the Department of Health Sciences. Furthermore, Danny taught human osteology and introductory courses in biological anthropology at the University of Tennessee and anatomy and physiology at Pellissippi State Technical Community College.