5-1990

Metacarpal Entheses Changes as Evidence of Labor Differences in Non-Agricultural and Agricultural American Indian Skeletons

Catherine M. Goldsmith

To the Graduate Council:

I am submitting herewith a dissertation written by Catherine M. Goldsmith entitled "Metacarpal Entheses Changes as Evidence of Labor Differences in Non-Agricultural and Agricultural American Indian Skeletons." I have examined the final electronic 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.

Richard L. Jantz, Major Professor

We have read this dissertation and recommend its acceptance:

P. S. Willey, William M. Bass, John R. Finger

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a dissertation written by Catherine M. Goldsmith entitled "Metacarpal Entheses Changes as Evidence of Labor Differences in Non-Agricultural and Agricultural American Indian Skeletons." I have examined the final 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 Philosopohy, with a major in Anthropology.

Richard Jantz, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Provost
and Dean of the Graduate School

METACARPAL ENTHESES CHANGES AS EVIDENCE OF LABOR DIFFERENCES IN NON-AGRICULTURAL AND AGRICULTURAL AMERICAN INDIAN SKELETONS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Catherine M. Goldsmith

May 1990

ACKNOWLEDGMENTS

I am grateful to my committee for their trust and encouragement as this study was pursued. Many have assisted in bringing the ideas of this study into reality.

Thanks to those who made it possible to collect the data: in Knoxville, Dr. P. Willey for access to the Arikara, Averbuch and Anderson collections at the University of Tennessee Department of Anthropology, and Dr. Jefferson Chapman for access to the Eva, Three Mile, Big Sandy, Cherry and Ledbetter materials at the Frank H. McClung Museum of the University of Tennessee; in Lexington, Dr. George Milner and John Carter for access to the Indian Knoll collection at the University of Kentucky.

I would also like to thank those who assisted in the processing and preparation of the data: my committee Chair, Dr. Richard Jantz for helping me formulate and organize the task; Dr. Gonzalo Mendieta of the Wichita State University Department of Math and Statistics for helping in practically applying those guidelines; Dr. Chapman for discussion and demonstration of atlatl use; Wayne Conyers for insights into pottery making; Julia McCray-Goldsmith for the hand position graphics; Karen Schaff for permission to use her etching "The Glass Bead Game"; Dale Goldsmith for taking the photographs; Kitzel Services for processing the photographs; the Roxbury Parish Manse for the ideal retreat in which to study and write; Dale Goldsmith for typing the manuscript.

Three generations of my family have supported me in every way possible over the past eight years. Without their help, none of this would have been possible.

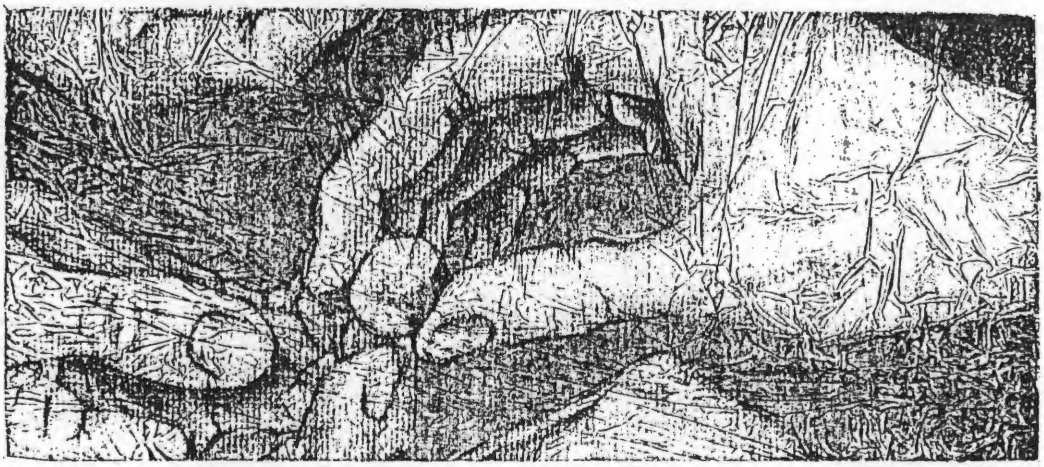
I am indebted to my professors and fellow students for leading me into the wonderful world of bones: particularly to Dr. Willey who taught me to study them, to Dr. Jantz who taught me to understand them, and to Dr. Bass who taught me to revere them.

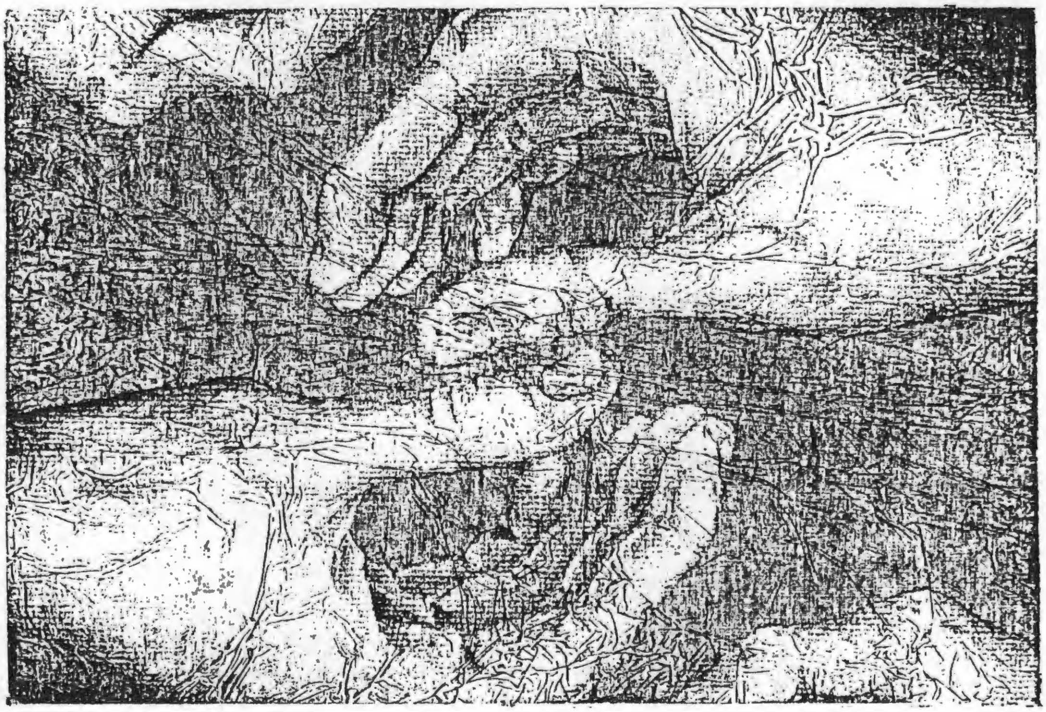
ABSTRACT

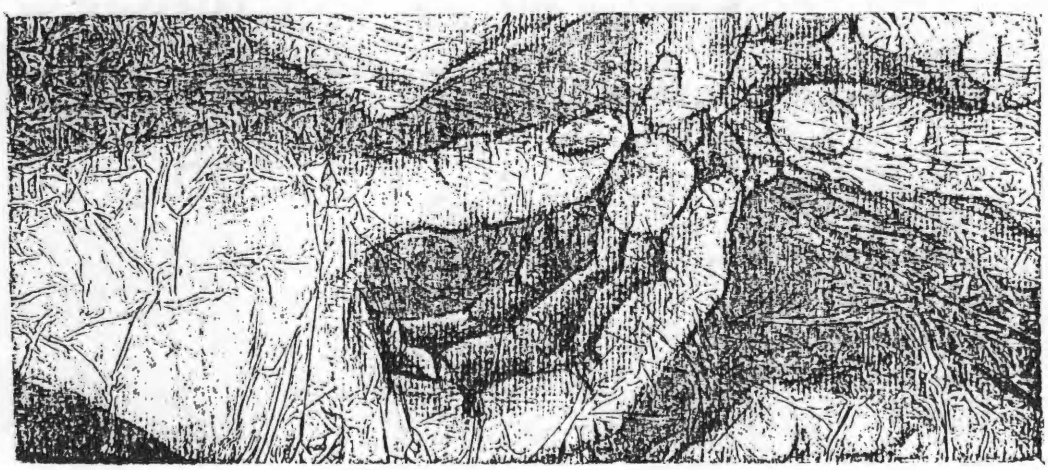
This investigation is to find differences in labor costs imprinted on skeletons of non-agricultural and agricultural subsistence groups in America. Eight entheses developments of muscles on metacarpals were measured comparing samples taken from Archaic Tennessee and Kentucky hands with those from Tennessee and South Dakota agricultural populations.

The two subsistence groups show agricultural hands have larger entheses for seven of the eight insertions. Cross-sectional dimensions of the sampled metacarpals show shape changes between the two groups. These are interpreted as reflecting changes in work loads on the hand, with heavier, more frequent, and larger loads being manipulated by the later, agricultural people. Increased lengths of metacarpals four and five in the agricultural peoples is interpreted as advantageous to the power grip that requires musculature on the ulnar side of the hand.

Efforts were made to interpret types of activities performed by specific muscle combinations, both within groups and by individuals.







Unlike soft tissue, bone is a biological record. Events in its past are recorded in a unique symbology on durable tablet. Although all the symbology cannot yet be translated, bones will keep until we learn to read better (Frost, 1963:vii).

PREFACE

Why Metacarpals

During the Spring Quarter of 1983, this investigator measured metacarpals from the University of Tennessee Arikara collection, searching for characteristics that might be used as genetic markers (Goldsmith, 1983). One of the least satisfactory measurements used in this study was curvature; this measurement was determined by the distance from the volar surface mid shaft to a line parallel with the furthest volar extension of the proximal and distal ends. Three things became obvious from observing the bones as this measurement was taken. First was the surprising variation, particularly on the proximal volar surface of the second metacarpal, even between hands of the same person. The second was the acknowledgement that it was not curvature that was being measured but rather the quantity of seemingly amorphous lumps on the volar bases of the bones. The third was that this observer, and perhaps others, had overlooked information the metacarpals might carry--of their own intrinsic nature--in an effort to use them as a convenient research resource.

The explanation for the observed variations must lie in previous work accomplished on these wonderful bones. After perusing the abundant literature on metacarpals, it was found that they had been used as a research resource to study many topics. Some of them were: age determination (Greulich and Pyle, 1959; Garn et al., 1967a); prediction of adult stature (Tanner et al., 1975; Musgrave and Harneja, 1978); human identification (Greulich, 1960); normal growth (Garn et al., 1975;

Dvlevsky, 1980); abnormal growth and nutrition (Yarbrough et al., 1977); abnormal growth and inherited syndromes (Gall et al., 1972; Hayes and Say, 1977; Park, 1977; Moerman, 1981; Butler et al., 1986); ethnic determination (Davies et al., 1980); arthritic conditions (James et al., 1982); osteoporosis (Garn, 1970; Horsman et al., 1981); osteoporosis and ethnic groups (Plato et al., 1982); twin studies (Kimura, 1983); bone grafting (Nathan and Fowler, 1976); handedness (Plato et al., 1980); grip strength (Plato and Norris, 1980); and continuing bone growth throughout life (Garn et al., 1967b; Garn et al., 1968).

The accessibility of the hand to x-ray has made it the ideal locus for serial studies that require comparative examination of the same subject (Garn et al., 1967a). The second metacarpal has been used as typical, perhaps because it is larger than the fourth and fifth metacarpals, more clearly visible in x-ray than the third metacarpal, and more easily identified because of its forked proximal end. Researchers treat MC2 as a real bone that represents the other 206 and draw conclusions for the whole by their study of that part (Plato and Norris, 1980). Though highly prized for its cross sections at midshaft, as dry bone in the skeleton it has not been studied for its own morphology.

Metacarpal preservation should be as good as other bones if excavated correctly (Sundick, 1978:232). Metacarpals are well represented in many skeletal collections of post cranial material. Their presence in the collections from Nanjemoy (74-75% of minimum number of individuals, totalling 529 metacarpals) (Ubelaker, 1974;35,36), Tranquility (seven "hands" from 25 adults) (Angel, 1966:3), Tepexpan (10 metacarpals!) (Genoves, 1960), Shanidar (25 metacarpals described and

measured) (Trinkaus, 1983), the Hadar Formation (18 identifiable metacarpals) (Bush et al., 1982; Marzke, 1983), Olduvai (a second metacarpal base) (Napier, 1962b), Sterkfontein (several metacarpals) (Ricklan, 1987), and Swartkrans (four metacarpals) (Susman, 1988) attests to their durability through time.

Only anatomy texts provided explanations for the irregular bone deposits observed on the Arikara metacarpals (Grant, 1951; Gray, 1977). Those "lumps" represented loci for insertions of a bewildering number of ligaments and tendons into the bony structure of the hand. To pursue the metacarpal morphology was to pursue the function of the entire hand.

Dr. William Bass supported and encouraged the initial venture into that study which was completed in 1984, using metacarpals from the University of Tennessee Arikara Collection (Goldsmith, 1984). Methods of measurement developed at that time have been largely applied to this work, and are described in Chapter Four that follows. One outcome of that study was the discovery that different patterns of hand use were revealed by variations in the size and shape of the insertion sites for each sex. The possibilities of comparative information were further expanded when perusal of Archaic metacarpals revealed very different patterns from those of the Arikara.

As a result, measurements taken of metacarpals from non-agricultural and agricultural skeletons are examined in this study in an effort to see if the differences in the insertion sites--entheses--might clarify differences in magnitudes and kinds of work.

(Abbreviations used in this study are found in Appendix A, p.239.)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER 1

INTRODUCTION

The scope of anthropology is broad--so broad that numerous sub-fields have been developed in order to investigate the full range of information available on man and his behavior. In the early years, anthropologists were content to describe the rich flood of evidence pouring in from world wide exploration, using systems of categorizing, naming, and labeling. Next came the placing of information in a comparative framework (Robertson, 1812; Morgan, 1877; Murdock, 1967), often using the observer's culture and values as the standards by which all others were categorized. As time passed, observers noted that categories of other groups did not remain constant; that cultural configuration was not stable. A new wave of descriptive scholars once more observed human behavior, now categorized as a sub-discipline--culture change. Informed by changing patterns long obvious to archeologists, culture change scholars began developing a body of theories that endeavored to explain as well as describe changes in cultural behavior (Steward, 1955; White, 1959; Bee, 1974). These theories of explanation again reflected the culture and values of the theorists, just as the taxonomists' theories had.

At a time when migration and conquest were actively occurring, both were seen as the causes for cultural change (Foster, 1960; Spicer,

1962). Again more effort was spent in defining the patterns of change than in searching for their cause--colonization and conquest being a given in the "western" culture those anthropologists represented.

Various leaps ahead--such as fire, the wheel, pottery and metal tools--were cited by culture change theorists as the high points on the road of progress. Food production came to be seen as the pivotal event that lifted man from the frantic animal search for resources and placed him in control of his environment (Childe, 1956). A new wave of description and explanation washed over the discipline that concentrated on the coming of food production into man's cultural developments (Binford and Binford, 1968; Netting, 1977).

Each scholar scrutinized the event through the lens of his own subdiscipline. Culture area specialists mobilized to determine when it had occurred in their areas (Braidwood, 1962; Coe and Flannery, 1964; MacNeish, 1967; Gorman, 1971; Asch et al., 1972). Other researchers traced the changes in the seeds first chosen to convert man the hunter into man the farmer (Watson, 1969; Ucko and Dimbledy, 1969; Chapman and Shea, 1981). The social evolutionists showed evidence of "readiness", the inevitable next step in sedentism, for such a significant development (Sauer, 1952; Service, 1972). Archeology was called upon to reveal the "when" of the event, using Carbon-14 dating to amplify previous traditional methods of stratification and settlement patterns.

Physical anthropologists joined in the search for the "when and where" of the invention of food production, striking a sound of discord in the chorus of praise. While examining skeletons in order to search for those signs of the where and when of agriculture, physical

anthropologists began finding evidence that problems such as nutritional anemia (Katz et al., 1974; Palkovich, 1984; Cohen and Armelagos, 1984), increase in tooth decay (Turner, 1979), decreased growth rates (Nickens, 1967; Larsen, 1984), increased incidence of disease (Lallo et al., 1978; Rose et al., 1984), increased warfare induced trauma (Perzigian et al., 1984; Cook, 1984), and increased mortality ratios (Buikstra, 1977; Cassidy, 1984; Goodman et al., 1984; Cohen and Armelagos, 1984) accompanied the entrance of agriculture into man's world.

Mark Cohen (1977) published a probing search for an explanation of why man had left hunting and gathering behind and turned to agriculture which was to his detriment. Writing in a time when world population increase was a crisis, Cohen grasped the anti-Malthusian theory of Boserup that states changes in agricultural technology occur in response to those in population density, rather than the opposite (Boserup, 1965).

Joined by paleopathologists in a 1984 symposium, Cohen and Armelagos searched for evidence of detrimental changes in human health with the coming of agriculture. They concluded:

> Although the data point fairly clearly to a decline in health associated with the origins of agriculture, it is not yet clear whether they confirm the particulars of the (Boserupian) population pressure model of agricultural origins. The generally negative slope of health and nutrition do conform to the model. . . . On the other hand, the data, though mixed, suggest an overall decline in work load and physical stress that may have helped to motivate the economic transition...In some studies, therefore, it is possible to interpret pathology trends in terms of the scenario described by Reidhead (1980) in which populations are seduced by declining labor costs associated with agriculture...(Cohen and Armelegos, 1984:595).

The question of a "better life" is left unanswered.

At the close of the symposium, one further area of study suggested was

> Change in bone remodelling patterns as an indicator of changing action patterns seems a fruitful area to look into the future--both for a better understanding of the causes and consequences of the rise of agriculture and for investigating occupational specialization (Roosevelt, 1984:575).

This is the point where this research joins the discussion.

Extensive research has been done on teeth and their response to changes in food types. Effects on the post-cranial skeleton have recently been examined (Ruff et al., 1984; Bridges, 1989b). This study will examine another part of man's body that is in the closest contact with his work and food processing, the hand. Using collections of pre- and post-agricultural American Indians, changes in the metacarpals will be studied that show changes in kinds and amounts of work. Specifically studied will be the built-up areas of bony platforms (entheses) that support the tendon attachments of the hand. The study is limited to those muscles that insert in bone (many insert in soft tissues leaving no skeletal record). The ultimate goal will be to discover if those measured entheses in the agricultural hands show greater use than those of the non-agricultural hunter-gatherers. Then, hopefully, we will know whose hands were investing the most labor in providing food--those who only harvested, or those who planted and cultivated as well.

CHAPTER 2

HAND BONE REMODELLING

Bone Remodelling

Bone has been described as having five principle functions. It provides the rigid framework to keep the body erect (Ortner and Putschar, 1981) and to counter gravity (Salter, 1983). It serves as the levers that are mechanically necessary for locomotor function and movement; it contains spaces for hemopoietic tissues; in its molecular composition are stored calcium, phosphorus, magnesium and sodium that can be released when needed; it protects vital soft tissues. This study deals with the first two functions.

Other studies have shown that bone has a tensile strength that resists being pulled apart equaling 12,000 pounds per square inch parallel to the longitudinal grain of the bone (Frost, 1964:125). Its strength in countering forces of compression are even greater (Shipman et al., 1985). Although it has tensile strength similar to that of cast iron, it is three times lighter and much more flexible (Ascenzi and Bell, 1972:327).

> As a tissue, bone is primarily adapted to compression, and under natural conditions, failure in the diaphysis as a result of pure compression is very rare (Lovejoy et al., 1976:491).

Since bone is such a solid, stable, durable material, always recognizable in distinctive form, it may be overlooked as a dynamic tissue that can change. Paleopathologists have noted and described those changes in bone that respond to fracture, disease and joint damage, but response of healthy bone to increased stress is a little explored field.

This is not a new idea. It was first recognized and formulated by Wolff in 1892 and has come to be known as Wolff's law. Since his description of the phenomenon, it has been reaffirmed (Ascenzi and Bell, 1972; Lovejoy et al., 1976; Burr, 1980; Plato and Norris, 1980).

> A perceptive man who watches living bone grow or adapt to disease must realize that he is seeing an exquisitely controlled directionality and metering of the cell behavior responsible for the form, size and location in space of bone (Frost, 1964:vii).

> The everyday activities of humans leave a permanent record in their skeleton (Merbs, 1983:iii).

> During life the amount of bone tissue and its distribution around the medullary cavity are adjusted to compensate for regularly occurring stresses . . . . The corollary of Wolff's Law is that changes in function or stress induce changes in structure (Shipman et al., 1985:59,48).

That bone can change its shape in response to stress is accepted fact.

There is still ongoing research as to when these changes happen and what processes produce them. Some feel that remodelling during growth is the only time that change occurs.

> The apparent association between physical stress and bone size has its origin prior to reaching adulthood (Plato and Norris, 1980:147).

> A diaphysis reponds to the total mechanical stresses imposed upon it during development, and these result from the combined activity of all muscles effecting strain in the bone (Lovejoy et al., 1976:490).

Others have examined changes in bone that have taken place in adulthood (Garn et al., 1967b; Garn et al., 1968; Garn, 1970; Smith, 1971; Garn et al., 1973; Pfeiffer, 1980; Ruff and Hayes, 1983a, 1983b; Salter, 1983). This study will pursue changes that occur both during growth and after adulthood is reached, since the forces causing these changes are present throughout life.

Early theorists saw bones as "merely static weight bearers" (Ascenzi and Bell, 1972:318) and therefore determined that changes would be mainly seen in the lower limbs, and some researchers today still follow this theory (Woo et al., 1981;.Ruff and Hayes, 1983a, 1983b; Ruff et al., 1984). Others now consider bones of the upper limbs as responding to the pull of the muscles that attach to them, with similar changes in form as seen in the weight bearing lower limbs (Lovejoy et al., 1976:490; Pfieffer, 1980; Ruff and Jones, 1981; Hamilton, 1982; Merbs, 1983; Bridges, 1985; Dutour, 1986).

> The shape of a bone is determined by the way in which the loads on it are located in space around its circumference and along its length. These factors are determined by a) the attachment and direction of pull of muscle; b) whether the attachment comes to a point as in a tendon attachment or is broad as with the fleshy origin of Quadriceps Femoris; c) the relative power of various muscle groups and d) the way in which muscle contractions are timed during normal usage (Frost, 1964:32).

The weight alone of muscles (2.4 times that of bone) (Ascenzi and Bell, 1972:314) influences the form of the bone supporting them. But

the pull of the muscle is even greater than its weight: "The loads due to body weight are usually less than 0.3 the magnitude of the muscle loads (Frost, 1964:32)."

How is that force of weight and muscle pull translated into action within the bone?

> It must never be forgotten that bone in the living organism is a living tissue. Throughout life there is a two way chemical traffic between bloodstream, cells and matrix, as a result of which the composition and structure of bone from the molecular level to the macroscopic is always changing (Pritchard, 1972a:3).

Bone and blood are intimately related, having arisen from the same embryological mesoderm (Shipman et al., 1985:22). It is now thought that once a stressed bone has signaled for help--both through a series of micro-fractures (Martin and Burr, 1982; Burr et al., 1984; Shipman et al., 1985:57) and a change in the piezoelectric current emitted by that bone (Currey, 1968; Ascenzi and Bell, 1972:333; Lanyon and Baggott, 1976:442; Pritchard, 1979:15; Salter, 1983; Shipman et al., 1985:62)--that monocytes circulating in the blood stop at the stressed bone site and begin their work as osteoclasts (Hancox, 1972:62; Pritchard, 1972b:37; Frost, 1980:221; Shipman et al., 1985:26).

Bone is removed parallel to the lines of tension (Frost, 1980:221), and new bone is laid down perpendicular to the strained surface (Frost, 1964:19).

> Bone has a special negative feedback system in which the strains at bone surfaces are converted into signals that guide special kinds of cells. Due to this guidance the cells adjust the size and shape of bone in such a way that future strains are minimized (Frost, 1967:54).

Enthesis Formation

These same responses to stress occur at the sites where tendons attach to bones (Frost, 1964:36-37). The change in those tendon attachment sites is the principle thrust of this study. The pull on the tendon induces the clastic/blastic activity that subsequently produces a bony platform known as an enthesis (McCart, 1979:98; Salter, 1983:201). As the tendons are used more and more by a developing child, the enthesis is built by the osteoclasts first excavating the existing bone surface; then the osteoblasts lay down the new, larger and stronger attachment platform (Figure 1). Recent experiments have shown bone remodelling is greatly increased under an intermittent load as opposed to a similar static load applied continuously. Evidently the remodelling procedure is activated again and again (Lanyon and Rubin, 1984).

The clastic, excavating stage has been examined by this researcher as seen in the metacarpals of Arikara sub-adults and in the x-ray studies of Levine (1972) on bone notching. This clastic process takes approximately three months (Frost, 1980:223) and may not be present for observation.

Tendons also increase in dimension in response to greater activity of the muscle attached:

> Transverse growth is set by the physical forces on it, a simple negative feedback system acting to add new tendon substance laterally when its longitudinal strain exceeds some minimum value (Frost, 1967:70)

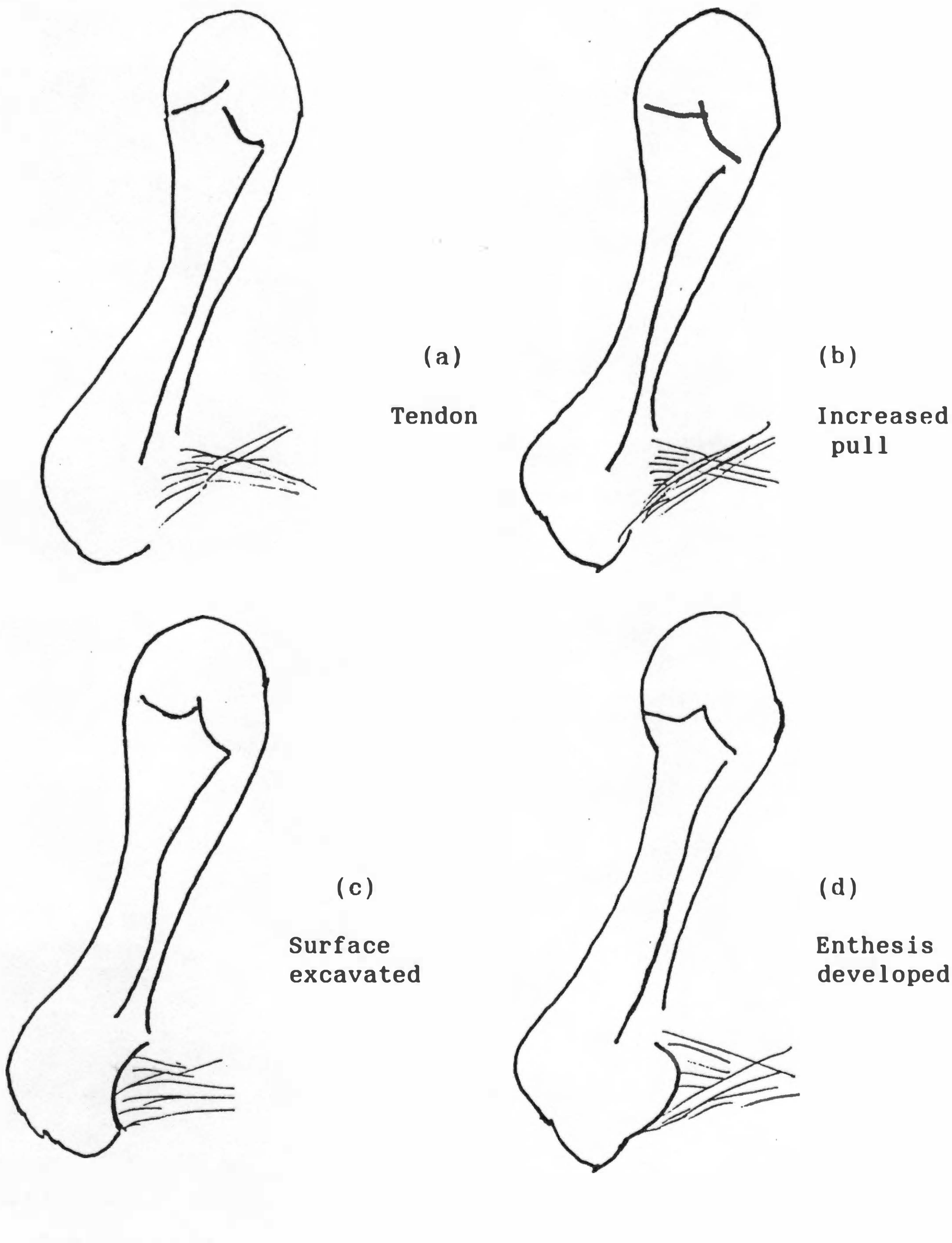


Figure 1. Enthesis Formation (after Frost, 1964, 1980).

since

> The cross section of tendons is exactly suited to the power of the muscles that pull through them. One never finds tendons in normal people which are too small or large for the muscle that activates them (Frost, 1964:105).

Frost outlines the process by which tendons increase in size in order to carry the increased mechanical load of the muscles attached to them.

> under repeated nontrivial tension loads that stretch the tissue beyond some as yet undetermined limit . . . some of the resident fibrocytes activate and make additional collagen, which increases the cross-section and thus the tensile strength and stiffness of the structure . . . ; the thickness, and thus the total strength of such structures reflects the mechanical loads they carry rather than any direct action of the endocrine mechanisms that control skeletal growth. In other words, again, function dictates structure (Frost 1980:220).

It needs to be clarified that the activity-induced changes in tendons are not caused by the tendon ripping out of the bone. The connective fibers in the tendon go on and penetrate into the bone, and virtually never become unattached. Hence the platform can increase in size while the muscle is still actively pulling on the bone. Collagen fibers in the tendon are strong and can withstand a pulling force of several 100 kilograms per square centimeter without breaking or elongating greatly (Shipman et al., 1985:281). The tendon may rupture at the muscle attachment, or the bone may be avulsed when a piece breaks out at the attachment site (Salter, 1983:23). This would indeed be referred to as an enthesopathy as used by Dutour (1986). Tendons may fray and rupture when drawn over a rough joint surface in such pathologies as

rheumatoid arthritis; however, of the insertions documented in this study, tendon ruptures of the Extensor Carpi Radialis, Extensor Carpi Ulnaris, and Flexor Carpi Radialis have never been observed, testifying to the success of enthesis building on those muscles (Verdan, 1979b:155,160).

Cultural Effects on the Skeleton

Numerous studies have been done recently in an effort to detect cultural effects on the skeleton (Iscan, 1988:215). Some have used changes in biomechanical loading in order to produce observable changes in the bone. This has usually involved submitting animals to surgical or exercise procedures that have created unnatural stress in order to yield an effect (Ruff, 1988; Schaffler, 1988; Lanyon, 1976).

Other studies have concentrated on decoding the messages hidden in bone from archeological collections by comparing cross sectional shape changes either by sectioning bones or using computerized axial tomography (Burr, 1980; Ruff & Hayes, 1983a, 1983b; Ruff et al., 1984; Brock & Ruff, 1988; Robbins et al., 1989).

Most previous studies of cultural effects on bone have concentrated on the examination and comparison of joint surfaces (Angel, 1966; Ortner, 1968; Jurmain, 1977; Pickering, 1979; Jurmain, 1980; Merbs, 1983). Many hand function studies have concentrated on joint function as well (Marzke, 1983; Marzke and Shackley, 1986). Newer studies have led to questons regarding the value of joint studies as the most effective means of investigating cultural activities (Bridges, 1989a:196; Rogers and Waldron, 1989:292). In this current study, joint activity was not

selected as a data source for several reasons. Entheses offered a much more direct means of explaining what muscles were acting on the bone and a better opportunity of estimating what activities were being performed. Interpreting activity through joint action takes the process one step further and clouds the explanation. Moreover, the definition of causes of joint damage--capsule inflamation, mechanical stress, or both--compounds problems of interpretation. Why study a door by examining the hinges? "There is evidence that the area of ligament attachment on a bone (the enthesis) may demonstrate a more direct link with use and exercise than the joints themselves" (Rogers and Waldron, 1989).

This is not to default joint studies already done, many of which have yielded surprising insights into human activity. The "exemplary study" of Merbs (Iscan 1988:215) serves as a model of both the frustrations of joint studies (Merbs urges that questions should not be asked of skeletal material that it cannot answer [Merbs 1983:2]) and the insight into causation that can result:

> The ultimate goal of this kind of study is to be able to reconstruct behavioral patterns of the past from pathological changes observed in skeletal remains. The value of this kind of tool for forensic as well as historical reconstruction should be obvious (Merbs, 1983:5).

Merbs finds two basic types of activity that cause joint damage. The first is doing some activity repeatedly that, though in itself is not "hard work", by its repetition fails to allow for cartilage recovery. This activity introduces the concept of a time factor. The repairing forces cannot catch up with the frequency of the damage, as in patterns of severe tooth wear. The second joint damage initiator is

some activity that is so forceful it damages the cartilage. Since it is the force that does the damage, repetition is not necessarily involved (Merbs 1983:159).

In this current study serious note is taken of Merbs' diagnostic interpretation of joint damage, and the double causes of "too often" and "too much"; or, frequency and force will be part of the investigative design for causation of enthetical platforming.

Merbs also shares his insights in interpreting the discovery of more joint damage on arms than on lower limbs of the skeletons he investigated. He states that since man has been bipedal for a long time, natural selection has had ample opportunity to dispose of the errors in man's walking equipment. But it is the upper limbs that have been subject to changing activities as man creates and recreates his own environment.

> The key to understanding the patterning of degenerative pathology lies to some extent in those kinds of activities which separate the hominids from other animals, erect posture and bipedal locomotion, but especially in those activities which have turned humans into highly effective hunters, creators of unique micro-environments and elaborators of culture in general (Merbs 1983:158).

Mark Cohen introduces the term "artificial agricultural economy" as a recent human invention--an artifact manufactured by human hands (Cohen and Armelagos, 1984:2). This study will search for and examine physical factors in the metacarpals that may reveal natural selection's efforts to help those hands catch up with the damage that agricultural activities have caused.

Metacarpal Remodelling

Since most remodelling in bones is caused by muscle pulls (Frost 1964:32), it is necessary to inquire if such processes are present in the non-weightbearing muscles of the hands. This study will endeavor to prove that such processes do take place in the hand. Nathan and Fowler's remarkable study (1976) covering a period of 52 years traces the replacement of a fifth metacarpal with a tibial graft, and shows how a bone splint was transformed into a functional, characteristically formed fifth metacarpal by the action of the muscles pulling on it. Function does determine form, even in the hand.

This study will deal principally with entheses formed during the course of normal activity. The metacarpals support many muscles in the hand and serve as tendon attachments for numerous flexors and extensors.

Although the muscle mass for most of the activity of the hand rests in the forearm (radius and ulna), the muscle action and pull is directly placed upon the bones of the hand. These bones respond exactly like the other bones of the body referred to in this chapter. Previous research states, ". . . grip strength was shown to be positively correlated with total width cortical thickness, and cortical area (of the second metacarpal)" (Plato and Norris, 1980:135). Metacarpals will be dealt with in this study with the expectation of seeing meaningful changes in the form of cross-sectional diameters and entheses heights and diameters as valid for the non-weight bearing hand as for the weight bearing bones.

CHAPTER 3

HAND MUSCLE FUNCTIONS

In order to search for meaning in the pattern of metacarpal entheses, it is necessary to understand the working of the hand--what it can and cannot do. During the course of studying the hand, even the soberest of anatomists has been captivated by its intricacies.

> The hand is an important functioning organ requiring rest and performing the greatest part of activities, including locomotion if need be. Through the hand, as through sight and hearing, we form a conception of the outside world. It is truly the extension of our brain into the surrounding world; it is the mirror of our innermost response to the outside world (Kaplan, 1965:3).

In Verdan's (1979) introduction to his text on hand tendon surgery he writes, "May the following chapters safeguard the living strength of our manual workers, the masterpiece of all instruments, the hand" (Verdan, 1979a:3).

> Under the skin, the hand is as tightly packed with anatomical devices as a pocket calculator is with electrical hardware, and like the later, the contents are encased in an unyielding framework (Napier, 1976:9).

The Hand as a Generalized Organ

Even while extolling the wonders of the hand, scholars acknowledge it is not unique in its form and function, but rather in its incorpora-

tion by man as a cultural tool (Napier, 1976:2). The organ that swims and swings, writes and wrings has kept pace with the galloping development of man's brain by staying generalized in evolutionary terms (Napier 1956:913). As Charles Darwin noted, the hand is part of the stamp that "Man, with all his noble qualities and God-like intellect still bears to remind him of his mammalian origins" (Napier, 1976:16).

The five digit hand is seen in reptiles 200 million years ago, and the shorter digit thumb, the eight carpals of the wrist and five metacarpals have been a functioning unit for 65 million years (Napier, 1976:2).

> It is a surprise to many that the human hand, which can achieve so much in the field of creative art, communicates such subtle shades of meaning, and upon which the preeminence of Homo sapiens in the world of animals so largely depends, should constitute in a structural sense, one of the most primitive and generalized parts of the human body (Napier, 1962a:56).

But it is that very generalized form that has enabled it to be useful for so long. The specialized organ that is fine tuned to a peculiar environment is the one that becomes obsolete when that environment changes. The generalized organ is not left behind, dangling off the limb of an evolutionary tree, but maintains enough flexibility in form and function to be incorporated in future surviving organisms (Sahlins and Service, 1968:18).

The variation described by anatomists in hands today (Singh, 1959)--ranging from changes in location of muscle insertions, nerve innervation and vascular branching--is maddening to the student and surgeon but testifies to the reservoir of alternatives still available for selection

(Grant, 1951:99A-F; Singh, 1959; Kaplan, 1965:138-142, 243-259; Johnson and Cohen, 1975:vii).

Those specialized parts of human anatomy--brain, foot, face, hip--do not bear the primitive stamp of the hand (Napier, 1976:2). As a result, the similarity of the hand in all primates--apparent to any zoo visitor--has been difficult for even scholars to believe. In tracing the progress of human development, the hand has not been as useful a benchmark (Susman, 1988) as other more specialized organs since,

> the primitive forebears of man were equipped with a hand of essentially human form long before the cerebral capacity necessary to exploit its potential had appeared (Napier, 1962a:56).

Consequently, we still see many prehuman characteristics present in the hand of Homo sapiens today (Kaplan, 1965:3; Ricklan, 1987). Such structures as the three pads at the base of the fingers, the base of the thumb (thenar eminence) and the "heel" of the hand (hypothenar) may be the easiest to note (Napier, 1976:5). Opinion is divided on whether the pads serve as protection against terrestrial locomotion, arboreal brachiation, or both (Marzke, 1971:62; Jenkins and Fleagle, 1975; Susman and Stern, 1979:565). Modern man joins the higher primates in the capability of pronating and supinating the hand 180 degrees (Marzke, 1971:65), of bearing considerable weight on a complex of 27 closely packed and strapped bones (Kelley, 1971:308; Marzke, 1971:73), of pinching and picking up small objects with an independent index-thumb combination while supporting weight on the other three digits (Marzke, 1971:62), of having an enlarged carpal space that permits greaater

activity by flexors in hanging by the hands (Marzke, 1971:65; Susman and Stern, 1979), but at the same time prevents bow stringing of those flexors when tensed under a load. Even the saddle shaped joint at the base of the first metacarpal, for some time thought to be uniquely human, is also present in all the apes except the gibbon (Marzke, 1971:68).

Several structural features permit the hand to be such an adaptable and adaptive organ. Some of these are the multiple complex of small bones encased in a tough integument, with muscular systems that cooperate to manipulate both parts and the whole (An et al., 1979). These bones are shaped and placed to serve as both stabilizing factors and fulcra for the mechanical action.

The carpal complex of eight irregular bones is closely packed to stabilize the wrist (MacConaill and Basmajian, 1977:294), carrying the force of action to the radius from such actions as carrying and brachiating, or by the same avenue transporting force from the arm to the hand. If we consider those eight bones in two rows of four, the joint between the radius and proximal row, the radiocarpal joint, is the location of most of the movement when the hand is flexed toward the ulnar side (Hamilton, 1976:103; Kaplan, 1965:248). The joint between the two carpal rows, the midcarpal joint, is even more active especially when the hand is bending back on the wrist and toward the radial side (Hollinshead and Jenkins, 1981:160). The final joint between the distal carpal row and the proximal metacarpals is the least mobile, since the proximal second and third metacarpals are nearly without movement (Ricklan, 1987:644). Another way to look at the suspensory function of the

carpal-metacarpal complex is as the framework of a marionette, the fingers becoming the dancing puppets.

Extrinsic and Intrinsic Muscles

The light weight hand (.9 lb. or .6% of a 150 lb. man, [Williams and Lissner, 1962:15]) maintains its super mobility not only by the system of multiple small bones, but by having 70% of the muscle weight that moves the hand remain in the forearm.

> The reduction in bulk obtained by the transformation of the muscles into tendons allows a far greater number of muscles to have access to the hand than would otherwise be possible (Hollinshead and Jenkins, 1981:127).

The large, power muscles originate relatively far away on the distal humerus. These are the extrinsic muscles whose bellies form the rounded outlines of the proximal two thirds of the forearm. These "outsiders" are each bound into a tendon that continues down the remainder of the forearm, inserting in specific locations on the carpals, metacarpals, and phalanges. Those on the dorsal surface of the arm draw the hand and fingers back, and by that function are extensors. Those on the underside of the arm continue toward and through the palmar area, drawing the hand into a fist, and are thereby labeled flexors.

Another group of muscles--"insiders"--arises and inserts within the hand itself. These are short, smaller muscles known as the intrinsics. One group is clustered into the thenar eminence at the base of the thumb; another forms the hypothenar on the heel of the hand, and a third group is located between the metacarpals and out onto the phalanges.

Although these intrinsic muscles are incorporated in larger movements of the hand, their main function is to spread the hand and draw it back together.

Directional Hand Actions

It is necessary to clarify actions and directional terms for hand functions (Plates 1,2,3). Extension draws the hand parallel with the floor with fingers straight (Figure 2); flexion draws the hand down with fingers curved (Figure 3). Abduction spreads the fingers apart from an imaginary line running the length of the middle finger (Figure 4); adduction draws the fingers back toward that same line (Figure 5). In the anatomical position, the palms face anterior, placing the medial toward the little finger, the lateral toward the thumb. This study will avoid the use of those two terms that can easily confuse, and instead will use the term radial for toward the thumb side of the hand (Figure 7), and ulnar indicating toward the little finger (Figure 6).

The thumb has its own planes of action, although the same terms are used in description. To clarify these terms, this study will use the following definitions for actions of the thumb. When a ruler is placed across the back of the hand, the thumb is extended as it moves away from the other fingers, toward the end of the ruler (Figure 8). The thumb is flexed when it moves back toward the other end of the ruler, across the palm of the hand (Figure 9). When the ruler is held between the thumb and the hand, the thumb is abducted when it moves toward the end of the ruler that is down from the palm (Figure 10). The thumb is adducted when it returns to its place holding the ruler (Figure 11).

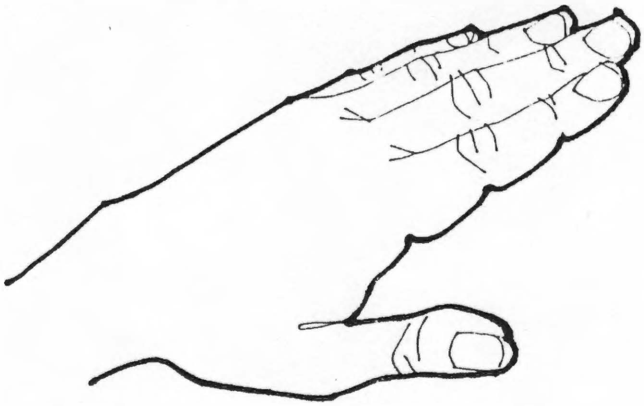


Figure 2. Hand extended.

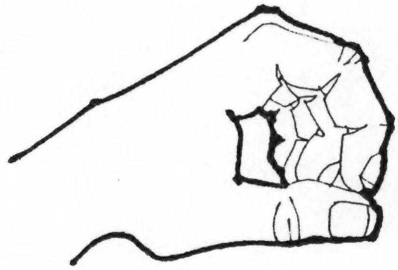


Figure 3. Hand flexed.

Figure 4. Hand abducted.

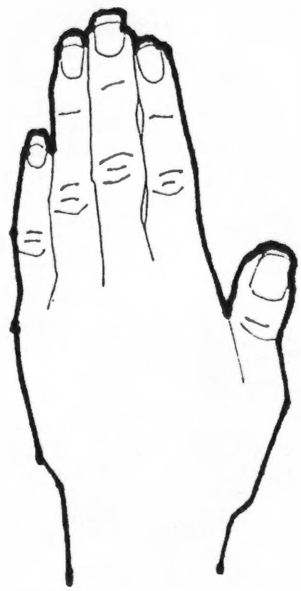


Figure 5. Hand adducted.

Plate 1. Hand Positions

Figure 6. Hand turned ulnar.

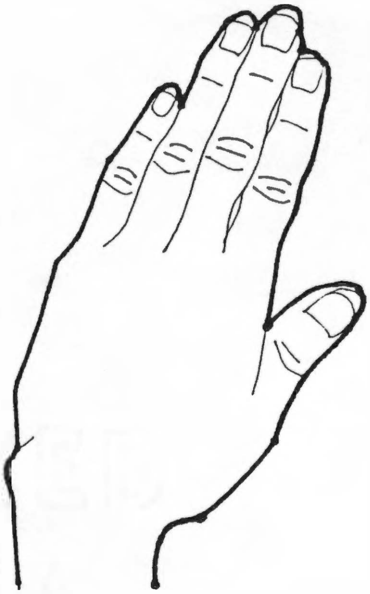


Figure 7. Hand turned radial.

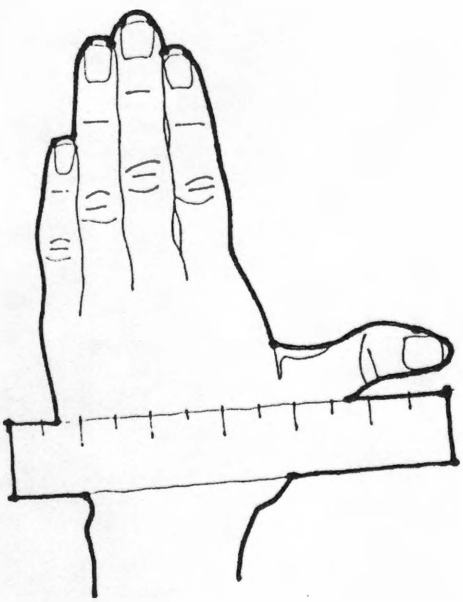


Figure 8. Thumb extended.

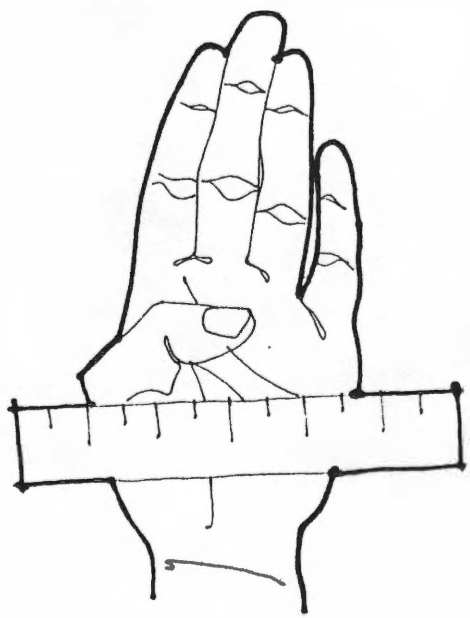


Figure 9. Thumb flexed.

Plate 2. Hand and Thumb Positions

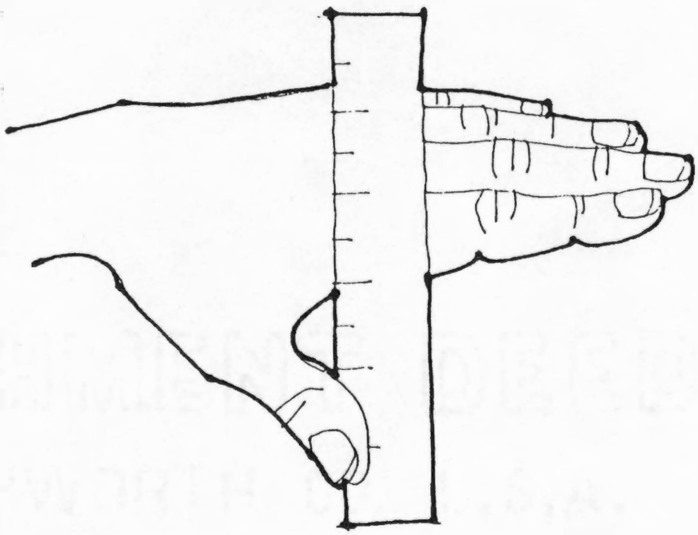


Figure 10. Thumb abducted.

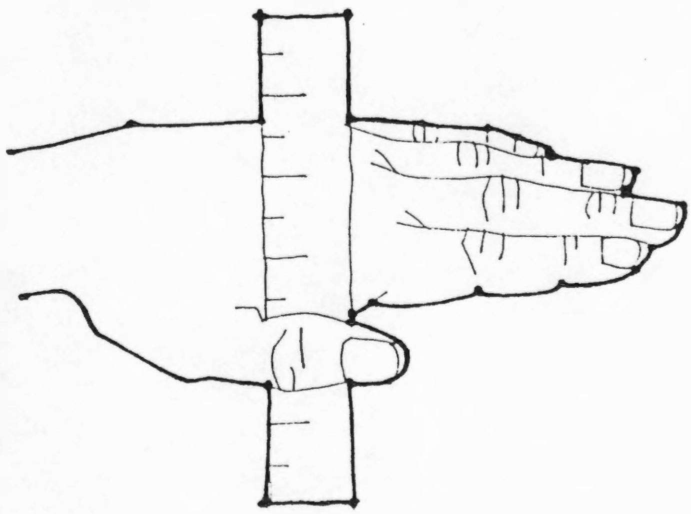


Figure 11. Thumb adducted.

Plate 3. Thumb Positions

Functional Hand Anatomy

In describing and interpreting the actions of the hand, there are several problems that prevent crisp definitions. With so many bones and muscles acting and being acted upon within the same area, cooperation is a must. This may mean several muscles cooperate to perform an action while others relax and are pulled along passively (Basmajian and DeLuca, 1985:291; Kaplan, 1965:14). It may also mean that muscles that have been named for their location and principle function are found taking part in actions that are the opposite of that name (MacConaill and Basmajian, 1977:284). Some examples of such hand muscle synergism are:

> Adduction of the thumb toward the palm . . . can be brought about only through the combined actions of the adductor and the extensor pollicis longus (Hollinshead and Jenkins, 1981:94)

or

> There is a comparative shortness of the long flexors of the fingers, so that complete extension of the wrist and the metacarpo-phalangeal joints are required for efficient flexion of the distal and proximal inter-phalangeal joints (Kaplan, 1965:202).

The specific actions of the hand and wrist muscles were first discovered and described by Duchenne in 1867, using electric current (Faradization) applied to different muscles to see what action resulted when a charge was applied (Duchenne, 1867:111; MacConaill and Basmajian, 1977:6). Much later electromyography was developed, using tiny wires inserted into the muscles, that record the actions of the muscles initiated by the individual, rather than causing the action (Long et

al., 1970:55). This later method has given us the insight into muscles grouping in action according to the task. Finally, electromyography has been combined with cinematographic x-ray to yield information on what happens to the bones in the hand at the same time muscle actions are recorded (MacConaill and Basmajian, 1977:13). In this study, general hand anatomical information has been selected from the following sources: Moseley, 1955; Romanes, 1964; Thompson, 1965; Poland et al., 1977; An et al., 1979; Armstrong et al., 1979; Winckler, 1979.

Both sensory and motor structures of the human brain have a disproportionately large area allocated to the hand (Washburn, 1972). The guidance and nutrient systems of the hand reach their destination after a journey from their origins, over the shoulder, elbow, and wrist joints. The innervation comes from the fifth through eighth cervical and the first thoracic nerves (Hollinshead and Jenkins, 1981:154). The blood supply comes from the subclavian arteries and returns via the subclavian veins (Gray, 1977:514,609). Once in the hand, both nerves and blood vessels fan out to richly supply every area. There is considerable variation in the pathways of dispersal, many areas receiving branches from several systems as a safeguard against loss of function.

Groupings of connective tissues bind the multiple components of the hand together firmly, while still maintaining flexibility. Beginning at the wrist, the carpals are interconnected by many, tiny short ligaments that curve the bone group into a dorsally arched complex, directing force to and from the hand through the capitate in the center (MacConaill and Basmajian, 1977:274). Broad bracelets of connective tissue circle the dorsal surface of the wrist (Extensor Retinaculum) and the

volar surface (Flexor Retinaculum) attaching the tubercle of the trapezius to the hamate hook, forming a tunnel with the arched carpal bones (Hollinshead and Jenkins, 1981:133). The Extensor Retinaculum contains small channels for the passage of the long tendons from the extrinsic extensors, while the extrinsic flexors enter together through the carpal tunnel on the volar (palmar) side of the wrist. A thick extension of connective tissue covers the palm with a tough cartilage pad (palmar ligament) protecting the volar side of each knuckle at the metacarpo-phalangeal joints (Hollinshead and Jenkins, 1981:171). On the dorsal side, a tough but flexible hood covers each finger joint, visible on the surface by the pleated skin over each knuckle. The heads of metacarpals two through five are closely attached by the extra tough transverse metacarpal ligament.

The muscles activating this uniquely organized structure always pull toward their origins. Therefore, in order to abduct and adduct the hand and fingers, muscles have to arrive at their insertions by a diagonal route (Fahrer, 1979). Some extrinsic tendons cross the wrist diagonally to accomplish this, while other intrinsic muscles arise on the very retinaculum binding the wrist, and cross quickly to their insertions. Still others, the interossei between the metacarpals, are pennate or bipennate in form, the muscle fibers being inserted diagonally into an action bearing tendon.

"Just as the primary function of a muscle is to contract and then to relax, so the essential requirement of an intact tendon is to glide" (Verdan, 1979a:1). Encased in capsules filled with synovial fluid, singly or in groups, the tendons glide back and forth--the extensor and

flexor systems complementing one another. The flexors glide as much as 4 cm. at the base of the fingers and more than 8 cm. at the wrist (Verdan, 1979a:1).

Since the flexors are shorter at rest than the extensors (the resting hand has slightly flexed fingers), the lumbrical system--attached to both flexors and extensors at the metacarpo-phalangeal joint--pulls the flexors distally to permit the extensors to work (Long, 1968:973). Likewise, the flexors cannot grip tightly unless the extensors bend the wrist backwards slightly during flexion (Duchenne, 1867:115; Hollinshead and Jenkins, 1981:191).

For the hand to function usefully, the arm that supports it must be free of collision with the torso (Shipman et al., 1985:101) and must position the hand directionally--palm up or palm down. The first and most basic action necessary for a hand to perform its necessary tasks is to counter the pull of gravity (Landsmeer, 1979:30); very little work is done with the hand hanging straight down (Hollinshead and Jenkins, 1981:154). It is the powerful unit of extensor muscles whose tendons attach at the proximal bases of the metacarpals that pulls the hand parallel to the floor, positioning it for the finger activities which follow (Hollinshead and Jenkins, 1981:181). The center of gravity in the hand is along the axis of the third metacarpal in just about the center of the palm (Williams and Lissner, 1962:15). That point is drawn upwards on the platform of metacarpals snugly packed into the distal carpal row, movement taking place at the midcarpal joint (Hollinshead and Jenkins, 1981:170).

Power Grip and Precision Grip

In trying to explain and understand the group actions within the hand, scholars have approached the problems in terms of the tasks to be done. Two main categories have been agreed upon--power grip and precision grip, with sub-variations in each category (Napier, 1976:12). Power grip is when the fingers and palm act as the two jaws of a gripping force, pressing an object into the palm tightly and then manipulating it in that securely gripped position (Long et al., 1970:854; Napier, 1956:909). (Napier [1962b] has shown that Oldowan tools could have been made by early Hominid hands using only the power grip.) A modern example is holding a hammer handle. The main force is performed by the extrinsic muscles, particularly the squeezing flexors, but they require the extensors to pull the wrist back for a good, tight grip. The power in a power grip is exerted toward the ulnar side of the hand since metacarpals four and five have hinge joints at their proximal ends and can squeeze tightly (Basmajian, 1971:100A). (It will be recalled that metacarpals two and three are nearly immobile at their proximal ends.) The thumb is actually used to lock the other fingers into position in such a grip (Napier, 1956:908). A larger dimensioned object such as a ball or jar lid requires the power grip with some additions from the shorter intrinsic muscles to abduct and adduct the hand (Basmajian and DeLuca, 1985:299).

The precision grip manipulates an object without clamping it tightly to the palm (Long et al., 1970:854). This action has been used by some to define the genus Homo (Leakey et al., 1964:7). Others have

found that combinations of the power and precision grips must have been used to manipulate unmodified stone tools by Australopithecines (Marzke and Shackley, 1986). To use the precision grip, the fingers may be in any combination of flexion or extension, with the radial side of the hand predominating using the opposition of the thumb to fingers two and three (Napier, 1956:911), see page vi in Preface. Turning a screw or sewing requires the precision grip. The two grips may be combined--as in turning a screw driver when the ulnar side of the hand is gripping the handle and the radial trio turns the shaft (Long et al., 1970:863); or, when opening a jar lid, the power grip first loosens the lid then the precision grip finishes the job (Napier, 1976:13). Some have suggested a third category of action--the hook grip--which is used to suspend brachiators from a tree limb, or reversed in position serves to carry buckets or basket handles (Napier, 1976:12). Functionally, the hook grip is really a form of the power grip with the greatest force on the ulnar side of the hand.

The newborn comes equipped with the power grip (on a parent's index finger) and long before he can walk is proficient at capturing a tiny piece of lint off the floor with a determined precision pinch.

CHAPTER 4

RESEARCH DESIGN

Hand Entheses and Muscles Studied

The extensors and flexors of the wrist are called upon to position the hand for nearly every action. The area of insertion on the metacarpals is clearly marked, with the size of the insertion platform, the enthesis, corresponding to the amount of use the hand has experienced. Unfortunately the universality of function of these muscles makes it difficult to clearly discriminate what action each was performing. Nevertheless, these have been chosen as principle topics for this study.

Of the seven muscle insertions recorded (Plates 4 and 5), three are from the wrist extensors, one is from the wrist flexors, two are used in the opposition of the thumb and ulnar side of the hand, and one is used in adduction and abduction of the thumb. It is hoped that by studying these singly and in combination, it may be possible to develop definitions of what activities were carried out by hands of hunter-gatherers, and if they differ from those of the agriculturalists.

Extrinsic muscles selected for study are the Extensor Carpi Ulnaris (Figure 12), Extensor Carpi Radialis Brevis (Figure 13), Extensor Carpi Radialis Longus (Figure 14), and Flexor Carpi Radialis (Figure 17). Intrinsic muscles studied are the Opponens Pollicis (Figure 16), First Dorsal Interosseous (Figure 18), and Opponens Digiti Minimi (Figure 15).

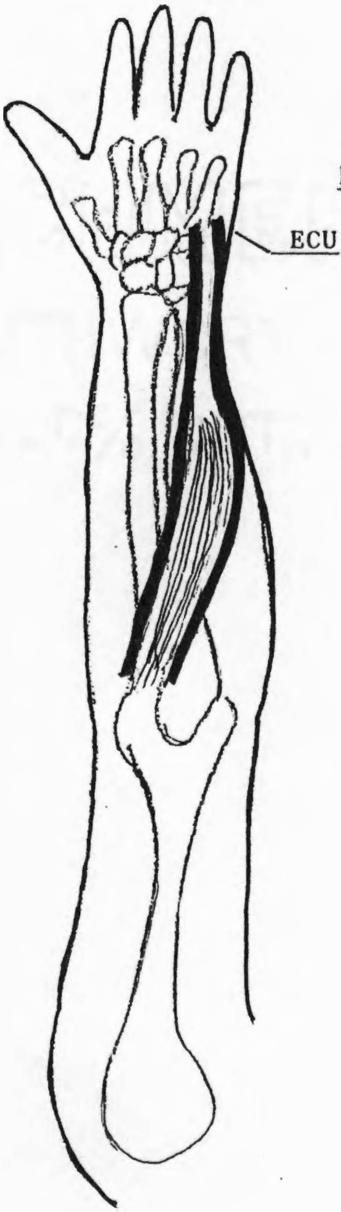


Figure 12. Extensor Carpi Ulnaris

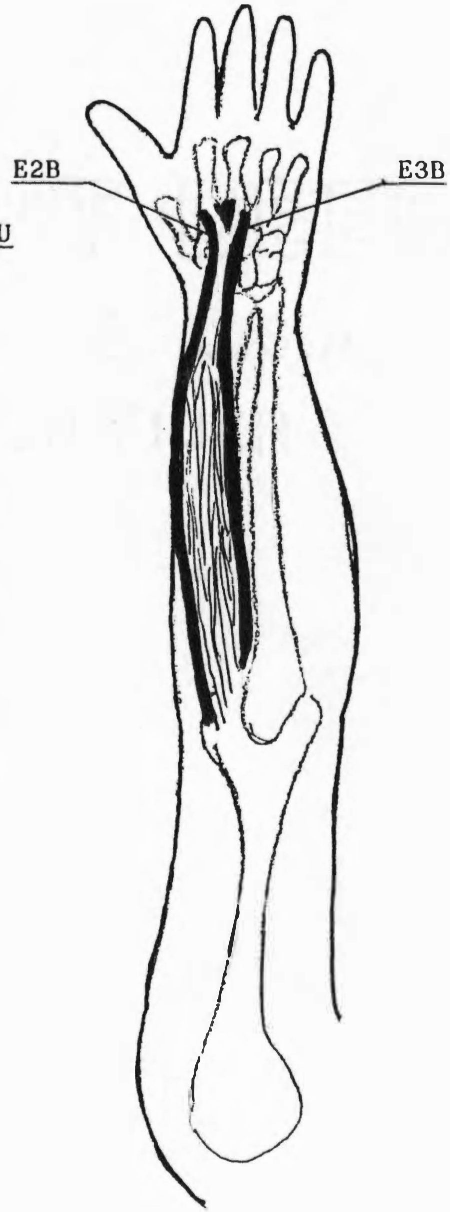


Figure 13. Extensor Carpi Radialis Brevis

Figure 14. Extensor Carpi Radialis Longus

Plate 4. Extensor Muscles

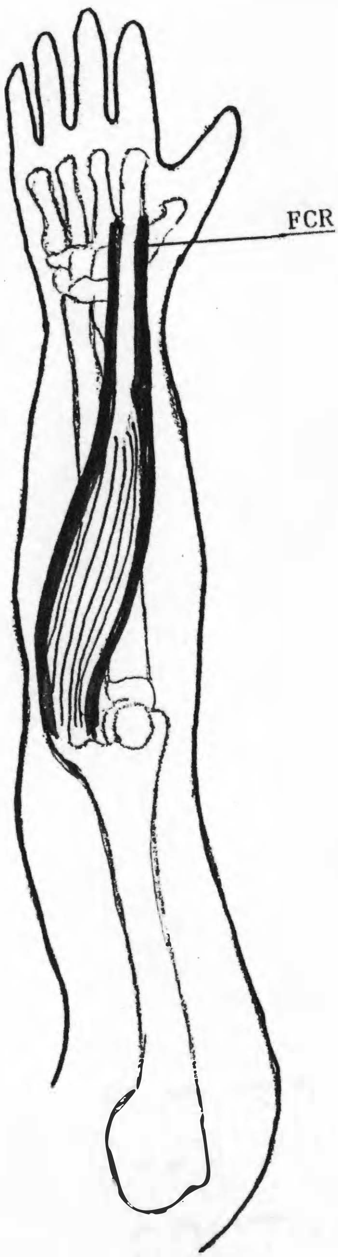


Figure 17. Flexor Carpi Radialis

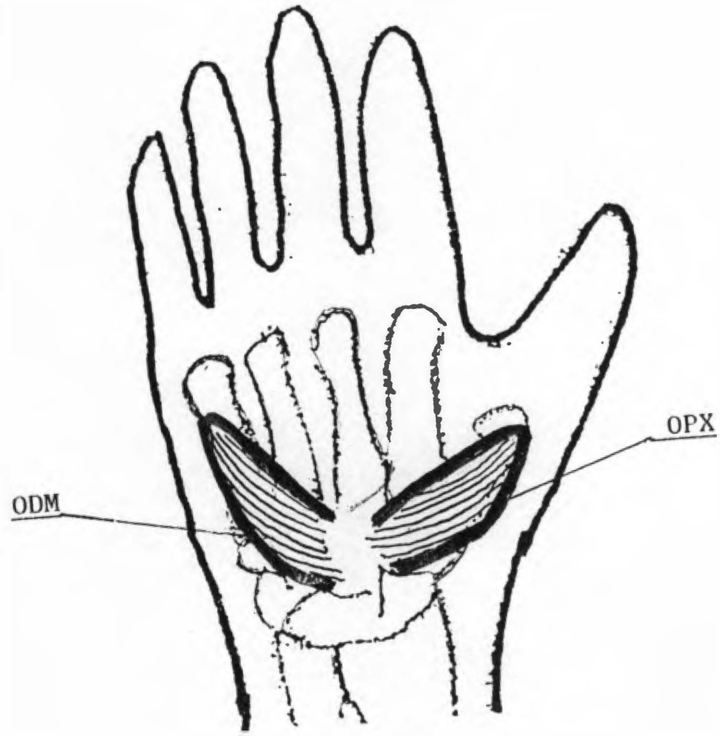


Figure 15. Opponens Digiti Minimi

Figure 16. Opponens Pollicis

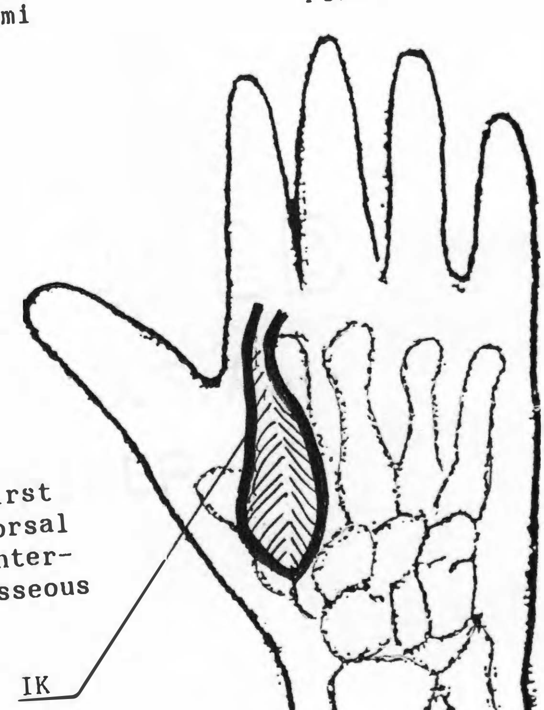


Figure 18. First Dorsal Interosseous

Plate 5. Flexor and Intrinsic Muscles

1. In the thenar eminence, Opponens Pollicis (Figure 16). An intrinsic muscle, it originates from the Flexor Retinaculum in the proximal center of the palm and inserts a short distance later in a shelf like line running along the radial, dorsal edge of the first metacarpal.

Activitated by the median nerve, it helps draw the thumb across the palm toward the ulnar side. It is a key muscle in grasping tools such as hoe and hammer firmly (Hollinshead and Jenkins, 1981:194), in holding tightly to large objects in a power grip (Basmajian and DeLuca, 1985:303,305), and in pinching firmly the tips of fingers four and five in a precision grip. In this study, the Opponens Pollicis will be referred to by the initials OPX.

2. Located in the web between the thumb and index finger, the First Dorsal Interosseous (Figure 18), an intrinsic muscle that originates along the ulnar surface of MC1 and the dorsal radial surface of MC2. This bipennate muscle inserts into the extensor hood on the radial side of the proximal phalanx at the metacarpal-phalangeal joint of the index finger. Activated by the ulnar nerve, its function is to draw the thumb and index finger together in a pinching motion when the index is flexed (Basmajian and DeLuca, 1985:295). It can be palpated in the web, while drawing the thumb toward the hand when fingers are spread and are extended palm down on a flat surface (Kaplan, 1965:225).

It is especially active on a long pinch against resistance, or when the index finger is flexed at the metacarpal-phalangeal joint, but extended at the inter-phalangeal joint, or when action is rapid, such as quickly waving "bye-bye" from the metacarpal-phalangeal joint. In the precision grip, the First Dorsal Interosseous keeps the index abducted

against the adducting pressure of the thumb (Long et al., 1970:862-864; Basmajian and DeLuca, 1985:292). This muscle is more prominent in humans than in the other primates with the exception of the gibbon (Marzke, 1971:80). In this study, the first dorsal interosseous is referred to by the initials IK, after the Indian Knoll collection where its prominence was first observed.

3. On the radial side of the wrist, Extensosr Carpi Radialis Longus (Figure 14). An extrinsic muscle, it originates in the common extensor tendon at the lateral epicondyle of the distal humerus. Innervated by the radial nerve, it travels the entire length of the forearm, passing through the Extensor Retinaculum and inserting on the proximal radial surface of MC2.

One of the anti-gravity extensors, it not only lifts the hand but abducts it to the radial side (Kaplan, 1965:253). This muscle is particularly active in drawing the hand back to assist the flexors in making a fist (MacConaill and Basmajian, 1977:283). It also aids both in flexing and supinating the forearm (Hollinshead and Jenkins, 1981:150,161). The contraction of the belly of the Extensor Carpi Radialis Longus can be palpated just distal to the elbow crease when the hand is drawn backwards in a fist. In this study it is referred to by the initials ERL.

4. On the volar side of the wrist, Flexor Carpi Radialis (Figure 17). An extrinsic muscle originating from the common flexor tendon on the medial epicondyle of the humerus, it is innervated by the median nerve. It passes obliquely across the ventral side of the forearm, entering the hand just to the edge of the carpal tunnel (Hollinshead and Jenkins,

1981:138) having its own synovial sleeve, and inserts in the center of the volar surface of proximal MC2. A powerful bipennate muscle, this is one of the two principal flexors of the wrist, Flexor Carpi Ulnaris (not studied here) being the other (Kaplan, 1965:138). It draws the hand ventrally toward the radial side, contracting strongly when the fingers are flexed. When completely flexed it contributes to pronating the forearm and bending the elbow (Kaplan, 1965:251; Hollinshead and Jenkins, 1981:159). It balances and controls the extension of the fingers, and is active in almost every function of the hand. The tendon can be palpated by placing the open hand under the corner of a table, and when the effort is made to lift, the Flexor Carpi Radialis is the tendon on the radial side of the two that can be felt at the volar wrist (Hollinshead and Jenkins, 1981:146). In this study it will be referred to by the initials FCR.

5. Another of the extrinsic anti-gravity extensors, the Extensor Carpi Radialis Brevis (Figure 13) arises from the lateral epicondyle of the humerus, just distal to the origin of ERL (Kaplan, 1965:140). Innervated by the radial nerve, as is its companion muscle, the ERL, they both share a synovial sheath in entering the base of the metacarpal area through the Extensor Retinaculum (Hollinshead and Jenkins, 1981:150). The Extensor Carpi Radialis Brevis inserts both on the dorsal proximal surface of MC2 on the ulnar side, and on the dorsal proximal surface of MC3 on the radial side. It is the more active of the two radial extensors, both in slow and fast movement (Basmajian and DeLuca, 1985:290). In this study, the Extensor Carpi Radialis Brevis

insertion on MC2 will be referred to by the initials E2B, and that on MC3 as E3B.

6. The third of the three wrist extensors, Extensor Carpi Ulnaris (Figure 12 [p.32]). This muscle originates on the lateral epicondyle, as do the other two wrist extensors, but distal and posterior to their common tendon. It also includes muscle fibers from the fascia of the other muscles, and is bound in its own fascial tunnel attached along the posterior border of the ulna (Kaplan, 1965:141). Passing over the ulnar styloid process, it inserts into the ulnar side of proximal MC5. Innervated by the radial nerve, the primary function of the Extensor Carpi Ulnaris is to draw the hand back, joining the Flexor Carpi Ulnaris (which is not included in this study) in turning the hand toward the ulnar side (Kaplan, 1965:253). It takes part in the normal flexion of the fingers (Kaplan, 1965:199), automatically going into action to stabilize the wrist during forced extreme flexion; the other two extensors do not (Basmajian and DeLuca, 1985:290). Duchenne noted that in a pathological hand without the use of the Extensor Carpi Ulnaris, the entire hand moved radially when the thumb was extended (Duchenne, 1867:119). The tendon of this muscle can be palpated passing the styloid process of the ulna when the wrist is extended (Hollinshead and Jenkins, 1981:156). In this study this muscle will be referred to by the initials ECU.

7. Along the ulnar side of the hypothenar eminence, Opponens Digiti Minimi (Figure 15 [p.33]). This is an intrinsic muscle, originating from the Flexor Retinaculum and the hook of the hamate. Its insertion along the ulnar border of MC5 extends almost the full length of the

bone. Innervated by the ulnar nerve, this opponens is active in opposition to the thumb, in cupping the hand and in grasping tools (Hollinshead and Jenkins, 1981:177; Basmajian and DeLuca, 1985:302). It can be palpated in its action of tightening the hypothenar as it responds to the opposition of the thumb moving toward the ulnar side of the hand. In this study the Opponens Digiti Minimi will be referred to by the initials ODM.

Methods

Every effort was made to select individuals for study that had both right and left hands represented. In the cases where all ten metacarpals were not present, the complement was not used to substitute for the missing bone. Preference was given to individuals who had a measurable femur present, since physiological length of that bone was used as the standard for a component of size of person (Bass, 1971:168). Sex was determined by the observations of Phenice on the pubis (Phenice, 1969), and/or measurements of the heads of the humerus and femur (Bass, 1971), and anterior/posterior measurement of the tibia (Symes, 1982), and/or other anatomical locations (Acsadi and Nemeskeri, 1970).

Three age categories were used. Only bones with epiphyses completely attached were measured, and any hand that retained an epiphyseal line on the distal metacarpals was listed as "young". Categorized as "old" was anyone who evidenced severe lipping on the vertebra, severe tooth wear or was edentate, or showed a smooth disintegrating surface on the pubic symphysis. Listed as "middle" was anyone between these two extremes.

Using a sliding caliper, each of the ten metacarpals was measured in millimeters for maximum length and dorsal-volar and medial-lateral widths at mid-shaft. The length measurement was taken between the most distal and most proximal points of the bone, following the longitudinal axis of the diaphysis. The longest axis of the enthesis deposit was considered length (Figure 19); the shorter as width. Height was measured using a contour gauge and palatometer.

The gauge is a simple tool composed of a series of metal needles held in place by a central bar. The needles protrude out of the side and slide easily from one side to the other. When pressed against any object, the needles are displaced on the contact side and form the duplicate shape on the opposite side (Figure 20). That shape can then be measured for depth and height. That reading can be taken by placing the "feet" of a palatometer on either side of the raised needles and extending the arrow tipped calibrated bar to the highest point extending from the gauge (Figure 21). The reading on the highest measurement was always taken.

Measurements were statistically processed by procedures from the SAS Institute, Inc. Each enthesis is described morphologically and by preliminary maximum and minimum measurements, all subsistence and sex groups combined. The eight enthesis locations are indicated in Figures 22 and 23.

Opponens Pollicis (OPX) inserts along a large part of the radial border on the dorsal face of MC1. In hypertrophic examples it extends radially from the surface of the bone, the greatest extension being

Figure 19. Measuring length of Extensor Carpi Radialis Longus on MC2.

Figure 20. Bone impression on contour gauge.

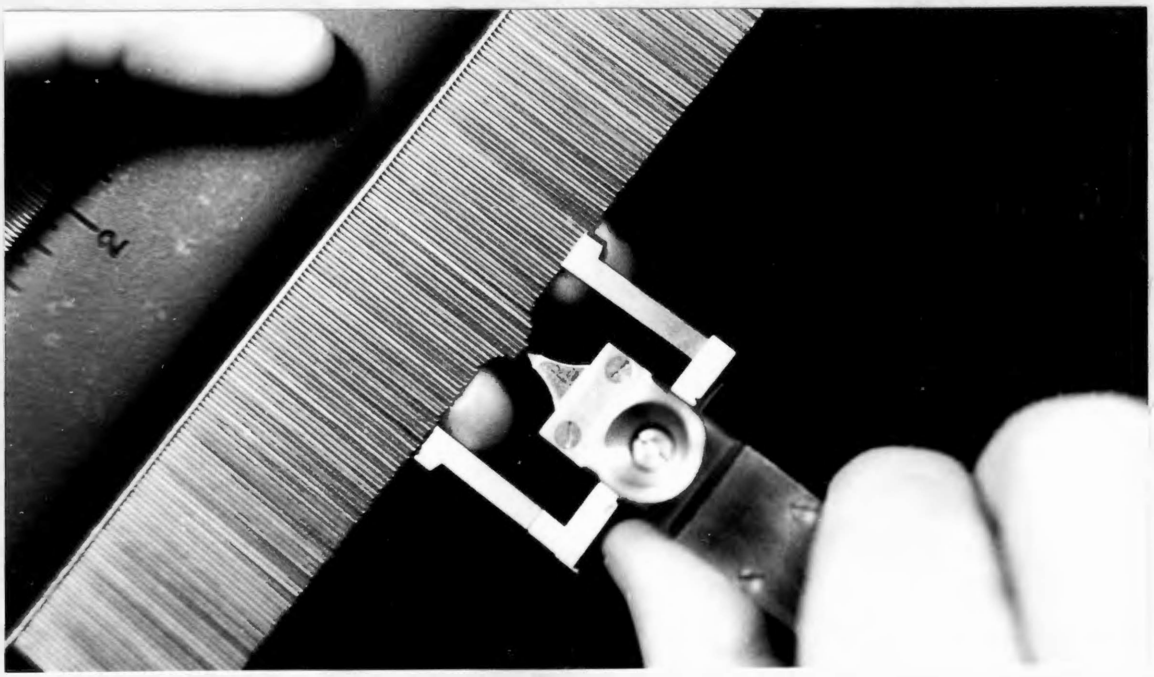


Figure 21. Contour gauge and palatometer.

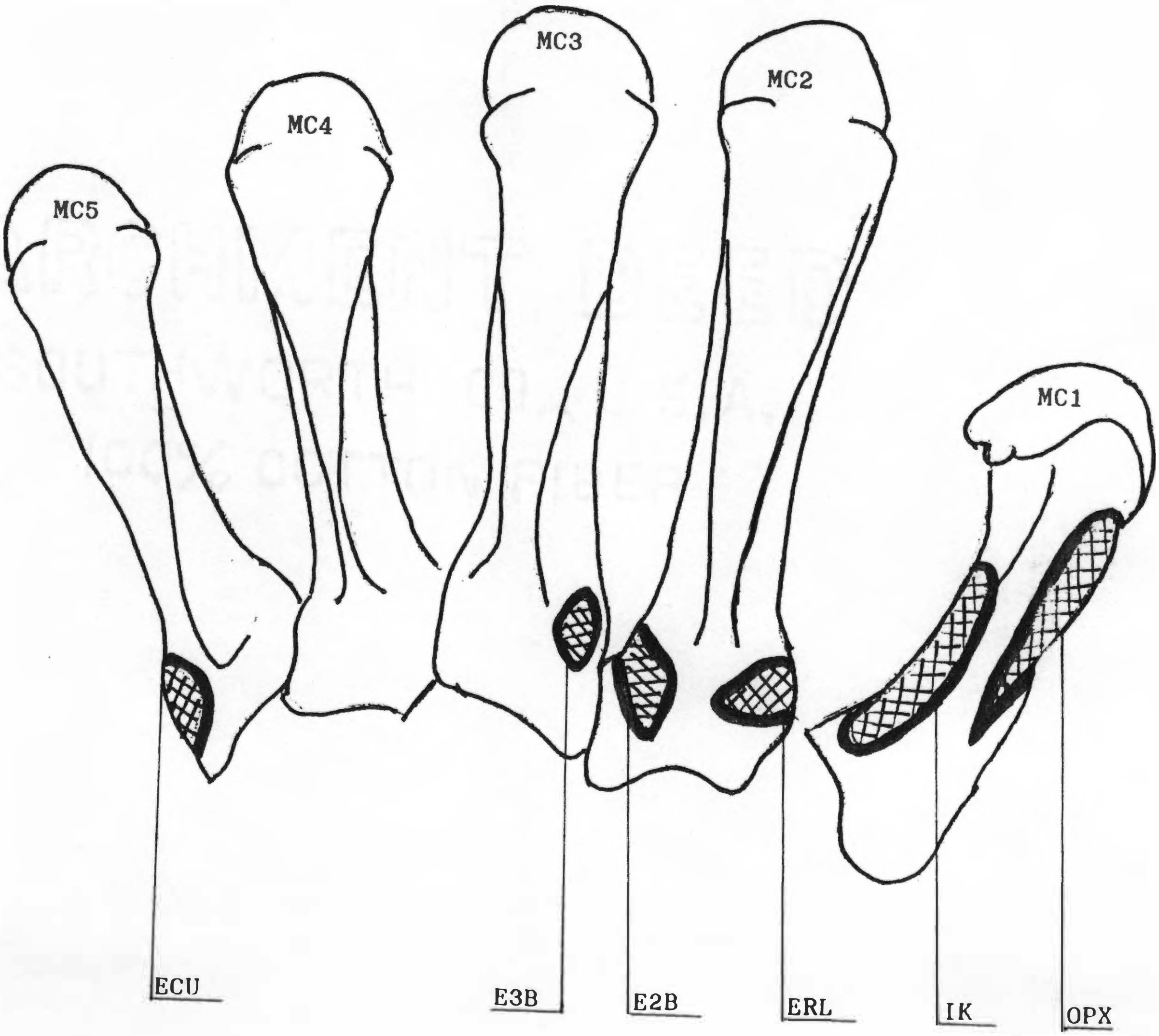


Figure 22. Entheses locations: dorsal view.

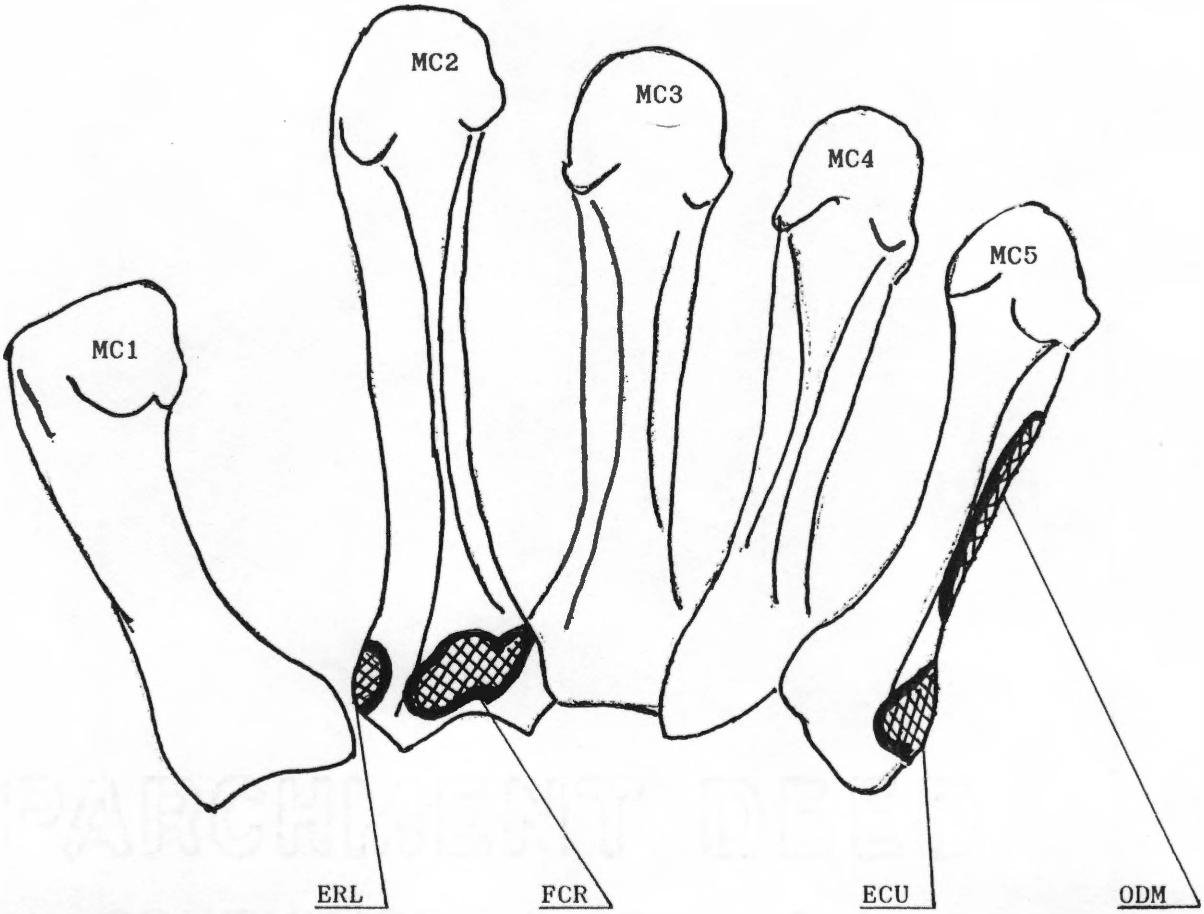


Figure 23. Entheses locations: volar view.

toward the distal end. It is one of the first entheses to form and has been observed in some Larson children at age six. Two measurements were taken (Table 1). Length is proximal-distal along the diagonal axis of the enthesis. Height was recorded by the contour gauge and represents the maximum distance that the shelf-like ridge extends from the surface of the bone (Figure 22, MC1; Figures 37* [p.265] and 47 [p.275]).

TABLE 1

OPPONENS POLLICIS ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	236	20.00	7.00	232	20.00	7.00
Height	235	4.00	1.00	226	4.50	1.00

First Dorsal Interosseous (IK) has two origins, one on MC2 and the other on MC1. It is the enthesis at the origin site on MC1 that is studied here. The area involved is on the ulnar shaft of the bone. It is a long, narrow trench, wider proximally and narrowing toward the distal end. It usually includes the nutrient foramen and, in hypertrophic examples, is surrounded by a bony ring, the whole structure rising on a raised platform. Length was measured proximal-distal of the axis of the insertion (Figure 22, MC1; Figure 38 [p.267]); width represents the average of several measurements taken at equal distance across the long trench. Height was taken using the contour gauge and includes both the depth of the trench and the height of the bony ring (Table 2).

---

* Figures 26-49 are found on Plates 6-17 in Appendix C.

TABLE 2

FIRST DORSAL INTEROSSEOUS ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	221	23.00	8.00	222	26.00	9.00
Width	222	8.00	1.00	224	6.80	2.40
Height	224	3.50	1.00	227	3.50	1.00

Extensor Carpi Radialis Longus (ERL) inserts into the dorsal radial surface of proximal MC2. The raised enthesis is half-moon shaped, on the top side of a circular disc. The lower half-moon is not raised, but only shows a change in bone texture. The raised upper half-moon portion was measured for length, running medial-lateral, and width represents the average of several measurements taken at equal distance across the half-moon area (Figures 19, 22, and 23, MC2; Figures 37 [p.265] and 39 [p.267]). Height was taken by contour gauge at the maximum elevation of the half-moon area from the surface of the bone (Table 3).

TABLE 3

EXTENSOR CARPI RADIALIS LONGUS ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	244	12.00	5.00	234	13.00	6.00
Width	243	6.80	2.50	233	6.60	2.60
Height	244	5.00	1.00	231	4.50	1.00

Flexor Carpi Radialis (FCR) inserts onto a flat area at the proximal end of the volar surface of MC2. The insertion is a raised,

circular lumpy area with an ulnar extension, the whole having somewhat the shape of a tadpole (Figure 23, MC2; Figures 40 [p.269] and 46 [p.273]). The ulnar "tail" may represent part of the origin of the Adductor Pollicis, but it was measured with the FCR since it forms a visible unit. Length was measured medial-lateral and width represents the average of several measurements taken at equal distance proximal-distal of the enthesis. Height was determined by the contour gauge at the highest elevation (Table 4).

TABLE 4

FLEXOR CARPI RADIALIS ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	246	17.00	8.00	234	16.00	7.00
Width	245	7.60	3.10	234	9.00	2.50
Height	246	5.00	1.50	231	5.00	1.50

Extensor Carpi Radialis Brevis Two (E2B) is one of two insertions measured for this muscle, and is located on the dorsal ulnar side of proximal MC2, just across from the ERL insertion. E2B is a raised bony area that runs obliquely across the ulnar fork of the bone (Figure 22, MC2 [p.42]; Figures 26 [p.255], 33 [p.261], 39 [p.267]). The enthesis is narrower distally and wider proximally. The oblique axis was used as the length measurement with width the average of several measurements taken at equal distance perpendicular to the length. Height was taken by the contour gauge at the highest point from the bone surface (Table 5).

TABLE 5

EXTENSOR CARPI RADIALIS BREVIS TWO ENTHESIS MEASUREMENTS: MILLIMETERS

Measurement	Left			Right		
	N	Maximum	Minimum	N	Maximum	Minimum
Length	238	14.00	6.00	231	13.00	6.00
Width	237	8.00	2.60	230	8.20	2.60
Height	237	4.50	1.00	227	4.50	1.00

Extensor Carpi Radialis Brevis Three (E3B) is the second of two insertions measured for this muscle and is located on the radial edge of the dorsal surface of the proximal end of MC3. The enthesis is round to oval on a ridge that continues proximally to form the styloid process (Figure 22, MC3 [p.42]; Figure 41 [p.269]). The length was measured along the proximal-distal axis of the enthesis; the width represents the average of several measurements taken at equal distance medial-lateral of the enthesis; the height was measured by contour gauge at the highest point from the dorsal surface of the bone (Table 6).

TABLE 6

EXTENSOR CARPI RADIALIS BREVIS THREE ENTHESIS MEASUREMENTS: MILLIMETERS

Measurement	Left			Right		
	N	Maximum	Minimum	N	Maximum	Minimum
Length	244	13.00	4.00	242	14.00	5.00
Width	244	5.60	2.50	242	5.70	2.60
Height	242	4.50	1.00	242	5.50	1.50

Extensor Carpi Ulnaris (ECU) inserts into the proximal, ulnar end of the dorsal and ulnar surfaces of MC5. The enthesis is large and distinctive in shape--like a chocolate chip pressed into the edge of the bone (Figures 22 and 23, MC5 [pp.42 and 43]; Figure 42 [p.271]). Length was measured proximal-distal; width was averaged from several dorsal-volar measurements taken at equal distance, and height was determined directly by the palatometer from the surface of the bone (Table 7).

TABLE 7

EXTENSOR CARPI ULNARIS ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	211	14.00	5.00	201	14.00	3.00
Width	209	6.80	2.20	201	7.10	2.50
Height	206	6.00	1.00	202	6.00	1.50

Opponens Digiti Minimi (ODM) has a long, slender insertion covering nearly the whole length of the ulnar border of MC5 (Figure 23, MC5 [p.43]; Figures 32 [p.261], 43 [p.271], 44 [p.271]). The insertion site was measured for length along the distal-proximal axis; the width represents an average of measurement taken at equal distance along the length of the insertion (Table 8).

TABLE 8

OPPONENS DIGITI MINIMI ENTHESIS MEASUREMENTS: MILLIMETERS

	Left			Right		
Measurement	N	Maximum	Minimum	N	Maximum	Minimum
Length	203	34.00	7.00	195	30.00	9.00
Width	196	5.60	1.00	189	6.50	1.50

Additional photographic records of the entheses of ERL. E3B, and ECU can be seen in a recent study by Ricklan (1987).

Origin of Samples

Data for this study were gathered from nine sites; eight are in the University of Tennessee, Knoxville collections, and the ninth--Indian Knoll--is in the University of Kentucky collection at Lexington. These sites were chosen because they represented subsistence activities that were clearly either pre- or post agriculture. The earlier, non-agricultural groups cover a large span of time in the archaic cultural period. The later, agricultural group spans a much shorter period of time. The transitional period between the two was not sampled since the goal of the study was to compare work loads of agricultural and non-agricultural peoples from the record on hand bones. The sites selected and measured for this study and their cultural periods are shown in Table 9. The time span included is displayed in Figure 19 [p.40].

1. Eva (Plate 6, Figures 26 and 27 [p.255])

The Eva site (Site One in this study) was excavated in 1940 by the Works Progress Administration (WPA) under the Tennessee Valley Authority (TVA). Thirty four sites were salvaged from the banks of the Tennessee River and its feeder streams in the western part of the state, before innundation by the formation of Kentucky Lake (Lewis and Kneberg, 1947:1). Little was known of the archaic complex at that time. First thought to be a backward, conservative people who were too set in their ways to grasp the cultural advances going on all around them (Lewis and

TABLE 9

SAMPLE ORIGINS FOR THIS STUDY

Site Number	Site Name	Date	Culture Period	Female	Male
1	Eva (6BN12)	5200±500 B.C. (Lewis and Lewis, 1961)	Early Middle Archaic	6	6
2	Three Mile (6BN12)	5000-3500 B.C.	Middle Archaic (Griffin, 1974: 112; Chapman 1977:21)	11	12
3	Anderson (40WM9)	6495±205 B.P. 6720±220 B.P. (Joerschke, 1983:18)	Middle Archaic	15	12
4	Big Sandy (6BN12)	4210-2240 B.C. (Amick, 1985: 25)	Late Archaic (Griffin, 1974:112)	12	13
5	Indian Knoll (OH2)	3325±300 B.C. 2013±350 B.C. (Blakely,1971)	Late Archaic	21	23
6	Cherry (84BN74)	2500±500 B.C. (Magennis, 1977:28)	Terminal Archaic	9	16
7	Ledbetter I (9BN25)	2080±260 B.C. (Bowen, 1975:35) 1770 BC-30 B.C. (Bowen,1975:33)	Terminal Archaic	20	13
8	Averbuch (40DV60)	1275-1400 A.D. (Eisenberg, 1986:6)	Late Mississippian	28	29
9	Larson (39WW2)	1750-1785 A.D. (Jantz, 1973:17)	Post-contact Coalescent	18	18

Kneberg, 1947:13,14,38), it was necessary to find new explanations after the time depth was clarified, adding 5,000 years to their antiquity (Lewis and Kneberg, 1947:38; Lewis and Lewis, 1961:13). The one Carbon-14 date from the lowest level of the Eva site of 5200±500 B.C. has been used to estimate time periods for superimposed strata (Lewis and Kneberg, 1959:164). In this study, the work of Chapman (1977) on the Eastern valley of the state along the Little Tennessee River will be used to help establish dates more firmly for the sites in western Tennessee. Chapman had the advantage of excavating similar sites many years later using more advanced dating techniques (Chapman, 1985:17). Parallels in artifact types, frequencies and stratification from the western sites point to similar, well-dated assemblages in the east.

Five of the collections in this study come from the WPA work in western Tennessee. The Eva site yielded 183 human burials, although only 10 percent of the midden was excavated (Lewis and Kneberg, 1947:7). Four distinct strata were identified, and the earliest, stratum IV containing the Carbon-14 date of 5200 B.C., will be the level employed in this study. This level contained 17 burials, 12 of which are used.

Eva is characterized by large, basal notched stone points named for the site, and the large quantity of animal bone in the midden. Of the 14,000 bones in this stratum, 88 percent are deer (Lewis and Lewis, 1961:22). Some mussel shells suggest shellfish as a dietary supplement (Lewis and Lewis, 1961:17). Hunting and skin working tools of stone, bone and antler are present (Lewis and Lewis, 1961:50,77,104). Studies in eastern Tennessee on other resources show that nuts, particularly hickory, were always an important part of Early and Middle Archaic sub-

sistence patterns (Chapman and Shea, 1981:77). The tool complex places the site in Early Middle Archaic, possibly extending the date back from 5200 B.C. to nearer 6000 B.C. (Griffin, 1974:95,97; Lewis and Lewis, 1961:13; Chapman, 1977:21,27).

2. Three Mile (Plate 7, Figures 28 and 29 [p.257])

Three Mile (Site Two), is from the stratified Eva complex, and is separated from the Eva phase (Site One) by a discontinuity of flood-deposited sand and silt (Lewis and Lewis, 1961:9). It is characterized by a dense deposit of mussel shells, numerous needles and fishhooks, five times fewer bone remains than Eva, and predominence of the Morrow Mountain point. The later is considered the time marker of the Middle Archaic Cultural period, 5000-3500 B.C. (Griffin, 1974:112). Chapman's dates list Morrow Mountain closer to the earlier date (Chapman, 1977:21). Lewis and Kneberg estimate the later one (Lewis and Kneberg, 1959:164). Of the 102 burials excavated from the Three Mile stratum (Lewis and Lewis, 1961:107), 23 were used in this study.

3. Anderson

Anderson, (Site Three) a newly excavated site (1980) in Middle Tennessee from Williams County near Nashville, yielded 73 burials, 27 of which are used in this study (Dowd, 1981). This site is a shell midden and has been dated by both Carbon-14 dates of 6720±220 B.P. and 6495±205 B.P., and artifact assemblages at between 4770 B.C. and 3000 B.C. (Joerschke, 1983:15; Hofman, 1984:5). This places it in the Middle Archaic, about the same time and culture period as the Three Mile site,

with the added advantage of more recent techniques of collection and interpretation of floral and faunal materials.

> an abundance of deer and gastropod remains as well as the presence of plant processing tools at sites like Anderson support the idea of a "broad spectrum economy" for Middle Archaic populations in Middle Tennessee (Joerschke, 1983:20).

4. Big Sandy

Big Sandy (Site Four) represents the upper level (stratum I and plowzone) at the Eva site (Lewis and Lewis, 1961:9), and should not be confused with the Big Sandy site some 20 miles northwest of the Eva site (Lewis and Kneberg, 1947:3) or with the Big Sandy points from the Early Archaic period (Walthall, 1980:50). Of the 60 individuals buried in stratum I and plowzone, 25 were selected for this study. In contrast to the Three Mile stratum immediately beneath it, Big Sandy is characterized by the total absence of mussel shells (Lewis and Lewis, 1961:9). Possible dwelling floors (Lewis and Lewis, 1961:15), one fourth as many bones as Three Mile (or 5 percent of the lowest, Eva level faunal deposit), and absence of skin working tools (Lewis and Lewis, 1961:50) place the Big Sandy level in the Late Archaic (Griffin, 1974:112). The Late Archaic is described as a time of intensified gathering and increased dependence on vegetal materials (Chapman and Shea, 1981:70; Watson, 1969:233-234; Walthall, 1980:75). The Benton Point predominates in this level (Lewis and Lewis, 1961:33) and since it is considered "transitional middle to late archaic type" (Amick, 1985:27) places Big Sandy at the very early beginning of the Late Archaic. Carbon-14 dates

from the Leftwich site with similar artifact typology are 4210 and 2240 B.C. (Amick, 1985:25; Hall et al., 1985:75).

5. Indian Knoll

Indian Knoll (Site Five) is a shell mound site on the Green River in Ohio County of western Kentucky. It was excavated by the University of Kentucky and the WPA; the collection is stored at Lexington. Of 521 measurable adults, 44 were selected for this study using established sex and age determinations (Snow, 1948; Johnston and Snow, 1961; Stewart, 1962). The Carbon-14 dates of 3325±300 B.C. and 2013±350 B.C. place Indian Knoll toward the early part of the Late Archaic. The huge deposit of bone (including 3,101 deer astragali [Webb, 1946:334]) plus variations in burial depths and positions (Webb, 1946:132-137), may indicate the origins of the site are still earlier. The presence of pottery may extend habitation of Indian Knoll into and beyond the Terminal Archaic. The large number of conical pestles (1,379) and bone awls (6,413) (Webb, 1946:232) may suggest shellfish processing (Webb, 1946:231).

6. Cherry (Plate 8, Figures 30 and 31 [p.259])

Cherry (Site Six) is located about 12 miles north and west of the Eva site, and was excavated in 1941 by the TVA-WPA team, prior to flooding by Kentucky Lake (Magennis, 1977:15). This Late Archaic site yeilded 70 burials of which 25 were selected for this study. Exhibiting features such as pits and post molds, ("a large number of pits . . . contained much animal bone and occasionally artifacts" [Bowen,

1975:70]), this single component site is estimated by Magennis as contemporaneous with Big Sandy, 2500-1000/500 B.C. (Magennis, 1977:28). Five hundred potsherds were found in the plowsoil and may indicate a slightly later date (Lewis and Kneberg, 1947:2). Artifact defined activities indicate similarities between the Cherry and Ledbetter sites (Bowen, 1975:88), with equal effort going to animal processing and plant food processing (Bowen, 1975:73,86; Higgins, 1982:16).

7. Ledbetter (Plate 9, Figures 32 and 33 [p.261])

The Ledbetter Landing site (Site Seven), excavated in 1940, is also from western Tennessee, some 15 miles directly south of the Eva site. A shell midden yielding 118 burials (Lewis and Kneberg, 1947:8), the 33 sampled for this study are all from stratum I (Lidberg, N.D.:1), the upper of the two layers. No structures were found, but a variety of artifacts including 1,000 potsherds in that upper stratum indicate it is late in the Late Archaic. Pottery is often used as the criterion separating Archaic and Woodland Culture periods, but the presence of pottery is also definitive of Terminal Archaic--a transitional period (Griffin, 1974:76). Others have studied the two Ledbetter strata together (Bowen, 1975), or just the lower stratum II (Higgins, 1982). Stratum I has been selected for this study since it represents the very end of the Archaic period.

8. Averbuch (Plate 10, Figures 34 and 35 [p.263])

Averbuch (Site Eight) is a Late Mississippian site near Nashville, excavated in 1977 and 1978 by the University of Tennessee. Of 888

skeletons from three cemeteries (Eisenberg, 1986), most in limestone box graves, 57 were selected for this study. Numerous Carbon-14 dates place the occupation of the site between 1275 and 1400 A.D. (Eisenberg, 1986:4). The Averbuch people were maize agriculturalists whose diets also included a variety of faunal material (Crites, 1984; Romanoski, 1984). Evidence of ranked social organization was expected but was not observed (Klippel, 1984:I.14.4); stress from nutritional and disease interaction was observed (Berryman, 1981:185; Eisenberg, 1986:74).

9. Larson (Plate 11, Figures 36 and 37 [p.265])

Larson (Site Nine) is an Arikara site from Walworth County, South Dakota. Excavated as part of the Missouri Basin salvage program from 1966-1968, the abundant skeletal material represents the Coalescent traditon in the protohistoric period from 1750-1785 (Jantz, 1973:17). Of the 628 individuals recovered, 36 were selected for this study. The Arikara were agriculturalists and hunters and food collectors, but were in population decline from nutritional deficiencies, infections, and intertribal warfare (Owsley and Bass, 1979:153).

Sample Grouping

The seven Archaic sites are grouped together in this study because they represent subsistence patterns that do not include agriculture. Covering a time span of 5-6,000 years (Figure 24) and including such varied food sources as deer, small mammals, shell fish, fish, nuts, seeds and other vegetal resources, it is easy to overlook what commonalities were shared. They all took part in the same varied menu with

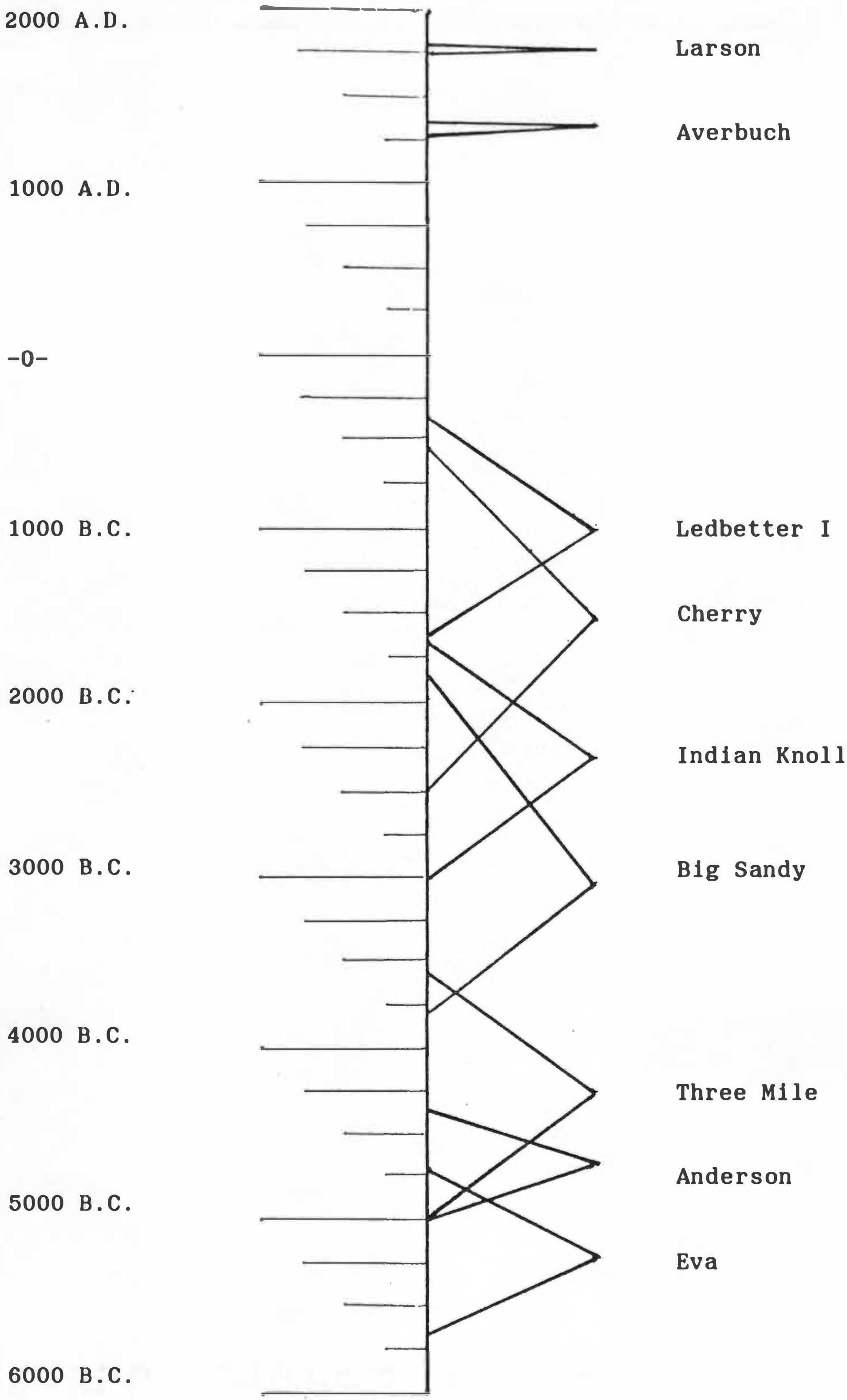


Figure 24. Time Span of Sites Sampled

only the frequencies changing through time; they were all dependent on the food resources provided by nature; all lived in the same climatic area with access to about the same resources; all were atlatl hunters; none were farmers.

Lewis and Lewis suggest there is a genetic relationship evidenced in aberrant tooth displacement of the Eva, Three-Mile and Big Sandy groups (Sites One, Two and Four of this study) (Lewis and Lewis, 1961:156). Since the present study deals with cultural activities of the hand, no effort has been made to develop a system to test possible genetic relationships among the Archaic peoples.

Averbuch and Larson sites have been grouped together as an agricultural unit. Though they are much closer in time than are the Archaic components (about 400 years) (Figure 24), they are geographically distant, located some 1000 miles apart. Studies have been done that compare Indian Knoll and Mobridge (another Arikara site) concluding that greater incidence of extra-vertebral osteoarthritis at the Arikara site might be the result of differences of activity patterns (Kelley, 1980). Other studies compare Indian Knoll and Averbuch, concluding that a higher level of degenerative joint disease involvement at Averbuch reflects differences in activity patterns (Pierce, 1987: 206,208). This study will compare activity patterns on the metacarpals rather than on the joints, using Arikara and Averbuch together.

The Arikara were a Caddoan-speaking people and are thought to have migrated to South Dakota from somewhere in the South. Caddoans are considered a Mississippian cultural variant from Louisiana and Arkansas (Hudson, 1976:5,91). Nevertheless, it is not the purpose of this study

to imply these are related peoples. From diverse climates, the natural resources they drew upon were diverse as well. But the maize they hoped to sustain them imposed the same patterns of labor and deprived them of the same nutritional resources that had to be supplemented by whatever hunting and gathering their environments provided.

> In spite of their advantages in supplying a high yield of food energy, each of the staple cereal crops has nutritional limitations, and none can be depended upon as a sole source of energy and nutrients (Haas and Harrison, 1977:76).

These farmers were bow and arrow hunters. Both groups used maize cultivation supplemented by hunting and gathering; both experienced population decline (Owsley and Bass, 1979:153; Berryman, 1981:73).

Since all cultures develop a system of assigned tasks by sex, this study will take the division of labor seriously, dividing the data into two groups by sex. Comparisons will be made between agricultural and non-agricultural women, and between agricultural and non-agricultural men.

Hypotheses

Larger entheses on agricultural hands

One of the first hypotheses to be tested in this study will be to see if the diameter of the measured tendon insertions increases from the non-agricultural to the agricultural people, indicating more work was required of those muscles. Not only how much, but which muscles increase in size should reveal the kinds of activities that required more work by the hand.

An immediate problem confronted in the pursuit of this hypothesis is that the agricultural people had larger hands than the non-agricultural people (Tables 13 and 14 [p.74]). Susman and Creel (1979), in their study of early hominoid hands, confronted this same problem and tried a number of size adjustments, none of which was totally satisfactory from either a theoretical or practical standpoint, and none eliminated the influence of size. They advise employing numerous techniques that are not related and then cautiously comparing results. This study will attempt to do that.

Handfemr procedure

Following Susman and Creel's admonition, a new set of variables entitled Handfemr was generated by SAS. In this procedure every measurement on an individual's hands was divided by his or her own femur length. This was done not only to overcome the size problem but also to provide comparisons between groups and left and right hands within groups. Unfortunately, apart from the problems of using ratio data, the sample was truncated since not all observations (individuals) had measureable femur material. Specifically, the non-agricultural female sample was reduced by 22%; the non-agricultural males by 16%; the agricultural females by 6%; the agricultural males by 10%.

In comparing ratio data (Handfemr variables), statistically the presumption of normalcy in the samples may not be present. As a precaution, the non-parametric SAS procedure NPAR1WAY was used on the Handfemr data to determine size differences rather than T tests. This procedure

produced both ANOVA and Wilcoxson test scores. The more conservative score was used as a further precaution in the comparisons.

Size problems

The larger hand was heavier, requiring greater muscle (and hence tendon diameter) to do the same activities done by the earlier, smaller hands. It is necessary, therefore, to see if the rate of increase of the agricultural hands is greater than the increase in the size of person. Femur length, the only other measurement taken on the sampled skeletal material, was chosen to represent the size of the individual.

If the increase in tendon diameter only reflects the increase in hand size, we would expect the left and right scores to increase equally, and would also expect the same increase in both sexes. If either of these can be disproved, then we can know that changes between the subsistence groups is not dependent on just changes in hand size.

What is the increase in size of person and how does this compare to increase in metacarpal lengths? Since we have mean femur lengths for each of the four groups (male, female, agricultural, non-agricultural), we can use the relationship of that measurement to each of the metacarpal lengths to determine the increase in hand size from the earlier to the later group (Table 12 [p.73]). If the hand increases at the same rate as femur length, the ratios should be the same. This has to be calculated in order to see if the increase in hand size itself might be an adaptive advantage to the agricultural people, or if the hand just tags along as part of the body that is larger for some totally different system's advantage (Van Horn, 1972:326).

Since the wrist extensors have the task of lifting the hand against gravitational forces, we would expect those four muscles to increase their efforts equally as the hand increases in size (and weight). Therefore the measures of the extensors' diameters should stand in the same relationship to the length of the metacarpals, if no other forces are increasing the muscles' diameters. Again right and left should be equal if this is the only factor.

Once there is a clarification of whether or not the change in tendon diameter is merely a response to increased size of hand, more specific hypotheses can be tested dealing more directly with specific hand actions.

Enthesis height

One question to be asked is what does the enthesis height measurement represent? If the diameter indicates repeated "nontrivial tension loads" (Frost, 1980:220), does the height represent the same, or perhaps the frequency of the activity, or both? What is the correlation pattern of enthesis diameter to height? Does it change from the non-agricultural to the agricultural? Different types of work should leave different height patterns of distribution. If frequency is represented by height it should increase through time with scores reflecting that increase from the young through middle to old age.

Metacarpal midshaft diameter

Another source of information that needs to be interpreted is the change in the two diameters (dorsal-volar, medial-lateral) of each

metacarpal. There is a difference between agricultural and non-agricultural, but once again it must be determined whether or not the change in bone shape is merely an allometric response to change in length. To test this, ratios of length to each width by each bone are calculated and compared. If those ratios are the same for each subsistence group, the diameter changes are length dependent.

If the ratios are different, then a new source of information is available. Since the interosseous muscles arise from the sides of the shafts of each metacarpal, changes in the activity of these muscles should leave changes on the bone. These muscles serve to spread the hand in holding larger tools, and to draw the fingers together in a tight grip of those tools. Increased effort on larger tools should yield changed diameter measurements.

Greater left hand increase

Another hypothesis to be tested is that hunters and gatherers who had access to foods requiring little processing used the dominant right hand the most to collect food. Other studies on left-right differences among East Indians have shown the right MC1 to be longer and all five to be heavier than the left metacarpals (Singh, 1979). Similar tests on U. S. males show right hand metacarpals with higher length, width, and total area measures, but no difference in medullary width. "Differential stress" of the dominant hand is suggested as causative (Plato et al, 1980). Michael Glassow (1980) in tracing the step-by-step transition to agriculture by people in the Southwest, shows how every possible resource was gradually expanded as gatherers became gardners. This

meant expanding and enlarging land use, plant and animal resources, and social organization as well as new tools and seeds. The left hand might be considered as an unexploited resource to be recruited into the labor of food production and processing by agriculturalists. Should this be true, increase in enthesis areas and heights and metacarpal diameters would be expected to be larger for the left hand than for the right as we compare the agriculturalists to the non-agriculturalists.

IK

The First Dorsal Interosseous, particularly used by the non-agriculturalists, was first identified in this study while observing the Indian Knoll collection. This muscle's action draws the thumb against the index strongly, against resistance, with the index extended from a flexed metacarpal-phalangeal joint. Among other activities, it may reveal the preferred method for opening shell fish. If so, the highest readings on both diameter and height of the enthesis should be from those sites with shell mounds (Sites Two, Three, Five and Seven). If both right and left hands were used as a pair in this action, agricultural peoples would be expected to have less difference between left and right scores.

ERL use

Another specific muscle-defined action would be the ERL on the hands of sewers. Merbs points out this area of the dominant hand is particularly active in women sewing skins (Merbs 1983:155). It may be the same action was used by those who did weaving and basketry who had

less access to hides and animal skins. What differences do we see between agricultural and non-agricultural women? Is there a difference in right and left hands?

Precision grip predominates in non-agricultural hand

Though not specifically measured, the Adductor Pollicis used to draw the thumb and third finger together, originates from the length of the shaft of MC3 on the volar side. Since the first three digits predominate in precision grips, we expect higher scores for both the IK and MC3 dorsal-volar score (where the thumb adductor originates) in the non-agricultural hand as opposed to the agricultural hand. By the same token, higher scores in muscles controlling the ulnar-power grip side of the hand would be expected of agricultural groups. Marzke and Shackley (1986), in defining hand function, point out that most actions of the first three fingers are used in meat processing (cutting skin, muscle, sinew; removing meat from bone; scraping and sharpening sticks) whereas processing of vegetal materials requires the whole hand (digging, pounding nuts) (Marzke and Shackley, 1986:450).

Atlatl evidence

The Indian Knoll burials yielded atlatl hooks and handles from both male and female graves (Webb, 1946:330). Did women use atlatls? Is there any way to look for this in the hand measurements? The hand action used in atlatl throwing probably consisted of the extension of the hand straight back followed by a strong forward flexion. These paired actions should leave evidence in the entheses of the E2B and E3B

and the FCR. Although women's hands are smaller than men's hands, the ratios should be similar. This will be tested by combining the extensor diameter scores in relation to the flexor scores, and comparing the male and female ratios. The same process will be followed on the height measurements. If the ratios are the same, the same action may have been performed, possibily atlatl throwing. If the ratios are different, different actions are evident.

Studies in the response of the humerus to cultural activities have shown significant differences in cross-sectional shapes (Smith et al., 1983; Ruff and Jones, 1981; Hamilton, 1982) and enthesopathies (Dutour, 1986) between right and left humeri from the same individual. Bridges (1988) compared the humeri of Archaic and Mississippian males from northwestern Alabama, an area very similar in both climate and archeological remains to those in this current study (Walthall, 1980), and failed to find right-left differences that could be assigned to atlatl throwing.

Bow and arrow evidence

Pickering's (1979) study of the Late Woodland Ledders site, although limited to arthritic joint damage, reveals extreme stress in males is most pronounced at the wrist (Pickering, 1979:52). Theorizing that use of the bow and arrow was causing the damage, Pickering suggests

> locomotor activity may involve not only active or primary stress but also passive or secondary stress; archery, for example, produces active stress on the elbow and shoulder of the release arm and passive stress on the support arm (Pickering, 1979:52).

The concept of passive stress is difficult to test, but in this study the effects of the bow and arrow will be traced in both hands. Looking at the male left hand, a large increase in scores would be expected over the atlatl left hand, especially in the ECU--the strength bracing extensor, and the ERL toward the radial side--working synchronically with the ECU to keep the hand stable. In the male right hand the first of the two actions where elevated scores might result is in the adducting palmar interosseous that pinches the index and middle fingers together to hold the arrow; the second area is in the mechanisms for drawing the bow string, both the FCR that flexes the hand, and the central extensors at the back of the wrist that stabilize the hand, E2B and E3B. The ECU is called into action when extreme strength is required and would be expected to be incorporated into the forceful drawing of a bowstring. If we discover increases in these right hand scores over those of the atlatl right hand, they would represent the expected evidence for behavioral changes in hunting techniques.

<u>Hafted tool evidence</u>

The two Opponens muscles, OPX on the thumb and ODM on MC5 in the heel of the hand are principal holders of hafted tools. As agriculturalists developed more extensive use of hafted tools, we would expect considerable increase in the evidence of Opponens muscle usage on the hands. Use of the ax would be expected to cause increased scores on the right hand, while the hoe and wooden pestle would affect both the right and left. High increase of OPX and ODM correlation scores in the

left hand would be expected in the agricultural hands, as would low left-right correlation for each Opponens.

Using hafted tools also calls into play the ulnar side of the hand where MC4 and MC5, with their hinged carpal-metacarpal joints, can be pressed tightly to a handle. To trace this, increased action of the ECU, stabilizing the Flexor Carpi Ulnaris (for which we have no data) should be present. Additional action of the dorsal and palmar inter-ossei between MC3 and MC4, and MC4 and MC5 should also be present, as evidenced by expanded diameters of those two shafts. Longer length measurements on MC4 and MC5 would support even more muscular activity in the ulnar portion of the hand.

Age changes

If the tasks performed with the hand cause the bone supporting the muscle to build up, it should be possible to trace that accumulation with age. This can be tested by comparing scores among the three age cohorts (young, middle, old). Is there an increase, and is the pattern of differences between the non-agricultural and agricultural people the same at all ages? If the agriculturalists worked harder, it would be expected that the difference in young scores would be closer to the total group difference if they were recruited into the work force at an earlier age. It would also be expected that the older agricultural hands would be kept working as long as possible.

Adaptive Traits

Since Hrdlicka, it has been traditional to refer to cultural effects on skeletal material as pathology rather than adaptive growth, and the causative processes as stress rather than adaptation (Goodman et al., 1988; Iscan, 1988; Cohen and Armelagos, 1984; Ortner & Putschar, 1981; Ubelaker, 1982). In the course of collecting data for this study, many unusual characteristics were noted as the metacarpals were scrutinized. Since "discrete skeletal traits may be as much a function of nongenetic factors as genetic factors" (Armelagos et al., 1982) these findings will be referred to as "adaptive traits", rather than pathologies. However, this list of traits includes fractures, which certainly are evidence that something wrong has happened and that natural selection has been outdistanced by cultural demands. But healed fractures are evidence that something right has happened--an existing pre-selected system has functioned well to meet new cultural needs on the body. The adaptive traits will be listed by person (both hands will count only as one, not two) by groups on a presence/absence basis. These will be included in Appendix B, pages 240-254, since the information they provide contributes to the discussion but is not part of the hypotheses.

CHAPTER 5

FINDINGS

Metacarpal Lengths and Widths

Before the information in the metacarpal entheses can be studied, it is necessary first to understand the structure and changes of the bones on which those entheses are located (Tables 10 and 11).

A cursory examination of lengths and widths in Tables 10 and 11 shows that with the exception of the dorsal-volar measure of MC1, the agricultural hands are larger than the non-agricultural hands. These length differences are statistically significant (Tables 16 [p.76] and 24 [p.87]). A second glance through the length and width data shows the right hand measurements to be greater than the left for all agricultural lengths and widths of both sexes. The non-agricultural hands have larger measurements on the right for all widths in both sexes, but the male fifth and female second, third, fourth and fifth lengths do not.

The increase in length and width size may only reflect the increase in size of the agricultural over the non-agricultural people. Using Tables 12 and 13, mean metacarpal total length ratios with femur length show that for females, non-agricultural left and right are nearly identical--left .6429 and right .6426; agricultural females, however, how a difference with the left ratio equalling .6653 and the right .6710. The same contrast is seen in the male ratios with the non-

TABLE 10

FEMALE METACARPAL LENGTH AND WIDTH MEASUREMENTS: MILLIMETERS

	Non-Agricultural						Agricultural					
	Left			Right			Left			Right		
Meta-carpal	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
Length												
1	75	39.72	2.17	70	40.37	2.21	40	42.87	2.24	40	43.46	2.08
2	74	60.38	2.66	74	60.33	2.65	42	64.40	3.26	40	64.87	3.32
3	65	59.74	2.54	70	59.33	2.80	38	64.30	2.98	36	64.63	2.99
4	57	51.09	2.68	61	51.03	2.64	43	56.16	2.81	32	56.46	3.21
5	62	46.84	2.64	59	46.59	2.63	35	50.74	2.68	35	51.42	2.89
Dorsal-Volar												
1	79	7.52	.65	74	7.66	.65	42	7.30	.64	41	7.46	.65
2	84	7.42	.70	85	7.55	.75	43	7.53	.57	44	8.02	.66
3	74	7.58	.60	84	7.91	.75	41	8.01	.59	41	8.51	.56
4	75	5.92	.58	75	6.35	.58	43	6.43	.54	37	6.67	.55
5	69	5.52	.62	69	5.78	.55	37	5.79	.56	35	6.01	.64
Medial-Lateral												
1	79	8.93	.87	74	9.40	.85	42	9.63	1.08	41	10.03	1.00
2	84	6.72	.59	84	6.79	.57	43	7.20	.58	44	7.51	.65
3	74	6.54	.48	85	6.68	.53	41	7.02	.56	41	7.18	.41
4	75	5.28	.48	75	5.49	.46	43	5.62	.57	37	5.89	.71
5	69	6.26	.69	69	6.44	.80	37	6.50	.44	35	6.77	.70

TABLE 11

MALE METACARPAL LENGTH AND WIDTH MEASUREMENTS: MILLIMETERS

	Non-Agricultural						Agricultural					
	Left			Right			Left			Right		
Meta-carpal	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
Length												
1	73	42.97	2.77	70	43.01	2.35	36	46.12	2.29	42	46.54	1.90
2	72	64.12	3.51	68	64.89	3.05	41	69.04	2.74	44	70.45	3.02
3	77	63.67	3.34	75	63.53	3.34	42	68.51	3.06	40	69.53	3.38
4	68	54.17	2.99	69	54.31	3.17	38	59.40	2.67	40	60.36	2.78
5	69	50.35	2.93	65	50.06	3.54	37	54.47	2.01	37	55.43	2.02
Dorsal-Volar												
1	80	8.38	.73	77	8.63	.90	38	8.28	.63	42	8.53	.73
2	89	8.08	.69	81	8.31	.81	43	8.53	.50	46	9.08	.62
3	88	8.30	.78	79	8.75	.83	45	8.81	.69	42	9.16	.63
4	83	6.66	.67	78	6.87	.74	42	7.04	.58	43	7.56	.62
5	79	6.31	.77	70	6.52	.73	38	6.52	.54	40	6.93	.57
Medial-Lateral												
1	80	9.85	1.15	77	10.26	.94	38	10.68	.83	42	11.04	1.05
2	89	7.42	.76	81	7.64	.76	43	7.96	.56	46	8.73	.64
3	88	7.11	.53	88	7.30	.61	45	7.67	.54	42	7.88	.49
4	83	5.88	.61	78	6.07	.68	42	6.09	.50	43	6.56	.64
5	80	6.89	.73	71	7.21	.79	38	7.56	.66	40	7.66	.98

agricultural males scoring left .6326 and right .6338; the agricultural male ratios are left .6545 and right .6650. The ratios show the agricultural males have a larger hand than the non-agricultural in relation to the size of person (femur length) and a larger right than left as well. The increase in hand size is not just a reflection of longer femur length. The femur length increase (Table 12) of 4.39% for females, 4.46% for males is less than the total metacarpal length increase (left only) of 8.03% for females and 8.08% for males (Table 13).

TABLE 12

FEMUR LENGTH MEANS BY SUBSISTENCE AND SEX

	Non-Agricultural			Agricultural			
	N	Mean	S.D.	N	Mean	S.D.	Percent increase
Female	73	400.91	14.61	43	418.51	13.82	4.39
Male	79	435.15	18.36	42	454.59	17.02	4.46

By digit these increases reveal a pattern of change that also reflects more than just size increase. This can be seen by taking each digit as a percent of the whole hand (Table 14).

The relationship of metacarpal lengths to one another within the hand can be seen by calculating Z scores (Table 15).

When the differences in lengths and widths by subsistence group are submitted to T tests those differences show that the patterns of significant differences are only uniform for metacarpal lengths (Table 16). The significant differences in widths are not uniform by sex or between left and right hands.

TABLE 13

METACARPAL LENGTH TOTALS (1+2+3+4+5) OF SAMPLES FROM THIS STUDY BY SEX AND SUBSISTENCE

	Female Mean		Male Mean	
	Left	Right	Left	Right
Non-Agricultural	257.77	257.65	275.28	275.80
Agricultural	278.47	280.84	297.54	302.31
Percent increase	8.03		8.08	

TABLE 14

PERCENT INCREASE IN METACARPAL LENGTH FROM NON-AGRICULTURAL TO AGRICULTURAL BY DIGIT: MILLIMETER DATA

	Female		Male	
Metacarpal	Left	Right	Left	Right
1	7.93	7.65	7.33	8.18
2	6.65	7.52	7.67	8.56
3	7.63	8.93	7.60	9.44
4	9.92	10.64	9.65	11.13
5	8.32	10.36	8.18	10.72

TABLE 15

METACARPAL LENGTH CHANGES AS SEEN BY Z SCORES

Metacarpal	Female Left	Female Right	Male Left	Male Right
	Non-Agricultural		Non-Agricultural	
1	-1.50	-1.47	-1.49	-1.47
2	1.12	1.16	1.12	1.18
3	1.04	1.02	1.06	1.01
4	-.05	-.06	-.10	-.10
5	-.60	-.65	-.58	-.61
	Agricultural		Agricultural	
1	-1.55(-)	-1.56(-)	-1.54(-)	-1.55(-)
2	1.05(-)	1.07(-)	1.10(-)	1.11(-)
3	1.04	1.04(+)	1.03(-)	1.01
4	.05(+)	.03(+)	-.01(+)	-.01(+)
5	-.60	-.58(+)	-.58	-.56(+)

Key: (+) = agricultural larger than non-agricultural
(-) = agricultural smaller than non-agricultural

TABLE 16

T TESTS OF METACARPAL LENGTH AND WIDTH SIGNIFICANCE BY SUBSISTENCE AND SEX: MILLIMETERS

	Female		Male	
	Mean Difference		Mean Difference	
Measure-ment	Left	Right	Left	Right
Metacarpal Length				
1	3.15 ***	3.09 ***	3.15 ***	3.53 ***
2	4.02 ***	4.54 ***	4.92 ***	5.56 ***
3	4.65 ***	5.30 ***	4.84 ***	6.00 ***
4	5.07 ***	5.43 ***	5.23 ***	6.05 ***
5	3.90 ***	4.83 ***	4.12 ***	5.37 ***
Dorsal-Volar Width				
1	[.22]	[.20]	[.10]	[.10]
2	.11	.47 **	.45	.77 ***
3	.43 **	.60 ***	.51 ***	.41
4	.51 ***	.32 *	.38 **	.39 *
5	.27 *	.23	.21 *	.42 **
Medial-Lateral Width				
1	.70 **	.63 **	.83 ***	.78 ***
2	.48 ***	.72 ***	.54 ***	1.09 ***
3	.48 ***	.50 ***	.56 ***	.58 ***
4	.34 **	.40 *	.21 *	.49 **
5	.24	.33 *	.67 ***	.45 *

Key: *** = p < .0001
** = p < .001
* = p < .05
[] = Non-agricultural measure is larger

Another approach to changes between the agricultural and non-agricultural metacarpals is to compare the shape of the cross-sectional diameters of each bone at mid-length. None of the metacarpal shafts is round in any hand, but approaches a triangular shape in cross-section. A ratio score for each bone reveals that MC1 and MC5 are the flattest, or similar to flat isosceles triangles. MC2 and MC3 appear deeper in cross-section, with MC2 most equal in the two diameters. Using the mean medial-lateral score to divide the mean dorsal-volar score, the group differences can be seen (Table 17). The lower score indicates a flat cross-section  ; the higher score indicates a deeper cross-section  .

The disadvantage of using ratio data is that either variable (dorsal-volar or medial-lateral) could be responsible for the changes in those ratios. However, since T tests for significant differences have been calculated (Table 16) it is possible to see which variable in Table 17 is contributing most to the ratio change. Those with greater significant dorsal-volar change are in brackets; those with greater significant medial-lateral change are in parentheses.

Table 17 shows the greatest change in shape for both hands and both sexes is the broadening and flattening of MC1 in the agricultural hands. Both left and right MC2 broaden in the female agricultural hand, whereas in the agricultural males only right MC2 is noticeably flatter. The other interesting male difference is the flatter, broader left MC5 in the agricultural males whereas the right MC5 is virtually identical in shape in the non-agricultural and agricultural males. The left MC4 is deepest in both sexes in the agricultural hands but the right MC4 is

TABLE 17

CROSS-SECTIONAL RATIOS (D-V / M-L) OF METACARPAL WIDTHS BY SEX AND SUBSISTENCE

	Female			Male		
Metacarpal	Non-Agricultural Ratio	Agricultural Ratio	Difference	Non-Agricultural Ratio	Agricultural Ratio	Difference
Left						
1	.8421	.7580	(.0841)	.8507	.7752	(.0798)
2	1.1041	1.0458	(.0583)	1.0889	1.0716	(.0173)
3	1.1590	1.1410	(.0180)	1.1673	1.1486	([.0187])
4	1.1212	1.1441	[.0229]	1.1326	1.1559	[.0233]
5	.8817	.8907	[.0090]	.9158	.8624	(.0534)
Right						
1	.8148	.7437	(.0711)	.8411	.7726	(.0685)
2	1.1119	1.0679	(.0560)	1.0876	1.0400	([.0476])
3	1.1841	1.1852	([.0011])	1.1986	1.1624	(.0362)
4	1.1566	1.1324	([.0242])	1.1317	1.1067	(.0250)
5	.8975	.8877	(.0098)	.9042	.9046	.0004

flattened in both sexes in the agricultural hand. The non-agricultural male right MC3 is distinct in its greater depth over all other ratio scores as well as its own MC3 left.

Differences between left and right cross-sectional shapes can be seen in Table 18. All four groups have the deeper MC1 in the left hand, the deeper MC3 on the right. The agricultural male hand shows larger left and right differences in MC2, MC4, and MC5. The non-agricultural females show the right hand with deeper scores on MC2 through MC5, the greatest difference in MC4. The agricultural females show only MC2 and MC3 with deeper scores on the right.

The advantage of using ratios within a group is that it offers an escape from the problem of size differences between individuals and between groups. For instance, it is clear that the cross-sectional shapes of the metacarpals are different for both sexes and both subsistence groups (Table 17), despite male hands being larger than female, and agricultural hands larger than non-agricultural.

Not only shapes but cross sectional areas are also different between the two subsistence groups (Table 19). Using the formula for the area of a triangle (1/2) L x H, and substituting mean scores of medial-lateral for length and dorsal-volar for height, a rough pattern can be seen for the differences. Since none of the metacarpals is an exact triangle, these figures are only approximate.

What can be seen is that not only are the cross-sectional shapes different, but the approximate amount of bone in those cross-sections is increased in all agricultural metacarpals. If this increase were an allometric concomitant of the length increases (Table 14) we would

TABLE 18

WIDTH RATIO DIFFERENCES BETWEEN RIGHT AND LEFT HANDS WITHIN GROUPS

Meta-carpal	Female Non-Agri-cultural	Female Agri-cultural	Male Non-Agri-cultural	Male Agri-cultural
1	.0273	.0143	.0096	.0026
2	.0078(R)	.0220(R)	.0013	.0316
3	.0250(R)	.0442(R)	.0313(R)	.0138(R)
4	.0354(R)	.0117	.0009	.0492
5	.0158(R)	.0030	.0116	.0422

Key: (R) = Right ratio is greater (deeper).

TABLE 19

DIFFERENCES BETWEEN NON-AGRICULTURAL AND AGRICULTURAL CROSS-SECTIONAL AREAS (APPROXIMATED) OF METACARPALS : MILLIMETERS

	Male				Female			
	Non-Agri-cult.	Agri-cult.	Differ-ence	% of diff.	Non-Agri-cult.	Agri-cult.	Differ-ence	% of diff.
Left								
1	33.57	35.14	1.57	4.67	41.27	44.21	2.94	7.12
2	24.93	27.10	2.17	8.70	29.97	33.94	3.97	13.24
3	24.78	28.11	3.33	13.43	29.50	33.78	4.28	14.50
4	15.62	18.06	2.44	15.62	19.58	21.43	1.85	9.44
5	17.27	18.81	1.54	8.91	21.73	24.64	2.91	13.39
Right								
1	36.00	37.41	1.41	3.91	44.27	47.08	2.81	6.34
2	25.63	30.11	4.48	17.47	31.74	39.63	7.89	24.85
3	26.41	30.55	4.14	15.67	31.93	36.09	4.16	13.02
4	17.43	19.64	2.21	12.67	20.85	23.81	2.96	14.19
5	18.61	20.34	1.73	9.29	23.50	26.54	3.04	12.93

expect some uniformity in the two patterns. The greatest length increases are in the ulnar digits of the agricultural hands (both sexes) whereas the greatest cross-sectional area (Table 19) increase is in the agricultural male right MC2 (underlined) with the next highest increases in the agricultural female right MC2 and MC3.

In a further effort to lay a solid base of understanding of the nature of lengths and widths of the metacarpals before doing comparative studies of the entheses, variables were correlated with femur length (Table 20).

Rather than clarifying relationships between metacarpal size and femur length, the correlation coefficients show lack of uniformity both between hands and between subsistence groups and sexes. Correlation coefficients on lengths ran from .17 to .66 with the most common correlation with the femur around the .40's level. Slightly higher correlations are seen for left than right, males than females, and radial lengths than ulnar ones. The width correlations with the femur length ran from -.13 to .31, most at the .20's level or less.

Since the width measurements show less significant correlation with femur length than do metacarpal lengths, there is the possibility that the widths may have been modeled by cultural activity. If so, the data for the age cohorts within each group might reveal the progress of those changes through the course of a collective lifetime. In Tables 21 and 22, lengths and widths are listed according to sex, subsistence, and age.

Some discoveries from these raw measurements are that older metacarpal lengths are shorter than middle age lengths; widths follow

TABLE 20

PEARSON CORRELATION COEFFICIENTS OF METACARPAL LENGTHS AND WIDTHS WITH FEMUR LENGTH BY SEX AND SUBSISTENCE

	Female		Male	
Metacarpal	Non-Agricultural	Agricultural	Non-Agricultural	Agricultural
Left Length				
1	.50*	.40*	.48*	.66*
2	.47*	.48*	.56*	.51*
3	.46*	.44*	.49*	.36*
4	.40*	.45*	.48*	.52*
5	.40*	.37*	.46*	.30
Right Length				
1	.45*	.46*	.40*	.42*
2	.48*	.49*	.45*	.47*
3	.43*	.37*	.54*	.47*
4	.32*	.49*	.55*	.40*
5	.17	.38*	.44*	.55*
Left D-V				
1	.17	.15	.11	.25
2	.06	,04	.14	-.07
3	.06	.19	.27*	.06
4	.17	.13	.07	.09
5	-.02	-.09	.07	.19
Right D-V				
1	.16	.15	.31*	.08
2	.10	.14	.14	-.07
3	.06	.26	.26*	.31
4	.17	.14	.23*	-.12
5	.03	-.02	.22	-.02
Left M-L				
1	.14	.17	.31*	.05
2	.38*	.01	.25*	.05
3	.17	.29	.24*	.25
4	.27*	.06	-.02	.17
5	.14	.13	.22*	.16
Right M-L				
1	.19	.08	.08	-.00
2	.23*	.26	.36*	-.13
3	.30*	.12	.32*	.05
4	.38*	.14	.13	-.01
5	.32*	-.01	.16	-.04

Key: * = correlation significant at $p < .05$

TABLE 21

FEMALE METACARPAL MEAN LENGTHS AND WIDTHS
BY SUBSISTENCE AND AGE: MILLIMETERS

	Non-Agricultural			Agricultural		
	Young	Middle	Old	Young	Middle	Old
Femur						
	400.25	399.07	404.14	416.40	424.56	413.08
Metacarpal						
Left length						
1	39.68	39.78	39.50	42.56	43.30	42.70
2	59.79	61.00	60.08	64.26	64.63	64.15
3	59.30	59.84	59.87	63.42	64.92	64.68
4	51.07	51.00	50.80	55.23	57.08	56.00
5	46.52	47.04	46.60	50.00	52.04	50.35
Right length						
1	40.10	40.45	40.39	43.35	43.84	43.00
2	60.22	60.89	59.78	64.30	65.50	64.62
3	59.02	59.91	58.76	64.42	65.00	64.45
4	50.75	51.23	50.73	55.34	58.26	56.10
5	46.26	47.33	45.65	50.62	52.53	50.77
Left D-V						
1	7.44	7.59	7.51	7.40	7.20	7.35
2	7.18	7.60	7.44	7.18	7.67	7.62
3	7.39	7.64	7.70	7.70	8.16	8.22
4	5.86	5.94	5.95	6.30	6.38	6.68
5	5.42	5.75	5.34	5.71	5.80	5.90
Right D-V						
1	7.71	7.72	7.57	7.64	7.35	7.40
2	7.43	7.68	7.51	7.73	8.05	8.40
3	7.84	7.88	8.01	8.25	8.71	8.54
4	6.23	6.39	6.45	6.57	6.69	6.80
5	5.83	5.86	5.61	5.91	5.96	6.22
Left M-L						
1	8.78	9.05	8.92	9.00	9.79	10.30
2	6.54	6.80	6.79	7.07	7.34	7.13
3	6.45	6.58	6.56	6.93	6.96	7.22
4	5.25	5.30	5.26	5.50	5.64	5.77
5	6.11	6.45	6.17	6.46	6.61	6.40
Right M-L						
1	9.32	9.47	9.38	9.53	10.23	10.40
2	6.60	7.00	6.76	7.43	7.63	7.40
3	6.56	6.69	6.79	7.07	7.18	7.31
4	5.50	5.50	5.45	5.92	5.65	6.15
5	6.31	6.56	6.45	6.54	6.85	6.94

TABLE 22

MALE METACARPAL MEAN LENGTHS AND WIDTHS
BY SUBSISTENCE AND AGE: MILLIMETERS

	Non-Agricultural			Agricultural		
	Young	Middle	Old	Young	Middle	Old
Femur						
	434.66	437.23	431.23	457.63	454.37	450.57
Metacarpal						
Left length						
1	42.92	43.33	42.16	45.00	46.88	45.12
2	63.63	64.75	63.45	68.05	69.81	68.27
3	63.52	64.07	62.88	66.72	69.15	68.60
4	53.36	54.69	53.66	58.56	59.86	59.00
5	50.34	50.48	50.00	53.75	54.95	52.93
Right length						
1	42.92	43.00	43.13	46.04	47.19	45.37
2	64.43	65.20	64.62	69.22	71.40	69.20
3	63.82	63.71	62.92	67.94	70.59	68.75
4	54.32	54.70	53.55	59.55	61.02	59.37
5	49.93	50.07	50.16	53.92	55.97	55.14
Left D-V						
1	8.23	8.40	8.41	8.33	8.33	8.12
2	7.61	8.10	8.38	8.40	8.65	8.40
3	7.91	8.41	8.36	8.45	8.95	8.81
4	6.37	6.62	6.85	6.85	7.17	6.99
5	5.94	6.45	6.32	6.50	6.56	6.43
Right D-V						
1	8.50	8.73	8.54	8.40	8.73	8.12
2	7.66	8.51	8.37	9.05	9.22	8.81
3	8.21	8.79	9.09	9.05	9.22	9.15
4	6.50	6.90	7.08	7.25	7.43	6.83
5	6.12	6.61	6.68	7.00	6.84	7.11
Left M-L						
1	9.38	9.98	9.84	10.88	10.69	10.43
2	7.00	7.55	7.48	7.60	8.17	7.85
3	6.91	7.23	7.05	7.35	7.81	7.68
4	5.56	5.93	6.02	5.85	6.28	5.88
5	6.73	6.91	6.97	7.87	7.50	7.43
Right M-L						
1	9.75	10.28	10.54	11.13	11.06	10.87
2	7.53	7.66	7.68	8.45	8.98	8.45
3	7.60	7.36	7.41	7.55	7.02	7.90
4	5.80	6.15	6.13	6.35	6.72	6.30
5	7.21	7.05	7.52	8.12	7.71	7.11

that pattern for non-agricultural women and agricultural men; widths for agricultural females and non-agricultural males do not.

In Tables 21 and 22, the younger metacarpal lengths for all four groups are shorter than the middle age lengths (one exception); the young width scores are less than the middle widths with three exceptions in agricultural females, two in non-agricultural males and four in agricultural males. The magnitude of differences between young and middle width scores is very different, with differences (reduced scores) between young and middle males being much greater in both non-agricultural and agricultural males than in either female group. Age does appear to have an effect on both length and width scores. It is difficult to define that difference more clearly until we can eliminate the stature differences that accompany not only the subsistence and sex differences but the age cohorts as well.

Lengths and Widths Interpreted by Handfemr Procedure

Using the Handfemr procedure, new ratio data were generated on length and width measurements (Table 23). Testing for differences in lengths and widths of metacarpals in the Handfemr program using NPAR1WAY showed more discrete differences than T tests in the selection of significant differences between groups (Table 24).

As a double check of whether dividing by femur length yields accurate conclusions, the left-right correlation scores for the raw measurements were compared with those of the Handfemr ratios (Table 25). Those that show the greatest difference are presumed to respond the most to femur length. These are seen in the male width measurements. The

TABLE 23

HANDFEMR RATIO MEANS OF METACARPAL LENGTHS AND WIDTHS
BY SEX AND SUBSISTENCE

	Female				Male			
	Non-Agricul.		Agricultural		Non-Agricul.		Agricultural	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Left LN								
1	.0991	.0047	.1025	.0050	.0991	.0056	.1014	.0038
2	.1504	.0065	.1539	.0069	.1478	.0067	.1515	.0055
3	.1495	.0061	.1538	.0068	.1464	.0068	.1504	.0067
4	.1272	.0063	.1341	.0063	.1251	.0062	.1304	.0052
5	.1167	.0059	.1217	.0062	.1155	.0063	.1201	.0050
Right LN								
1	.1007	.0051	.1042	.0046	.0090	.0052	.1027	.0042
2	.1510	.0060	.1545	.0071	.1490	.0069	.1553	.0066
3	.1485	.0067	.1547	.0073	.1466	.0067	.1525	.0069
4	.1275	.0067	.1353	.0067	.1249	.0060	.1323	.0061
5	.1163	.0071	.1227	.0065	.1153	.0056	.1222	.0042
Left D-V								
1	.0187	.0016	.0174	.0015	.0192	.0018	.0182	.0013
2	.0184	.0018	.0179	.0014	.0186	.0017	.0188	.0012
3	.0189	.0016	.0190	.0012	.0190	.0017	.0193	.0016
4	.0147	.0015	.0153	.0013	.0153	.0016	.0154	.0013
5	.0137	.0016	.0138	.0013	.0145	.0019	.0143	.0012
Right D-V								
1	.0190	.0016	.0177	.0015	.0200	.0018	.0187	.0017
2	.0186	.0019	.0190	.0016	.0192	.0019	.0200	.0016
3	.0197	.0020	.0202	.0012	.0201	.0019	.0200	.0013
4	.0158	.0015	.0159	.0013	.0158	.0016	.0160	.0016
5	.0143	.0014	.0143	.0016	.0149	.0016	.0152	.0013
Left M-L								
1	.0222	.0022	.0230	.0026	.0226	.0027	.0234	.0019
2	.0167	.0013	.0172	.0015	.0169	.0017	.0175	.0013
3	.0163	.0012	.0167	.0013	.0163	.0012	.0168	.0012
4	.0131	.0011	.0134	.0014	.0135	.0015	.0134	.0011
5	.0156	.0018	.0155	.0016	.0159	.0016	.0166	.0014
Right M-L								
1	.0232	.0021	.0239	.0025	.0237	.0023	.0242	.0025
2	.0170	.0014	.0179	.0015	.0175	.0017	.0193	.0017
3	.0167	.0013	.0171	.0012	.0168	.0013	.0172	.0012
4	.0136	.0010	.0142	.0016	.0139	.0015	.0144	.0015
5	.0160	.0019	.0161	.0017	.0165	.0018	.0168	.0023

TABLE 24

HANDFEMR METACARPAL LENGTH AND WIDTH SIGNIFICANT DIFFERENCES: NPAR1WAY

Variable	Female Non-Ag w. Ag.		Male Non-Ag w. Ag.		Non-Ag. Male w. Female		Ag.Male w. Female		Female Young Non-Ag w. Ag.		Male Young Non-Ag w. Ag.		Female Old Non-Ag w. Ag.		Male Old Non-Ag w. Ag.	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Meta-carpal Length																
1	**	**	*	**						*			*			
2	*	*	*	***	(*)									*		
3	*	***	*	***	(*)					*			*	*		
4	***	***	***	***		(*)	(*)		*	*			*	*		
5	***	***	**	***						*			*	*		
D-V Width																
1	[**]	[**]	[*]	[**]	*		*	*				[*]				[*]
2				*			*	*				*		*	[*]	
3																[*]
4	*				*							*				
5					*	*		*								[*]
M-L Width																
1												*	*	*		
2		**		***				*		*						
3													*			
4														*	*	
5			*				*				*					[*]

Key: *** = p < .0001
** = p < .001
* = p < .05
() = Female measure is larger
[] = Non-Agricultural measure is larger.

TABLE 25

PEARSON LEFT-RIGHT CORRELATION COEFFICIENTS COMPARED BETWEEN MILLIMETER SCORES AND HANDFEMR PROCEDURE

	Female				**Male**			
	Non-Agricultural		Agricultural		Non-Agricultural		Agricultural	
Variable	Mm.	Handfemr	Mm.	Handfemr	Mm.	Handfemr	Mm.	Handfemr
Metacarpal								
Length								
1	.92	.90	.94	.92	.87	.85	.89	.85
2	.92	.92	.93	.92	.93	.92	.87	.90
3	.89	.91	.91	.90	.90	.88	.88	.90
4	.93	.93	.91	.89	.92	.89	.94	.92
5	.87	.87	.90	.89	.88	.90	.88	.89
D-V Width								
1	.74	.80	.74	.77	.61	.61	.68	.72
2	.70	.74	.60	.62	.53	.52	.55	.70
3	.71	.76	.48	.43	.70	.70	.63	.65
4.	.54	.55	.55	.60	.69	.66	.54	.61
5	.54	.58	.82	.87	.60	.60	.48	.50
M-L Width								
1	.75	.79	.85	.85	.42	.38	.16	.25
2	.44	.49	.53	.55	.57	.51	.29	
3	.57	.55	.35	.36	.46	.55	.53	.60
4	.43	.38	.55	.55	.48	.48	.64	.69
5	.58	.57	.60	.66	.42	.52	.33	.29

only left-right correlations not significant at $p < .05$ are agricultural male medial-lateral MC1 and MC5.

To review, the preliminary work on metacarpal widths and lengths as a basis for understanding enthesis changes has yielded information and techniques that may be used to enhance the enthesis studies. Distinct and significant changes have been noted that are not related to stature differences. In relationship to femur length, women's hands (metacarpals) are longer than men's though men's are deeper and wider in cross-section. The length discrepancy reflects the greater dimorphism in stature than in hand length (Table 26).

This study is limited to the metacarpal rays since phalanges are not included in the data. The overall change between subsistence groups shows the non-agricultural people with a mitten-shaped palm designed to facilitate precision action on the radial side. The agricultural hand has a square shaped palm, longer on the ulnar side with a larger, flatter MC1 to better grasp and anchor the power grip (Figure 25 [p.211]).

Metacarpal Entheses Measures

The entheses will be studied and compared by subsistence and sex following the approach used for the metacarpal lengths and widths. The data have been organized from the radial to the ulnar side and the measures are listed as follows: from MC1: OPX length and height; IK length, width, and height; from MC2: ERL length, width, and height; FCR length, width, and height, E2B length, width, and height; from MC3: E3B

TABLE 26

MALE-FEMALE DIMORPHISM

	Non-Agricultural	Agricultural
Femur	.9213	.9206
Metacarpals (Left total)	.9363	.9359

length, width, and height; from MC5: ECU length, width, and height; ODM length and width (Tables 27 and 28).

The entheses measurements for the two subsistence groups were compared by sex, and T tests were calculated to find significance (Table 29). Although the agricultural measurements seem overwhelmingly greater than the non-agricultural one, there is considerable variation in the magnitude of the differences. The influence of the size of the person must be considered as in the lengths and widths of the metacarpals. In order to see which of the entheses measurements is influenced most by the person's femur length, correlation tests were performed on the relationship of entheses measurements with femur length (Table 30).

It is difficult to identify a pattern in the entheses-femur length correlations. Very few of the correlation scores are significant at the level of $p < .05$. Non-agricultural females show significant correlation for two out of 22; non-agricultural males show six as significant. Both male and female agricultural groups have only one significant correlation score for each group at $p < .05$. Non-agricultural male scores show the highest correlation with femur length; agricultural males show the least.

TABLE 27

FEMALE ENTHESES MEASUREMENTS: MILLIMETERS

	Non-Agricultural						Agricultural					
	Left			Right			Left			Right		
Variable	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
OPX												
LN	80	11.07	2.03	72	11.90	2.16	41	13.14	1.59	42	13.50	2.03
WD	80	1.77	.61	71	1.92	.61	40	1.96	.60	41	2.15	.69
IK												
LN	75	15.06	3.01	73	15.28	2.23	38	14.76	2.42	38	15.13	2.67
WD	75	3.90	.72	73	4.01	.69	38	3.80	.69	39	3.93	.75
HT	75	2.00	.58	73	2.08	.69	38	1.68	.58	39	1.70	.59
ERL												
LN	79	7.50	1.09	76	7.65	.89	43	8.65	1.44	40	8.90	1.37
WD	78	4.00	.65	76	4.03	.68	43	4.63	.71	40	4.68	.54
HT	78	2.55	.58	75	2.78	.58	44	2.79	.53	40	2.97	.64
FCR												
LN	80	9.86	1.36	76	10.15	1.33	43	10.90	1.26	40	10.87	1.11
WD	80	4.51	.57	76	4.47	.81	43	5.33	.85	40	5.15	.74
HT	80	2.89	.58	76	2.72	.57	43	3.09	.60	40	2.96	.58
E2B												
LN	75	8.10	.89	75	8.12	.84	42	8.97	1.25	40	8.78	1.09
WD	74	4.30	.58	75	4.31	.69	42	4.84	.76	40	4.73	.66
HT	74	2.47	.51	72	2.48	.50	42	2.66	.58	40	2.51	.59
E3B												
LN	74	7.60	1.26	80	8.28	1.33	41	8.80	1.07	38	9.02	1.56
WD	74	3.72	.52	80	3.84	.54	41	4.04	.54	38	4.09	.48
HT	74	2.80	.60	80	3.02	.60	40	2.96	.51	38	3.26	.58
ECU												
LN	62	7.91	1.58	60	8.40	1.54	35	8.82	1.29	34	8.88	1.24
WD	62	4.39	.69	60	4.48	.70	35	5.18	.67	34	5.12	.69
HT	62	2.87	.78	61	2.87	.69	34	3.42	.53	34	3.57	.59
ODM												
LN	62	16.53	3.60	60	16.53	3.32	35	20.85	2.45	34	20.35	3.04
WD	59	3.00	.56	57	3.20	.73	35	3.55	.70	34	3.50	.68

TABLE 28

MALE ENTHESES MEASUREMENTS: MILLIMETERS

	Non-Agricultural						Agricultural					
	Left			Right			Left			Right		
Vari-able	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
OPX												
LN	80	12.05	2.03	76	13.03	1.96	35	14.82	2.06	42	15.33	2.28
HT	80	2.20	.64	74	2.27	.66	35	2.62	.79	40	2.75	.83
IK												
LN	72	15.77	2.69	71	15.97	2.61	36	15.88	1.80	40	16.15	2.03
WD	73	4.05	.91	72	4.14	.74	36	3.95	.57	40	4.13	.50
HT	74	2.03	.64	74	2.09	.60	37	2.02	.58	41	2.07	.63
ERL												
LN	82	8.18	1.03	74	8.24	1.14	40	9.56	1.29	44	9.86	1.23
WD	82	4.21	.76	73	4.21	.74	40	5.21	.78	44	5.08	.55
HT	82	2.76	.62	73	2.83	.75	40	3.31	.61	43	3.32	.49
FCR												
LN	83	10.89	1.47	74	11.08	1.24	40	12.32	1.95	44	12.35	1.67
WD	82	4.99	.81	75	4.90	.77	40	5.81	.76	43	5.65	1.14
HT	82	3.02	.54	73	2.99	.65	41	3.47	.63	42	3.51	.59
E2B												
LN	80	9.23	1.02	73	9.10	1.15	41	10.04	1.22	43	10.30	1.01
WD	80	4.68	.61	72	4.73	.71	41	5.46	.85	43	5.51	.89
HT	80	2.69	.61	72	2.67	.56	41	3.09	.70	43	3.11	.64
E3B												
LN	85	8.50	1.57	82	8.62	1.61	44	9.56	1.04	42	9.78	1.20
WD	85	3.99	.63	82	4.06	.62	44	4.17	.59	42	4.26	.57
HT	84	2.92	.64	82	3.04	.79	44	3.42	.62	42	3.73	.70
ECU												
LN	77	8.76	1.76	69	8.85	1.44	37	10.37	1.29	38	10.52	1.58
WD	75	4.64	.79	69	4.90	.76	37	5.29	.82	38	5.46	.73
HT	73	2.87	.82	69	3.03	.74	37	3.63	.72	38	3.69	.71
ODM												
LN	68	17.79	3.67	64	17.42	3.48	38	21.21	3.12	37	21.32	2.77
WD	64	3.30	.58	62	3.41	.69	38	3.82	.58	36	4.05	.53

TABLE 29

T TESTS OF ENTHESES SIGNIFICANT DIFFERENCES:
BY SUBSISTENCE AND SEX: MILLIMETERS

	Female Differences		Male Differences	
Variable	Left	Right	Left	Right
OPX				
LN	2.07 ***	1.60 **	2.77 ***	2.30 ***
HT	.19	.23	.42 *	.48 *
IK				
LN	[.30]	[.15]	.11	.18
WD	[.10]	[.08]	[.10]	[.01]
HT	[.32] *	[.38] *	[.01]	[.02]
ERL				
LN	1.15 ***	1.25 ***	1.38 ***	1.62 ***
WD	.63 ***	.65 ***	1.00 ***	.87 ***
HT	.24 *	.19	.55 ***	.49 ***
FCR				
LN	1.07 ***	.72 *	1.43 ***	1.27 ***
WD	.82 ***	.68 ***	.82 ***	.75 **
HT	.20	.24 *	.45 **	.52 ***
E2B				
LN	.87 **	.66 *	.81 **	1.20 ***
WD	.54 **	.42 *	.78 ***	.78 ***
HT	.19	.03	.40 *	.44 **
E3B				
LN	1.20 ***	.74 *	1.06 ***	1.16 ***
WD	3.32 *	.25 *	.18	.20
HT	.16	.24 *	.50 ***	.69 ***
ECU				
LN	.91 *	.48	1.61 ***	1.67 ***
WD	.79 ***	.64 ***	.65 **	.56 **
HT	.55 ***	.70 ***	.76 ***	.66 ***
ODM				
LN	4.32 ***	3.82 ***	3.42 ***	3.90 ***
WD	.55 **	.30 *	.52 ***	.64 ***

Key: *** = p < .0001
** = p < .001
* = p < .05
[] = Non-agricultural measure is larger

TABLE 30

PEARSON CORRELATION COEFFICIENTS OF ENTHESES SCORES WITH FEMUR LENGTH BY SUBSISTENCE AND SEX (LEFT HAND ONLY)

	Female		Male	
Variable	Non-Agricultural	Agricultural	Non-Agricultural	Agricultural
OPX				
LN	.13	.18	.38*	.13
HT	.07	.07	.11	.03
IK				
LN	.15	.50*	.13	.00
WD	.16	-.08	.05	.08
HT	.02	.03	.10	.04
ERL				
LN	.05	.03	.21	.13
WD	.24*	-.01	.18	.15
HT	.14	.11	.03	.08
FCR				
LN	.30*	.11	-.00	.10
WD	.09	.06	.25*	.23
HT	-.07	-.02	-.02	.11
E2B				
LN	.19	-.09	.09	.11
WD	.13	.17	.23*	-.06
HT	.16	.05	-.05	-.03
E3B				
LN	-.00	.21	.14	.29
WD	.04	.08	.09	-.03
HT	.00	.28	.14	-.02
ECU				
LN	.19	.12	.19	.14
WD	.20	.03	.35*	-.20
HT	.21	-.07	.10	-.08
ODM				
LN	.19	.16	.26*	-.06
WD	.09	.24	.29*	.32*

Key: * = correlation significant to $p < .05$

A further possible approach in comparing the entheses scores would be to determine the relationship of those entheses to the size of the metacarpal on which they are located (Table 31). These correlation scores show that the entheses are somewhat more closely related to the size of the metacarpal supporting them than to femur length. Non-agricultural males have the highest correlation scores between the entheses and the metacarpals; the agricultural females have the least. E2B has the highest of all the entheses correlation scores with its MC2. Some influence other than the size of the person is determining the differences in the size of the entheses.

All entheses scores were submitted to the Handfemr procedure in which each individual's variables were divided by that individual's femur length yielding ratios that could be compared in an effort to avoid the problem of size differences (Table 32).

The same advantages and disadvantages inherent in the Handfemr entheses scores apply as described for metacarpal lengths and widths. Validity of the procedure on these measures was checked by a comparison of left-right correlation scores (Table 33) and comparisons for significant differences were made using the SAS NPAR1WAY program with the same decision parameters as for metacarpal lengths and widths (Table 34).

As in the length and width studies, the Handfemr procedure limits those differences that are significant. Male-female and young and old test results are listed in Table 34 for discussion in Chapter 6.

TABLE 31

PEARSON CORRELATION COEFFICIENTS OF ENTHESES WITH SUPPORTING METACARPAL BY SUBSISTENCE AND SEX (LEFT ONLY)

	Female						Male					
	Non-Agriculture			Agriculture			Non-Agriculture			Agriculture		
	LN	D-V	M-L	LN	D-V	M-L	LN	D-V	M-L	LN	D-V	M-L
	Metacarpal One						Metacarpal One					
OPX												
LN	(.43)	.07	.10	-.16	-.00	.22	.02	.19	.14	.08	-.17	.05
HT	.17	.03	.20	.11	-.05	(.37)	.12	(.30)	.15	.15	-.16	-.15
IK												
LN	(.47)	-.18	(.24)	.07	.04	.30	(.44)	-.11	-.06	(.47)	-.02	.22
WD	.24	.18	.18	.03	.08	.19	.10	.23	(.25)	.17	(.35)	.00
HT	(.25)	.08	.19	.19	-.05	(.45)	-.00	.18	.20	(.37)	.10	.06
	Metacarpal Two						Metacarpal Two					
ERL												
LN	.04	(.35)	.14	(.35)	(.37)	.28	.22	(.35)	(.32)	.27	.13	.42
WD	.07	(.27)	-.12	.07	.28	.15	.13	(.41)	(.25)	.26	.22	.26
HT	.12	(.37)	(.30)	-.05	.28	.25	.13	(.36)	.10	.20	(.33)	(.48)
FCR												
LN	.13	.13	.08	(.34)	(.39)	.10	(.25)	.08	.12	.08	.29	(.33)
WD	.13	(.20)	.18	.01	(.48)	.13	-.05	(.29)	.10	.09	.23	-.07
HT	.10	.23	.17	.008	.25	.11	.19	.18	.09	.15	-.24	-.07
E2B												
LN	.15	(.48)	(.33)	(.34)	(.50)	.22	(.32)	(.38)	(.37)	(.42)	(.36)	(.34)
WD	.14	(.30)	.06	.08	.24	.04	.21	(.42)	(.35)	(.55)	(.58)	(.53)
HT	.10	(.27)	.11	-.09	(.45)	.04	(.25)	(.26)	(.45)	(.33)	.25	(.43)
	Metacarpal Three						Metacarpal Three					
E3B												
LN	.08	(.35)	.04	.15	.19	.22	.12	(.30)	.18	.05	.15	-.11
WD	.07	(.40)	.23	-.13	.20	-.17	.12	(.47)	(.29)	-.05	(.36)	-.09
HT	.02	(.39)	.02	.01	.22	-.01	.21	(.28)	.18	.26	.24	-.01
	Metacarpal Five						Metacarpal Five					
ECU												
LN	.04	-.005	.08	.10	.06	-.05	(.54)	(.52)	(.28)	(.45)	(.35)	.28
WD	.07	.05	.18	(.39)	(.37)	.09	(.32)	.22	.20	(.22)	.02	.05
HT	-.06	.11	.14	.01	.30	-.17	(.49)	.48	(.34)	(.60)	(.37)	.09
ODM												
LN	(.52)	(.30)	.14	.19	.16	.06	.01	.03	-.02	(.48)	.12	.26
WD	.11	(.42)	(.40)	.11	.25	.28	.00	.23	.08	.07	.24	.16

Key: parenthesis = $p < .05$
underlined = $p < .0001$

TABLE 32

HANDFEMR RATIO MEANS FOR ENTHESES BY SEX AND SUBSISTENCE

	Female				Male			
	Non-Agricultural		Agricultural		Non-Agricultural		Agricultural	
Variable	Left	Right	Left	Right	Left	Right	Left	Right
OPX								
LN	.0281	.0300	.0315	.0324	.0279	.0298	.0324	.0337
HT	.0044	.0047	.0047	.0052	.0051	.0052	.0056	.0060
IK								
LN	.0379	.0384	.0352	.0362	.0369	.0369	.0351	.0357
WD	.0098	.0101	.0089	.0093	.0093	.0095	.0087	.0090
HT	.0049	.0050	.0040	.0040	.0047	.0047	.0045	.0045
ERL								
LN	.0184	.0191	.0207	.0212	.0188	.0189	.0211	.0215
WD	.0097	.0100	.0110	.0111	.0096	.0095	.0116	.0111
HT	.0062	.0067	.0066	.0071	.0062	.0064	.0073	.0072
FCR								
LN	.0241	.0255	.0262	.0260	.0250	.0254	.0274	.0272
WD	.0112	.0110	.0127	.0122	.0114	.0113	.0127	.0122
HT	.0072	.0067	.0074	.0070	.0069	.0069	.0076	.0077
E2B								
LN	.0201	.0202	.0215	.0210	.0212	.0207	.0221	.0227
WD	.0106	.0105	.0116	.0113	.0107	.0109	.0120	.0121
HT	.0061	.0060	.0064	.0060	.0061	.0060	.0068	.0069
E3B								
LN	.0186	.0205	.0211	.0218	.0193	.0199	.0207	.0211
WD	.0092	.0095	.0095	.0096	.0092	.0093	.0090	.0093
HT	.0070	.0074	.0070	.0077	.0065	.0068	.0074	.0082
ECU								
LN	.0193	.0206	.0212	.0213	.0200	.0201	.0230	.0232
WD	.0109	.0112	.0124	.0122	.0106	.0111	.0116	.0120
HT	.0070	.0070	.0082	.0085	.0065	.0068	.0080	.0081
ODM								
LN	.0410	.0411	.0500	.0489	.0410	.0401	.0469	.0473
WD	.0075	.0080	.0085	.0084	.0075	.0078	.0084	.0090

TABLE 33

PEARSON LEFT-RIGHT ENTHESES CORRELATION COEFFICIENTS COMPARED BETWEEN MILLIMETER SCORES AND HANDFEMR PROCEDURE

	Female				Male			
	Non-Agricultural		Agricultural		Non-Agricultural		Agricultural	
Variiable	Mm.	Hand-femr	Mm.	Hand-femr	Mm.	Hand-femr	Mm	Hand-femr
OPX								
LN	.50	.50	.10	.03	.42	.28	.76	.75
HT	.51	.49	.66	.67	.46	.41	.78	.81
IK								
LN	.51	.54	.53	.49	.56	.54	.46	.47
WD	.32	.32	.54	.57	.46	.48	.27	.33
HT	.45	.55	.78	.80	.57	.51	.75	.77
ERL								
LN	.38	.41	.65	.67	.55	.57	.69	.74
WD	.20	.14	.23	.23	.61	.63	.09	-.00
HT	.53	.55	.53	.58	.56	.54	.20	.21
FCR								
LN	.22	.15	.55	.55	.38	.44	.64	.68
WD	.34	.43	.46	.46	.46	.35	.36	.37
HT	.50	.55	.37	.42	.58	.56	.34	.40
E2B								
LN	.43	.46	.55	.59	.40	.33	.66	.67
WD	.43	.39	.23	.20	.45	.42	.67	.69
HT	.27	.27	.63	.63	.35	.36	.46	.51
E3B								
LN	.55	.55	.68	.68	.56	.58	.63	.47
WD	.50	.53	.47	.33	.52	.48	.45	.45
HT	.38	.40	.51	.49	.73	.75	.57	.65
ECU								
LN	.63	.60	.63	.63	.59	.57	-.03	-.06
WD	.43	.46	.50	.56	.48	.43	.30	.39
HT	.70	.82	.46	.48	.74	.72	.79	.80
ODM								
LN	.71	.70	.55	.59	.44	.44	.63	.65
WD	.60	.64	-.13	-.09	.18	.10	.31	.20

TABLE 34

ENTHESES SIGNIFICANT DIFFERENCES: HANDFEMR-NPAR1WAY

Vari- able	Female Non-Ag w. Ag.		Male Non-Ag w. Ag.		Non-Ag. Male w. Female		Ag.Male w.Female		Female Young Non-Ag. w. Ag.		Male Young Non-Ag. w. Ag.		Female Old Non-Ag. w. Ag.		Male Old Non-Ag. w. Ag.	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
OPX																
LN	**	*	***	**									**		*	
HT				*	*											
IK																
LN									[*]							
WD	[*]	[*]							[*]							
HT	[*]	[*]							[*]							
ERL																
LN	**	*	***	***					*	*			*			
WD	**	**	***	***					*		**	*	**			
HT			**	*							*			*		
FCR																
LN	**		*	*					*	*			*			
WD	**	*	***	*							*	*	**	*		
HT			*	*				*								
E2B																
LN	*		**	**	*			*				*	*	*		
WD	*	*	*	*					*	**		*	*			
HT				*				*				*				
E3B																
LN	**		*						*	*		*	*	*		
WD																[*]
HT			*	**		(*)										
ECU																
LN	*		***	***			*	*	*		*	*				
WD	**	*	*	*					*	*						
HT	*	**	**	**					**	*						
ODM																
LN	***	***	**	***			(*)		**	*			*	**		
WD	**		**	**					*		*	*	*			

Key: *** = p < .0001
** = p < .001
* = p < .05
() = Female measure is larger
[] = Non-Agricultural measure is larger

Hypotheses

Larger entheses on agricultural hands

To test the hypotheses proposed in Chapter 4, it is clear that some entheses are larger on agricultural hands, the pattern being quite distinct for each hand and each sex.

Using the adjusted scores from the Handfemr procedure (Table 34), the agricultural women show significant differences for entheses measures in 13 out of 22 left hand scores, 8 out of 22 right hand scores. The agricultural men show significant increases in 16 out of 22 left hand scores, 17 out of 22 right hand scores. By contrast, the non-agricultural women show larger scores than the agricultural women only in IK width and height for both left and right hands (4 out of 44 scores); the non-agricultural men compared to the agricultural men show none.

The left and right scores do not increase equally for each sex, showing that the changes are not simply the result of the activity of larger hands.

Size problems

The hand size increase is greater than the stature increase (p.70), but the gains are not uniform since the ulnar metacarpals' increase exceeds the radial ones (Tables 14 [p.74] and 24 [p.87]).

Using changes in length and width (Table 34, columns 1 and 2), increases in diameters of entheses (length and width) show the absence of equal increase for both left and right and both sexes which would be

expected if responding only to increases in hand size (metacarpal length). The lack of uniform significant increases by hand also indicates that those changes are the result of some force other than just a larger hand.

Each wrist extensor's relationship to its metacarpal is tested in Table 31 (p.96). These correlation scores show very different relationships for each sex and subsistence group. Tendon attachments are not merely responding to larger hands on larger people.

Enthesis height

There are several ways of studying the differences in entheses heights. One approach is to see if there is a difference in the distribution of height scores. OPX and ODM are excluded since only two dimensions were measured. The OPX "height" is the distance of the entire shelf from the radial surface of MC1 (Figure 22 [p.42]) and is not the same as the other heights measured.

The six height measurements can be summed and the distributions compared without removing the size of person element (Table 35). This approach shows that the height distribution of the IK in the non-agricultural women exceeds that of the agricultural women. The female ECU scores reverse that difference. The same difference in the IK heights is seen between the two male groups, but the ECU reversed pattern--although present--is not so pronounced.

Another way to examine the distribution scores for height is by calculating the mean and standard deviation for the heights of those six

TABLE 35

ENTHESES HEIGHT DISTRIBUTION: PERCENT OF TOTAL

	Female				Male			
	Non-Agri-cultural		Agricultural		Non-Agri-cultural		Agricultural	
	Left	Right	Left	Right	Left	Right	Left	Right
Height Total	15.58	15.95	16.60	16.97	16.29	16.65	18.94	19.43
Percent of Total								
IK	.1283	.1304	.1012	.1001	.1246	.1255	.1066	.1065
ERL	.1636	.1742	.1680	.1750	.1712	.1699	.1747	.1708
FCR	.1854	.1705	.1861	.1744	.1853	.1795	.1832	.1806
E2B	.1585	.1554	.1602	.1479	.1651	.1603	.1631	.1600
E3B	.1797	.1893	.1783	.1921	.1792	.1825	.1805	.1919
ECU	.1842	.1799	.2060	.2103	.1761	.1819	.1916	.1899

entheses with that measure in each hand, and then determining the Z score for each enthesis height (Table 36).

If height of entheses represents frequency of action, the change in percents and Z scores from non-agricultural to agricultural in both female and male hands shows a shift from the radial to the ulnar side of the hand. This can be confirmed by comparing height scores once they have been adjusted in the Handfemr procedure (Table 34 [p.99]).

One further approach to understanding the meaning of the height measurement is to see how it relates to length and width within the same enthesis. For instance, how closely is the IK height correlated with IK length, or with IK width (Table 37)?

These correlations show that the closest relationships are between non-agricultural females and males, and the highest within enthesis correlation is in the ERL insertion.

TABLE 36

ENTHESES HEIGHT DISTRIBUTION BY Z SCORE

	Female				Male			
	Non-agricultural		Agricultural		Non-agricultural		Agricultural	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean	2.59	2.65	2.76	2.82	2.71	2.77	3.15	3.23
S.D.	.58	.57	.77	.80	.59	.60	.76	.78
Variables								
IK	-1.01	-1.00	-1.40(-)	-1.40(-)	-1.15	-1.13	-1.48(-)	-1.48(-)
ERL	-.06	.22	.03(+)	.18(-)	.08	.10	.21(+)	.11(+)
FCR	.51	.12	.42(-)	.17(+)	.52	.36	.42(+)	.35(-)
E2B	-.12	-.29	-.12	-.38(-)	-.03	-.16	-.07(-)	-.15(+)
E3B	.21	.64	.25(+)	.55(-)	.35	.45	.35	.64(+)
ECU	.48	.38	.85(+)	.93(+)	.27	.43	.63(+)	.58(+)

Key: (+) = agricultural larger than non-agricultural
(-) = agricultural smaller than non-agricultural

TABLE 37

PEARSON CORRELATION COEFFICIENTS OF ENTHESIS HEIGHT WITH ITS LENGTH AND WIDTH, AND LENGTH WITH WIDTH (LEFT ONLY)

	Female		Male	
	Non-Agricultural	Agricultural	Non-Agricultural	Agricultural
OPX				
LN with HT	.30	.61	.37	.22
IK				
LN with HT	.26	.47	.28	.29
WD with HT	.08	.37	-.07	.24
LN with WD	.12	.25	.21	.15
ERL				
LN with HT	.50	.56	.38	.41
WD with HT	.54	.47	.53	.51
LN with WD	.40	.32	.44	.36
FCR				
LN with HT	.09	.26	.23	.14
WD with HT	.24	.53	.32	.06
LN with WD	.15	.37	.18	-.13
E2B				
LN with HT	.28	.40	.21	.34
WD with HT	.43	.46	.44	.33
LN with WD	.30	.29	.29	.44
E3B				
LN with HT	.53	.49	.46	.33
WD with HT	.49	.19	.50	.37
LN with WD	.48	-.02	.53	.29
ECU				
LN with HT	.69	-.16	.66	.32
WD with HT	.55	.26	.40	.46
LN with WD	.54	.31	.34	-.02

Using the Handfemr data, enthesis scores were traced by age to see if the height measurement continues to increase through time (Tables 38 and 39).

For the females, most scores do increase with age for both subsistence groups, with the height measurement increasing most frequently. For the males, all scores (left, right) increase for the non-agricultural, while the only agricultural height increases (throughout life) are in the left. The agricultural right shows increases from young to middle, but decreases in 18 of the 22 measures from middle to old.

Height does increase through lifetime for all groups, but so do the other measures. Frequency of use must therefore contribute to those changes.

Metacarpal midshaft diameter

The hypothesis dealing with midshaft diameter considers whether the width changes are length dependent. Since all metacarpal lengths are significantly different (Table 24 [p.87]) but very few of the widths are, the midshaft changes are not merely a result of larger metacarpals. Tables 17 (p.78), 18 (p.80) and 19 (p.80) more clearly outline what those shape and mass changes are.

Greater increase in left entheses score

Regarding expected greater increase in left hand scores than in right ones, Table 34 (p.99) shows that for the women, 13 left scores and eight right scores show significant increase from non-agricultural to agricultural. For the males, 16 left scores and 17 right scores show

TABLE 38

INCREASE IN FEMALE ENTHESES HEIGHT SCORES
BY AGE AND SUBSISTENCE

	Non-Agricultural				Agricultural			
	Left		Right		Left		Right	
Variable	Increase Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid to Old
OPX								
LN	-	-	-	=	+	+*	-	+
HT	+	-	+	+*	+	+*	+	+*
IK								
LN	-	+	+	+*	+	+*	+	+*
WD	-	+	+	+*	+	+*	=	+
HT	+	+*	+	+*	+	+*	+	+*
ERL								
LN	+	+*	+	+*	+	+*	=	+
WD	+	-	-	+	=	+	+	+*
HT	+	+*	+	+*	+	+*	+	+*
FCR								
LN	-	+	+	-	-	+	-	+
WD	+	-	-	+	+	+*	-	+
HT	+	+*	+	+*	+	+*	+	+*
E2B								
LN	+	+*	+	+*	+	+*	-	+
WD	+	+*	+	+*	=	+	-	+
HT	+	=	+	=	+	+*	+	+*
E3B								
LN	+	+*	+	+*	+	+*	-	+
WD	+	+*	+	+*	+	=	+	-
HT	+	-	+	+*	+	+*	+	+*
ECU								
LN	+	+*	+	-	+	=	-	+
WD	+	=	+	=	+	-	-	+
HT	+	+*	+	+*	-	+	+	-
ODM								
LN	+	-	+	-	=	+	-	+
WD	+	-	+	-	-	+	+	+*

Key: + = increase
- = decrease
= = the same
* = continued increase throughout lifetime

TABLE 39

INCREASE IN MALE ENTHESES HEIGHT SCORES
BY AGE AND SUBSISTENCE

Variable	Non-Agricultural				Agricultural			
	Left		Right		Left		Right	
	Increase Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid. to Old	Incr. Young to Mid.	Incr. Mid. to Old
OPX								
LN	-	-	+	-	+	+*	+	+*
HT	+	+*	+	+*	+	-	+	-
IK								
LN	+	-	+	+*	-	+	+	-
WD	+	-	+	+*	+	-	+	-
HT	+	+*	+	+*	+	+*	+	-
ERL								
LN	+	-	+	+*	+	-	+	-
WD	+	+*	+	+*	+	-	+	-
HT	+	=	+	+*	+	-	+	-
FCR								
LN	+	+*	+	+*	+	-	+	=
WD	+	+*	+	+*	+	-	=	-
HT	+	+*	+	=	+	+*	+	-
E2B								
LN	+	+*	+	+*	+	-	+	-
WD	+	+*	+	+*	+	-	+	-
HT	+	+*	+	+*	+	-	+	-
E3B								
LN	+	+*	+	+*	+	+*	+	-
WD	+	+*	+	+*	+	+*	-	-
HT	+	+*	+	+*	+	+*	+	-
ECU								
LN	+	+*	+	+*	+	-	=	+
WD	+	+*	+	+*	+	-	+	-
HT	+	+*	+	+*	+	-	+	-
ODM								
LN	+	-	-	+	+	+*	+	-
WD	+	+*	+	+*	+	-	-	+

Key: + = increase
- = decrease
= = the same
* = continued increase throughout lifetime

significant increase from non-agricultural to agricultural. For the females, though only one left hand score shows highly significant ($p < .0001$) differences, eight show high significant differences ($p < .001$) exceeding the right. Left exceeds right in female differences, and in significant increases the magnitude of that increase is greater for the left as hypothesized. This is not true for the men's scores where nearly identical increases for each hand are found. It must not be presumed, although the number of increased scores are the same in right and left, that all the same muscles changed in both hands. The explanation of which muscles changed by sex and hand, and an effort to explain why will be considered in Chapter 6.

IK

The IK scores were examined to answer the question of principal use of this muscle by the shell mound people. Table 27 (p.91) shows non-agricultural women with higher scores on both hands for width and length than agricultural, and Table 34 (p.99) shows those differences to be statistically significant. This is the only muscle score that is higher in the non-agricultural people than in the agricultural. For the males, the non-agricultural men have higher IK scores than the agricultural on the width and height measures (Table 29 [p.93]), though that difference is not statistically significant (Table 34). Comparative tests of young people (Table 34, column 5) show that those differences are well established in the female left hand before maturity is reached. When the IK scores are examined by site other patterns can be detected (Table 40).

TABLE 40

IK MEANS (HANDFEMR) BY SEX, HAND, AND SITE

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
					Female				
Left IK									
LN	.0355	.0401	.0335	.0328	.0427	.0402	.0314	.0363	.0342
WD	.0109	.0091	.0095	.0083	.0102	.0097	.0101	.0090	.0089
HT	.0046	.0051	.0051	.0056	.0048	.0047	.0045	.0041	.0040
					Female				
Right IK									
LN	.0363	.0387	.0348	.0379	.0411	.0418	.0349	.0358	.0366
WD	.0112	.0097	.0095	.0092	.0107	.0110	.0089	.0089	.0098
HT	.0046	.0056	.0056	.0059	.0048	.0055	.0034	.0041	.0039
					Male				
Left IK									
LN	.0291	.0384	.0345	.0346	.0384	.0384	.0350	.0342	.0362
WD	.0094	.0106	.0073	.0085	.0101	.0092	.0082	.0083	.0090
HT	.0039	.0048	.0052	.0062	.0040	.0054	.0043	.0041	.0050
					Male				
Right IK									
LN	.0319	.0376	.0357	.0372	.0382	.0388	.0310	.0339	.0377
WD	.0089	.0102	.0089	.0079	.0099	.0098	.0106	.0087	.0093
HT	.0054	.0048	.0056	.0052	.0041	.0049	.0043	.0040	.0052

When the three IK scores for each sex and hand are ranked and clustered by site, both hands for both sexes have the highest scores in Sites Six, Two and Five. Sites Two (Three Mile) and Five (Indian Knoll) were expected; Site Six was not since it (Cherry) has been characterized as being far from water and having no shells. What this study shows us is that the people of that site were engaged in a parallel activity, or perhaps spent part of their gathering routine in the pursuit of shellfish. Evidently non-shell mound burial does not eliminate the possibility of shellfish usage. By the same token, Site Seven (Ledbetter I) is listed as a shellmound and was expected to show evidence of that activity in the hand. Instead, Site Seven was consistently ranked in the lowest three sites for IK scores, with the two agricultural Sites Eight and Nine. Evidently shell mound burial does not always testify to shellfish usage.

Regarding right and left differences, contrary to expectations hypothesized in Chapter 4, agricultural females score highest on correlation coefficients of left-right scores on the IK enthesis (Table 33 [p.98]). Non-agricultural female and male scores are very similar, showing greater left-right differences than the agricultural females. Agricultural males show the least left-right correlation for length and width measures, but high left-right correlation on the height measure for IK.

ERL use

In searching for evidence of sewing done by the female hand, the ERL that draws the hand back and/or toward the thumb on the dominant

(right) hand is the focus of the principal action. ERL female scores for left-right differences show that although differences for length and width in non-agricultural women are slightly greater (Table 41), the height difference is equal. That may signify a difference in kind of work done by the female right hand, rather than amount of work. Left-right correlation scores (Table 41) show greater differences in non-agricultural length and width, but very small height difference. Both subsistence groups have significant scores on length and height, but not width. If the right hand dominated in sewing action, it would be expected to be seen in height differences.

Another approach to the differences in sewing action is to see how close the correlation is between ERL and E2B for each hand in each group (Table 41). Since the E2B extends the hand, but the ERL both extends and pulls the hand radially, the lower correlation might indicate increased difference in activity of each muscle. Table 41 shows those correlation scores for the non-agricultural females to be very similar for both hands (all scores statistically significant) rather than a lower score in the right hand. The agricultural scores show non-significant correlation on the width measurement, but length and height are significant in both hands. This might indicate a difference in activity.

Finally, since the radial pull of the ERL would be counterbalanced by the opposite pull of the ECU on MC5, correlations were calculated for this pair of extensors (Table 41). Greater radial pull would be expected to produce higher ERL/ECU correlations. Table 41 shows much higher ERL/ECU correlations in height for the non-agricultural women--

TABLE 41

FEMALE ERL TESTS BY SUBSISTENCE

	Non-Agricultural			Agricultural		
	Left-Right Differences					
	Left	Right	R - L	Left	Right	R - L
ERL						
LN	.0184	.0191	.0007	.0207	.0212	.0005
WD	.0097	.0100	.0003	.0110	.0111	.0001
HT	.0062	.0067	.0005	.0066	.0071	.0005
	Pearson Left-Right Correlation Coefficients					
ERL						
LN		.41*			.67**	
WD		.14			.23	
HT		.55**			.58*	
	Pearson Correlation Coefficient ERL with E2B					
	Left	Right		Left	Right	
ERL and E2B						
LN	.31*	.33*		.57**	.50*	
WD	.40*	.30*		.17	.08	
HT	.23*	.27*		.61**	.48*	
	Pearson Correlation Coefficients ERL with ECU					
	Left	Right		Left	Right	
ERL and ECU						
LN	.19	.13		.14	.21	
WD	.07	.35*		.17	.07	
HT	.46*	.59**		-.05	-.12	

Key: * = p < .05
** = p < .0001

but for both hands! Both left and right heights are significant, as is right width. Using both correlation combinations, greater ERL use should show low E2B/ERL correlation and high ECU/ERL correlation. Only the last combination is significant for the non-agricultural females. The right height correlation of ERL with ECU in the non-agricultural females is highly significant ($p < .0001$) and may be the only certain marker of right hand sewing activity.

Failure of the other three tests to definitely support this leads to acceptance of the original hypothesis. This avenue of research did not yield information to prove right handed sewing activity in non-agricultural women.

Precision grip predominates in non-agricultural hand

One insertion not measured in this study is that of the Adductor Pollicis that draws the thumb toward the tip of the middle finger in the precision grip. Since it arises on the volar diaphysis of MC3, testing the dorsal-volar measure of that bone may yield information on that muscle. Testing for predominance in precision grip, the slightly greater dorsal-volar width on the MC3 is found (Table 23 [p.86]) in female left agricultural (.0190) contrasted with non-agricultural (.0189), and right agricultural (.0202) contrasted with non-agricultural (.0197). The male left agricultural (.0193) contrasted with the male non-agricultural (.0190) follows the same pattern, but the male right score (.0201 compared to .0200) in the non-agricultural is slightly greater. None of these differences is statistically significant (Table 24 [p.87]). The MC3 dorsal-volar score (Tables 10 [p.71] and 11 [p.72]) is the highest

of all dorsal-volar scores for both sexes, both hands, and both subsistence groups (except non-agricultural male left MC1) showing the precision grip was used actively by everyone. If we follow the MC3 dorsal-volar scores across the left-right correlation row in Table 25 (p.88) we find the lowest correlation (more active right hand) is clearly in agricultural women. This is confirmed by the shape difference ratios in Table 18 (p.80) (MC3, agricultural female) that shows the agricultural women to have a very busy precision-gripping right hand. Table 16 (p.76) shows that although the non-agricultural women have lower MC3 dorsal-volar scores on both hands than the agricultural women, when compared by shape (Table 17 [p.78]), the non-agricultural females' left is deeper. The exceptionally deep MC3 third dorsal-volar of non-agricultural males has already been noted (Table 17).

Precision grip involving Adductor Pollicis was used by both agricultural and non-agricultural people with the agricultural females' right hand predominating.

Regarding higher scores on the ulnar, power grip side of the hand, Table 34 (p.99) shows significant differences in all three ECU male scores, left and right, and both ODM male scores, left and right. For the females, all scores except ECU right length and ODM right height are significantly different. That means that 18 of those 20 ulnar measurements (10 per sex, five per hand) are greater in agricultural hands, five of them to the degree of $p < .0001$. The conclusion is that the agricultural people were using the ulnar musculature of the hand a great deal more than the non-agricultural people, or stated differently, that the non-agricultural peoples made much less use of the power grip.

Atlatl evidence

Regarding the question of whether or not women used atlatls, the investigation into the comparative ratios of E2B and E3B to FCR showed only the $\frac{E2B}{FCR}$ right width ratio the same (Table 42). Other ratios although close--all within 4%--fail to form parallel patterns. Non-agricultural male-female comparisons (Table 34, column 3 [p.99]) show no significant differences for all right hand FCR and E2B scores. Different ratios but scores that are not significant fail to support the possibility that the same activity may have been performed (i.e., atlatl throwing). However, there is no clear pattern of male scores to disprove the female atlatl possibility.

Following Bridges' (1988) left-right studies done in search of atlatl evidence on the humerus, differences in left-right entheses correlation of E2B and FCR were found to have the greater FCR scores in the left hand for both sexes (Table 43).

This is not indicative of both using the atlatl since the same pattern prevails in the agricultural women (Table 27 [p.91]). E2B right minus left scores show no parallels between sexes.

Examining the left-right differences from the standpoint of correlation, we would expect the men--if they were the throwers--to show a greater difference, or less left-right correlation (Table 44).

Non-agricultural females show less left-right correlation in FCR height and E2B height than the males. The non-agricultural males show less left-right correlation in FCR width and E2B length than the females. FCR height and E2B width have very similar correlation scores.

TABLE 42

EXTENSOR-FLEXOR RATIOS OF NON-AGRICULTURAL FEMALES AND MALES

Ratio	Non-Agricultural Females Left	Non-Agricultural Females Right	Non-Agricultural Males Left	Non-Agricultural Males Right
		E2B / FCR		
LN	.8215	.8000	.8475	.8212
WD	.9534	.9642	.9378	.9653
HT	.8546	.9117	.8907	.8929
		E2B + E3B / FCR		
LN	1.5922	1.6157	1.6280	1.5992
WD	1.7782	1.8210	1.7374	1.7938
HT	1.8235	2.0220	1.8576	1.9096

TABLE 43

FCR AND E2B RIGHT - LEFT DIFFERENCES BETWEEN NON-AGRICULTURAL FEMALES AND MALES: MILLIMETERS

Variable	Female Right - Left	Male Right - Left
FCR		
LN	.29	.19
WD	-.09	-.09
HT	-.17	-.03
E2B		
LN	.02	-.13
WD	.01	.05
HT	.01	-.02

TABLE 44

PEARSON LEFT-RIGHT CORRELATION COEFFICIENTS FOR E2B AND FCR:
NON-AGRICULTURAL FEMALES AND MALES: HANDFEMR

Variable	Females	Males
FCR		
LN	.15	.44*
WD	.43*	.35*
HT	.55**	.56**
E2B		
LN	.46*	.33*
WD	.39*	.42*
HT	.27*	.36*

Key: * = $p < .05$
** = $p < .0001$

This series of tests does not show either male dominance or female participation in expected actions. It may be that atlatl throwing left little evidence on the hands since the majority of the force must have been on the humerus and forearm. Recent studies in sports medicine to determine weightlifting requirements (kilograms per moment [kg/m]) to prepare athletes for various sports have shown the following: javelin throw requires (kg/m) .99 for wrist flexion, .58 for wrist extension; whereas golf drive requires (kg/m) 5.0 for wrist flexion, 7.5 for wrist extension. The maximum on this scale is required by hammer throw with (kg/m) at 50.00 for wrist flexion, 90.00 for wrist extension (Plagenhoef, 1971:157,158). The javelin would seem to parallel most closely the activity involved in atlatl throwing, and is the least demanding on the wrist muscles. One further area of the hand to be examined--rather than those muscles used in throwing-would be those muscles used in holding the atlatl. This will be discussed in Chapter 6.

Bow and arrow evidence

Is the increase in entheses scores significant for the agricultural male left hand--stabilizing the bow--over the non-agricultural male left, particularly in the ECU and the ERL? Table 34 (p.99) shows both these extensors to have significant height score differences in all measures, with the ERL length and width and ECU length significant to $p < .0001$.

In the right hand there is a highly significant ($p < .0001$) difference in the agricultural male MC2 medial-lateral width (Table 24, column 2 [p.87]; Figure 49 [p.277]) that also appears as significant in agricultural female-male differences (Table 24, column 4). The broadening of MC2 would not only stabilize the bone, but provides a larger surface for the origin of the First Palmar Interosseous muscle. This muscle draws the second and third fingers together in a pinching action when the metacarpal-phalangeal joint is extended but the interphalangeal joints are flexed. This is the standard arrow-holding position of the right hand. First Palmar Interosseous also is active in clockwise tip-to-tip and pad-to-pad motion of the first three fingers in precision grip, but silent in counter-clockwise rotation where the IK and OPX are active (Landsmeer, 1979:31).

It should also be noted in Table 17 (p.78) regarding the cross-sectional shape of MC2 that the agricultural male right MC2 ratio DV-ML of 1.04 is flatter than any other male MC2, MC3 or MC4 (the palmar interosseous supporters) cross-section in either hand. Table 16 (p.76) lists the increase in the agricultural male MC2ML measure as 1.09 mil-

limeters, by far the greatest of all medial-lateral right increases. The greatest dorsal-volar difference is the .77 millimeter increase on the same right male bone.

It is important, however, not to overlook the absence of this medial-lateral increase in the young and old non-agricultural male comparisons in columns six and eight of Table 24 (p.87). It is not significantly different from the non-agricultural males in the young or the old cohorts. This will be discussed in Chapter 6.

The second area in the right hand bearing bow and arrow evidence (p.67) is in the E2B, E3B, and ECU extensors and the FCR. Table 34 (p.99), column 2 shows the agricultural male significantly larger on all right FCR measures, all right E2B measures, right E3B height, and all right ECU measures.

Hand changes for males as a possible result of bow and arrow usage are seen as hypothesized.

Hafted tool evidence

In examining the possible increases in OPX on MC1 and ODM on MC5 for use in holding hafted tools, there is a significant difference (Table 34, columns 1 and 2 [p.99]) for both left ($p < .001$) and right ($p < .05$) OPX lengths in the female. In the males, both left ($p < .0001$) and right ($p < .0001$) OPX lengths are greater for the agriculturalists, as is the right hand OPX height measurement ($p < .05$). For the ODM scores, only the female right width does not show significant increase. These differences support the hypothesis of greater hafted tool use by the agricultural people.

Left-right correlation scores for each of these two opponens muscles and OPX with ODM correlations show the greatest use of both hands together is in the non-agricultural female ODM and agricultural male OPX (Table 45). The agricultural female left-right correlations are very

TABLE 45

PEARSON LEFT-RIGHT CORRELATION COEFFICIENTS FOR OPX AND ODM

	Female		Male	
Variable	Non-Agricultural	Agricultural	Non-Agricultural	Agricultural
OPX				
LN	.50**	.03	.28*	.75**
HT	.49**	.67**	.41*	.81**
ODM				
LN	.70**	.59*	.44*	.65**
WD	.64**	-.09	.10	.20

Key: * = $p < .05$
** = $p < .0001$

difficult to interpret since one measure of muscle usage for both opponens shows high left-right correlation (.67), but the other measurement of the same muscle very low (.03). This implies that some very different activities must have been carried on by each hand. Correlation scores on the two opponens being used together point to that action being significant in agricultural female right and agricultural male left (Table 46).

In looking for evidence of increased action in the ulnar side of the hand--the strength factor in the power grip--the ECU is the only muscle measured from this complex. In Table 34, columns 1 and 2 (p.99) the length, width, and height of the agricultural measurements increase

TABLE 46

PEARSON CORRELATION COEFFICIENTS FOR OPX WITH ODM

	Female				Male			
	Non-Agri.		Agricultural		Non-Agri.		Agricultural	
Variable	Left	Right	Left	Right	Left	Right	Left	Right
Length	.04	-.12	-.17	.16	.19	.09	.34*	.05
Width	.01	.17	.08	.47*	.01	-.03	.00	.12

Key: * = $p < .05$

significantly for both male left and right hands. For the female, all but the right length of ECU increases significantly. The increase in the length of MC4 and MC5 has already been mentioned (Table 14 [p.74]). This increase not only changed the shape of the palm but provided greater surface for the attachment of the ulnar Interossei (Dorsal Three and Four, Palmar Two and Three). From Table 24 (p.87) it is noted that only female MC4 dorsal-volar and male left MC5 medial-lateral show significant changes in width measures of these ulnar metacarpals. However, in Table 19 (p.80) an increase in bone mass--although not statistically significant--can be seen for all MC4 and MC5 widths in both sexes, and Table 17 (p.78) shows shape changes on the ulnar cross sections in all but the male right MC5.

Age changes

In dealing with the question of increasing accumulated bone on metacarpals from young through middle to old age, it can be seen in Tables 38 (p.106) and 39 (p.107) that many of the entheses do continue to enlarge from young through middle to old age for all groups except the old agricultural male right hand.

In Table 38 (p.106), the non-agricultural women show continuing increase in entheses measures from middle to old age (13 of 22 left, 15 of 22 right) that are not as great as those from young to middle age (18 of 22 left, 19 of 22 right). The increase in entheses size for agricultural women, however, is greater for the older women than the middle aged in 19 of 22 left, 20 out of 22 right; the agricultural young to middle age scores are increased in only 16 of 22 left and 11 of 22 right. As hypothesized, younger non-agricultural women reached mature measures later (18 left and 19 right young scores are not at the mature level) than the younger agricultural women (only 16 left and 11 right young scores are not at mature level). Moreover, older women were actively doing work that caused bone deposits on entheses to increase much more in agricultural females than non-agricultural females. For the males (Table 39 [p.107]), 21 out of 22 scores increased with middle age maturity for both non-agricultural hands and for the left agricultural hand. The young agricultural male right hand shows 18 out of 22 scores less than the mature middle age cohort. Young men's hands were not put to work as early as those of younger women for either group.

Older non-agricultural men were kept actively in the work force as noted by the continued increase in their entheses scores for middle to older men--16 out of 22 left, 20 out of 22 right. But, the older agricultural males have an increase from the middle age cohorts of only 8 out of 22 left and 3 out of 22 right. Yet, in Table 34, column 8 (p.99), when the older males of each susbistence group are compared for enthesis scores, only one right score (E3B width) is significantly

greater for the longer-working, old, non-agricultural hand. The non-agricultural men have continued work longer, but their work was still not as stressful to hands as the hands of the agricultural old men who no longer labored at peak male work. The question of whether the older agricultural men were absorbed into the work force of the older agricultural women is discussed in Chapter 6 (p.157).

CHAPTER 6

INTERPRETATION OF FINDINGS AND ADDITIONAL RESULTS

New information from the data will be included in this chapter. More concentration will be placed on what the differences are between the groups studied, rather than on whether or not they are different.

The first concern will be to provide possible explanations to questions raised in Chapter 5. Following that, an effort will be made to interpret the hand peculiarities of each site against the background of the archeological data found at those sites.

Increase in Size

It became clear during the collection of the data that the later agricultural sites had longer measures in both the femur lengths and metacarpal lengths than the earlier sites. When listed by site and cultural period, those increases are sequential (Tables 47 and 48). A gradient can be seen in the metacarpal and femur measurements inclined toward the larger people in the later sites.

Change in the size of people through time has long been a topic for research and discussion. Apart from obvious nutritional and growth arguments, an amazing variety of etiologies has been proposed such as annual temperature and latitude (Roberts, 1953; Newman, 1960; Boyce, 1979), Bergmann's Rule (Newman and Munro, 1955), altitude (Frisancho

TABLE 47

HAND SIZE MEANS SHOWING INCREASE THROUGH TIME
BY SITE AND SEX (LEFT HAND)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Female: Millimeters									
Femur	395.83	399.88	398.36	401.33	400.71	400.71	407.90	419.60	417.00
Metacarpal length									
1	38.60	38.70	39.16	39.54	40.57	39.64	40.50	42.68	43.11
2	59.50	59.42	58.72	59.95	60.95	61.42	61.35	63.79	65.22
3	59.25	58.62	58.90	59.70	59.86	60.83	61.12	63.85	64.80
4	51.75	49.80	50.00	51.44	50.56	51.83	53.37	55.94	56.47
5	45.40	45.78	45.50	46.00	47.13	48.20	49.62	50.76	50.72
Female: Handfemr Ratios									
Metacarpal length									
1	.0980	.0970	.0978	.0995	.1012	.1003	.0970	.1017	.1034
2	.1526	.1474	.1465	.1500	.1521	.1536	.1494	.1518	.1564
3	.1520	.1483	.1480	.1493	.1496	.1515	.1486	.1522	.1554
4	.1336	.1264	.1236	.1283	.1266	.1291	.1297	.1330	.1354
5	.1138	.1143	.1131	.1143	.1178	.1227	.1181	.1218	.1217
Male: Millimeters									
Femur	432.50	425.87	433.75	437.16	435.43	433.71	446.50	456.95	451.44
Metacarpal length									
1	40.00	41.18	42.37	43.14	43.02	43.85	44.77	45.97	46.33
2	60.50	62.81	63.05	63.37	64.06	65.17	67.14	68.95	69.16
3	61.20	62.70	63.11	63.50	63.21	64.30	66.75	68.29	68.80
4	53.25	53.00	53.05	54.50	53.68	55.11	56.33	59.47	59.33
5	48.16	50.62	50.16	50.00	49.61	51.25	51.75	54.15	54.80
Male: Handfemr Ratios									
Metacarpal length									
1	.0932	.0999	.0960	.0982	.0989	.1015	.1018	.1008	.1022
2	.1399	.1523	.1453	.1464	.1473	.1551	.1463	.1500	.1532
3	.1408	.1508	.1451	.1444	.1453	.1487	.1482	.1486	.1524
4	.1218	.1280	.1228	.1304	.1236	.1273	.1252	.1293	.1314
5	.1103	.1191	.1138	.1143	.1142	.1191	.1152	.1189	.1214

TABLE 48

MEAN FEMUR LENGTH AND LEFT METACARPAL TOTAL LENGTHS
BY SITE: MILLIMETERS

SITE	FEMALE FEMUR LN	METACARPAL LN TOTALS (1+2+3+4+5)	MALE FEMUR LN	METACARPAL LN TOTALS (1+2+3+4+5)
1	395.83	254.50	432.50	263.11
2	399.88	252.32	425.87	270.31
3	398.36	252.28	433.75	271.74
4	401.33	256.63	437.16	274.51
5	400.71	259.07	435.43	273.49
6	400.71	261.92	433.71	279.68
7	407.90	265.96	446.50	286.74
8	419.60	277.02	456.95	296.83
9	417.00	280.32	451.44	298.42

and Baker, 1970), social stratification (Buikstra, 1976), sex (Hall, 1985), marriage practices (Bowles, 1932), and religious origins (Kaplan, 1954).

One of the most creative and convincing explanations is by Stout who states that after histomorphometric analyses of bone kinetics for two Illinois Woodland populations--the first, non-agricultural, the second corn agriculturalists--increased bone turnover in the agricultural population is seen. Stout theorizes that this might show that parathyroid activity had increased to compensate for low calcium content in a corn diet, resulting in more and faster bone turnover during growth (Stout, 1978).

Some researchers have introduced the relationship of human behavior and physical activity to stature change (Brues, 1959; Smith, 1971; Frayer, 1981; Bridges, 1989b). Small body size may optimize functional capacity (Frisancho and Baker, 1970); conversely, small body size may be

"maladaptive if it significantly reduces individual productivity and work capacity" (Hass and Harrison, 1977:90). A ten-year longitudinal study on 3,000 subjects in the U.S.S.R., using radio-active isotopes and roentgenography, showed (a) variations of bone shape and structure characteristics for a given occupation or sport; (b) change of profession or trade provoked changes in structure corresponding to new type of loading; (c) physical work favors growth of bone in length (Prives, 1956). More recently, researchers have determined that the transition to agriculture in the Southeast has caused such changes in stature patterns as: agricultural people are taller as a result of "less rigorous life-style" (Joerschke. 1983), or, agricultural people are smaller since "bone is resorbed in the absence of functional demand" (Larsen, 1981; Ruff et al. 1984); and, Archaic and Mississippian people are the same height since changing activities cause increase in width but not length of long bones (Bridges, 1982). Also it is noted that "behavioral alterations differentially affected females" (Larsen, 1980) as opposed to "no significant change was found in bone length" when testing for decreased sexual dimorphism (Bridges, 1982).

Considering these conflicts in current interpretation, this study will only point out that an increase in femur length and metacarpal lengths does occur through time among the sites sampled.

Other extensive work on size changes as reflected in sexual dimorphism (Hamilton, 1982; Gray and Wolfe, 1980; Frayer, 1980; Wolfe and Gray, 1982; Hall et al., 1985) does not apply here since the dimorphic ratio for both subsistence groups in femur and hand are so similar. The male-female femur ratio for the non-agricultural sample is .9213, for

metacarpals, .9363; the male-female femur ratio for the agricultural sample is .9206, for metacarpals, .9359.

The relationship between metacarpal length and femur length is shown in the first part of Table 20 (p.82) of this study, where 38 of the 40 metacarpal lengths show significant correlations ($p < .05$) with femur length. It should be noted, however, that the correlations range from .17 to .66 with MC2 scoring highest, MC5 the lowest.

In earlier British regression studies, using both male and female left and right hands sampled by x-ray, equations were generated to predict stature from metacarpal measures. The authors, acknowledging a three percent error, produced a "rough and ready estimate of living stature where all else fails" (Musgrave and Harneja, 1978:117). Their correlation scores for the relationship between metacarpals and stature in the living (in the .60 to .70 range) are similar to the highest scores in this study of skeletal correlation between metacarpals and femora.

Of greater concern is the increase in hand size that is twice the percentage of the increase in femur length (p.70). When examined by age, this sample, which is grouped into agricultural and non-agricultural by sex, shows the shortest femora among the elderly in three out of the four groups (see Tables 21 [p.83] and 22 [p.84]). If long bone length is related to activity, division of labor by age and sex as well as by subsistence patterns needs to be considered (Burton and White, 1984).

Studies in the relationship of grip strength to stature done in India conclude that stature is the most important variable contributing

to muscular strength (Malik and Nath, 1980). Others however have determined that total bone width correlates most directly with grip strength (Plato and Norris, 1980). It may be that increased bone width accompanies increased stature.

Tooth size decrease, hand size increase

Hinton, Smith and Smith conclude in their 1980 study:

> The Mississippian period . . . represented by the dental sample in this study begins around 1300 . . . By this time the subsistence pattern had changed to a strategy based primarily on food production (maize cultivation), supplemented by hunting and collecting. Thus where the main focus of the diet had shifted to a dependence on maize, other dietary components prevalent in Archaic and Woodland times still appear to have been retained in the Mississippian period, albeit in lesser proportions. However, the dentition of the Mississippian peoples not only exhibits a reduction in size, but also a reduction in degree of attrition . . . . The synchronous nature of these rather dramatic changes suggests that the reduction in tooth size is most likely due to a change in subsistence and/or food preparation and concomitant reduced attritional stress on the dentition [underlining added] (Hinton et al., 1980:241).

The sample used in this dental study includes many of the same sites used in the current hand study from Tennessee. As tooth attrition and size were reduced, those researchers found stature increasing (Hinton et al., 1980:240). In this study, if hand size and entheses increase, it might facilitate increased food processing outside of the mouth. Sexes were combined in the dental sample making it unfortunately difficult to fit the hand data to the tooth data. If it could be done, we expect the tooth size decrease to occur while the hand size increases.

Hand Shape Changes

Research into changes in relative proportions of long bones is less abundant than that of stature change (Frayer, 1981). This is an area of particular concern for this study considering the inequitable increase in the length of the ulnar MC4 and MC5 (Table 14 [p.74]). Studies that do exist show that there is a higher correlation in growth patterns in the bones of the hand across the rows than down the rays; that the most active growth centers for elongation in the hand are in the peripheral bones one and five; and that the pattern of related lengths of bones in the hand is established early in fetal life--at 13 weeks (Roche and Herman, 1970; Takai, 1977; Garn et al., 1975:43).

Some other force outside of normal growth patterns must have caused MC4 and MC5 in this study to elongate. From research on bone remodelling, the Hueter-Volkmann Law states, "that pressure retards and traction accelerates the growth rates in the cartilagenous plates separating epiphyses and diaphyses" (Lovejoy et al., 1976).

In dealing with similar changes in gibbon hands, Van Horn warns, "hands perform various functions, and the survival value of form cannot be accurately evaluated by correlations with single isolated functions" (Van Horn, 1972) and reminds that selection is a compromise since the entire phenotype, not just one characteristic, survives.

Whatever fortuitous factors produced the larger, broader, squarer palms in the agricultural people, the change was certainly to their advantage. The increased palmar area enabled expanded contact surface for grasping hafted tools; the increased areas of attachment of ulnar

flexors and extensors enabled greater power to be exerted in the power grip. To understand this advantage, the reader should grasp a pencil firmly against the palm; then, when extreme pressure is exerted on the pencil, note that the origin of that maximum force is from the ulnar side. (Recent studies aimed at explaining why increased joint pressure in the hand produces ulnar drift indicate that the ulnar collateral ligaments at the joints are stiffer [James et al., 1982].) Since this research does not include phalangeal studies, we can only presume the increase in finger length was commensurate with that of the palm. This needs to be tested.

The larger hand enables the use of larger, heavier tools. The OPX is documented in modern studies (Basmajian and DeLuca, 1985) as being called into play for grasping large, round objects pressed into the palm. The statistically significant increase in enthesis size of the OPX from the non-agricultural to the agricultural, both hands and both sexes (Table 34 [p.99]), testifies to increased use of larger tools.

The earlier, non-agricultural people used tools which were manipulated mainly between the first three digits and the palm in a "leister" grip. Such tools as the 1,379 conical stone pestles excavated at Indian Knoll (Webb, 1946) or the "puzzling" pounders in the Three Mile shell mound stratum of the Eva Site (Lewis and Lewis, 1961) fit in the first three fingers.

In within-hand proportion, the first two metacarpals are actually shorter in the agricultural hand than in the non-agricultural hand when related to total hand measure (Table 15 [p.75]). Those elongated radial metacarpals were well adapted to the non-agricultural tools.

The other length difference is the difference between the right and left hands. Only the agricultural males have an increase of right over left in all five metacarpals (Table 11 [p.72]). The non-agricultural males have a similar left-right increase only in MC2. In length, the non-agricultural females show right over left increase in MC1, but a significant decrease in right from left in MC3 (Table 10 [p.71]). It would seem probable that all left-right differences are the result of bone buildup from activity of the hand. It is known that some growth on these bones continues into adulthood (Garn et al., 1967b). Since it is not known where the addition is added (proximal, distal, or both), speculating on the causal activity would be foolish. Whatever "it" was, "it" affected all five of the right metacarpal lengths in the agricultural people.

When examined in terms of age (Tables 21 [p.83] and 22 [p.84]) the longest metacarpal measurements are in the middle age cohort (36 out of the 40 measurements), presumably the most active group carrying the major work load. Only the non-agricultural females left MC3 and MC4, and non-agricultural males right MC1 and MC5 deviate from that pattern. If bone lengths are simply grouped according to longer or shorter than the middle age cohort, there is no pattern for the non-agricultural males and females in either hand. This is not true for the agricultural people where both hands and both sexes favor the young for the smaller measurement (34 out of the 40 measurements) and the old with the next longest scores. If the bone length reveals activity, the older hands in both subsistence groups have more relaxed tasks compared to the middle age cohorts.

After the metacarpal lengths and widths were converted to Handfemr ratio scores by dividing each of the individual's measurements by that person's femur length, the new scores were listed in Table 23 (p.86). The statistically significant differences between groups of those Handfemr scores in Table 24 (p.87) show a variety of differences that will be examined in several different ways. One procedure is to list and compare the differences in those scores. Such differences with the percent of increase and decrease (taken from figures in Table 23) are listed in Table 49. Particularly high and low differences may indicate the types of activities that changed the shape of the hands. A five percent and above increase from non-agricultural to agricultural (underlined in Table 49) usually indicates a level of difference of more than one standard deviation. Statistical significances of those differences are listed in Table 24. Low percent of increase also deserves scrutiny since it may point to larger measures in the non-agricultural population.

The peculiar differences in metacarpal length and width scores are: for the women: larger MC4 and MC5 lengths in both agricultural hands; greater dorsal-volar depth in the non-agricultural hands, especially in MC1; the greater increase in medial-lateral width of right MC2 in agricultural women, and large medial-lateral MC5 width in non-agricultural women; for the men: the larger agricultural MC4 and MC5

TABLE 49

DIFFERENCES AND PERCENT OF DIFFERENCE BETWEEN NON-AGRICULTURAL AND AGRICULTUAL LENGTHS AND WIDTHS: HANDFEMR

Metacarpal	Female Non-Ag to Agricultural Difference	Female % Dif.	Male Non-Ag to Agricultural Difference	Male % Dif.
Left Length				
1	.0034	3.43	.0023	2.52
2	.0035	2.32	.0037	2.50
3	.0043	2.87	.0040	2.73
4	.0069	5.42	.0053	4.23
5	.0050	4.28	.0046	3.98
Right Length				
1	.0035	3.47	.0037	3.73
2	.0035	2.31	.0063	4.22
3	.0062	4.17	.0059	4.02
4	.0078	6.11	.0074	5.92
5	.0064	5.50	.0069	5.98
Left Dorsal-Volar Width				
1	-.0013	-6.95	-.0010	-5.20
2	-.0005	-2.70	.0002	1.07
3	.0001	.52	.0003	1.57
4	.0006	4.08	.0001	.65
5	.0001	.72	-.0002	-1.37
Right Dorsal-Volar Width				
1	-.0013	-6.84	-.0013	-6.50
2	.0004	2.15	.0008	4.16
3	.0005	2.53	-.0001	-.49
4	.0001	.63	.0002	1.26
5	.0000	0.00	.0003	2.01
Left Medial-Lateral Width				
1	.0008	3.60	.0008	3.53
2	.0005	2.99	.0006	3.55
3	.0004	2.45	.0005	3.06
4	.0003	2.29	-.0001	.74
5	-.0001	-.64	.0007	4.40
Right Medial-Lateral Width				
1	.0007	3.01	.0005	2.10
2	.0009	5.29	.0018	10.28
3	.0004	2.39	.0004	2.38
4	.0006	4.41	.0005	3.59
5	.0001	.62	.0003	1.81

Key: Underlined = five % or more increase or decrease

lengths on the right, and larger MC4 length on the left; the greater dorsal-volar depth of non-agricultural men on both left and right MC1's, and generally large dorsal-volar measures by non-agicultural men in all but the right MC2; medial-lateral width differences on men show each hand quite distinct; the left male medial-lateral shows a large measure for non-agricultural men only on MC4, with MC5 increase larger for agricultural males. On the right, the medial-lateral increase for agricultural males shows the greatest difference of all measures in the very broad MC2 (10.28% increase) contrasted with a small increase in the medial-lateral of MC5.

Length changes by age

Another important clue to the variety of differences in scores is the age at which those differences appear. When scores are compared within age cohorts but between subsistence groups those differences are seen in Table 50 (females) and 51 (males).

In Tables 50 and 51 we note that some of these length differences in middle age were not present in the young age groups. This is particularly astonishing when the significantly increased lengths of MC4 and MC5 are noted in the agricultural populations after epiphyseal growth has stopped. (It will be recalled that all metacarpals in the "young" category have epiphyseal caps attached, but still had at least one line of union visible.) Pfeiffer (1980) has noted similar increase in humeri lengths from young to older adults in a skeletal sample from Ontario dated at 1600 A.D.

TABLE 50

FEMALE DIFFERENCES AND PERCENT OF DIFFERENCE NON-AGRICULTURAL TO AGRICULTURAL LENGTH AND WIDTH INCREASES BY AGE: HANDFEMR

Meta-carpal		Young Difference	Young % Dif.	Middle Difference	Middle % Dif.	Old Difference	Old % Dif.
Length							
Left	1	.0028	2.81	.0032	3.21	[(.0048)]	4.89
	2	.0046	3.06	.0007	.45	[(.0062)]	4.17
	3	.0038	2.55	.0018	1.19	[.0082]	5.53
	4	.0051	4.00	.0071	5.56	[(.0096)]	7.63
	5	.0032	2.74	.0068	5.82	[(.0074)]	6.42
Right	1	.0044	4.44	.0028	2.75	[(.0034)]	3.37
	2	.0041	2.72	.0010	.65	[(.0071)]	4.77
	3	.0064	4.30	.0031	2.05	[(.0100)]	6.86
	4	.0064	5.03	.0084	6.51	[(.0100)]	7.94
	5	.0055	4.74	.0056	4.73	[(.0092)]	8.09
Dorsal-Volar							
Left	1	-.0007	-3.80	-.0023	-1.20	(-.0009)	-4.83
	2	-.0005	-2.80	-.0011	-5.82	[(.0001)]	.54
	3	.000	.00	-.0003	-1.56	.0007	3.66
	4	.0007	4.86	-.0001	-.67	.0014	9.52
	5	.0003	2.23	-.0007	-4.89	(.0111)	8.33
Right	1	-.0006	-3.17	-.0023	-11.91	(-.0007)	-3.76
	2	-.0002	-1.09	-.0003	-1.57	(.0017)	8.37
	3	.0003	1.53	.0004	2.02	[.0007]	3.51
	4	.0003	1.93	-.0004	-2.48	.0005	3.44
	5	-.0003	-2.06	-.0008	-5.47	.0013	9.48
Medial-Lateral							
Left	1	-.0002	-.91	.0004	1.76	(.0026)	11.76
	2	.0006	3.65	.0004	2.36	[.0003]	1.77
	3	.0005	3.10	-.0003	-1.81	.0013	8.07
	4	.0002	1.53	.0000	.00	(.0009)	6.92
	5	.0003	1.97	-.0004	-2.48	[(.0002)]	1.30
Right	1	.0002	.88	.0003	1.26	(.0019)	8.18
	2	.0012	7.22	.0006	3.42	[(.0009)]	5.32
	3	.0005	3.03	.0000	.00	.0008	4.73
	4	.0005	3.64	-.0001	-.72	(.0017)	12.87
	5	.0000	.00	-.0001	-.61	(.0008)	5.00

Key: () = non-agricultural score less than preceding age
[] = agricultural score less than preceding age

TABLE 51

MALE DIFFERENCES AND PERCENT OF DIFFERENCE NON-AGRICULTURAL TO AGRICULTURAL LENGTH AND WIDTH INCREASES BY AGE: HANDFEMR

Meta-carpal		Young		Middle		Old	
		Difference	% Dif.	Difference	% Dif.	Difference	% Dif.
Length							
Left	1	.0004	.40	.0032	3.22	[(.0019)]	1.93
	2	.0013	.88	.0054	3.65	[(.0022)]	1.48
	3	.0000	.00	.0061	4.16	[(.0032)]	2.19
	4	.0053	4.30	.0057	4.54	([.0038)]	3.00
	5	.0013	1.12	.0061	5.28	[(.0040)]	3.47
Right	1	.0004	.39	.0062	6.30	[-.0006]	-.60
	2	.0016	1.07	.0082	5.50	[(.0054)[	3.62
	3	.0000	.00	.0094	6.43	[(.0026)]	1.76
	4	.0037	2.94	.0093	7.43	[(.0052)]	4.19
	5	.0031	2.67	.0082	7.11	[.0060]	4.95
Dorsal-Volar							
Left	1	-.0001	-4.68	-.0010	-5.20	[-.0013]	-6.63
	2	.0008	4.57	.0007	3.80	[-.0015]	-7.61
	3	.0004	2.20	.0005	2.60	[(-.0004)]	-2.06
	4	.0004	2.73	.0005	3.28	[-.0008]	-5.00
	5	.0005	3.67	-.0002	-1.37	[(-.0006)]	-4.08
Right	1	-.0013	-6.63	-.0006	-3.01	[(-.0031)]	-15.27
	2	.0019	10.67	.0009	4.63	[(-.0002)]	-1.03
	3	.0007	3.70	.0003	.99	[-.0015]	-7.10
	4	.0010	6.80	.0006	3.79	[-.0016]	-.9.75
	5	.0013	9.28	.0001	.66	.0001	.64
Medial-Lateral							
Left	1	.0025	11.68	.0007	3.07	[(-.0001)]	-.43
	2	.0007	4.40	.0009	5.23	[(-.0001)]	-.58
	3	.0002	1.26	.0006	3.63	[(.0003)]	1.84
	4	-.0001	-.77	.0003	2.22	[-.0013]	-9.21
	5	.0016	10.32	.0008	5.06	[-.0003]	-1.80
Right	1	.0018	8.00	.0008	3.38	[-.0016]	-6.50
	2	.0011	6.35	.0023	13.14	[.0007]	3.93
	3	.0003	1.86	.0008	4.76	[.0001]	.58
	4	.0005	3.78	.0008	5.71	[(-.0005)]	-3.52
	5	.0013	7.87	.0007	4.34	[-.0029]	-16.57

Key: () = non-agricultural less than preceding age
[] = agricultural less than preceding age

MC4 and MC5 are the most mobile metacarpals at their proximal ends, so bone may have been deposited there. MC2 and MC3 are nearly immobile at the carpal-metacarpal joint.

In searching through the correlation data to find other activities associated with this increase in length of MC4 and MC5 that occurs in the middle category of age in the agricultural population, it was found that the lengths of MC4 and MC5 are highly correlated with one another ($p < .0001$) for both sexes, both subsistence groups, within each hand, and between hands (right MC4 and left MC4, right MC5 and left MC5).

Width changes

In comparing the changes in metacarpals between the non-agricultural and agricultural people, changes in widths as well as changes in lengths are noted. Other studies on metacarpal widths have documented such changes, but they are based on a research design of left-right differences rather than subsistence differences. Some studies have shown that the addition of new bone is due to cortical apposition, not an increase in medullary width (Plato et al., 1980), and that width of the MC2 shows less heritability than does length (Kimura, 1983).

In biomechanical studies on the changes of bone diameter, Smith et al. point out that as diameter increases, so does the weight-bearing ability of a bone (Smith et al., 1983). It is difficult to conceive of metacarpals as being weight bearing bones, but it is possible to trace differences in the diameters that may point to different intensities of work done by the hand.

As seen in Table 17 (p.78), the agricultural MC1's are broader and flatter in both sexes and both hands. This represents first of all reduced depth in MC1 since the IK muscle that arises from the radial length (increasing the dorsal-volar width) is not used as much by the agricultural people as by the non-agricultural. The IK muscle is the one hand muscle in this study that predominates statistically as always larger in both hands and both sexes of the non-agricultural people (see Table 34 [p.99]. The flatter MC1 also represents an increase in the OPX activity in the agricultural hand where it is used for (a) increased intensive extension of the thumb; (b) increased intensive adduction of the thumb; (c) increased intensity of grasping an object (Close and Kidd, 1969:1606); (d) pressing an object against opposing fingers four and five, particularly a large cylindrical object shaped like a water glass (Basmajian and DeLuca, 1985:304); (e) continuous firm pressure in opposition (Hollinshead and Jenkins, 1981); (f) final anchor on the other grasping four fingers that are pressed against the palm (Napier, 1956:908).

In Table 16 (p.76), the greatest raw score increase in width is the singular difference in the right male hand of the medial-lateral width on MC2, also noted as significant in Table 25 (p.88) at $p < .0001$. The considerable dorsal-volar increase of this same bone produces a ratio of 1.0400 (Table 17 [p.78]) that masks its singularity when compared to the non-agricultural male right of 1.0876. Only when viewed in cross sectional area in Table 19 (p.80), is the real significance of the difference of this bone noted as having increased in robusticity beyond all others. As described on page 118 of Chapter 5, this is considered to

be an artifact of arrow pinching and bow string pulling. Plato and Norris's studies concentrating on MC2 conclude that high bone mass and density in that bone is directly correlated with high physical stress (Plato and Norris, 1980).

The increased size of the agricultural male MC5 both in flatness (left) (Table 17 [p.78]) and in area (Table 19 [p.80]) is also interpreted as part of the bow and arrow complex. In supporting both the ODM and ECU, the left MC5 carries the work of the muscles that provide strength against resistence and balance the radial pull of the powerful ERL, plus cupping the hand to provide a secure grasp of the bow.

Changes in the width measures of MC4 (both depth and width increase for agricultural males and females in both hands) reflect increased activity in the ulnar musculature of the hand. Two interosseous muscles, the Third Dorsal and the Second Palmar, attach to the sides of MC4 shaft and are strongly active and powerful in (a) first spreading hands to make the palm broader, then drawing the hand back together; (b) spherical grip (Long et al., 1970); (c) adduction and ulnar rotation in squeeze and ball grasps (Long et al., 1970); (d) maintaining fingers in maximum abduction and rotation around the ulnar edge of a cylinder or spherical object (Marzke, 1971); (e) facilitating the power grip (Long et al., 1970). In the unloaded hand, the Second Palmar Interosseous helps in bending fingers from extension toward flexion at the metacarpal-phalangeal joint (Long et al., 1970). These muscles cannot work during the closing of the full hand or when the fingers are fully flexed (MacConaill and Basmajian, 1977; Hamilton, 1976).

Grasping any tool for processing corn would easily explain the heavy use of muscles on MC4. Long considered women's work, lifting and dropping the large, top-weighted pole in a mortar procedure or grasping a circular or cylindrical stone mano to grind grain against a metate would both require these actions. Comparable male activity remains unexplained.

The non-agricultural male right MC3 is very peculiar because its depth-to-width ratio exceeds all other measures--any bone in any hand (Table 17 [p.78]). This is not easily seen on the statistical Table 24 (p.87) since the dorsal-volar and medial-lateral measures per se are not extreme, but rather their relationship one to the other. This sort of cross sectional shape is what would be expected in a hand that made extreme use of the Adductor Pollicis (arising from the volar surface of MC3) that draws the thumb toward the finger tips of digits two and three in a precision grip. Such a common action would hardly be a male specialty in the division of labor; the non-agricultural female score on the shape of right MC3 is the most similar to the non-agricultural male's with a ratio of 1.1841 compared to the male 1.1986. In addition, it may be that the deeper shaft of the right MC3 provided a greater area for the origin of the Second Dorsal Interosseous used to keep MC2 and MC3 abducted from one another or its accompanying Palmar Interosseous used to draw the fingers together when the metacarpal-phalangeal joint is extended. Both these actions are involved in supporting, pinching, and releasing the dart associated with an atlatl.

The cross-sectional areas of the approximate amount of bone in the widths and their differences by sex, subsistence, and hand is listed in

Table 19 (p.80). If those differences are viewed in terms of percent and the width increases are compared to the length increases in Table 49 (p.134), any thought of allometric parallels is difficult (Table 52).

TABLE 52

PERCENT OF LENGTH INCREASE AND PERCENT OF CROSS-SECTIONAL WIDTH INCREASE FROM NON-AGRICULTURAL TO AGRICULTURAL: MILLIMETER DATA

		Female		Male	
Metacarpal		% Length increase	% Cross-sectional width increase	% Length increase	% Cross-sectional width increase
Left	1	7.93	4.67	7.33	7.12
	2	6.65	8.70	7.67	3.24
	3	7.63	13.43	7.60	14.50
	4	9.92	15.62	9.65	9.44
	5	8.32	8.91	8.18	13.39
Right	1	7.65	3.91	8.18	6.34
	2	7.52	17.47	8.56	24.85
	3	8.93	15.67	9.44	13.02
	4	10.64	12.67	11.13	14.19
	5	10.36	9.29	10.72	12.93

In interpreting the percent of approximated cross-sectional width differences it is necessary to be aware that large differences may mean one of two things. The first is a much larger cross section in the agricultural bones such as the already described agricultural male right MC2 (24.85%); the other possibility could be a very small cross sectional bone in the non-agricultural hand as the basis for comparison, such as in the female left MC4 (Table 10 [p.71).

Another approach to width differences is the correlation of those measures with femur length as seen in the dorsal-volar and medial lateral sections of Table 20 (p.82). If changes in widths reveal

changes in activity, then it is important to note that not a single width measure in the agricultural columns retains a significant correlation with the femur. Since no norms exist for what correlations with the femur would be expected for non-modified metacarpals, this is an area for future study. If there were no pre-modified correlation, it is difficult to explain the numerous significant correlations in the non-agricultural male scores. If the low correlation of width scores with the femur does reflect cultural activity, it would appear that dorsal-volar measures are affected more than the medial-lateral ones.

Length and width changes may be examined by age to determine when those changes occur. From Table 24 (p.87) we see that all lengths are significantly different for the full population comparison, but that for the young group this is not so. The young females show that the agricultural hands have already established the length difference in left MC4, and right MC1, MC3, MC4, and MC5 while epiphyseal union lines are still present. Using U.S. median standards for white females, the epiphyses of all five metacarpals are attached by age 14.9 years (Roche, 1976:79). For the young males, there is no statistically significant length difference between non-agricultural and agricultural (Table 24), but Table 51 (p.137)--Young Male column--shows those changes are starting for all but MC3. This young female-male difference in timing can be interpreted in several ways: one is that agricultural young women are put to work before young men; another is that the kind of work being done was more stressful to females than to males. Both of these interpretations are heightened by the difference in age of maturity onset

between sexes that for U.S. metacarpal epiphyseal fusion takes place in females 2.2 years before males (Roche, 1976:45).

The only significantly different score in young female widths (Table 24, column 5 [p.87]) is the greater right MC2 medial-lateral. Table 50 (p.136) shows that this difference is at its greatest in the young women. The dorsal-volar young score on the same bone shows the non-agricultural young women with the greater score. This could mean just a very narrow, deep MC2 in the non-agricultural young and that seems to be the case. The dorsal-volar width of the young non-agricultural female is .0183, the young agricultural female is .0185; but the medial-lateral measures are .0166 and .0178 respectively. The old female scores show that this difference in right MC2 medial-lateral width is no longer distinctive among the old. Recent studies done on post-menopausal women's metacarpal cortical widths show no significant difference between right and left hands (Horsman et al., 1981), implying leisure years may lead to resorbtion.

Regarding women's length scores, changes happened young, reached their peak during middle years and most continued into old age. Width differences do not start as early but continue into old age; some appear first among the old (Tables 24 [p.87] and 50 [p.136]).

The male picture is different, as noted in Table 51 (p.137), on lengths, but five width differences are significant in the young. The singular large right MC2 has only expanded its dorsal-volar dimensions in the young, the medial-lateral broadening occurring in middle age. By old age, any bow and arrow distinctions between non-agricultural and agricultural males are gone, with only the right MC4 medial-lateral

being larger in the old agricultural males. The length continues to grow, width does not (Table 51). This is because of the drop in old male agricultural scores (see the last column in Table 51) which would give the impression that they are out of the hunting force and seemingly not part of the work force at all. Studies done by Plato et al. show that for MC2, larger bones do not always indicate greater cortical mass (Plato et al., 1982).

By contrast, the old agricultural women's scores are high enough to raise the total female scores to exceed those of the non-agricultural women, masking the fact that the non-agricultural female scores in the middle years are greater than the agricultural for all dorsal-volar increases and for the ulnar medial-lateral ones (see Table 50 [p.136]).

A final method of comparing the lengths and widths between subsistence groups is to compare right and left correlation scores. Using the Handfemr data in Table 25, columns two, four, six, and eight (p.91), the non-agricultural and agricultural correlations can be compared. A low correlation score between the right and left of the same measure is interpreted as indicating different action was occuring. A high correlation score would imply that both hands were involved in similar activities.

In Table 25 (p.91), the non-agricultural males and females both have high right and left correlation on lengths; the agricultural male and female do as well, with the exception of less right and left equality in length of MC1 for both sexes. Dorsal-volar widths in females show the non-agricultural with high left-right correlation on MC3DV, the agricultural females much lower. By contrast, those positions are

reversed in MC5DV with the non-agricultural females showing a lowered left-right correlation score, agricultural females with a greatly elevated one. Male dorsal-volar left-right correlation scores are most diverse for MC1 and MC2 with the agricultural males showing high correlation, non-agricultural males showing less. On medial-lateral scores again a divergence on MC3 can be seen with non-agricultural females showing a higher left-right correlation score than agricultural females. Those positions are reversed on MC4 and MC5. The male medial-lateral left-right correlation scores are interesting, with the agricultural males showing very different activity being done by MC1 and MC5, but high similarity in activities for MC4. Non-agricultural medial-lateral left-right correlation scores show the lowest similarity between right and left MC1's, but the remainder are similar to one another around .50, i.e. without distinct pattern.

Entheses Differences

Before any interpretation of the hand enthesis scores can even be attempted, it must be acknowledged that several inherent problems shadow the clarity of the analysis. The first two problems are grounded in the anatomy of the hand itself: (a) that it is nearly impossible to move one part of the manual apparatus involving the metacarpals and still expect other interconnected parts to remain immobile; and, (b) that the cooperative nature of the muscular system requires the same muscle to act as agonist, protagonist, or synergist, all three leaving the same record on the same enthesis without the distinction of which role was played. The third problem is a cultural one--that every hand carried

out many activities building up layers of bone on the entheses. A high score indicates great activity, but may represent several kinds of activities laminated into a tangle of evidence that could be easily misread. Only repeated activity of the same muscle combinations would leave the same high scores on those entheses involved.

The distinctives of each group (non-agricultural/agricultural, female/male) must be discovered in the fabric of comparative scores. Knowing those scores that are statistically different (Table 34 [p.99]) is just the beginning. It is necessary to see when (in what age group) those differences are greatest and if changes in the differences are real or an artifact of the paired scores moving apart, together, or parallel through time. Left and right differences also must be examined for those tasks that we know were not shared by both hands. This will be done for a limited number of known activities that should yield differences that can be interpreted. The majority of causes will probably remain a mystery, since many specific activities (such as games) are beyond our knowledge.

Entheses/femur length correlation

Very few correlations of femur length and left entheses are significant at $p < .05$ (Table 30 [p.94]). The non-agricultural males have six significant correlations, but there is only one each for the agricultural males and females and only two for the non-agricultural females. This might be interpreted as very weak support indeed for studies that correlate stature and grip strength. In this study, size

of person does not seem to be directly related to the intensity or amount of work done by the hand.

Entheses/metacarpal length and width correlation

Size of hand, however, does seem to have much more influence on size of entheses. In Table 31 (p.96), showing correlation scores for entheses and their supporting metacarpals, testing just the left hand, the non-agricultural males again show the closest relationship between bone size and entheses. They show 28 out of a possible 66 correlation scores significant to $p < .05$, and even 5 at the $p < .0001$ level. Agricultural males have 22 significant correlations; non-agricultural females have 20 and agricultural females have the least with only 12. Only one correlated pair is present in all four groups--E2B length and 2DV, an example of the predominance of the dorsal-volar measures in the correlated relationships. The non-agricultural females and males share 13 correlated combinations, 10 of those involving the dorsal-volar measure. The agricultural females and males share only three measures--the already-mentioned E2B length and 2DV being the only one involving the dorsal-volar measure. Correlations of muscles with their supporting metacarpal show which muscles have the most significant pairings: E2B--23; ERL--14; ECU--13; IK--9; E3B--8; FCR--7; ODM--5; OPX--3. Of the eight randomly scattered highly significant correlations of entheses with metacarpals at the $p < .0001$ level in Table 31, none occurs in the agricultural scores.

Between-entheses correlation

As division of labor becomes more intensified there is the possibility that muscle action might become more clearly defined. Between-entheses correlation scores were calculated for all measurements within each hand. In analyzing those scores by sex and by subsistence, the non-agricultural groups have a higher percent of possible combinations significant at $p < .05$ as well as a larger quantity of highly significant correlations at $p < .0001$. These are summarized in Table 53.

TABLE 53

NUMBER OF SIGNIFICANT BETWEEN-ENTHESES CORRELATIONS BY GROUP AND HAND

Group	Number at $p < .05$	Number at $p < .0001$
Right (of 211 possible combinations)		
Non-ag. females	64	7
Ag. females	47	1
Non-ag. males	72	8
Ag. males	41	1
Left (of 211 possible combinations)		
Non-ag. females	66	5
Ag. females	58	4
Non-ag. males	78	8
Ag. males	35	0

These are only binary correlations, but are still statistical indicators of greater variety of action (non-agricultural) or more limited number of actions (agricultural).

Differences in the entheses scores have been tested for significance in Table 34 and are listed with their percent of difference in Table 54

TABLE 54

NON-AGRICULTURAL TO AGRICULTURAL DIFFERENCES IN ENTHESES SCORES AND PERCENT OF DIFFERENCE: HANDFEMR

	Female				Male			
	Left		Right		Left		Right	
	Difference	% of Dif.	Difference	% of Dif.	Difference	% of Dif.	Difference	% of Dif.
OPX								
LN	.0034	12.09*	.0024	8.00*	.0045	16.12**	.0039	13.08*
HT	.0003	6.81	.0005	10.63	.0005	9.80	.0008	15.38*
IK								
LN	-.0027	-7.12	-.0022	-5.72	-.0018	-4.87	-.0012	-3.25
WD	-.0009	-9.18*	-.0008	-7.92*	-.0006	-6.45	-.0005	-5.26
HT	-.0009	-18.36*	-.0010	-20.00*	-.0002	-4.25	-.0002	-4.25
ERL								
LN	.0023	12.50*	.0021	10.99*	.0023	12.23**	.0026	13.75**
WD	.0013	13.40*	.0011	11.00*	.0020	17.54**	.0016	16.84**
HT	.0004	6.45	.0004	5.97	.0007	10.14*	.0008	11.59*
FCR								
LN	.0021	8.71*	.0005	1.96	.0024	9.60*	.0018	7.08*
WD	.0015	13.39*	.0012	10.90*	.0013	11.40**	.0009	7.96*
HT	.0002	2.77	.0003	4.40	.0007	10.14	.0008	11.59*
E2B								
LN	.0014	6.96*	.0008	3.96	.0009	4.24*	.0020	9.66*
WD	.0010	9.43*	.0008	7.61*	.0013	12.14*	.0012	11.00*
HT	.0003	4.91	.0000	.00	.0007	11.47	.0009	15.00*
E3B								
LN	.0025	13.44*	.0013	5.96	.0014	7.25*	.0012	6.03
WD	.0003	3.26	.0001	1.05	-.0002	-2.17	.0000	.00
HT	.0000	.00	.0003	4.05	.0009	13.65*	.0014	20.58*
ECU								
LN	.0019	9.84*	.0007	3.39	.0030	15.00**	.0031	15.42**
WD	.0015	13.76*	.0010	8.92*	.0010	9.43*	.0009	8.10*
HT	.0012	17.14*	.0015	21.42*	.0015	23.07*	.0013	19.11*
ODM								
LN	.0090	21.95**	.0078	18.97**	.0059	14.39*	.0072	17.95**
WD	.0010	13.33*	.0004	5.00	.0009	12.00*	.0012	15.38*

Key: * = NPAR1WAY significant (Table 34)
** = significant to p < .0001 (Table 34)

The agricultural scores predominate in all but the IK measures, the male E3B width, and the height measures for female right E2B and left E3B. The differences and percent of difference are not particularly distinctive as to kinds of work until they are broken down by age and sex (Tables 55 and 56).

<u>Agricultural female entheses interpretation</u>

Using the $p < .0001$ scores of Table 34 (p.99) to indicate the activity groupings in the agricultural hand (on Table 54), we find only the ODM length indicated for the women. The action of the ODM is to cup the ulnar side of the hand in opposition to the OPX-directed thumb. This paired action cannot be separated and may be noted by the reader pressing on the ulnar heel of the right hand and sensing the contraction of the ODM as the thumb is extended and then flexed (brought around) toward the ulnar side. The lengthwise increase of the ODM indicated in the agricultural scores points toward greater effort to extend the ulnar side of the hand in opposition and in continuous firm pressure in holding tools (Basmajian and DeLuca, 1985:302; Hollinshead and Jenkins, 1981). Since the ODM significant difference is bilateral, a two-handed action may be indicated and certainly agrees with the task of lifting and dropping the heavy wooden cylinder in grinding corn. The female ODM score difference is already significantly present in the young women and must represent work started early in life (see Table 34, column five).

Of the two agricultural sites in this study, Site Eight represents Mississippian culture patterns that include such tasks for women as gardening with digging stick and short-handled hoe, weaving, pottery and

TABLE 55

FEMALE ENTHESES DIFFERENCE AND PERCENT OF DIFFERENCE
NON-AGRICULTURAL TO AGRICULTURAL BY AGE: HANDFEMR

	Young				Middle				Old			
	Left Dif.	% of Dif.	Right Dif.	% of Dif.	Left Dif.	% of Dif.	Right Dif.	% of Dif.	Left Dif.	% of Dif.	Right Dif.	% of Dif.
OPX												
LN	.0004	1.33%	.0034	10.75%	.0030	10.79%	.0005	1.72%	(.0078)	29.77%	.0035	11.98%
HT	.0000	.00%	.0001	2.43%	-.0001	-2.00%	.0003	6.25%	(.0009)	19.56%	.0014	26.41%
IK												
LN	-.0054	-14.36%	-.0020	-5.44%	.0009	2.48%	-.0027	-6.94%	-.0030	-7.40%	-.0016	-4.01%
WD	-.0018	-18.36%	-.0010	-10.20%	-.0005	-5.20%	-.0012	-12.00%	.0001	.99%	.0002	1.90%
HT	-.0012	-27.90%	-.0005	-12.82%	-.0007	-14.00%	-.0014	-25.92%	-.0005	-8.92%	-.0011	-18.33%
ERL												
LN	.0023	13.45%	.0024	13.18%	.0013	7.02%	.0012	6.18%	.0037	18.68%	.0032	16.16%
WD	.0015	16.66%	.0009	9.04%	.0002	1.96%	.0013	13.26%	(.0023)	23.00%	.0011	10.28%
HT	.0009	17.64%	.0000	.00%	.0000	.00%	.0005	7.35%	.0004	5.55%	.0010	13.33%
FCR												
LN	.0025	10.28%	.0031	12.97%	.0007	2.45%	-.0022	-13.09%	.0036	14.69%	(.0012)	4.72%
WD	.0003	2.72%	.0008	7.20%	.0014	12.38%	.0009	8.33%	(.0031)	27.67%	.0027	24.54%
HT	.0002	3.07%	.0004	6.55%	-.0001	-1.38%	-.0002	-2.81%	.0006	7.59%	.0012	17.64%
E2B												
LN	-.0001	.51%	.0002	1.00%	.0012	5.97%	-.0001	-.50%	.0038	18.18%	.0029	13.67%
WD	.0014	14.43%	.0017	17.89%	.0002	1.81%	.0000	.00%	.0013	15.92%	.0008	7.70%
HT	-.0001	-1.78%	-.0002	-3.57%	.0001	1.54%	-.0001	1.61%	.0010	15.62%	.0004	6.34%
E3B												
LN	.0023	13.37%	.0020	10.81%%	.0026	13.75%	-.0012	-5.66%	.0031	15.73%	.0037	16.97%
WD	.0006	6.97%	.0006	6.59%	.0003	3.19%	.0003	3.12%	-.0001	-1.02%	[-.0007]	-7.07%
HT	.0001	1.63%	.0004	6.06%	-.0001	-1.35%	.0001	1.33%	(.0006)	8.21%	.0005	6.17%
ECU												
LN	.0040	23.52%	.0027	14.75%	.0016	8.12%	-.0017	-7.72%	.0002	9.47%	(.0014)	6.48%
WD	.0019	19.00%	.0019	18.44%	.0015	16.07%	.0000	.00%	[.0010]	9.84%	.0013	11.11%
HT	.0027	50.00%	.0025	41.66%	.0006	8.21%	.0014	19.44%	.0003	3.61%	[.0005]	6.32%
ODM												
LN	.0087	21.21%	.0078	18.97%	.0081	19.50%	.0033	7.76%	(.0108)	26.93%	(.0137)	34.86%
WD	.0015	21.73%	.0002	2.77%	.0001	1.25%	.0000	.00%	(.0017)	22.97%	(.0012)	15.00%

Key: () = non-agricultual old less than middle; [] = agricultural old less than middle

TABLE 56

MALE ENTHESES DIFFERENCE AND PERCENT OF DIFFERENCE
NON-AGRICULTURAL TO AGRICULTURAL BY AGE: HANDFEMR

	Young				Middle				Old			
	Left Dif.	% of Dif.	Right Dif.	%of Dif.	Left Dif.	% of Dif.	Right Dif.	% of Dif.	Left Dif.	% of Dif.	Right Dif.	% of Dif.
OPX												
LN	.0025	8.77%	.0024	8.21%	.0040	14.19%	.0043	14.23%	(.0088)	33.08%	(.0057)	19.45%
HT	.0007	15.90%	.0011	26.19%	.0008	15.68%	.0011	20.75%	[.0002]	3.67%	[.0003]	5.55%
IK												
LN	.0002	.55%	-.0016	-4.46%	-.0026	-6.97%	-.0004	-1.07%	(-.0012)	-3.30%	[-.0027]	-7.25%
WD	-.0002	-2.27%	-.0010	-10.86%	-.0006	-6.38%	-.0005	-5.10%	-.0010	-10.75%	[.0000]	0.00%
HT	-.0003	-7.89%	.0002	5.55%	-.0001	2.08%	.0001	2.04%	-.0002	-4.00%	[-.0008]	-15.38%
ERL												
LN	.0022	12.64%	.0020	11.29%	.0028	14.58%	.0034	17.80%	[(.0014)]	7.40%	[.0006]	3.06%
WD	.0026	30.95%	.0026	30.95%	.0022	22.91%	.0016	16.49%	.0013	12.50%	[.0002]	2.00%
HT	.0015	28.30%	.0011	20.37%	.0014	22.95%	.0009	13.63%	.0000	.00%	[.0001]	1.47%
FCR												
LN	.0005	2.00%	.0016	6.42%	.0034	13.54%	.0022	8.69%	[.0017]	6.80%	.0015	5.76%
WD	.0015	13.63%	.0018	16.66%	.0016	14.03%	.0012	10.61%	[.0006]	5.12%	[-.0007]	-6.25%
HT	.0010	15.87%	.0012	18.75%	.0004	5.63%	.0009	12.85%	.0015	21.42%	[.0003]	4.28%
E2B												
LN	.0007	3.44%	.0019	9.13%	.0014	6.57%	.0025	12.13%	[.0004]	1.86%	[.0001]	.46%
WD	.0011	11.22%	.0015	14.70%	.0021	19.62%	.0014	12.72%	[-.0001]	-.89%	[.0001]	.89%
HT	.0000	.00%	.0013	26.00%	.0012	19.67%	.0011	17.74%	.0006	9.23%	[.0001]	1.58%
E3B												
LN	.0020	11.49%	.0022	12.57%	.0014	7.17%	.0015	7.42%	.0013	6.34%	[.0006]	2.85%
WD	.0008	9.87%	.0010	11.36%	-.0003	-3.22%	.0001	1.08%	-.0006	-6.18%	[-.0014]	-14.14%
HT	.0008	14.54%	.0006	9.83%	.0009	13.43%	.0019	27.94%	.0012	17.14%	.0014	19.44%
ECU												
LN	.0046	26.28%	.0050	27.77%	.0035	17.41%	.0027	13.30%	[.0002]	9.13%	.0025	11.68%
WD	.0013	13.00%	.0008	7.61%	.0012	11.32%	.0011	9.90%	[.0005]	4.46%	.0000	.00%
HT	.0009	16.07%	.0011	19.29%	.0025	40.32%	.0019	27.94%	[-.0002]	-2.56%	[.0000]	.00%
ODM												
LN	.0048	12.18%	.0042	10.12%	.0051	12.02%	.0078	19.35%	(.0099)	25.51%	[(.0087)]	23.20%
WD	.0018	27.27%	.0018	24.65%	.0010	12.98%	.0011	13.92%	[-.0005]	-6.32%	[.0008]	9.87%

Key: () = non-agricultural old less than middle; [] = agricultural old less than middle

basketry making, curing skins, and endless corn pounding (Hudson, 1976:80,109,264). The eastern flint corn that came into use about 1200 A.D. (Hudson, 1976:293) required

> . . . a pestle, ten feet long--as small around as the arm. The upper end is an unshaped mass which serves to weight it down and to give force to this pestle in falling back, so that the corn may be crushed more easily. They pound it in a wooden crusher or mortar which they make of a trunk of a tree, hollowed by means of burning embers . . . . They sometimes make bread without lye, but rarely because that requires too much corn; it is difficult to make since they reduce it to flour only with the strength of their arms (Swanton, 1931:38).

The illustration of corn grinding found in Lewis and Kneberg (1958:159) is excellent.

Katz et al. (1974) have shown alkalai (lye) treatment of dried corn was a nutritional necessity, though it was first thought of as a means to soften the corn for easier processing. Soaking the grain first may have made pounding easier. This treatment required pottery for soaking containers, wood ashes, or possibly the lime liberated in burning limestone or shells. All of these are represented in the Averbuch archeological remains (Berryman, 1981; Klippel and Bass, 1984; Romanoski, 1984; Crites, 1984). (Since Katz et al. demonstrate that available nutrients are directly related to methods of corn processing, it may be that nutritional differences from differences in processing the same food source could account for the height differences seen in the prehistoric corn-dependent populations of the Southeast.)

Other scores noted in both hands for agricultural females in youth (Table 55) are the ERL and FCR length, and ECU. These three muscles could well be a part of the pestle pounding action. The ERL draws the

hand back radially, transmitting action to the radialcarpal and metacarpal joints (Kaplan, 1965:233); plus it is very active as a synergist in prehension and making a fist (MacConaill and Basmajian, 1977:283). Against strong resistance, the ERL is joined by E2B and E3B and especially ECU. These three extensors also join together with their companion flexors to produce the side-to-side motion (abduction, adduction) of the grasping hand (MacConaill and Basmajian, 1977:281). One other function of the wrist extensors, particularly the ERL, is to prevent the hand from being forced to the ulnar side, as in holding a heavy jug by its handle (MacConaill and Basmajian, 1977:283).

This same combination of high scores is seen in the older women as well as in the younger. The middle age cohort presents a very different picture, with the non-agricultural females having greater or equal scores in five out of 22 measures in the left hand, and 11 out of 22 in the right. Of the remaining scores in Table 55, the percent of difference is very small (3% or under) for an additional eight in the left and four in the right showing the middle age non-agricultural women to have very active hands. Only the ERL right scores are indisputably dominated by the agricultural women in the middle age cohort.

In the old women--although both non-agricultural and agricultural continue a pattern of increasing entheses scores--the agricultural females again have significantly higher scores on many muscles (see the next to the last column on Table 34 [p.99]). This pattern of female scores by ages is interpreted as (a) agricultural girls are recruited into the work force earlier than non-agricultural; (b) non-agricultural females are more active than agricultural at all ages on the IK (the

thumb and index pincher). (c) Middle age non-agricultural and agricultural women shared many of the same tasks at about the same level of intensity. (d) Agricultural women continued to work hard into old age, building even bigger entheses to support even harder working muscles. (e) Non-agricultural old women who continued in their tasks do so with reduced intensity--only scoring higher than the old agricultural females in the IK and the left EC3 width.

Agricultural male entheses interpretation

In the men's entheses differences, Table 34 (p.99) shows highly significant ($p < .0001$) differences in five left hand scores and four right hand ones. In searching the young scores to see at what age those difference are noted, the significant ones had all occurred in the agricultural males during youth. Many of those differences can be assigned to bow and arrow activity. The same ERL, FCR, ECU, and ODM quartet that was seen on the females and was interpreted as a grip holder for the cylindrical pestle would be exactly the combination expected to hold the bow with the left hand, anchored by a left OPX. But we find the same muscle complex predominating in the male agricultural right hand with only modified significance (Table 34, column 2) for right OPX, right ERL height, and right FCR width; significance is increased for the right E2B height, E3B height, and ODM length. That same left group plus the added right intensity could be interpreted as enabling the right hand to hold the arrow and pull the bowstring. DeSoto's men reported that for the Indians of the Southeast, bows were so strong that the Spaniards could not draw the string back to

the face; the Indians could pull it as far as their ears. They also reported Indian boys in that area were given little bows at age three (Hudson, 1976:245). No wonder the entheses are well formed on the young hand. Other activities must have raised the scores as well. Clearing fields (Hudson, 1976:264) and building fortifications (Lehmer and Jones, 1968:22-23) were usually male-assigned tasks requiring a strong grasp in both hands. Games requiring the grasp of hafted sticks and rackets may have left their mark as well (Williams, 1930:429; Abel, 1939:175).

Perhaps the most impressive scoring difference in the male entheses pattern is the score reduction in the old agricultural men. Note that the final column in Table 34 (p.99)--with the exception of OPX--is virtually blank, which means non-agricultural and agricultural old males had very similar measurements. (By contrast, the old agricultural females had 15 out of the 44 scores significantly greater than the old non-agricultural females.) This is also seen in the scores of the old agricultural men in Table 56 (p.153) where 10 left and 17 right entheses scores are smaller than their own middle age scores. In searching for evidence that the old agricultural men might have been assigned women's work, none of the remaining high scores in the old male column except the left OPX was found to match any female scores of significant difference in any column of Table 34. If old agricultural men were doing women's work, the only enthesis that shows it was the left thumb OPX.

Non-agricultural female entheses interpretation

In searching through the entheses scores for definition of the non-agricultural women's tasks, the researcher is confronted with combined

data from seven sites representing nearly 6,000 years of activity. When compared to the agricultural scores, the non-agricultural data is uniform enough to produce conclusions already discussed. But when viewed site by site, there is a great variety of scores and tasks they might represent. Those elements of uniformity that can be decoded are seen first in those few items in Table 34 (p.99) where the non-agricultural women's scores dominate those of the agricultural women. The second area of searching is in the blank spaces of that same table indicating non-agricultural women's scores were high enough to prevent a statistical difference.

The First Dorsal Interosseous (IK in this study) is clearly put to greater use by the non-agricultural than by the agricultural women. This use starts early in youth (Table 34 [p.99]), in both hands (Table 55 [p.152]), length and width, dropping in mid-age (Table 38 [p.106]), rising again in old age. For the non-agricultural women this was a muscle of the young and old--used enough during middle age to maintain a consistent height buildup through life on both hands. To review the structure and function of this muscle, its location is in the web between the thumb and index finger. This is a small (functional length not more than 2.25 cm) but powerful bipennate muscle, the strength coming from the numerous oblique fibers inserted into the common tendon which subsequently inserts into the extensor apparatus of the first phalanx of the index finger (Kaplan, 1965:13; MacConaill and Basmajian, 1977:121). Multi-pennate muscles have a short range of motion and limited speed of contraction, but are powerful, as opposed to the long strap muscles that sacrifice power for speed and range of motion (Frost,

1967:74; Kelley, 1971:148). The IK pulls the index and thumb tightly together and holds tightly to a small-dimensioned item in the precision grip, rotating it clockwise, assisted by the biceps in supinating against resistance (Long, 1970:854,860; Basmajian and DeLuca, 1985:279).

This action would seem to describe opening mussel shells--either with the bare hand or assisted by bone awls such as those found in maximum abundance in shell mound sites. Six thousand four hundred and thirteen split bone awls were excavated from the Indian Knoll site (Site Five), 26 of those awls from burials (Webb, 1946:232). At Site Two, 110 awls and 20 needles were excavated from that level as opposed to 108 awls and one needle in the Eva layer beneath, or 31 awls and five needles in the Big Sandy layer above (Lewis and Kneberg, 1959:64; Lewis and Lewis, 1961:77). However, Dr. Paul Parmalee (personal communication) suggests that no one in his right mind would try prying open mussel shells when simply exposing them to the sun causes them to die and release the muscle that closes the shell. Even muskrats are proficient in using this method. Further, Dr. Parmalee reports the shells in the shell mounds show no evidence of being pried open with stone tools or of being smashed to access the meat. He suggests steaming as an effective opening method as well (Parmalee, 1986: personal communication).

It may be that the quantity of awls and high IK scores represents retrieval of gastropod resources also found in abundance at Indian Knoll, which would seem even more labor intensive (Webb, 1946:129; Parmalee and Klippel, 1974). That shell was valued for more than just garbage at that site and that considerable effort must have been spent in working it is evidenced by the 24,975 shell artifacts found in burial

association (Webb, 1946:235). Exotic marine shell, evidence of Late Archaic exchange systems, was also valued at Indian Knoll where it is found in large numbers as well (Goad, 1980:111).

In collecting data from the Indian Knoll collection for this study, it was noted that the largest IK entheses were on individuals who had experienced dental wear, damage, or pathologies that might prevent active chewing (Robbins, 1977:16).

To see what other hand actions non-agricultural women were doing apart from the IK, it is necessary to read Table 55 (p.153) in terms of underlying measures. These are the scores where non-agricultural females either have scores higher, equal to, or no more than 3% less than the agricultural women. These scores are underlined in Tables 55 and 56 (p.153). By age groups, these underlying non-agricultural women's scores show 18 for the young, 28 for the middle, and nine for the older age cohorts. In the young there is a pattern of activity in the height scores that seems perplexing. However, it should be recalled that the six central entheses in this study (IK, ERL, FCR, E2B, E3B, ECU) have three measures each--two in diameter and the third in height. It is possible that as the diameter of the entheses increased with intensified pulls in the direction of those measures, height would be the last to change. Conversely, on those entheses differences where height changes in the non-agricultural young females, but other measures do not, this may be interpreted as equal or greater frequency of action--enough to raise the enthesis--but the strength of the pull on the tendon was not great enough to change directional length and width measures. It will be noted in most of the young height scores where the

non-agriculturals are equal to or near 3% (left FCR, left E2B, left E3B, right ERL, right E2B) that the length and/or width is much larger in the young agricultural. The same height pattern is seen in the non-agricultural left hand of the middle age group (left ERL, left FCR, left E2B, left E3B). The right non-agricultural scores, however, show very active right hands at work in the middle age women. Those measures particularly used are right FCR, right E2B, and right E3B. The older women's scores show the agricultural women dominating work scores--with the exception of E3B width to be discussed later in this chapter.

Table 57 was constructed using the age score differences from Table 55 (p.152). Column one indicates the number of measurements that show which muscles are being used most by the non-agriculturalists in all age cohorts; column three indicates which ones are used by the agricultural women. The muscles are then ranked in columns two and four, with the rank of one indicating the most use, the rank of six, the least.

TABLE 57

FEMALE MUSCLE ENTHESES SCORES RANKED
(from TABLE 55)

		Non-Agricultural Female		Agricultural Female	
Number possible		Number at 3% or below	Rank	Number at 3% or above	Rank
OPX	12	5	5	7	5
IK	18	18	1	0	6
ERL	18	3	6	15	1
FCR	18	6	4	12	2
E2B	18	9	2	9	4
E3B	18	8	3	10	3
ECU	18	3	6	15	1
ODM	12	3	6	9	4

The non-agricultural women are using the IK (rank 1), the E2B (rank 2), and E3B (rank 3) the most--those that pinch and extend. The agricultural women by contrast are using the ERL (rank 1) and ECU (rank 1) most, with FCR (rank 2) and E3B (rank 3) following. The ECU represents both strength and ulnar action, and is interestingly paired with ERL, the radial puller, in both groups; for the agricultural women, the pairing at rank one shows frequency of use, for the non-agricultural women rank six shows lack of it.

In summary, the non-agricultural female IK is seen to be active in all ages, joined in mid age by the FCR, E2B, E3B, and ECU--all of which are used enough in youth to produce height rises in measurement--with the exception of ECU. This confirms the already stated observation that the non-agricultural women were precision grip users; so were the agricultural women with power grip added.

Compared correlation scores of which entheses pairs non-agricultural women used together may shed further light on what types of work they were doing. Thorough analysis of those comparisons is a project for future study.

Of the already noticed differences for just the right hand, the active IK is most often associated with the OPX and ECU, showing those actions of grasping and pinching, or pinching and turning clockwise against resistance. The most common muscle pairings are between and among the extensors, confirmed in the middle age listings of Table 55 (p.152). Least used by the non-agricultural females were combinations involving the OPX and ODM.

Of the 61 significant pairs in the non-agricultural female right hand, seven are significant to $p < .0001$; four of those highly significant correlations are duplicated in the male non-agricultural right hand scores.

Non-agricultural male entheses interpretation

The male non-agricultural entheses Handfemr scores are the lowest compared to the agricultural males, or either female group. They have the highest number of right hand significantly correlated pairs ($p < .05$), 72. It will be recalled they also show the least cultural modification of metacarpal length and width measures in relation to their entheses (Table 31 [p.96]). Nevertheless, their entheses scores continue to rise from young through old age in 19 of the 22 right measures as opposed to only one right measure increasing through all three age cohorts in the agricultural hands (Tables 56 [p.153] and 39 [p.107]). The non-agricultural males' work left minimal though incremental evidence.

It is difficult, therefore, to trace the distinctive actions of the non-agricultural males using methods that seemed to extract meaningful data from the other groups. Because of this, an effort was made to see if any evidence would fit with atlatl use--starting with the task rather than the score differences (Merbs, 1983:150-157).

In researching the mechanics of atlatl use, Brues joins Boas in suggesting its invention was to increase effective velocity of the spear, but adds that its adoption by people of lateral build was to compensate for the disadvantage of a short arm (Brues, 1959:464). This

concept of the artificial extension of the arm has been used to explain the function of a rigid, one-handed atlatl, and subsequent damage to both shoulder and elbow with its use (Webb and DeJarnette, 1942;270-286; Merbs, 1983:150; Angel, 1966:3; Pierce, 1987:200; Dutour, 1986). Webb, however, in trying to classify Indian Knoll burial artifacts by function, envisions the atlatl as a flexible, elastic tool that adds energy to the throw in terms of a flat spring. Webb died before his discovery was disseminated but his family and colleagues have recently published his notes on the atlatl posthumously (Webb, 1981). Previous to that, practical experimentation was conducted by other researchers in an effort to determine not only how effective the wooden tool was but the role of the stone and antler artifacts thought to be associated with it. Experiments showed that nearly any combination of length, width, and projectile point could be effective. Points weighing three to four ounces excavated from the Eva Site were useful. T. M. N. Lewis successfully threw several such darts with the conclusion, "Anyone whose muscle coordination is good, can, within a short time, become an efficient user of the throwing stick" (Hill, 1948) Results of such applied archeology useful for this study are the following conclusions on how the hand is used in atlatl theory:

> ...the ball of the thumb and the third and fourth fingers [i.e. four and five] formed the grip upon the stick while the tip of the thumb and the first two fingers [i.e. digits two and three] held the dart until its release...(Hill, 1948:71)

and

> In thick cover...both hands were brought into play by holding the device low and partly in front of the body (Hill, 1948:72).

A running atlatl battle, starting with Howard's work in American Antiquity and finishing with repeated rebuttals in the Plains Anthropologist deals with the mechanics of the spear thrower (Howard, 1974, 1976; Butler, 1975, 1977; Patterson, 1975). A crucial discovery from that skirmish which pertains to this study deals with why the hook or spur that holds the dart on the atlatl is so short, often rounded, and coupled with a mere "dimple" in the end of the shaft. "The dart must be free to rotate about the spur as the atlatl is describing an arc when in motion" (Butler, 1977:61)

What is learned from all this ancillary research is: (a) atlatls changed through time as the tool was made more and more efficient; (b) Webb's study shows that an elastic, springy atlatl required a tight grip on a weighted handle as evidenced by a stratified series of more and more secure hand holds found at Indian Knoll (Webb, 1981); (c) Hill's "hands-on" experience shows that the thumb and digits four and five must be used to accomplished secure grip--possibly aided by the left hand; (d) Butler's experiments to avoid spearing his own foot revealed that the rotating dart shaft must be freely engaged on the spur and consequently between the slightly flexed index and middle fingers as well.

As the enthesis data is scrutinized, the combination searched for is that which would account for a laid back, palm up "cub scout" salute of the hand. As noted earlier, this is very similar to the arrow holding position with the exception of the loose pinch between index and

middle finger. The bow and arrow hunter needed a more secure hold while drawing the string, hence the early evidence of expanded right First Palmar Interosseous that pinches (adducts) the index and middle fingers together.

Further support for the non-agricultural male right hand showing evidence of holding the atlatl tightly with the first thenar area opposing fingers four and five can be seen in Tables 17 (p.78) and 51 (p.137). The absence of shape difference (Table 17) in the male right MC5 indicates the non-agricultural male hand was active in opposition. That activity is not evident in the young scores of male differences (seen in Table 51). It begins to be evident in the width differences of middle age, and is pronounced in the older male measures for right MC5 widths, and right MC5DV. This could be interpreted as non-agricultural male atlatl users continued their activity into old age; whatever the agricultural activity was that masked the scoring difference in youth, it had ceased in older men.

When the non-agricultural male correlation scores between entheses for the right hand are examined, of the 72 pairs significant at $p < .05$, nine pairs are highly significant at $p < .0001$. Of those nine, representing the most frequently paired activities, six are also significantly correlated in the non-agricultural female right hand. Taking the three remaining pairs as both highly correlated and distincitve to the non-agricultural male hand, a case could be made for those three as possible evidence for atlatl use.

In the highly correlated pair IK height with ERL width, the first reflects either frequency or intensity or both of the IK muscle. To

restate briefly, the IK presses the thumb and side of the index together; in so doing it would also counter the pull of the First Palmar Interosseous that draws the index and middle fingers together. (The Palmar First, in turn, counters the IK and keeps the index from rolling over on top of the thumb [Long et al., 1970:864-865].) ERL width reflects directionality, since this is the proximal-distal measure of the enthesis expressing radial-ulnar movement of the hand. Together this correlated pair represents a tight pinch when the hand is pulled toward the thumb. When the hand is hyper-extended and the elbow hyper-flexed in the atlatl throwing position, the flexors of the finger automatically pull the fingers into a claw position, but passively so since the flexors are shorter than the extensors. (The lumbricals are not pulling the flexors out.)

In the highly correlated pair IK height and E2B width, the IK functions as explained in the previous paragraph. The E2B measurement is proximal-distal on the dorsal base of right MC2 and marks hyper-extension--the hand is pulled way back on the wrist. Both the ERL and E2B contribute to the flexion of the forearm on the elbow (Hollinshead and Jenkins, 1981:150).

In the highly correlated pair FCR height and E2B height, high correlation reflects frequency, intensity, or both. FCR is the major flexor pulling the hand down into a grip; E2B pulls the hand straight back in the opposite direction and produces hyper-extension as its maximum action. These two work together--either to balance and stabilize one another as synergists, or alternately for every pull down there is a subsequent pull back as antagonist.

Site Rankings by Entheses

One way to compare the sites is to rank their entheses scores. This can be done using several different patterns in an effort to extract the distinctive characteristics of each site. In Tables 58 and 59 these are ranked (1=most developed) with sexes separate.

TABLE 58

FEMALE COMPOSITE ENTHESES RANK BY SITE: HANDFEMR

Enthesis	Site One L. R.	Site Two L. R.	Site Three L. R.	Site Four L. R.	Site Five L. R.	Site Six L. R.	Site Seven L. R.	Site Eight L. R.	Site Nine L. R.
OPX	3-4	4-6	4-7	2-5	1-1	3-6	5-8	1-3	1-2
IK	3-4	3-3	4-6	5-4	1-2	2-1	5-8	5-7	6-5
ERL	4-2	7-5	6-4	4-6	8-7	5-3	2-1	1-1	3-2
ECR	7-5	5-6	3-2	6-4	8-6	2-1	4-3	1-4	1-2
E2B	5-1	5-7	3-8	4-2	7-9	2-4	6-6	2-5	1-3
E3B	6-3	3-8	3-4	4-2	7-9	1-1	3-2	2-5	5-6
ECU	8-3	7-7	6-2	4-5	9-8	2-4	3-6	5-5	1-1
ODM	7-8	5-6	4-5	7-7	6-4	3-2	1-1	2-3	1-1

TABLE 59

MALE COMPOSITE ENTHESES RANK BY SITE: HANDFEMR

Enthesis	Site One L. R.	Site Two L. R.	Site Three L. R.	Site Four L. R.	Site Five L. R.	Site Six L. R.	Site Seven L. R.	Site Eight L. R.	Site Nine L. R.
OPX	5-5	7-4	8-5	2-4	4-3	4-2	6-5	3-2	1-1
IK	4-5	1-2	3-4	2-5	2-3	1-1	3-5	5-6	2-2
ERL	6-3	5-6	3-2	7-4	8-8	4-7	3-5	2-1	1-1
FCR	4-2	5-7	2-3	8-6	7-8	3-3	6-5	3-4	1-1
E2B	4-4	2-6	2-7	5-3	7-8	3-4	6-5	3-2	1-1
E3B	5-4	4-3	5-3	2-1	7-5	5-2	1-2	6-3	3-2
ECU	6-7	5-6	2-2	3-6	7-7	3-3	4-4	2-5	1-1
ODM	3-5	6-7	2-6	7-9	5-8	4-4	7-3	2-2	1-1

Since it would be expected that the two agricultural sites (eight and nine) would have the highest scores (rank=1,2,3), a listing of any high scores located in non-agricultural sites points to heavy usage of those muscles. Since ranking overlooks the amount of difference, an arbitrary limit of the top three scores and bottom three scores yields the most information for this sample. For instance, for the females, Site Five leads in the action of both muscles located on the thumb for both hands. At the same time, Indian Knoll is at the bottom for all the rest of the muscles, except the ODM.

This is not an effort to statistically prove that certain sites were using certain artifacts, but merely to explore relationships.

<u>Site One females</u> (Plate 6, Figure 26 [p.255])

The key action here falls in the right hand with a first ranking on E2B and second on ERL. These both represent a backward pull of the hand on the radial side and could reasonably imply skin-working and sewing. This is the Eva Site that yielded five times as many deer bones and over twice as many projectile points, blades, and skin-working tools (Lewis and Lewis, 1961:17,26) as the superimposed Three Mile Site above it. The actions of right E2B and right ERL are those discussed by Merbs (1983) as being used by the Inuit women for skin work, particularly sewing. Only one needle was found at Site One as opposed to 20 in Site Two, but 85 bone awls were found--as many as in Site Two. These were the tools used by the right hand. This is not an arctic climate, however, and skin clothing would not be a necessity for life (Lewis and Lewis, 1961:17,26,77; Merbs, 1983:154-155). Two women from this site--

both old--shared severe bilateral damage to proximal MC1. No tools were found as burial goods with the individuals sampled for this study--only jewelry.

<u>Site One males</u> (Plate 6, Figure 27 [p.255])

Only the right FCR and the right ERL rank high, as does the left ODM. This was a hunting, deer-dependent people with a relatively large group of chipped stone tools. The evidence of tight right Flexor grasp and radial pull, plus a strongly cupped left hand may indicate stone tool working. The lowest scores in left and right ECU point to very little use of the ulnar side of the hands or of the power grip. No burial goods were found with this sample.

<u>Site Two females</u> (Plate 7, Figure 28 [p.257])

This site is distinguishable by shell deposits, five times fewer animal bones than the deeper Eva level, and an increased number of needles, bone awls, and fishooks. Small stone tools indicate food processing was a prominent activity. The women's hands show little stressful activity compared to that of other sites, with only the paired IK's ranking third, evidence of precision grip use. The left E3B--the extensor that pulls the hand back and toward the ulnar side--also ranks third, but may just be used to counter radial action. No other evidence of ulnar power grip is present with both ECU's ranking a seventh out of nine.

Site Two males (Plate 7, Figure 29 [p.257])

This sample ranks first on the left IK, second on the right IK, which is the outstanding score as it was for the females from this site. Pinching and precision gripping appears to accompany dependence on riverine resources. They score second on the left E2B, pulling the left hand straight back, and third in the right E3B pulling the right hand back and ulnar. However, the ulnar muscles score low in both hands indicating emphasis on the precision grip. Both males and females from the Three Mile Site were found buried with dogs, antler tines, stone projectile points and one another. This may point to many shared tasks as seen in their similar hand scores.

Site Three females

The Anderson Site is from Williamson County, Tennessee, about 60 miles east of the Eva/Three Mile/Big Sandy complex. Projectile point styles are similar to those at Three Mile and Carbon-14 dates place it slightly later than the Eva date. Similarities of subsistence and work activities between Three Mile and Anderson would be expected, particularly since this too is a shell mound site with faunal remains similar to Three Mile (Joerschke, 1983:9,12,21). However, the ranked hand scores are not similar. For the women, the IK rank is not high, but the two right hand scores FCR and ECU are ranked second among all the sites. These are strength and power grip muscles when used in combination. The female left scores rank third for FCR, E2B, and E3B, showing grasping action and pulling back with the left hand. Either riverine resources

were not being used by the women (why else live on a shell mound) or they were using very different processing procedures than the Three Mile group. Smith places the Anderson Site much earlier in the time sequence, before the Eva Site. If this is so, the type of subsistence activities may have been different than those listed here (Smith, 1986:19). Dowd reports 30,000 pieces of animal bone were excavated from this site that were in excellent preservation because of the large quantity of gastropod shells. Dowd also reports many pestles of all kinds, but no mortars (Dowd, 1981). In the list of adaptive traits (Table 63 [p.246 in Appendix B]) it will be noted that more were from this site than from any other. For the women, much of this was on the thumb, yet neither OPX nor IK scores are outstanding. It may be that Eva and Anderson are contemporary. All older Eva women had evidence of trauma on proximal MC1.

Site Three males

For the men from Anderson, the scores overall are high; four second ranks in the left hand, two in the right, approximating agricultural site eight rather than the other non-agricultural sites. Both IK scores show more activity than Site Three females. Both flexor scores show strong action in grasping, as do the females. The peculiarly unbalanced scores in E2B also resemble the females, showing much action in pulling back (extension) of the left hand with very little in the right. Anderson men show much strong activity on the ulnar side of the hand, with ECU ranked second among all males in both hands, and ODM ranked second. It is difficult to identify what tasks would require strong ulnar

action, particularly in the left, as seen in the power grip, yet not contain the expected opposition in the thumb for holding larger tools; the left thumb score ranks eighth! It has been suggested that people from this Middle Archaic period took part in wide-ranging multiple food activities and were not a permanently located riverine people (Chapman, 1977:123; Joerschke, 1983:20). The hands seem to support that suggestion.

Site Four females

This group represents the top stratum of the stratified Eva Site and has been placed in the Late Archaic cultural period. An absence of shell debris in this level confirms this as a time when populations became more dependent on vegetal resources, particularly seed groups abundant in the Tennessee area. Of the bone found at the Big Sandy level, deer was still the favorite by far, but represents only 25% of the quantity in the underlying stratum Three Mile deer bone, and only 4% of the lowest stratum Eva deposit. Tools from this site reflect those changes with half as many chipped stone tools, and one third as many bone and antler tools as found at the Three Mile level. Of interest is an almost equal number of projectile points from the two levels, but no scrapers or skin working tools in the upper Big Sandy level (Lewis and Lewis, 1961:50). Ground stone pestles and grinding tools increase (Lewis and Lewis, 1961:67). The women's hands from this site show, first of all, closer rank scores between left and right than the three previous sites, indicating more paired actions. Both left OPX and right E2B rank second, the former showing large extended opposition in the

left thumb, the latter showing frequent or intense central extension of the right hand. The usual combinations that appear with those two leading muscles are not highly ranked here. The ulnar Opponens ranks a low seven, and other ranks fall in the middle range. Burial goods show women again with such artifacts as projectile points and antler flaker tines--thought to be male tools. Bone awls appear in both sex burials as well.

Site Four males

Ranked hand scores show strong left thumb activity with a second rank in both OPX and IK. Strong left ulnar action is evidenced by a second rank in the E3B and and a third in the ECU. The low rank of seven in ODM shows the cupped hand is not the action opposing the second ranked OPX. The very low (eight) left FCR shows a gripping left hand squeeze was not being used either. The surprising score in the right hand is first rank in the E3B that pulls the hand back and down. Perhaps paired with the same muscle in the left, this could be a two-handed action. The companion right E2B ranks high as well, although only third, drawing the hand straight back. If these were all used together (and there is no reason to believe they were), men pinched their left thumbs against some medium sized object and pulled it back and down while the right hand, not pinching nearly as hard, pulled quickly and straight back to the ulnar side. What we do know is that people at this level were producing just as many projectile points as people on the level before them, but bone evidenced the harvesting of only one fourth as many deer, with no skin-processing stone tools. This is also

the period of greatest change and experimentation with the atlatl as documented by Webb. These seemingly futile hunting artifact developments may account for the highest rate of hand fracture in the Site Four males among those studied (Table 63 [p.246 in Appendix B]). Previous studies of the burial goods from Big Sandy show significant association between adults and drill and hoe, indicating a mixed subsistence pattern and subsequent tasks for both sexes (Higgins, 1982:95).

Site Five females

Hand scores ranking in this shell mound group are striking: first rank in both left and right OPX, first in left IK, and second in right IK. Very low rankings (sevens, eights, and nines) in other entheses leave the left sixth and right fourth ranks of the ODM as possibly important. These women were grasping small and medium objects with both hands, cupping the right hand somewhat, the left even less, and that is all! That shellfish and snails were consumed over a long period of time is evident from the archeological record (Webb, 1946). The processing of such food, perhaps consumed in quantity to satisfy nutritional requirements, must have fallen to thumbs and teeth (Parmalee and Klippel, 1974; Smith, 1982:100). Only five of the females from this study had grave goods: one with a projectile point, one with a bone handle, and the others with shell beads.

Site Five males

The Indian Knoll male entheses ranks are similar to the unusual pattern of the females, although not so pronounced. The OPX and IK of left OPX rank fourth, right OPX third, left IK second, right IK third. The remainder are all sevenths and eighths except a fifth (average rank) on right E3B and left ODM. Burial goods for 12 males recorded from our sample include one with a scraper, three with atlatl weights or hooks, two with projectile points that probably killed them, eight with shell beads, and two with hairpins.

Cassidy (1984:324) suggests Indian Knoll contains several not yet defined strata. We can only conclude that the Site Five individuals from this study lived in a time when they did not use the multitude of stone tools excavated nor had they enjoyed the massive quantity of venison represented by 3,101 astragali (Webb, 1946; Robbins, 1977:16). The Eva Site, earlier by 1875 years, also had copious deer bone refuse, but their hands worked.

Site Six females (Plate 8, Figure 30 [p.259])

This is the Cherry Site, located about 12 miles north of the Eva Site. It is not on a major waterway; it contains pits and post molds; it represents a Late Archaic economy, although it has not been Carbon-14 dated. Compared to other women in this study, the rank scores of the hand entheses show that the Site Six women worked hard--the hardest of all non-agricultural women studied. Of the eight muscle insertions studied, a first or second rank occurs in six; the remaining two muscles

have a score of three. The high scores appear in both hands, with the E3B ranking first in both hands. Two other right hand scores rank first: the FCR and IK. The Cherry women's right hands were grasping small items radially, flexing the hand into a fist, and extending it slightly ulnar. The left hand joins in the extended ulnar pull, with impressive second place scores on FCR and IK to complement the right hand firsts. In addition, the left also ranks second on E2B (the central extensor) and ECU (the ulnar power muscle). This latter muscle is also used to counter extensive radial pull by the ERL, but that muscle in the left hand ranks fifth--the lowest of all Cherry left scores. Finally, there is evidence of strong opposition in the left hand with a third rank in the OPX and its usual paired Opponens from the opposite side of the hand, ODM. The ODM ranks even higher on the right with a second, but is not paired in opposition with the right OPX that ranks a low sixth. The radial pulling right ERL is third on the right. There is not a single muscle of the eight studied that does not have a first, second, or third rank in one hand or the other. With so much action represented, it is difficult to identify specific tasks. Those that can be suggested are: (a) grasping large objects with the power grip in the left hand but not the right; (b) ulnar flexed pull with both hands; (c) pinching small objects and precision work with the right hand; (d) possible alternating action with the left hand; (e) tight gripping of medium or small objects in the right fist with side-to-side action. The biggest departure from other non-agricultural scores is the high ranking of ulnar muscles. The high ranking IK scores are characteristic of non-agricultural shell mound sites. This is not such a site, though the

presence of some shells in the midden points to some use of that resource (Magennis, 1977:33).

Site Six males (Plate 8, Figure 31 [p.259])

The rank scores here, as among the Cherry females, are very high and notably different from other, earlier non-agricultural males. Some of the patterns are different from the females, however, and not quite as high. First to be noted are the left-right paired first rank of the IK. This is the pinching precision gripper muscle that characterizes non-agricultural sites, but is particularly active in groups found in association with major shell deposits. The right OPX is a high second, the thumb being very active in opposition, although the usual companion Opponens, ODM, is ranked fourth. E3B also ranks second and ECU, its neighbor power muscle, is third in the left as well. FCR, the strong flexor, is also paired, ranking third in both hands. The left E2B, ranked third, is not paired; the right E2B ranked an average fourth. The only low rank in the Site Six males is the right ERL--the radial extensor--at seventh, with its companion left fourth.

These are active hands, performing many tasks that include: (a) an extended grasping right thumb, opposing ulnar digits, but not with maximum effort; (b) both thumbs pressing against the index, with highest frequency and intensity; (c) both hands flexed and grasping, with the right extending to the ulnar side with strength; (d) the left ECU may just be countering the ERL in alternating movement of the hand; (e) the left Opponens are paired, OPX and ODM, in holding large objects, but only against average resistance.

Bowen has done a remarkable study assigning tools at this site to specific tasks. Bowen concludes that the most activity was in piercing, scraping, drilling, and hammering, and that they "concentrated their efforts on plant food gathering and the hunting of a variety of animals" (Bowen, 1975:86-87). If his analysis is accurate, and the hand rankings are accurate, these are the muscles in men and women that were used to perform those tasks. Site Six males were doing something that required a lot more work than hands in earlier sites.

Previous studies done of burial goods from the Cherry Site show significant association between males and working hides (Higgins, 1982:96). The same association would be expected for Site One (Eva) with its abundance of deer bone. There may be parallels between the male hands of Site One and Site Six, but they are difficult to discern.

Site Seven females (Plate 9, Figure 32 [p.261])

This site, the Ledbetter Landing Site (stratum one), is located 15 miles south of the Eva Site on a waterway. The sample for this study came from stratum one which was "plentifully interspersed with river shells of all local variety" (Lidberg, n.d.:i) and is treated here as Terminal Archaic. It will be noted in Table 47 (p.125) that both stature and hand size, after creeping upward in the first six sites in this study, increase greatly at Site Seven. The increase of femur length from Site Six is more than the standard error for both sexes (Table 60). Site Seven had bigger people and the females had bigger hands, i.e. the same relationship of hands to femur length as in Site Six (.6536 and .6520). The males have relatively smaller hands in relation to femur

TABLE 60

CHANGES BETWEEN SITES SIX, SEVEN, AND EIGHT IN FEMUR LENGTH, AND LEFT METACARPAL TOTALS

	Female	Male
Femur Ln. mean Site Six standard error	5.32mm	6.02mm
Femur Ln. difference Site Six to Site Seven	7.19mm	12.79mm
Site Six total Metacarpal Ln/Femur Ln ratio	.6536	.7100
Site Seven total Metacarpal Ln/Femur Ln ratio	.6520	.6421
Femur Ln. mean Site Seven standard error	3.21mm	3.91mm
Femur Ln. difference Site Seven to Site Eight	11.70mm	10.45mm
Site Eight total Metacarpal Ln/Femur Ln ratio	.6602	.6495

length (.7100 and .6421). Whatever initiated the femur length increase in the agricultural people apparently had already begun for the people of Ledbetter One.

The larger-handed women's rank scores in Site Seven introduce some new combinations to this study. The paired firsts on ODM represent peak activity on the ulnar side of both hands in cupping the palm and opposing the thumb. Thumb scores, however, are very low on the right and only average on the left. The same left-five/right-eight rank combination on OPX and IK point to more action in the left than in the right thumb, but reveal a great reduction in the non-agricultural characteristic, the IK precision muscle. Both ERL ranks are high with a right first and left second, and may be the radial part of the hand that the ODM is opposing, pressed tightly by the flexor (FCR). The FCR, however, rates only an average fourth on the left, although a higher three on the right. E2B, the central extensor, is paired with left and right sixth ranks. E3B and ECU, the ulnar extensors and strength muscles, show strong action with third rank on the left and second on the right for

E3B. The low score on ECU is difficult to explain, particularly when the accompanying ulnar ODM is so high. It may be that the ODM scores include information on the length increase of MC5 (see Table 48 [p.126]) which is 1.42mm longer than that of Site Six females; this is the greatest difference between sites of any MC5.

Possible actions described by these ranks are: both hands cupped, holding firmly some medium sized object against the palm; that object is too large to be pinched by the IK, too small to require the extended thumb anchor; once grasped, the action is not central extension, but possibly alternation.

Higgins' list of significant associations of Ledbetter burial goods applies only to stratum two which was not selected for use in this study. She rejects level one because of the quantity of pottery it contained. Others, however, list pottery as part of the artifact assemblage of this time period (Dye, 1977:63). The excavators interpreted that pottery as part of the integral artifacts in level one (Lidberg, n.d.:3). Pottery construction might produce the patterns of action seen on the Ledbetter female hands. Smith notes the "container revolution" as beginning even earlier in the Southeast (Smith, 1986:30). It may be that the ODM, ERL two-handed combination is the first record of seed processing with a wooden, vertical, cylindrical pestle.

<u>Site Seven males</u> (Plate 9, Figure 33 [p.261])

As noted in Table 48 (p.126), this group has the largest hands and greatest femur length of the non-agricultural samples. Of their ranked-hand muscle scores, E3B is the only paired high score, with left first

rank, and right second. This is similar to the pattern of males in Big Sandy, Site Four. Only the third ranked ODM on MC5 has a high rank for the right side, joined by the left IK and the left ERL, also with thirds. The other grouping of note is the sixth ranked left and fifth ranked right for OPX, FCR, and E2B--all middle level ranks. The paired fourth ranks on both left and right for ECU point to average action in support of the other extensors. The male hands do not show the ulnar action of the females. There is a decrease in thumb action from those of other non-agricultural males. The characteristic high IK rank is missing, with a fifth rank for the right. The right hand is not particularly active from the thumb down through E2B with slightly increased activity toward the ulnar side. The left third rank in the IK and ERL may have been used to grasp a small object and pull it radially or alternately with the ECU. The left hand was doing very little (seventh rank) opposition and cupping action. In short, neither precision nor power action was noted in these scores.

Bowen's study of Ledbetter artifacts shows them to be very similar to those of the Cherry Site, using stone tools for piercing, perforating, and drilling, but differing from those of the Cherry Site by scoring more tool evidence of grinding. Bowen also states in contrasting the Cherry and Ledbetter sites (sites Six and Seven in this study), "The people of the flood plain [Ledbetter Landing] were also hunting, but their gathering activities were more concentrated on riverine products" (Bowen, 1975:87). The shell debris in Site Seven would certainly support that description, but the hand ranks do not. It is the non-riverine hands from Site Six that have the stunningly high scores for

the IK precision grasp patterned like the other two shell mound sites, Site Two and Site Five.

Bowen and others have described a hunting-gathering seasonal round of food collection for the people of this area. It may be that the hands of those found in Site Six and Site Seven represent previous activity from another season. It is peculiar that they should all be so uncharacteristic of the sites in which they are found. Bowen also cautiously suggests that the Cherry and Ledbetter people might be one and the same (Bowen, 1975:88). This may be true for Ledbetter stratum two (not included here), but it seems highly unlikely for stratum one.

In collecting data for this study, Site Seven was unique in that the human skeletal material was curated with faunal items. In six of the eight females with unrecorded inclusions, and five out of five males with unrecorded inclusions, deer bone was present. Venison must still have been highly prized.

<u>Site Eight females</u> (Plate 10, Figure 34 [p.263])

A first look at the Site Eight, Averbuch, female rankings shows three first ranks and three second ranks in the left hand with only one first and two third ranks in the right. This is an agricultural site. The paired (fifth and seventh) IK ranks reveal a low level of precision and pinch activity. The high OPX shows very active extended thumbs grasping large diameter objects in opposition to the high scoring ODM's in both hands. The highest of all is the paired first rankings on the ERL that extends the hand radially. FCR, the flexor tight holder, is first on the left, fourth on the right. Merbs cites strong left action

in the Inuit as evidence of cutting a taughtly held skin or holding an object tightly for right hand operation on it (Merbs, 1983:183). E2B and E3B have high ranks of two on the left, but an average five on the right, used for central extension. The average fifth rank on both ECU's is hard to interpret; it is not countering the radial pull of the first ranked ERL, nor is it highly active in drawing the hand to the ulnar side.

One combination of actions that does seem clear would be the possibility of the wooden mortar and large pestle. The extended thumbs and the cupped ODM's could grasp the cylinder. The tightly pressed ERL's would lift the post, then loosen it as it was dropped into the wooden mortar to crush the grain.

Hide working may contribute to the high left scores as Merbs has described. Of the lithics found at the site, interpreted by function, light duty scraping is represented by more artifacts than by all other stone types combined (Klippel and Bass, 1984:I.11.7).

Hoeing, picking and shelling of corn added new tasks for the hand muscles. Weaving and basketry had been practiced throughout the Southeast at least as long as the sequence of sites in this study. Chapman identified textiles from the Early Archaic at Ice House Bottom and DeSoto's men were met by women wearing white, mulberry fiber clothes (Watson, 1969; Hudson, 1976:109; Chapman, 1977:107; Walthall, 1980:70). However, Averbuch is the first site studied here to yield textile evidence and a possible explanation for some of the high ranking hand muscle scores (Eisenberg, 1986:178).

On food processing, Smith has traced changes noted in dental attrition among the same people sampled for this study.

> The Archaic sample is characterized by a rapid attrition rate which is maintained throughout the lifetime of the sample members. Since the rate at which teeth are abraded has been attributed to food texture, it can be inferred that the consistency of the food bolus is appreciably different between the subsistence systems....The archeological data for the Archaic and Mississippian samples suggest that food preparation techniques and therefore, texture of the food bolus have undergone dramatic change....Data from ethnographic accounts as well as independent biological data indicates [sic] that agriculturalists of the mid-South engaged in extensive preparation of food prior to consumption (Smith, 1982:146,100,70).

For instance, Smith sites the following as being pounded into meal: goosefoot seeds (Hudson, 1976), acorns for meal (Swanton, 1931) and soup (Hudson, 1976), persimmons for bread (Hudson, 1976), meats shredded and pounded (Swanton, 1931).

> The collective assessment of the ethnographic account suggests that the indians of the Southeast preferred foods of a soft or mushy consistency (Smith, 1982:71).

This contrasts with accounts from Salts Cave of preserved Woodland materials in coprolites that showed an amazing range in types and sizes of swallowed materials used as food from small shells and feathers to hickory shell pieces as large as 10mm. This would indicate the Southeastern tradition of intensive food processing was not yet established. "The identity of most foods is obvious, indicating that very little food preparation other than cooking was practiced" (Watson, 1969:44). However, these non-processed foods do reveal that the experimentation in cultivation was well underway by the Early Woodland.

Carbon-14 dates of coprolites at Salt's Cave date 710 B.C. and show a possible 66% of plant material was from cultivated species (Watson, 1969:50,45).

Evidence of pottery is seen in the Southeast very early.

> "A major center of fiber tempered pottery in the Southeast is on the Tennessee River. The Wheeler series is the earliest pottery present in many shell middens of the Wheeler and Pickwick basins" (Griffin, 1974:100).

A variant of the Wheeler series, the Baumer type, was seen by this researcher still intermixed with skeletel material from Site Seven (Ledbetter Landing Site One) (Lewis and Kneberg, 1947:33).

In studying the Averbuch Site Eight hands, it became clear that they exhibited certain characteristics not incorporated in the original research design. Although the information was not systematically collected, it is included here as a possible contribution toward the interpretation of the Sight Eight female entheses ranks. Four things were noted. The first was a general impression that the metacarpal shafts two through five were flat on the dorsal side, and almost square in cross section rather than triangular. One interpretation of this is that the frequent and intense activity of the interossei between the shafts remodeled the sides of the bones. The frequent and intense action of extensor tendons to the fingers (not studied here) could have remodeled the dorsal surfaces since that part of the extensor apparatus is not encased in synovial sheaths but moves directly on the metacarpal dorsal surface (Hollinshead and Jenkins, 1981:185). Those tendons are visible in the back of elderly hands that have lost the protective fat

layer beneath the skin. Those tendons are flat and sometimes in a solid sheet (MacConnail and Basmajian, 1977:279). When they are joined in a flat sheet, action of the individual digit could be limited (Kaplan, 1965:68).

The second peculiarity of the Averbuch hands--usually women's--was a large triangular bone insertion site on the radial side of the proximal end of MC4 (Figure 34 [p.263]; Appendix B, 4-A [pp.244,252]). This bony deposit would support the origin of Palmar Second Interosseous, often used in a scissor grip to grasp small items between the third and fourth digits. This area is particularly well developed in New World monkeys and orangutans, enabling them to pick up small items since their first digit is too short for precise opposition (Napier, 1976:13).

The third modification noted at Averbuch was an insertion site on the radial and sometimes volar portion of the proximal end of MC5 (Figure 34 [p.263]; Appendix B, 5-E [pp.244,253]). This could have been in support of an active Third Palmar Interosseous adducting the little finger after it had been abducted by the Dorsal Fourth Interosseous. Also, it might represent an accessory insertion for the Flexor Carpi Ulnaris, not included in this study, which usually inserts on the pisiform, but is know to send fibers to the proximal portions of MC5, MC4, and even MC3. The function of the Flexor Carpi Ulnaris is to draw the hand toward the ulnar side, working with the ECU, plus it serves to fix the wrist during extreme action (Schade, 1970;64).

The fourth Averbuch peculiarity, especially on the older bones, was a small deposit of new bone on top of a partially resorbed, old enthesis--as if a retired hand were abruptly called into action.

All of these characteristics might have been the result of work with clay and pottery. Contemporary potters report that the parts of the hand that hurt after clay working are in the areas of the dorsal and palmar interossei mentioned here, and the area between the thumb and index (Conyers, 1989). The action represented is inserting the thumbs into a clay ball and pressing with extended fingers toward the palm.

Averbuch was certainly a clay working, pottery making site, with evidence of vessels in burials, sherds used to form the floors of stone burial boxes, and hearths made of prepared clay (Berryman, 1981:2,7; Reed, 1978:2). Adult burial artifacts were usually utilitarian (awls, potters anvils); ceramic vessels were occasionally found with adults. The most elaborate ceramics at the site were normally found with children. These include both human and animal effigy vessels, and human effigy ceramic figurines (Berryman, 1981:16).

Site Eight males (Plate 10, Figure 35 [p.263])

The males have several ranks similar to the Site Eight females. The high ranks in both hands for the opposition of OPX and ODM, the strong action in both hands by the ERL pulling them radially, and the low rank of the precision pincher IK, all are similar in both sexes. The male ranks show generally strong muscle action in all but the left E3B and the right ECU.

The bow and arrow combinations of strong left OPX, ERL, FCR, and ODM, plus right E2B are present, but would never be detected without changes in bone widths. The overall evidence of hard-working hands in the Averbuch males shows more than just hunting. It is not known what

role they played in active farming. Recent studies show that male contributions to agriculture increase with its intensification (Burton and White, 1984:568). The functional analysis of lithics may point more to hide processing than to agriculture (Klippel and Bass, 1984:I.11.7). What is known is that Mississippian sites had community activity and group projects.

> Planned communities, the demarcation of public space and public structures, the possible control of agricultural surplus, and evidence for organized communal labor projects all point to the likely presence of community-level positions of sociopolitical control and marked differential status [emphasis added]" (Smith, 1986:56).

The only Averbuch community activity noted--apart from the construction of the stone burial boxes--is the presence of a surrounding palisade perhaps built by some of those high ranking hands in the Site Eight males (Reed, 1978:4).

Site Nine females (Plate 11, Figure 36 [p.265])

The Larson female ranks share many similarities with the females of Site Eight: high scores of the large object-holding Opponens, OPX and ODM, in both hands; strong action of the fist-holder flexor FCR; and comparatively low use of the IK precision pincher. Left-right rank scores for the women of Site Eight and Site Nine show more similar patterns than any other two groups in this study (Table 58 [p.168]). The ERL is slightly lower in Site Nine than Site Eight, perhaps due to different methods of preparing corn. Ethnographic accounts report that both stone and wood tools were used to grind corn on the Upper Missouri

(Will and Hyde, 1967:158). E3B, used to extend the hand centrally and to the ulnar side, is the only other low score. Paired first rank for the ECU attests to the heaviest possible work.

Pottery, corn processing, meat drying and processing were tasks that might account for evidence of work on women's hands. This is the only site of the nine studied where we have ethnographic data that should be fairly accurate. For the Arikara women, we read that: (a) they did the cooking and kept the fires (Abel, 1939:182); (b) they did all the gardening, successfully producing trade corn, beans, tobacco, and pumpkins (Abel, 1939:148,131); (c) they built the earth lodges (Abel, 1939:148; Hurt, 1969:33); (d) they hoed the gardens (Hurt, 1969:34) with scapula hoes (Abel, 1939:49); (e) they produced a variety of pounded meat, corn, squash, and plum pemmican rolled into balls (Abel, 1939:91; Will and Hyde, 1967:158-159); (f) they dressed skins into a pliable leather used for fine garments for both sexes (Abel, 1939:78).

The Hidatsa women are recorded as shelling corn with the thumbnail (Will and Hyde, 1967:160), but unfortunately it is not known whether this is a universal corn shelling method, or whether it was noted merely because it was different. Contemporary corn shelling methods incorporate the full cob in the left hand, shelled by an empty cob in the right. This action requires opposition and interosseous action in both hands, and fits well with evidence from this study.

Site Nine males (Plate 11, Figure 37 [p.265])

High rank scores for every single muscle in both hands make it impossible to use those ranks to analyze the kinds of work done at this site. Ethnographic data indicate the following activities for Arikara men: (a) they used a bow made of walnut acquired by trade (Abel, 1939:171); (b) they were great runners, swimmers, and fishermen (Abel, 1939:173,91); (c) they got firewood for the women's fires (Hurt, 1969:33); (d) they cut logs for the women to use in building earth lodges (Hurt, 1969:33); (e) they split wood with a bison horn (Abel, 1939:149); (f) they helped the women build forts against attack and warfare (Abel, 1939:204).

The archeological report from the excavation of the Larson Site states: "the site was strongly fortified with a ditch, and remnants of an older ditch could be traced" (Bowers, 1967:205). A similar fortification from the Buffalo Pasture Site has been described as composed of logs five feet high and well-packed earth:

> The fortification system at Buffalo Pasture must have required an enormous outlay of both labor and materials . . . . It is likely that there were over 1,200 posts in the palisade . . . . The labor of cutting and setting the palisade posts obviously represented a major outlay of effort (Lehmer and Jones, 1968:22-23).

Fawcett (1988) has recently described patterns of wood collection and use along the Middle Missouri that include land clearing, lodge building, heating and cooking. Labor costs for wood procurement may have been extensive.

The final possibility of what left such an extreme work record on the Larson male hands is the observation--a hundred years later--that the Sioux used "Ricaras" as serfs to cultivate for them and take the place of women (Abel, 1939:130). It is not known if this practice was in effect earlier.

Studies by Burton and White show the longer the dry (cold) non-growing season, "the more time pressure may account in part for increased male participation in cereal crop agriculture." They further suggest ". . . a narrow seasonal window puts a premium on the labor of young men . . . [since] the physically demanding tasks...makes them the best candidates for farm labor" (Burton and White, 1984:570). The Larson Site is approximately 600 miles farther north than the Averbuch Site. With a relatively shorter growing season to produce the same corn crop, more intense labor would be required. Of the 16 ranked entheses scores (eight right and eight left), Site Nine males out-rank Site Eight males in 15; of the females, Site Nine out-ranks Site Eight in only nine entheses measures (Tables 58 and 59 [p.168]).

Recent studies on carries rate as an indicator of horticultural dependence show "the highest carries rate for the Post Contact Coalescent (Larson Site) may reflect a difficulty in procuring bison and a forced dependence on garden crops and general disruption at the time" (Masters, 1988:6).

(Note: Excellent illustrations of hand positions in action for both precision and power grips, in the non-agricultural and agricultural culture patterns, can be found in Lewis and Knebergs' Tribes that Slumber [1958].)

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Summary

Metacarpals provide an abundance of information on cultural activity. They join other skeletal parts known to reveal a record of human activity.

> There is no doubt that certain human performances will leave their marks on various parts of the skeleton in the form of kneeling facets, sacroiliac accessory facets, supinator crests and fossa of the ulna, and even anterior bony spikes in the mandibular condyles (Krogman and Iscan, 1986:405).

The original focus of this study, the entheses formed at the loci of tendon attachments, was greatly expanded by the contribution of the morphology of the bones themselves. The changes in size and shape of the metacarpals, both through time and within a lifetime, support and enrich the information collected from the entheses. Wolff's Law describes the condition of entheses and whole bones as well. Functional interpretation is the key to understanding the structural changes of the bone.

Noninvasive measurements taken in this study (75 for each individual having all ten metacarpals present and complete) yielded a network of data that could be manipulated easily, leaving the bones intact. Using those measurements in ratio form related to the size of the individual removed barriers of age and sex as well as size. This procedure pro-

vided opportunities for comparative studies between groups that has only been touched here. Other adaptive traits on the metacarpals observed during data collection were noted only by presence/absence and contributed to the functional interpretation (Appendix B).

Three approaches were taken in order to interpret and discuss the measurements. The first was to establish and test a series of hypotheses concerning the fundamental question of labor costs in the transition to agriculture (Chapter 5). Following that, the scoring patterns were examined for indications of functional action and kinds of cultural activities (Chapter 6). Finally, following the method pioneered by Merbs, a known activity was first described and the measurements then scrutinized to see if a pattern could be found congruent with the activity (Chapter 6). All three approaches yielded valuable, mutually supportive evidence that indicates a heavier work load in the agricultural population.

Conclusions

This study concludes:

That agricultural hands are larger and could do more work: All metacarpal lengths in both hands are greater in both sexes of the agricultural people even after adjustment by femur length. Bigger hands can do more work (Table 24 [p.87]). This increase is seen to be sequential through time (Table 47 [p.125]). The hand size increase from non-agricultural to agricultural is twice the percentage of femur length increase for both sexes (p.70). All entheses, except those of the IK, are larger in the agricultural hands.

That the precision grip predominated in the non-agricultural hands: The IK muscle shows greater action by every test in the non-agricultural hands (Tables 34 [p.99], 55 [p.152], 56 [p.153]). Correlated pairs used least by the non-agricultural women include OPX and ODM that are used for gripping large objects (p.162). The greatest contrasts through all ages showing high scores for non-agricultural women are seen in the IK, E2B, and E3B used in precision grip (Table 57 [p.161]). Agricultural women used precision grip plus power grip (p.162). Site rankings (Tables 58 and 59 [p.168]) show the greatest IK actions in non-agricultural sites.

That the power grip and ulnar side activity increases in the agricultural hands: The shape of the palm changes from non-agricultural to agricultural from increases in the lengths of MC4 and MC5 in both sexes (p.89). This definitive increase is not accounted for by any known studies in hand growth and may be from greater use of the ulnar musculature (p.130). The difference in palm shape starts in youth for both sexes and continues through old age for females, but reaches maximum difference in males during middle age (Tables 50 [p.136] and 51 [p.137]). The cross-sectional metacarpal shape changes in both sexes and hands of the agricultural people. The broader, flatter MC1 not only increases the span of the agricultural palm but anchors the power grip and supports the OPX (Table 17 [p.78] and 49 [p.134]). This muscle, the OPX, used in grasping large objects, is bigger in both hands of both sexes of the agricultural peoples (p.131). The greatest difference in male enthesis scores is significant at $p < .0001$ on both right and left for the ODM on MC5. This difference occurs in the young scores and

represents early ulnar activity and power grip tasks (Table 34 [p.99] and 56 [p.153]). Differences in entheses scores by age show that agricultural females work hard earlier and continue to do so into old age. As young women, the scores that show the greatest difference with the non-agricultural females are those combinations that show hard labor (p.155, 156, 162; Table 55 [p.152]). The enthesis that has the most increase from non-agricultural to agricultural for both hands and through all ages is the ECU, the primary ulnar power muscle (p.162, Tables 54 [p.150], 55 [p.152], 56 [p.153], 57 [p.161]). MC4 is expanded in both dorsal-volar and medial-lateral widths in the agricultural hands and provides a framework for the more active Dorsal and Palmar Interossei that produce gripping power on the ulnar side of the hand (Tables 49 [p.134], 50 [p.136], 51 [p.137]). Site rankings in Tables 58 and 59 show the highest rankings of ulnar muscles are found in the agricultural sites. The highest incidence of peculiar bony platforms that support expanded ulnar musculature is in the agricultural hand (Table 63 [p.246 in Appendix B]).

<u>That the agricultural scores show fewer discrete tasks, greater division of labor, more difference between sexes:</u> Length changes in agricultural females are underway before those in the males occur, indicating young females work earlier or harder in youth than agricultural males or non-agricultural females (Tables 24 [p.87], 50 [p.136], 51 [p.137]). Old agricultural females continue to work hard; old agricultural males appear to be removed from the work force (Tables 55 [p.152] and 56 [p.153]). Bow and arrow use by males begins early and is measureable in both bone width shape and entheses (Table 49 [p.134],

pp.118-119, Table 56 [p.153]). Agriculturalists have the fewest between-entheses correlations, or fewer combinations functioning together (Table 53 [p.149], p.148).

That the non-agricultural hands show more diversified, general action: Non-agricultural women have greater left-right differences in metacarpal cross-sections (Table 25 [p.88]). Non-agricultural males consistently have the highest correlation of metacarpal length and femur length, or entheses and metacarpals, showing minimum cultural modification of hands in relationship to the rest of the body. For each measured combination, agricultural people show the least correlation with femur length and metacarpal measurements (Tables 20 [p.82] and 37 [p.104]). Amounts and kinds of work have the least relationship to size of person in the agricultural people (Tables 30 [p.94] and 31 [p.96], p.147). The atlatl is very difficult to identify since non-agricultural female and male correlation scores are so similar (p.148). The greatest differences in left-right enthesis rankings by site are seen in the non-agricultural sites (Tables 58 and 59 [p.168]).

Interpretation of Conclusions

Some of the more easily seen results of this study are the marks on the metacarpals of increased use of the ulnar side of the hand, bow and arrow use, and pottery making by the agricultural people. But what do these activities have to do with agriculture, and, more to the point, how are they associated with population growth?

It is now agreed that the people of the Southeast had developed a successful system of using a wide variety of floral and faunal food

resources (Bowen, 1975; Dye, 1977; Crites, 1984; Smith, 1986). Studies of artifact remains, site location, nutritional content, and labor costs have shown that deer was always first choice (Cassidy, 1984). The archeological record, however, shows continuous shifts in the floral/faunal balance of resources used with the amount of deer bone being steadily reduced through time (Romanoski, 1984). Compensating shifts maintained the nutritional balance but labor costs changed. Students of tooth wear have found that periods of shellfish dependence result in dental destruction (Hinton, 1981). This study shows the same shellfish users as having the least evidence of hand wear. What cannot be disputed is that the food gathering procedure is directional from the more ideal resources toward the less ideal. Parmalee's vivid description of fresh water mussels as having the "texture and flavor of shoe leather" (Parmalee, 1986) removes any consideration that periods of shellfish dependence were the result of whim. The use of more palatable nuts, seeds, and other water resources, plus birds and other small animals continued through the 6,000 years covered in this study (Chapman and Shea, 1981).

The responses to a decreased supply of deer can be traced. One response might have been to give up the ideal; there is no evidence that this ever happened or that deer was not highly valued. It is always recovered in the archeological record.

Another strategy is to improve and update hunting methods. Ingenious efforts to make the atlatl more efficient have been traced by Webb's newly released research, yet the amount of deer bone continued to decrease. It may be possible to mark the cost of technological experi-

mentation in the high fracture incidence among the men of Site Four (Table 63 [p.246 in Appendix B])--a time when a variety of weights were added to the throwing stick yet the supply of deer plumetted. The atlatl was still in use at first white contact, but was reported by DeSoto's men as being used against them. The bow and arrow was the principal weapon among the prehistoric agriculturalists of the Southeast. Its increased energy efficiency provided by the spring of the bowstring, and its capability of releasing several arrows quickly provided advantages in both hunting and defense. Increased labor cost is recorded on the hands, both of them. However, no matter how efficient the bow or the bowman was at hunting and maintaining access to hunting territory (defense), the supply of deer was not increased.

The other strategy that accompanies more efficient hunting techniques is the investment of more energy in nut and seed resources whose supply can be controlled and expanded (Crites, 1978, 1985). Increased population would account for decreased territorial range in search of a decreased supply of deer. Ultimate dependence on grain resources is the most efficient use of reduced territorial range (Cohen, 1977).

The process was slow enough that subsistence strategies could be adjusted to fit increased demand on reduced natural resources and territory. DeSoto's men discovered a very well organized, efficient system of corn-dependent people who used the bow and arrow, not only to supplement the grain resource, but to defend the reduced territory in which it is grown. Turnbull's tragic description of the Ik documents what can happen to a society that does not have the time to invent efficient adaptive strategies to compensate for reduced range (Turnbull, 1972).

Rather than the alternative of despair taken by the Ik, the world's survivors have adopted technologies that enable them to make do in a cultural space that is increasingly limited by the expansion of their own species. In short, if enough deer were readily available, you would never need a bow. If enough deer were readily available, you would never need to depend on corn.

The tools of grain dependence must be more efficient than the earlier hand-held pestles and awls that could be manipulated with a precision grip. The more efficient tools were hafted, requiring the strength and greater surface of the expanded palm. Precision grip centering on the radial side of the hand was still necessary, so the ulnar side of the hand became the area that was developed to power the hafted tools. Grasping a stick was not a new idea to the primate mind or a new task for the primate hand. Attaching a blade of bone, stone, or antler to a stick was not a new idea to the hunter. Employing it in repetitive use was, and the hand paid the price.

When the food supply was commensurate with human demand, those wonderful first three fingers did the job nicely. When harvest was no longer a daily gift, but the reward for man's own labor, the entire hand was recruited.

Controlled resources had to contain nutrients useful to man. Those resources also had to be storeable until needed. Nuts were ideal and served well throughout the archeological record, but they could not be expanded quickly enough to supply man's growing need. Seed manipulation, and ultimately corn dependence, was the answer. But that very desirable quality of storeability required new technologies--not only

for storing (pits and vessels)--but for processing into edible food by a mouth that had not evolved to be a grain processor. It is the generalized hand that was adapted to the tasks of working amorphous clay into formed vessels and grinding formed grain into an amorphous edible mass. And it is on the hand, that "masterpiece of all instruments", that we see written in the bones, the progress of that "fatal bargain" (Verdan, 1979a:3; Cassidy, 1980:144).

So the ulnar expansion in use of the hand, the bow and arrow, and pottery are seen as cultural adaptations that accompany the necessity of agriculture in an increasingly populated world.

Recommendations for Future Study

1. Function is the key, not only to form, but to interpretion of bones of the hand. Those who have used the metacarpals as a research tool, immune to the bone remodelling laws, may wish to review some of their conclusions. In reviewing the literature, a few of the conclusions reached in the past that might be modified by including research on function are:

> Most cortical thickness measurements were conducted on the second metacarpal, because it is the largest of the handbones, it has the thickest compact bone, and it is usually morphologically more uniform than other bones of the hand . . . . After maturity, total width and length of the second metacarpal do not change significantly with age . . . . Bone size, total width and length show no correlation with age . . . . Since total bone width and length do not change significantly after adulthood, any effect of physical activity upon these measurements must be exerted early in life (Plato and Norris, 1980:131,134,135,143).

This 1980 study is based on a sample of 236 Caucasian males with a mean age of 58.6 years; 85% are college graduates. This is not a group that would have experienced continuing labor stress on hands.

Another study done in 1967 is based on a sample of 2,799 subjects from five different populations that may represent too diverse a pool to yield definitive data. The logic of metacarpal changes related to skull changes needs no comment.

> Based upon studies of the second metacarpal . . . . Measurements are free from left/right assymetry bias and not notably affected by occupation . . . . It is reasonable to summarize . . . that bone growth continues through the eighth decade, that it is not population specific or sex limited, and that it appears to be a general phenomenon in man . . . . The possibility that flexion stress is the prime stimulus seems unlikely in view of our data on continuing skull growth . . . . Since the second metacarpal is approximately circular in midshaft . . . (Garn et al., 1967b:316).

From the work of Musgrave in speculating on the function of the Neanderthal hand: "Whether these features reflect adaptation to his environment or imperfect development of manual skill is still not known (Musgrave, 1971:541)." (These conclusions are drawn from a sample that is of mixed age and sex.) Among other surprising analytical devices, the First Dorsal Interosseous (IK in this study) is listed by Musgrave as a power muscle with the intimation that the whole Neanderthal group was unable to perform an accurate tip to tip pinch grip of digits one and two. At the same time, the larger pulp area on the end of the thumb is noted as indicating power grip. Marzke and Shackley (1986) incorporate many of these assumptions in their study that endeavors to define hand movements in terms of what actions the joints will permit or curtail.

2. Understanding hand function can greatly contribute to discovery of pathologies in skeletal populations. For instance, absence of any interosseous lines on the metacarpal shafts leaves them resembling metatarsals more than metacarpals, and points to a paralysis of the ulnar nerve that innervates the interossei (Kaplan, 1965:201). It could also indicate damage superior to the Eighth Cranial (Srinivasan, 1979) and First Thoracic nerves (Hollinshead and Jenkins, 1981:183). This condition was observed in a middle aged female hand from Site Nine.

Various infectious diseases that produced periostitis of the metacarpals reflect general health conditions.

Lack of use as seen in resorbed entheses surfaces often points to trauma in the arm. Possible evidence of carpal tunnel syndrome indicated by layered entheses is described in 2-K (p.251) in Appendix B.

3. Once the parameters of a population have been determined for the metacarpals, there is abundant information for determining sex, age, handedness, and even cultural time period, i.e. forensic identification. For instance, if a very broad, right, second, male metacarpal were measured, particularly in contrast to the left, bow and arrow use might be suspected. Merbs informs us,

> consultation with the coach of a university archery team determined three areas of potential pathology, in the fingers holding the arrow and pulling back the bowstring, in the shoulder on this side, and in the shoulder of the arm holding the bow, probably in that order (Merbs, 1983:151).

4. Some untouched areas using metacarpal studies remain: (a) Investigating differences in growth and maturation rates. Measures of sub-adult metacarpals could complement research already done on Indian

children (Johnston, 1962; Merchant and Ubelaker, 1977; Sundick, 1978; Ubelaker, 1978). The lengths of all ten metacarpals are correlated with femur length ($p < .05$) in the young agricultural women, indicating a mature hand. Young non-agricultural males, however, have only one metacarpal length significantly correlated with femur length, indicating total hand growth and leg growth are different. Other research in this area could be helpful (Takai, 1977; Grant et al., 1981).

(b) Cultural clues on the hands of sub-adults may be used to determine sex. If three-year old boys were given bows, as DeSoto's men report, this ought to be visible in width measures, though epipheses are still not attached.

(c) Social stratification should be revealed by obvious differences between hard working hands and privileged hands. If cultural identification is certain, specific tasks or roles might be determined. Answers may be found to such questions as, "Who made Arikara pottery?" (Blakeslee, 1981:98).

(d) Metacarpal-defined work loads could contribute to differential mortality studies in skeletal populations. For instance, Kelley's (1980) work shows increased death rates for females over males at Indian Knoll and Mobridge (another Arikara site) in the 15-25 year age group (comparable to the young category in this study), with a reversed pattern for the 25-45 year old group. Site-specific sex differences of work loads could be calculated that might support Kelley's findings.

(e) Measuring and comparing metacarpal entheses may be used to assist in interpreting cultural changes in the old world as well as the new. Schoeninger (1982) concludes from extensive studies on stature

changes and chemical bone components that new methods of processing old foods were developed in the Middle East. Lacking archeological support for tool changes, hand activities might be used to clarify Schoeninger's theory (Schoeninger, 1982:48-49).

(f) Information on labor costs using hand entheses scores could be incorporated into subsistence change models (Reidhead, 1980).

Finally, individual hands could be compared with the means of their group using Z test scores. This might yield information on the behavior of specific individuals. As an example, this is done here with two individuals found with interesting burial goods.

Site Eight individual male hand profile (Table 61)

From Site Eight a middle aged male (No.101), aged 30-34 years old, was found buried with nine turkey bones drilled with holes, three not drilled, four bone tubes, a deer ulna awl, an unmodified deer innominate, and one non-Mississippian projectile point/knife (Klippel and Bass, 1984). His metacarpal scores were tested against the means for the males of Site Eight (Table 61).

A quick interpretation of the profile reveals a man whose femur length was somewhat longer than average, but who had short hands. Left MC3 and right MC5 are noticeably short. (These should be x-rayed for possible healed fractures.) Left and right MC1's are much deeper than average, perhaps supporting an active IK enthesis which has high height scores. Both fifth dorsal-volar measures are very low, implying a flat bone, perhaps shaped by the high scoring ODM's on both hands. The right

TABLE 61

PROFILE OF Z SCORES OF METACARPAL LENGTHS AND WIDTHS, AND ENTHESES, FOR 40DV60 -- 101 (Male)

Femur Length .29					
Left MC Ln.	1	-1.00	Right MC Ln.	1	-.67
	2	-.64		2	-.58
	3	-1.20		3	-.28
	4	-.74		4	-.72
	5	-.58		5	-1.18
Left D-V Wd	1	1.81	Right D-V Wd	1	2.27
	2	.91		2	-.26
	3	.25		3	1.37
	4	.70		4	1.01
	5	-1.27		5	-1.52
Left M-L Wd	1	-.86	Right M-L Wd	1	-.13
	2	1.14		2	.03
	3	-.28		3	.64
	4	2.54		4	1.51
	5	-.59		5	.52
Left Entheses			Right Entheses		
OPX	LN	.67	OPX	LN	-.31
	HT	1.93		HT	1.64
IK	LN	-2.89	IK	LN	.73
	WD	.36		WD	-.13
	HT	1.14		HT	1.06
ERL	LN	.89	ERL	LN	.45
	WD	1.22		WD	1.88
	HT	2.59		HT	.12
FCR	LN	-.26	FCR	LN	1.06
	WD	-1.17		WD	-1.45
	HT	-.57		HT	-.75
E2B	LN	1.35	E2B	LN	Missing
	WD	1.69		WD	Missing
	HT	.78		HT	Missing
E3B	LN	.36	E3B	LN	.83
	WD	.33		WD	.52
	HT	1.06		HT	.91
ECU	LN	-.26	ECU	LN	-.33
	WD	.96		WD	.34
	HT	.86		HT	1.90
ODM	LN	1.35	ODM	LN	1.46
	WD	.18		WD	1.87

third dorsal-volar is a high score, particularly opposed to its left partner, indicating a strong support for an active right Adductor Pollicis (see p.141). The peculiar measure is on the width of the fourth metacarpal, deep in the right, and extremely wide on the same bone. The right hand was active in grasping some large object calling for the ulnar digits to stretch and draw back together. Both OPX heights show active grasping of large objects. The very active left ERL, especially the height, suggests active bow grasping. The left ECU height, however, is only a little over average. Unfortunately, there is no right E2B score to add information on bow string pulling.

On the data chart are notes recording visual description stating the bones look short and strong, nicely contoured by the Interossei. The OPX is listed as "super for photos." A large triangular insertion is noted on left MC4, and a heavy First Palmar Interosseous line on right MC2. These would be 4-A (p.252) and 2-B (p.249) in Appendix B.

These are the seasoned hands of a bow and arrow hunter. Some other activity produced the heavy right MC4--impossible to interpret at this point.

Though his burial goods seem exceptional, the connections between them and his hunting and other activity is a matter of speculation. In a site where "evidence for obvious differences in social rank was not observed" (Klippel and Bass, 1984:I.14.4), the hands and the burial goods may represent achieved status.

Site Nine individual female hand profile (Table 62)

From Site Nine, a young to middle aged woman (No. 301-41A) was selected because of abundant burial goods and peculiar hands, visually recorded as "a strange person with hands that reflect a life of leisure."

Burial goods recorded include: red ochre above left shoulder and scattered around skull; under left shoulder was petrified wood, a five-hole shaft straightener, two four-hole shaft straighteners, a beaver tooth, and leather strap sections. Under the skull was found two large and two small beads and one large shell.

This woman had a longer femur than average, with extremely long metacarpals two through five in both hands (Table 62). Some of the left dorsal-volar scores are below average, but right MC3DV, MC4DV, and MC5DV are more than one standard deviation above the mean. This must reflect some use of the right hand, yet not much considering how large the bones must have been. The medial-lateral measurements on left MC2 and MC3 score high, but again may not indicate anything other than allometrically large widths on very long bones. The most interesting is the very low medial-lateral score on both MC5's, pointing to a small diameter, round bone, and virtually unused ODM. Of the 14 entheses height scores, 13 carry minus Z scores. These bones reveal muscles and hands that were not used.

The study value in this hand may lie in those few scores that are positively elevated, giving the viewer a glimpse of which unmodeled

TABLE 62

PROFILE OF Z SCORES OF METACARPAL LENGTHS AND WIDTHS, AND ENTHESES, FOR 39WW2 - 301-41A (Female)

Femur Length .86					
Left MC Ln.	1	-.04	Right MC Ln.	1	.08
	2	1.58		2	1.47
	3	1.21		3	1.42
	4	1.02		4	1.22
	5	1.05		5	.72
Left D-V Wd	1	-.72	Right D-V Wd	1	.65
	2	-.03		2	.04
	3	-.86		3	1.20
	4	.04		4	1.24
	5	.67		5	1.50
Left M-L Wd	1	-.37	Right M-L Wd	1	0.00
	2	1.74		2	.80
	3	1.28		3	1.68
	4	.48		4	.88
	5	-1.15		5	-1.33
Left Entheses			Right Entheses		
OPX	LN	-.64	OPX	LN	-.04
	HT	-1.24		HT	-1.42
IK	LN	-.80	IK	LN	.20
	WD	.75		WD	-1.20
	HT	-1.13		HT	-1.08
ERL	LN	-.24	ERL	LN	-.38
	WD	.90		WD	1.17
	HT	-.91		HT	-1.08
FCR	LN	1.14	FCR	LN	.49
	WD	.11		WD	.71
	HT	-.03		HT	-.57
E2B	LN	-.75	E2B	LN	-1.39
	WD	.39		WD	.01
	HT	-1.52		HT	-1.47
E3B	LN	.21	E3B	LN	-.02
	WD	.97		WD	1.54
	HT	-.56		HT	-.18
ECU	LN	.76	ECU	LN	1.29
	WD	.25		WD	-.73
	HT	.88		HT	-.50
ODM	LN	.62	ODM	LN	-.15
	WD	-.28		WD	.30

parts of entheses are large. However, most of the higher scores reflect a proximal/distal enthesis measurement taken on very long bones. The very big hands may be an expression of some pathological growth pattern, but that should not affect use. If illness prevented this person from ever working, how did those bones grow so long? Buikstra equates height with special status and access to resources (Buikstra, 1976:37). This person certainly had access to a large number of burial goods. Data collection notes show a large male MC1 with this burial--perhaps a part of a family member from a joint grave. Hands evidencing no work combined with abundant burial goods and a possible large burial companion may indicate ascribed status.

For The Future

It seems clear that metacarpals are a wonderful data resource. This study opened with Frost's statement:

> Unlike soft tissue, bone is a biological record. Events in its past are recorded in a unique symbology on durable tablet. Although all the symbology cannot yet be translated, bones will keep until we learn to read better (Frost, 1963:vii).

His conclusion that bones will keep until we learn to read them better is unfortunately no longer true. Not all physical characteristics are captured as graphically by prehistoric artists as the broad-palmed agricultural hand is from Mound State Monument (Figure 25). There is a current urgency to study well those skeletal collections that still wait. Metacarpals are a veritable untouched resource.

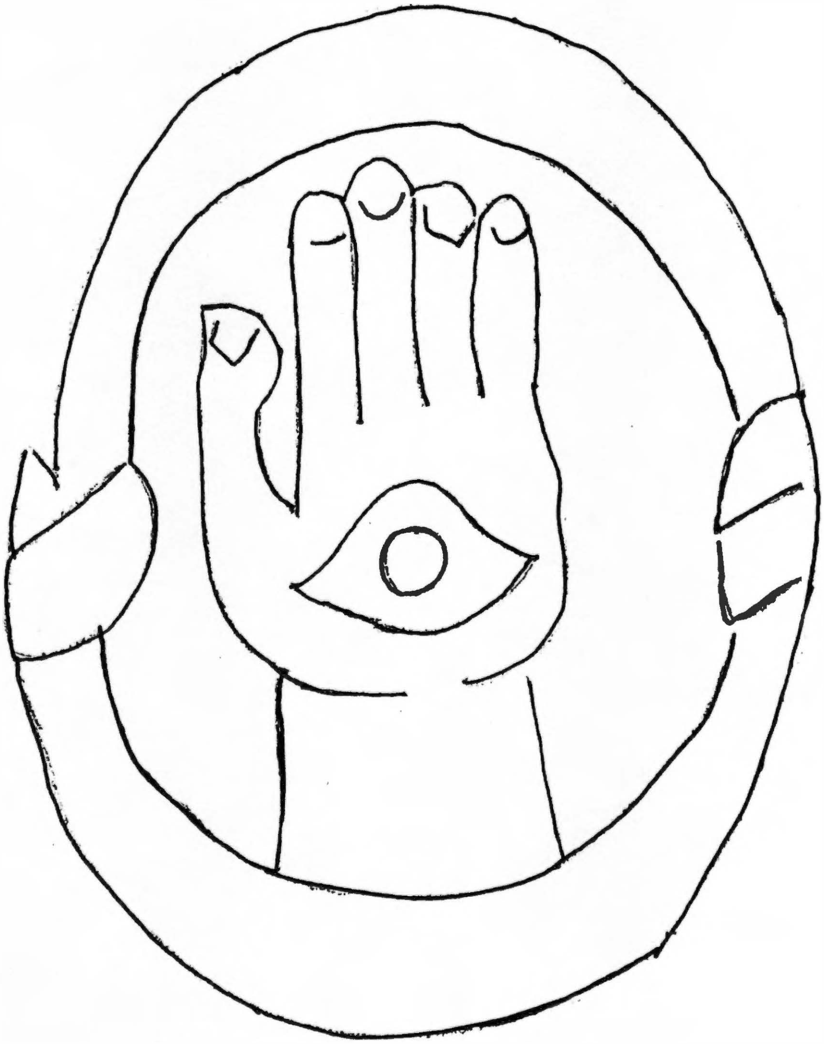


Figure 25. (from Hudson, 1976:395) From Mound State Monument, University of Alabama Museum of Natural History.

> With the reburial of archeological collections a distinct possibility in the future, all possible data must be collected and presented for the utilization of future researchers as well as those in the present scientific pool (Pierce, 1987:208).

It is hoped that others may share the delight of this researcher in becoming prehistoric palm readers.

LIST OF REFERENCES

LIST OF REFERENCES

Abel, A. H., ed.
1939 Tabeau's Narrative of Loisel's Expedition to the Upper Missouri. Norman: University of Oklahoma Press.

Acsadi, GY., and T. Nemeskeri
1970 History of Human Life Span and Mortality. Budapest: Akademiai Kiado.

Amick, D. S.
1985 Buried Late Holocene Terrace Site Testing in the Central Duck River Basin. In Exploring Tennessee Prehistory: A Dedication to Albert K. Guthe. Whyte, Boyd and Riggs, eds. Report of Investigations. Department of Anthropology. Knoxville: University of Tennessee, 42:23-38.

An, K.N., Chao E.Y., Cooney W.P. III, and R.L. Linscheid
1979 Normative Model of Human Hand for Biomechanical Analysis. Journal of Biomechanics 12:775-788.

Angel, J.L.
1966 Early Skeletons from Tranquillity, California. Washington: Smithsonian Press.

Armelagos, G. J., D. S. Carlson, and D. P. van Gerven
1982 The Theoretical Foundations and Development of Skeletal Biology. In A History of American Physical Anthropology 1930-1980. F. Spencer, ed. New York: Academic Press, 305-328.

Armstrong, T. J., D. B. Chaffin, and J. A. Foulke
1979 A Methodology for Documenting Hand Positions and Forces During Manual Work. Journal of Biomechanics 12:131-133.

Asch, N. B., R. I. Ford, and D. L. Asch
1972 Paleoethnobotany of the Koster Site: The Archaic Horizons. Illinois State Museum. Reports of Investigations 24.

Ascenzi, A., and G. H. Bell
1972 Bone as a Mechanical Engineering Problem. In The Biochemistry and Physiology of Bone. Second Edition. G. H. Bourne, ed. New York: Academic Press, Vol. I:311-352.

Basmajian, J. V., and C. J. DeLuca
1985 Muscles Alive. Their Functions Revealed by Electromyography. Fifth Edition. Baltimore: Williams and Wilkins.

Basmajian, J. V.
1971 Grant's Method of Anatomy. Eighth Edition. Baltimore: Williams and Wilkins.

Bass, W. M.
1971 Human Osteology: A Laboratory and Field Manual of the Human Skeleton. Columbia, Missouri: Special Publications of the Missouri Archeological Society.

Bee, R. L.
1974 Patterns and Processes. New York: The Free Press.

Berryman, H. E.
1981 The Averbuch Skeletal Series: A Study of Biological and Social Stress at a Late Mississippian Period Site from Middle Tennessee. Ph.D. Dissertation. Department of Anthropology. Knoxville: University of Tennessee.

Binford, L. R., and S. R. Binford, eds.
1968 New Perspectives in Archeology. Chicago: Aldine.

Blakely, R. L.
1971 Comparison of the Mortality Profiles of Archaic, Middle Woodland, and Middle Mississippian Skeletal Populations. American Journal of Physical Anthropology 34:43-53.

Blakeslee, D. J.
1981 Toward a Cultural Understanding of Human Microevolution on the Plains. Plains Anthropologist 26:93-106.

Boserup, E.
1965 The Conditions of Agricultural Growth. Chicago: Aldine.

Bowen, W. R.
1975 Late Archaic Subsistence and Settlement in the Western Tennessee Valley: A Reevaluation. M.A. Thesis. Department of Anthropology. Knoxville: University of Tennessee.

1979 The Late Archaic in the Upper Duck River Valley. Tennessee Anthropologist 4:140-159.

Bowers, A. W.
1967 Field Report: 1964 Excavations of the Davis and Larson Sites, near Mobridge, South Dakota. Plains Anthropologist 12:204-205.

Bowles, G.
1932 New Types of Old Americans at Harvard. Cambridge: Harvard University Press.

Boyce, M. S.
1979 Seasonality and Patterns of Natural Selection for Life Histories. American Naturalist 114:569-583.

Braidwood, R. J., and G. Willey, eds.
1962 Courses Toward Urban Life. Publications in Anthropology 32. New York: Viking Fund.

Bridges, P. S.
1982 Postcranial Size in Prehistoric Northern Alabama: Implications for Nutrition and Behavior. American Journal of Physical Anthropology 57:172.

1985 Structural Changes of the Arms Associated with Habitual Grinding of Corn. American Journal of Physical Anthropology 66:149.

1988 Atlatl Use in Degenerative Joint Disease. American Journal of Physical Anthropology 75:190.

1989a Osteoarthritis, Diaphyseal Dimensions and Strength of the Femur in the Prehistoric Southeastern United States. American Journal of Physical Anthropology 78:196.

1989b Changes in Activities with the Shift to Agriculture in the Southeastern United States. Current Anthropology 30:385-394.

Brock, S. L., and C. B. Ruff
1988 Diachronic Patterns of Change in Structural Properties of the Femur in the Prehistoric American Southwest. American Journal of Physical Anthropology 75:113-127.

Brues, A.
1959 The Spearman and the Archer--An Essay on Selection in Body Build. American Anthropologist 6:457-469.

Buikstra, J. E.
1976 Hopewell in the Lower Illinois Valley: A Regional Approach to the Study of Human Biological Variability and Prehistoric Behavior. Northwestern University Archeological Program Scientific Papers 2. Evanston: Northwestern University Press.

1977 Biocultual Dimensions of Archeological Study: A Regional Perspective. In Biocultural Adaptation in Prehistoric America. R. L. Blakely, ed. Southern Anthropological Society Proceedings 11. Athens: University of Georgia Press, 67-84.

Burr, D. B.
1980 The Relationship Among Physical, Geometrical and Mechanical Properties of Bone, With a Note on the Properties of Non-Human Primate Bone. Yearbook of Physical Anthropology 23:109-146.

Burr, D. B., R. B. Martin, and M. B. Schaffler
1984 Why Osteons? American Journal of Physical Anthropology 63:142.

Burton, M. L, and D. R. White
1984 Sexual Division of Labor in Agriculture. American Anthropologist 86:568-583.

Bush, M. E., C. O. Lovejoy, D. C. Johansen, and Y. Coppens
1982 Hominid Carpal, Metacarpal, and Phalangeal Bones Recovered from the Hadar Formation: 1974-1977 Collections. American Journal of Physical Anthropology 57:651-677.

Butler, M. G., F. J. Meaney, and S. G. Kaler
1986 Metacarpophalangeal Pattern Profile Analysis in Clinical Genetics: An Applied Anthropometric Method. American Journal of Physical Anthropology 70:195-201.

Butler, W. B.
1975 The Atlatl: The Physics of Function and Performance. Plains Anthropologist 20:105-110.

1977 Atlatl Functions, Fancy, Flex, and Fun: A Reply to Howard. Plains Anthropologist 22:161-162.

Cassidy, C. M.
1980 Nutrition and Health in Agriculturalists and Hunter-Gatherers: A Case Study of Two Prehistoric Populations. In Nutritional Anthropology. N. W. Jerome, R. F. Kandel, and G. H. Pelto, eds. Pleasantville, N.Y.: Redgrave, 117-145.

1984 Prehistoric Subsistence in the Central Ohio River Valley. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 307-345.

Chapman, J.
1977 Archaic Period Research in the Lower Little Tennessee River Valley--1975 Ice House Bottom, Harrison Branch, Thirty Acre Island, Calloway Island. Tennessee Valley Authority.

1985 Tellico Archeology: 12,000 Years of Native American History. Publications in Anthropology 41. Knoxville: Tennessee Valley Authority.

Chapman, J., and A. B. Shea
1981 The Archaeobotanical Record: Early Archaic Period to Contact in the Lower Little Tennessee River Valley. Tennessee Anthropologist 6:61-84.

Childe, V. G.
1956 Piecing Together the Past. London: Routledge and Kegan Paul.

Close, J. R., and C. Kidd
1969 The Functions of the Muscles of the Thumb, the Index, and Long Fingers. Journal of Bone and Joint Surgery 51A:1601-1620.

Coe, M. P., and K. V. Flannery
1964 Microenvironments and Mesoamerican Prehistory. Science 143:650-654.

Cohen, M. N.
1977 The Food Crisis in Prehistory. New Haven: Yale University Press.

Cohen, M. N., and G. J. Armelagos
1984 Editors Summation. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 585-601.

Conyers, W.
1989 Personal communication at Pottery Lab, McPherson College, McPherson, Kansas.

Cook, D. C.
1984 Subsistence and Health in the Lower Illinois Valley: Osteological Evidence. In Paleopathology at the Origins of Agriculture. M. H. Cohen and G. J. Armelagos, eds. New York: Academic Press, 235-269.

Crites, G. D.
1978 Paleoethnobotany of the Normandy Reservoir in the Upper Duck River Valley, Tennessee. M. A. Thesis. Department of Anthropology. Knoxville: University of Tennessee.

1984 Late Mississippian Paleoethnobotany in the Nashville Basin: The Evidence from Averbuch. In Averbuch: A Late Mississippean Manifestation in the Nashville Basin. Vol. I. W. E. Klippel and W. M. Bass, eds. Department of Anthropology. Knoxville: University of Tennessee, I.12.1-I.12.23.

1985 Middle Woodland Paleoethnobotany of the Eastern Highland Rim of Tennessee: An Evolutionary Perspective on Change in Human-Plant Interaction. Ph.D. Dissertation. Department of Anthropology. Knoxville: University of Tennessee.

Currey, J. D.
1968 The Adaptation of Bone to Stress. Journal of Theoretical Biology 20:91-106.

Davies, B. T., A. Abada, K. Benson, A. Courtney, and I. Minto
1980 A Comparison of Hand Anthropometry of Females in Three Ethnic Groups. Ergonomics 23:179-182.

Dowd, J. T.
1981 The Anderson Site (40Wm9). Tennessee Anthropological Association Newsletter 6:1-2.

Duchenne, G. B.
1867 Physiology of Motion. Translated by E. B. Kaplan in 1949. Philadelphia: W. B. Saunders Company.

Dutour, O.
1986 Enthesopathies (Lesions of Muscular Insertions) as Indicators of the Activities of Neolithic Saharan Populations. American Journal of Physical Anthropology 71:221-224.

Dvlevsky, I.
1980 Spatial Aspects of the Development of the Human Hand. Folia Morphologica 28:407-441.

Dye, D. H.
1977 A Model for Late Archaic Subsistence Systems in the Western Middle Tennessee Valley During the Bluff Creek Phase. Tennessee Anthropologist 2:63-80.

Eisenberg, L. E.
1986 Adaptation in a "Marginal" Mississippian Population from Middle Tennessee: Biocultural Insights from Paleopathology. Ph.D. Dissertation. Department of Anthropology. New York University.

Fahrer, M.
1979 The Anatomy of the Deep Flexor and Lumbrical Muscles. In Tendon Surgery of the Hand. C. Verdan, ed. Edinburgh: Churchill Livingstone, 16-24.

Fawcett, W. B.
1988 Changing Prehistoric Settlement Along the Middle Missouri River: Timber Depletion and the Historic Context. Plains Anthropologist 33:67-94.

Foster, G. M.
1960 Culture and Conquest. New York: Viking Fund.

Frayer, D.
1980 Sexual Dimorphism and Cultural Evolution in the Late Pleistocene and Holocene of Europe. Journal of Human Evolution 9:399-415.

1981 Body Size, Weapon Use, and Natural Selection in the European Upper Paleolithic and Mesolithic. American Anthropologist 83:57-73.

Frisancho, A. R., and P. T. Baker
1970 Altitude and Growth: A Study of the Patterns of Physical Growth of a High Altitude Peruvian Quechua Population. American Journal of Physical Anthropology 32:279.

Frost, H. M.
1963 Bone Remodelling Dynamics. Springfield, Illinois: Charles C. Thomas.

1964 Laws of Bone Structure. Springfield, Illinois: Charles C. Thomas.

1967 An Introduction to Biomechanics. Springfield, Illinois: Charles C. Thomas.

1980 Skeletal Physiology and Bone Remodelling. In Fundamental and Clinical Bone Physiology. M. R. Urist, ed. Philadelphia: J. B. Lippincott, 208-241.

Gall, J. C., Jr., A. M. Stern, A. K. Poznanski, S. M Garn, E. D. Weinstein, and J. R. Hayward
1972 Oto-Palato-Digital Syndrome: Comparison of Clinical and Radiographic Manifestations in Males and Females. American Journal of Human Genetics 24:24-36.

Garn, S. M., and C. G. Rohmann, T. Blumenthal, and F. N. Silverman
1967a Ossification Commonalities of the Hand and Other Body Parts: Their Implication to Skeletal Assessment. American Journal of Physical Anthropology 27:75-82.

Garn, S. M., C. G. Rohmann, B. Wagner, and W. Ascoli
1967b Continuing Bone Growth Throughout Life: A General Phenomenon. American Journal of Physical Anthropology 26:313-318.

Garn, S. M., B. Wagner, C. G. Rohmann, and W. Ascoli
1968 Further Evidence of Continuing Bone Expansion. American Journal of Physical Anthropology 28:219-221.

Garn, S. M.
1970 The Earlier Gain and the Later Loss of Cortical Bone in Nutritional Perspective. Springfield, Illinois: Charles C. Thomas.

Garn, S. M., A. K. Poznanski, and K. Larson
1973 Metacarpal Length, Cortical Diameters and Areas from the Ten-State Nutrition Survey. In Procedings of the First Workshop on Bone Morphology. Z. F. G. Jaworski, S. Klosevych, and E. Cameron, eds. Ottawa, Canada: University of Ottawa Press, 367-391.

Garn, S. M., A. R. Burdi, W. J. Babler, and S. Stinson
1975 Prenatal Attainment of Adult Metacarpal-Phalangeal Rankings and Proportions. American Journal of Physical Anthropology 43:327-332.

Genoves, S.
1960 Reevaluation of Age, Stature and Sex of the Tepexpan Remains, Mexico. American Journal of Physical Anthropology 18:205-217.

Glassow, M. A.
1980 Prehistoric Agricultural Development in the Northern Southwest: A Study in Changing Patterns of Land Use. Socorro, New Mexico: Ballena Press.

Goad, S. I.
1980 Patterns of Late Archaic Exchange. Tennessee Anthropologist 5:1-16.

Goldsmith, C.
1983 Metacarpals as a Possible Data Source for Human Variation Studies. Unpublished paper. University of Tennessee Osteology Laboratory.

1984 Metacarpal Muscle Insertions: A System for Scoring and Interpretation. Unpublished paper. University of Tennessee Osteological Laboratory.

Goodman, A. H., J. Lallo, G. J. Armelagos, and J. C. Rose
1984 Health Changes at the Dickson Mounds, Illinois (A.D. 950-1300). In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 271-305.

Goodman, A. H., R. B. Thomas, A. C. Swedlund, and G. J. Armelagos
1988 Biocultural Perspectives on Stress in Prehistoric, Historical, and Contemporary Population Research. Yearbook of Physical Anthropology 31:169-202.

Gorman, C.
1971 Hoabhinian and After: Subsistence Patterns in Southeast Asia during the Late Pleistocene and Early Recent Periods. World Archeology 2:300-320.

Grant, J. C. B.
1951 An Atlas of Anatomy. Third Edition. Baltimore: Williams and Wilkins.

Grant, P. C., P. H. Buschang, D. W. Drolet, and C. Pickerel
1981 The Effect of Changes in Muscle Function and Bone Growth on Muscle Migration. American Journal of Physical Anthropology 54:547-553.

Gray, H.
1977 Anatomy. Revised American Edition. New York: Bounty.

Gray, J. P., and L. D. Wolfe
1980 Height and Sexual Dimorphism of Stature Among Human Societies. American Journal of Physical Anthropology 53:441-456.

Greulich, W. W.
1960 X-Ray Films of Hand and Wrist in Human Identification. Science 131:155-156.

Greulich, W. W., and S. I. Pyle
1959 Radiographic Atlas of Skeletal Development of the Hand and Wrist. Second Edition. Stanford, California: Stanford University Press.

Griffin, J. W.
1974 Investigations in Russell Cave. National Park Service Publications in Archeology 13. Washington: U.S. Department of the Interior.

Haas, J. D., and G. G. Harrison
1977 Nutritional Anthropology and Biological Adaptation. Annual Review of Anthropology 6:69-101.

Hall, C. L., D. S. Amick, W. B. Turner, and J. L. Hofman
1985 Columbia Archeological Project Archaic Period Radiocarbon Dates. In Exploring Tennessee Prehistory. T. Whyte, C. Boyd, and B. Riggs, eds. University of Tennessee Department of Anthropology Report of Investigations. Department of Anthropology. Knoxville: University of Tennessee, 42:61-79.

Hall, R.
1985 The Question of Size. In Male Female Differences. A Biocultural Perspective. R. Hall, P. Draper, M. E. Hamilton, D. McGuines, C. M. Otten, and E. A. Roth, eds. New York: Praeger, 127-153.

Hamilton, M. E.
1982 Sexual Dimorphism in Skeletal Samples. In Sexual Dimorphism in Homo Sapiens: A Question of Size. R. L. Hall, ed. New York: Praeger, 107-147.

Hamilton, W. J., ed.
1976 Textbook of Human Anatomy. Second Edition. St. Louis: C. V. Mosby.

Hancox, N. M.
1972 The Osteoclast. In The Biochemistry and Physiology of Bone. Second Edition. G. H. Bourne, ed. New York: Academic Press, Vol I:44-67.

Harris, H., and J. Joseph
1949 Variation in Extension of the Metacarpo-Phalangeal and Interphalangeal Joints of the Thumb. Journal of Bone and Joint Surgery 31B:547-559.

Hayes, M., and B. Say
1977 Hand Pattern Profile Analysis (HPPA): A New Diagnostic Tool. Clinical Pediatrics 16:988-991.

Higgins, K. F.
1982 The Ledbetter Landing Site: A Study of Late Archaic Mortuary Patterning. M. A. Thesis. Department of Anthropology. Knoxville: University of Tennessee.

Hill, M. W.
1948 The Atlatl or Throwing Stick. Tennessee Archaeologist IV:37-44.

Hinton, R. J.
1981 Temporomandibular Joint Size Adaptations in Prehistoric Tennessee Indians. Tennessee Anthropologist 6:89-111.

Hinton, R. J., M. O. Smith, and F. H. Smith
1980 Tooth Size Changes in Prehistoric Tennessee Indians. Human Biology 52:229-245.

Hofman, J. L.
1984 Radiocarbon Dates from Ervin: A Mid Holocene Shell Midden on the Duck River in Middle Tennessee. Tennessee Anthropologist 9:2-5.

Hollinshead, W. H., and D. B. Jenkins
1981 Functional Anatomy of the Limbs and Back. Fifth Edition. Philadelphia: W. B. Saunders.

Horsman, A., M. Simpson, and F. Armes
1981 A Left/Right Comparison of Sequential Bone Loss from the Metacarpals of Post Menopausal Women. American Journal of Physical Anthropology 54:457-460.

Howard, C. D.
1974 The Atlatl: Function and Performance. American Antiquity 39:102-104.

1976 Atlatl Function: A Reply to Butler. Plains Anthropologist 21:313-314.

Hudson, C. D.
1976 The Southeastern Indians. Knoxville: University of Tennessee Press.

Hurt, W. R.
1969 Seasonal Economic and Settlement Patterns of the Arikara. Plains Anthropologist 14:32-37.

Iscan, M. Y.
1988 Rise of Forensic Anthropology. Yearbook of Physical Anthropology 31:203-230.

James, D. F., I. P. Clark, J. C. Colwill, and A. P. Halsall
1982 Forces in the Metacarpophalangeal Joint Due to Elevated Fluid Pressure--Analysis, Measurements and Relevance to Ulnar Drift. Journal of Biomechanics 15:73-84.

Jantz, R. L.
1973 Microevolutionary Change in Arikara Crania: A Multivariate Analysis. American Journal of Physical Anthropology 38:15-26.

Jenkins, F. A., Jr., and J. G. Fleagle
1975 Knuckle-Walking and the Functional Anatomy of the Wrists in Living Apes. In Primate Functional Morphology and Evolution. R. H. Tuttle, ed. The Hague: Mouton Publishers, 213-227.

Joerschke, B. C.
1983 The Demography, Long Bone Growth, and Pathology of a Middle Archaic Skeletal Population from Middle Tennessee: The Anderson Site (40WM9). M.A. Thesis. Department of Anthropology. Knoxville: University of Tennessee.

Johnson, M. K., and M. J. Cohen
1975 The Hand Atlas. Springfield, Illinois: Charles C. Thomas.

Johnston, F. E.
1962 Approaches to the Study of Developmental Variability in Human Skeletal Populations. American Journal of Physical Anthropology 31:235-254.

Johnston, F. E., and C. E. Snow
1961 The Reassessment of the Age and Sex of the Indian Knoll Skeletal Population: Demographic and Methodological Aspects. American Journal of Physical Anthropology 19:237-244.

Jurmain, R. D.
1977 Stress and the Etiology of Osteoarthritis. American Journal of Physical Anthropology 46:353-366.

1980 The Pattern of Involvement of Appendicular Degenerative Joint Disease. American Journal of Physical Anthropology 53:143-150.

Kaplan, B. A.
1954 Environment and Human Plasticity. American Anthropologist 56:780-800.

Kaplan, E. B.
1965 Functional and Surgical Anatomy of the Hand. Second Edition. Philadelphia: J. B. Lippincott.

Katz, S. H., M. L. Hediger, and L. A. Valleroy
1974 Traditional Maize Processing Techniques in the New World. Science 184:765-773.

Kelley, D. L.
1971 Kinesiology: Fundmanetals of Motion Description. Englewood Cliffs, N. J.: Prentice Hall.

Kelley, M. A.
1980 Disease and Environment: A Comparative Analysis of Three Early American Indian Skeletal Collections. Dissertation Abstracts International 41:1678-A.

Kimura, K.
1983 Skeletal Maturity and Bone Growth in Twins. American Journal of Physical Anthropology 60:491-197.

Klippel, W. E., and W. M. Bass
1984 Averbuch: A Late Mississippian Manifestaion in the Nashville Basin. Vol. I. Department of Anthropology. Knoxville: University of Tennessee.

Koebke, J.
1983 A Biomechanical and Morphological Analysis of Human Hand Joints. Berlin: Springer Verlag.

Krogman, W. M., and M. Y. Iscan
1986 The Human Skeleton in Forensic Medicine. Second Edition. Springfield, Illinois: Charles C. Thomas.

Lallo, J., G. J. Armelagos, and J. C. Rose
1978 Paleoepidemiology of Infectious Disease in the Dickson Mounds Population. Medical College of Virginia Quarterly 14:17-23.

Landsmeer, J. M. F.
1979 An Introduction to the Functional Analysis of the Fingers and the Hand. In Tendon Surgery of the Hand. C. Verdan, ed. Edinburgh: Churchill Livingstone, 25-32.

Lanyon, L. E., and D. G. Baggott
1976 Mechanical Function as an Influence on the Structure and Form of Bone. Journal of Bone and Joint Surgery 58B:436-443.

Lanyon, L. E., and C. T. Rubin
1984 Static vs. Dynamic Loads as an Influence on Bone Remodelling. Journal of Biomechanics 17:897-905.

Larsen, C. S.
1980 Prehistoric Human Biological Adaptation: A Case Study from the Georgia Coast. Ph.D. Dissertation. Department of Anthropology. University of Michigan.

1981 Functional Implications of Postcranial Size Reduction on the Prehistoric Georgia Coast, U.S.A. Journal of Human Evolution 10:489-502.

1984 Health and Disease in Prehistoric Georgia: The Transition to Agriculture. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 367-392.

Leakey, L. S. B., P. B. Tobias, and J. R. Napier
1964 A New Species of the Genus Homo from Olduvai Gorge. Nature 202:7-9.

Lehmer, D. J., and D. T. Jones
1968 Arikara Archeology: The Bad River Phase. Smithsonian Institution, River Basin Surveys. Publications in Salvage Archeology 7.

Lewis, T. M. N., and M. Kneberg
1947 The Archaic Horizon in Western Tennessee. Record Extension Series 23(4). Tennessee Anthropology Papers 2. Knoxville: University of Tennessee.

1958 Tribes That Slumber. Knoxville: University of Tennessee Press.

1959 The Archaic Culture in the Middle South. American Antiquity 25:161-183.

Lewis, T. M. N., and M. K. Lewis
1961 Eva: An Archaic Site. Knoxville: University of Tennessee Press.

Levine, E.
1972 Notches in the Non-epiphyseal Ends of the Metacarpals and Phalanges in Children of Four South African Populations. American Journal of Physical Anthropology 36:407-415.

Lidberg, G.
n.d. 9BN25--Ledbetter Field Report. Unpublished manuscript on file at Frank M. McClung Museum. Knoxville: University of Tennessee.

Long, C. H.
1968 Intrinsic-Extrinsic Muscle Control of the Fingers. Journal of Bone and Joint Surgery 50A:973-984.

Long, C. H., P. W. Conrad, E. A. Hall, and S. L. Furler
1970 Intrinsic-Extrinsic Muscle Control of the Hand in Power Grip and Precision Handling. Journal of Bone and Joint Surgery 52A:853-867.

Lovejoy, C. O., A. H. Burstein, and K. G. Heiple
1976 The Biomechanical Analysis of Bone Strength: A Method and Its Application to Platycnemia. American Journal of Physical Anthropology 44:489-506.

MacConaill, M. A., and J. V. Basmajian
1977 Muscles and Movements: A Basis for Human Kinesiology. Second Edition. Huntington, New York: Robert E. Krieger.

MacNeish, R. S.
1967 The Prehistory of the Tehuacan Valley. Austin: University of Texas.

Magennis, A. L.
1977 Middle and Late Archaic Mortuary Patterning: An Example from the Western Tennessee Valley. M.A. Thesis. Department of Anthropology. Knoxville: University of Tennessee.

Malik, S. L., and S. Nath
1980 Relationship of Grip Strength to Body Measurements and Age Among Punjabis of Delhi. Archeology and Physical Anthropology in Oceania 15:73-78.

Martin, R. B., and D. B. Burr
1982 A Hypothetical Mechanism for the Stimulation of Osteonal Remodelling by Fatigue Damage. Journal of Biomechanics 15:137-139.

Marzke, M. W.
1971 Origin of the Human Hand. American Journal of Physical Anthropology 34:61-84.

1983 Joint Functions and Grips of the Australopithecus afarensis Hand, with Special Reference to the Region of the Capitate. Journal of Human Evolution 12:197-211.

Marzke, M. W., and M. S. Shackley
1986 Hominid Hand Use in the Pliocene and Pleistocene: Evidence from Experimental Archeology and Comparative Morphology. Journal of Human Evolution 15:429-460.

Masters, C.
1988 Dental Pathologies and Attrition as Indicators of Subsistence on the Eastern Great Plains. Unpublished paper delivered at the 46th Plains Conference, Wichita, Kansas.

McCart, D. J.
1979 Arthritic and Allied Conditions. Ninth Edition. Philadelphia: Lea and Febiger.

Merbs, C. F.
1983 Patterns of Activity-Induced Pathology in a Canadian Inuit Population. Mercury Series, Archeological Survey of Canada 119. Ottawa: National Museums of Canada.

Merchant, V. L., and D. H. Ubelaker
1977 Skeletal Growth of the Protohistoric Arikara. American Journal of Physical Anthropology 46:61-72.

Moerman, M. L.
1981 Proportions of the Second Metacarpal in Normal Versus Growth-Impaired Children. Human Biology 53:599-615.

Morgan, L. H.
1877 Ancient Society, or Researches in the Line of Human Progress from Savagery, Through Barbarism to Civilization. New York.

Moseley, H. F.
1955 An Atlas of Musculoskeletal Exposures. Philadelphia: J. B. Lippincott.

Murdock, G. P.
1967 Ethnographic Atlas. Pittsburgh: University of Pittsburgh Press.

Musgrave, J. H.
1971 How Dextrous Was Neanderthal Man? Nature 233:538-541.

Musgrave, J. H., and N. K. Harneja
1978 The Estimation of Adult Stature from Metacarpal Bone Length. American Journal of Physical Anthropology 48:113-120.

Napier, J. R.
1955 The Form and Function of the Carpo-Metacarpal Joint of the Thumb. Journal of Anatomy 89:362-369.

1956 The Prehensile Movements of the Human Hand. Journal of Bone and Joint Surgery 38B:902-913.

1962a The Evolution of the Hand. Scientific American 207:56-62.

1962b Fossil Hand Bones from Olduvai Gorge. Nature 196:409-411.

1976 The Human Hand. Carolina Biology Readers 61. Burlington, North Carolina: Carolina Biological Supply Company.

Nathan, P. H., and A. Fowler
1976 Remodelling of a Metacarpal Bone Graft in a Child. Journal of Bone and Joint Surgery 58A:719-721.

Netting, R. McC.
1977 Cultural Ecology. Menlo Park, California: Cummings.

Newman, M. T.
1960 Adaptations in the Physique of American Aborigines to Nutritional Factors. Human Biology 32:288-313.

Newman, R. W., and E. H. Munro
1955 The Relation of Climate and Body Size in U. S. Males. American Journal of Physical Anthropology 13:1-15.

Nickens, P. R.
1976 Stature Reduction as an Adaptive Response to Food Production in Mesoamerica. Journal of Archeological Science 3:31-41.

Ortner, D. J.
1968 Description and Classification of Degenerative Bone Changes in the Distal Joint Surfaces of the Humerus. American Journal of Physical Anthropology 28:139-156.

Ortner, D. J., and W. G. J. Putschar
1981 Identification of Pathological Conditions in Human Skeletal Remains. Smithsonian Contributions to Anthropology 28. Washington: Smithsonian Institution.

Owsley, D. W., and W. M. Bass
1979 A Demographic Analysis of Skeletons from the Larson Site (39WW2) Walworth County, South Dakota: Vital Statistics. American Journal of Physical Anthropology 51:145-154.

Palkovich, A.
1984 Agriculture, Marginal Environments, and Nutritional Stress in the Prehistoric Southwest. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelegos, eds. New York: Academic Press, 425-438.

Park, E.
1977 Radiological Anthropometry of the Hand in Turner's Syndrome. American Journal of Physical Anthropology 46:463-470.

Parmalee, P. W.
1986 Personal communication July 31, 1986. Frank H. McClung Museum. Knoxville: University of Tennessee.

Parmalee, P. W., and W. E. Klippel
1974 Freshwater Mussels as a Prehistoric Food Resource. American Antiquity 39:421-434.

Patterson, L. W.
1977 Atlatl Function: Comments on Howard's Views. Plains Anthropologist 22:159-160.

Perzigian, A. J. and P. A. Tench, and D. J. Braun
1984 Prehistoric Health in the Ohio River Valley. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 347-366.

Pfeiffer, S.
1980 Age Changes in the External Dimensions of Adult Bone. American Journal of Physical Anthropology 52:529-532.

Phenice, T. W.
1969 A Newly Developed Visual Method of Sexing the Os Pubis. American Journal of Physical Anthropology 30:297-302.

Pickering, R. B.
1979 Hunter-Gather/Agriculturalist Arthritic Patterns: A Preliminary Investigation. Henry Ford Hospital Medical Journal 27:50-53.

Pierce, L.
1987 A Comparison of the Patterns of Involvement of Degenerative Joint Disease Between an Agricultural and Non-agricultural Skeletal Series. Ph.D. Dissertation. Department of Anthropology. Knoxville: University of Tennessee.

Plagenhoef, S.
1971 Patterns of Human Motion: A Cinematographic Analysis. Englewood Cliffs, New Jersey: Prentice-Hall.

Plato, C. C., and A. H. Norris
1980 Bone Measurements of the Second Metacarpal and Grip Strength. Human Biology 52:131-149.

Plato, C. C., J. Wood, and A. H. Norris
1980 Bilateral Asymmetry in Bone Measurements of the Hand and Lateral Hand Dominance. American Journal of Physical Anthropology 52:27-32.

Plato., C. C., R. M. Garruto, R. T. Yanagihara, K. M. Chen, J. L. Wood, D. C. Gajdusek, and A. H. Norris
1982 Cortical Bone Loss and Measurements of Second Metacarpal Bone. I. Comparisons Between Adult Guamanian Chamorros and American Caucasians. American Journal of Physical Anthropology 59:461-465.

Poland, J. L., P. J. Hobart, O. D. Payton, and C. L. Fairchild
1977 The Musculoskeletal System. Flushing, New York: Medical Examination Publishing Company, Inc.

Pritchard, J. J.
1972a General Histology of Bone. In The Biochemistry and Physiology of Bone. Second Edition. G. H. Bourne, ed. New York: Academic Press, Vol I:1-20.

1972b The Osteoblast. In The Biochemistry and Physiology of Bone. Second Edition. G. H. Bourne, ed. New York: Academic Press, Vol I:21-43.

1979 Bones. Second Edition. J. J. Head, ed. Burlington, North Carolina: Carolina Biological Supply.

Prives, M. G.
1960 Influence of Labor and Sport upon Skeleton Structure in Man. Anatomical Record 136:261.

Reed, A.
1978 Archaeological Excavation at the Averbuch Site: A Mississippian Occupation in the Nashville Basin. Tennessee Anthropological Association Newsletter 3:1-7.

Reidhead, V. A.
1980 The Economies of Subsistence Change: Test of an Optimization Model. In Modeling Change in Prehistoric Subsistence Economies. T. Earle and A. Christenson, eds. New York: Academic Press, 141-150.

Ricklan, D. E.
1987 Functional Anatomy of the Hand of Australopithecus africanus. Journal of Human Evolution 16:643-664.

Robbins, D. M., K. R. Rosenberg, and C. B. Ruff
1989 Activity Patterns in Late Middle Woodland, Delaware. American Journal of Physical Anthropology 78:290.

Robbins, L. M.
1977 The Story of Life Revealed by the Dead. In Biocultural Adaptation in Prehistoric America. R. L. Blakely, ed. Southern Anthropological Society Proceedings 11. Athens: University of Georgia Press, 10-25.

Roberts, D. F.
1953 Body Weight, Race and Climate. American Journal of Physical Anthropology 11:531-555.

Robertson, W.
1812 The History of America. Philadelphia.

Roche, A. F.
1976 Skeletal Maturity of Youth 12 to 17 Years. Department of Health, Education and Welfare Publications No. (HDA) 77-1642. U. S. Department of Health, Education and Welfare. Rockville, Maryland.

Roche, A. F., and R. F. Herman
1970 Associations Between the Rates of Elongation of the Short Bones of the Hand. American Journal of Physical Anthropology 32:83-88.

Rogers, J., and T. Waldron
1989 The Enthesis in Paleopathology. American Journal of Physical Anthropology 78:292.

Romanes, G. J.
1964 Cunningham's Textbook of Anatomy. Tenth Edition. London: Oxford University Press.

Romanoski, S. M.
1984 Analysis of the Faunal Remains from the Averbuch Site. In Averbuch: A Late Mississippian Manifestation in the Nashville Basin. W. E. Klippel and W. M. Bass, eds. Department of Anthropology. Knoxville: University of Tennessee, I.13.1-I.13.27.

Roosevelt, A. C.
1984 Population, Health, and the Evolution of Subsistence: Conclusions from the Conference. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 559-583.

Rose, J.C., B. A. Burnett, M. S. Nassaney, and M. W. Blaeuer
1984 Paleopathology and the Origins of Maize Agriculture in the Lower Mississippi Valley and Caddoan Culture Areas. In Paleopathology at the Origins of Agriculture. M. N. Cohen and G. J. Armelagos, eds. New York: Academic Press, 393-424.

Ruff, C. B.
1988 Skeletal Response of Aged Beagles to Increased Physical Exercise. American Journal of Physical Anthropology 75:264.

Ruff, C. B., and H. H. Jones
1981 Bilateral Asymmetry in Cortical Bone of the Humerus and Tibia--Sex and Age Factors. Human Biology 53:69-86.

Ruff, C. B., and W. C. Hayes
1983a Cross Sectional Geometry of Pecos Pueblo Femora and Tibiae--A Biomechanical Investigation: I. Method and General Patterns of Variation. American Journal of Physical Anthropology 60:359-381.

1983b Cross Sectional Geometry of Pecos Pueblo Femora and Tibia--A Biomechanical Investigation: II. Sex, Age, and Side Differences. American Journal of Physical Anthropology 60:383-400.

Ruff, C. B., and C. S. Larsen
1983 Changes in Femoral Structure with the Transition to Agriculture on the Georgia Coast. American Journal of Physical Anthropology 60:248.

Ruff, C. B., C. S. Larsen, and W. C. Hayes
1984 Structural Changes in the Femur with the Transition to Agriculture on the Georgia Coast. American Journal of Physical Anthropology 64:125-136.

Sahlins, M., and E. Service, eds.
1968 Evolution and Culture. Ann Arbor: University of Michigan Press.

Salter, R. B.
1983 Textbook of Disorders and Injuries of the Musculoskeletal System. Second Edition. Baltimore: Williams and Wilkins.

Sauer, C. O.
1952 Agricultural Origins and Dispersals. New York: American Geographic Society.

Schade, J. P.
1970 Introduction to Functional Human Anatomy. Philadelphia: W. B. Saunders.

Schaffler, M. B.
1988 Morphometric Analysis of Bone Structural Changes with Experimentally Altered Mechanical Loading. American Journal of Physical Anthropology 75:266.

Schoeninger, M. J.
1982 Diet and the Evolution of Modern Human Form in the Middle East. American Journal of Physical Anthropology 58:37-52.

Service, E.
1972 Primitive Social Organization. New York: Random House.

Shipman, P., A. Walker, and D. Bichell
1985 The Human Skeleton. Cambridge: Harvard University Press.

Singh, I.
1959 Variations in the Metacarpal Bones. Journal of Anatomy 93:262-267.

1979a Bilateral Asymmetry in Length and Weight of Metacarpal Bones. Journal of Anatomical Society India 28:22-24.

1979b Torsion in Metacarpal Bones and Bilateral Asymmetry. Journal of Anatomy 129:343-349.

Smith, B. D.
1986 The Archeology of the Southeastern United States: From Dalton to DeSoto, 10,500-500 B.P. In Advances in World Archeology. Vol. 5. F. Wendorf and A. E. Close, eds. New York: Academic Press, 1-64.

Smith, E. L.
1971 Bone Mineral Mass in Aged Women: Normals and Osteoporotics. Ph.D. Dissertation. University of Wisconsin. Dissertation Abstracts 4405-A.

Smith, M. O.
1982 Patterns of Association Between Oral Health Status and Subsistence: A Study of Aboriginal Skeletal Populations from the Tennessee Valley Area. Ph.D. Dissertation. Department of Anthropology. Knoxville: University of Tennessee.

Smith, P., R. A. Bloom, and J. Berkowitz
1983 Bone Morphology and Biomechanical Efficiency in Fossil Hominids. Current Anthropology 24:662-663.

Snow, C. E.
1948 Indian Knoll Skeletons of Site OH2, Ohio County, Kentucky, University of Kentucky Department of Anthropology and Archeology Reports IV(3), Part ii. Lexington: University of Kentucky.

Spicer, E. H., ed.
1962 Cycles of Conquest. Tucson: University of Arizona Press.

Srinivasan, H.
1979 Movement Pattern of Interosseous-Minus Fingers. Journal of Bone and Joint Surgery 61A:557-561.

Steward, J. H.
1955 Theory of Culture Change. Urbana: University of Illinois Press.

Stewart, T. D.
1962 Comments on the Reassessment of the Indian Knoll Skeletons. American Journal of Physical Anthropology 20:143-147.

Stout, S. D.
1978 Histological Structure and Its Preservation in Ancient Bone. Current Anthropology 19:601-603.

Sundick, R. I.
1978 Human Skeletal Growth and Age Determination. Homo 29:228-249.

Susman, R. L.
1979 Comparative and Functional Morphology of Hominoid Fingers. American Journal of Physical Anthropology 50:215-236.

1988 Hand of Paranthropus robustus From Member 1, Swartkrans: Fossil Evidence for Tool Behavior. Science 240:781-784.

Susman, R. L., and J. T. Stern, Jr.
1979 Telemetered Electromyography of Flexor Digitorum Profundus and Flexor Digitorum Superficialis in Pan troglodytes and Implications for Interpretation of the O.H. 7 Hand. American Journal of Physical Anthropology 50:565-574.

Susman, R. L., and N. Creel
1979 Functional Morphological Affinities of the Subadult Hand (O. H. 7) from Olduvai Gorge. American Journal of Physical Anthropology 51:311-332.

Swanton, J. R.
1931 Source Material for the Social and Ceremonial Life of the Choctaw Indians. Washington: Smithsonian Institution Bureau of American Ethnology Bulletin 103.

Symes, S. A.
1982 Sex Assessment of the Tibia by Discriminant Function Analysis. Unpublished paper. Department of Anthropology. Knoxville: University of Tennessee.

Takai, S.
1977 Principal Component Analysis of the Elongation of Metacarpal and Phalangeal Bones. American Journal of Physical Anthropology 47:301-304.

Tanner, J. M., R. H. Whitehouse, W. A. Marshall, M. J. R. Healy, and H. Goldstein
1975 Assessment of Skeletal Maturity and Prediction of Adult Height (TW2 Method). New York: Academic Press.

Thompson, C. W.
1965 Kranz Manual of Kinesiology. Fifth Edition. St. Louis: C. V. Mosby.

Trinkaus, E.
1983 The Shanidar Neanderthals. New York: Academic Press.

Turnbull, C.
1972 The Mountain People. New York: Simon and Schuster.

Turner, C. G.
1979 Dental Anthropological Indications of Agriculture Among the Jamon People of Japan. American Journal of Physical Anthropology 51:619-636.

Ubelaker, D. H.
1974 Reconstruction of Demographic Profiles from Ossuary Skeletal Samples. Washington: Smithsonian Institution Press.

1978 Human Skeletal Remains. Washington: Taraxacum.

1982 The Development of American Paleopathology. In A History of American Physical Anthropology 1930-1980. F. Spencer, ed. New York: Academic Press, 337-356.

Ucko, P. J., and G. W. Dimbleby, eds.
1969 The Domestication and Exploitation of Plants and Animals. Chicago: Aldine.

Van Horn, R. N.
1972 Structural Adaptations to Climbing in the Gibbon Hand. American Anthropologist 74:326-334.

Verdan, C.
1979a An Introduction to Tendon Surgery. In Tendon Surgery of the Hand. C. Verdan, ed. Edinburgh: Churchill Livingstone, 1-3.

1979b Spontaneous Tendon Ruptures at the Wrist in Rheumatoid Arthritis. In Tendon Surgery of the Hand. C. Verdan, ed. Edinburgh: Churchill Livingstone, 154-161.

Walthall, J. A.
1980 Prehistoric Indians of the Southeast. University, Alabama: University of Alabama Press.

Warfel, J. H.
1974 The Extremities. Fourth Edition. Philadelphia: Lea and Febiger.

Washburn, S. L.
1972 Tools and Human Evolution. In Biology and Culture in Modern Perspective. San Francisco: W. H. Freeman, 143-155.

Watson, P. J.
1969 The Prehistory of Salts Cave, Kentucky. Illinois State Museum Reports of Investigations 16. Springfield: State of Illinois.

Webb, W. S.
1946 Indian Knoll. University of Kentucky Department of Anthropology and Archeology Reports IV(3), Part 1.

1981 The Development of the Spearthrower. University of Kentucky Occasional Papers in Anthropology No. 2. Lexington: University of Kentucky.

Webb, W. S., and D. L. DeJarnette
1942 An Archeological Survey of Pickwick Basin in the Adjacent Portions of the States of Alabama, Mississippi and Tennessee. Washington: United States Government Printing Office.

Wedel, W. R.
1955 Archeological Materials from the Vicinity of Mobridge, South Dakota. Anthropological Papers 45. Bureau of American Ethnology Bulletin 157:69-188. Washington.

White, L.
1959 The Evolution of Culture. New York: McGraw Hill.

Will, G. F., and G. E. Hyde
1967 Corn Among the Indians of the Upper Missouri. Lincoln: University of Nebraska Press

Williams, M. W., and H. R. Lissner
1962 Biomechanics of Human Motion. Philadelphia: W. B. Saunders.

Williams, S. C., ed.
1930 Adair's History of the American Indians. Johnson City, Tennessee: Watauga Press.

Winckler, G.
1979 Normal Anatomy of the Flexor and Extensor Tendons of the Hand. In Tendon Surgery of the Hand. C. Verdan, ed. Edinburgh: Churchill Livingstone, 7-12.

Wolfe, L. D., and J. P. Gray
1982 Subsistence Practices and Human Sexual Dimorphism of Stature. Journal of Human Evolution 11:575-580.

Woo, S. L.-Y., S. C. Kuei, D. Amiel, M. A. Gomez, W. C. Hayes, F. C. White, and W. H. Akeson
1981 The Effect of Prolonged Physical Training on the Properties of Long Bone: A Study of Wolff's Law. The Journal of Bone and Joint Surgery 63A:780-787.

Yarbrough, C., R. Martorell, R. E. Klein, J. Himes, R. W. Malina, and J.-P. Habicht
1977 Stature and Age as Factors in the Growth of Second Metacarpal Cortical Bone in Moderately Malnourished Children. Annals of Human Biology 4:43-48.

APPENDICES

APPENDIX A

ABBREVIATIONS USED IN THIS STUDY

Bones

MC1 - Metacarpal one
MC2 - Metacarpal two
MC3 - Metacarpal three
MC4 - Metacarpal four
MC5 - Metacarpal five

Muscles and Their Insertions

OPX - Opponens Pollicis located on MC1
IK - First Dorsal Interosseous located on MC1
ERL - Extensor Carpi Radialis Longus located on MC2
FCR - Flexor Carpi Radialis located on MC2
E2B - Extensor Carpi Radialis Brevis located on MC2
E3B - Extensor Carpi Radialis Brevis located on MC3
ECU - Extensor Carpi Ulnaris located on MC5
ODM - Opponens Digiti Minimi located on MC5

Measures

LN - Length
WD - Width
HT - Height
ML - Medial/Lateral
DV - Dorsal/Volar

APPENDIX B

ADAPTIVE TRAITS

Key:

F=female; M=male; L=left; R=right; B=both; [1]=site number; 1=number of individuals.

1. First metacarpal

1-A: on the distal end, the radial/volar side of the articulation showed a buildup--a bone flap: [1] 2FL, 2MR; [2] 2MB; [3] 1FR, 8FB, 1ML, 10MB; [4] 2FL, 1FR, 3FB, 4MB; [5] 3LF, 5FB, 2LM, 2RM, 8BM; [6] 3FB, 1LM, 2RM, 5BM; [7] 1LF, 6FB, 3LM, 1RM, 1BM; [8] 1LF, 7BF, 4LM, 4RM, 7BM; [9] 1RM.

1-B: on the distal end, the ulnar/volar side of the articulation showed a buildup--a bone flap: [2] 1MB; [3] 1FB; [4] 1FB; [5] 1FR, 1ML, 1MR, 1MB; [6] 1FB; [7] 1FB; [8] 4FB, 2MB.

1-C: Flat tops on the distal end of the bone--the joint articulation was not curved, but flat: [3] 1FL, 1MR, 1MB; [4] 2MB; [5] 1FR, 2MB; [6] 1MR; [8] 2MR, 1MB; [9] 1FB, 1MR, 1MB.

1-D: A depression or dent on the center of the dorsal, distal portion, just before the articular surface of the MCP joint: [2] 1FL; [6] 1FB; [7] 1FL.

1-E: a depression or dent on the center of the volar surface distal portion, just before the articular surface of the MCP joint: [3] 2FR; [8] 1MR.

1-F: eburnation of the distal joint surface: [1] 1FL, 1FR; [2] 1MR; [5] 1FB, 2MR; [9] 1FR, 1MR.

1-G: Extended bone projection on medial and lateral sides of the distal end of the bone, like ears, ulnar: [3] 1FB; [7] 1FR; [8] 1FB. Both ulnar and radial: [7] 3ML, 1MR.

1-H: Extreme lumpy bony ring around the insertion of the IK muscle: [2] 1FR, 1ML, 1MR, 1MB; [4] 1FL, 1FR; [6] 1ML; [7] 1FL; [8] 2ML, 1MR, 4FR

1-I: Lumpy bone deposits along the insertion of the OPX on the radial side of MC1: [2] 2FL; [5] 2MR; [6] 1MR; [8] 1FB, 1MR, 3ML; [9] 1ML, 2MR, 1MB.

1-J: Extended shelf (half-moon shaped) of bone on the proximal volar extension (saddle): [5] 1FL, 1FB; [8] 1ML, 2MR; [9] 1FB, 1MB.

1-K: Extended shelf of bone on dorsal proximal extension: [1] 1FB.

1-L: Prong or ulnar extended hook on proximal ulnar end of bone: [3] 1FB; [5] 1FB; [9] 1ML.

1-M: No saddle contour on proximal but just rounded end at articulation: [1] 1FL; [8] 1ML.

1-N: Entire bone contoured: [1] 1FL; [3] 2FL, 2MR, 2MB; [5] 1FR, 1FB; [7] 2FR; [9] 4MR, 1ML, 1MB.

1-O: Arthritic deposits on proximal:

1-P: Healed fractures: [1] 1FL; [4] 2MR; [8] 2MR.

2. <u>Second metacarpal</u>

2-A: Pronounced ridge running proximal/distal on the dorsal shaft of bone--Crista Dorsalis (Musgrave, 1971).

2-B: Pronounced ridge on dorsal surface of shaft, but runs more diagonal, in the proximal 1/3 area, more distal on the ulnar side, proximal on the radial side. Sometimes double. It does not intersect with (2-A). This is not just a bumpy line, but the edge of a smooth, contoured area that seems to wrap around the ulnar side. First seen but not annotated in Three Mile; noted in all sites from Big Sandy on (four through nine): [3] 4FR, 6MR; [4] 1FR, 2MR, 1ML; [6] 2ML; [7] 4FR, 2FB, 4MR, 3ML; [8] 6FR, 3FL, 1FB, 9MR, 1ML, 3MB.

2-C: Distal head of entire bone twisted toward the radial side with an extra upbuilt layer of bone on the volar radial side--like a beak. Extreme forms also have extra bone on dorsal/ulnar portion of head. When viewed straight on, the distal end looks diamond shaped: [3] 1FB; [4] 1FR, 1FB; [9] 1MB.

2-D: Crest running the length of the volar side of shaft: [1] 1FR; [2] 1ML, 1MB; [3] 1FR, 1FB, 1ML; [5] 1FL, 3FB, 1MR.

2-E: Lumps of bone on ridge 2-B:

2-F: Hole on distal dorsal epiphyseal union line: [6] 1MR.

2-G: Hole in ERL: [3] 1FR; [4] 1FL, 3FR, 2MB; [6] 1FL; [7] 1FL, 1MR.

2-H: New bone layer on ERL: [8] 1FL; [9] 1MR.

2-I: Flat FCR: [3] 1MB; [4] 1FR, 1FB; [6] 1MB; [8] 2FL, 1FR, 1MR; [9] 1FB, 1ML, 1MB

2-J: Dent on ulnar side of FCR: [3] 2FR; [8] 1FL, 2FB.

2-K: Layered new bone on FCR: [1] 1MR; [2] 1MB; [3] 1FR, 1MR; [5] 2FL, 1FB, 2FR, 1ML, 1MR; [6] 1ML; [7] 1FR, 1ML; [8] 1FL, 1FR, 1ML, 1MR, 1MB; [9] 2FB, 3MR, 1MB.

2-L: Trench ulnar of E2B: [8] 1RF, 1RM.

2-M: Layered new bone on E2B: [5] 2FL, 1FR, 1ML, 5MR; [9] 1FL, 1FR.

2-N: Contoured MC2: [5] 1ML; [8] 2FR; [9] 1ML.

2-O: Expanded shelf on ulnar dorsal proximal: [6] 1FL; [7] 1ML; [8] 1FR, 2FB, 1MB.

2-P: Healed fracture: [2] 2MR

3. Third metacarpal

3-A: Volar crest: [2] 1MR; [5] 1FL, 2FB.

3-B: E3B runs diagonal of shaft rather than parallel to proximal/distal axis: [1] 1MR; [2] 3FR, 1MR; [4] 1FR, 1MR; [5] 7FR, 4MR; [6] 2FR; [7] 1ML; [8] 1FL, 1FB, 1MR.

3-C: Flat E3B: [2] 2MB; [4] 1MB; [6] 1ML.

3-D: New bone layer on E3B: [3] 1FB; [5] 1MR; [7] 1FR, 1ML; [8] 1MR, 1FB.

3-E: Extra lump on dorsal proximal of M3 but across from E3B on ulnar side: [6] 1FB.

3-F: Trench under E3B: [6] 1FR, 1MR.

3-G: Peculiar clover shaped proximal dorsal with dents on both sides: [3] 1FR, 1FB; [7] 1BF.

3-H: Enlarged head with volar bone "beard": [3] 2FL, 1FR.

3-I: Healed fracture: none.

(Great variation was noticed on both the length and width of the styloid process on the proximal radial end of this bone. Since function was unknown, it was not included in this study. Clarification of its

function is another area for future research. Marzke and Shackley found the MC3 styloid stabilizes the human hand during hammering, pounding, and grasping [Marzke and Shackley, 1986:451].)

4. Fourth metacarpal

4-A: Triangular bone insertion site on proximal radial side: [3] 3FB, 2MR, 3MB; [5] 1FR; [6] 1MR, 2ML; [7] 1FB; [8] 8FB, 2ML, 9MB; [9] 2MB.

4-B: Triangular bone insertion on proximal ulnar side: [6] 1MB; [9] 1FB.

4-C: Trauma: cut or gash on distal ulnar 4: [6] 2FR, 2MR.

4-D: Proximal/volar insertion: [3] 3FB, 6MB; [7] 3FR, 3FB, 1MR; [8] 1FB, 7MB; [9] 1MB.

4-E: Healed fracture: [4] 1ML; [5] 1MR.

5. Fifth metacarpal

5-A: Head twisted to the ulnar side, with beak: [4] 1FL, 1FB; [6] 1ML, 1MB; [8] 1ML, 2MR.

5-B: Broad, flat proximal fifth: [7] 1FR, 1FB, 1MR, 1MB.

5-C: Volar crest on MC5: [7] 1MB; [8] 1FR, 2MR; [9] 1ML.

5-D: Volar trench on MC5 (parallel crests): [3] 1FB; [7] 2FL, 4FR, 1ML, 4MR; [8] 3FL, 2FR, 1FB.

5-E: Insertion lump on proximal radial MC5: [3] 1FR; [5] 1ML; [7] 1MR; [8] 6BF, 4MR, 2ML, 5MB; [9] 1FR, 2FB, 9MB.

5-F: Diagonal ECU: [3] 1FR, 1ML; [4] 1FL, 1FR, 1ML, 2MR; [5] 1ML; [6] 2ML; [7] 1ML, 1MR, 1MB; [8] 2FL, 5FR, 1FB, 2ML, 5MR, 1MB; [9] 1ML.

5-G: Flat ECU: [2] 1ML; [3] 1FB; [4] 1FB, 1ML; [5] 1FR.

5-H: New bone layers on ECU: [4] 1FR; [8] 2FL, 1ML.

5-I: Bone lumps (deposit) on insertion line of ODM: [4] 1LF, 1FR, 2ML, 1MB; [5] 2FL, 2FR; [6] 3FL, 1MR; [8] 4ML, 2MR; [9] 5FL, 3FB, 8ML, 4MR, 4MB.

5-J: Contoured bone: [3] 1FL, 1FB; [8] 2FL, 3FB, 1MR; [9] 1ML, 1MB.

5-K: Healed fracture: [1] 1FR; [2] 2ML, 2MR; [3] 1MR; [4] 2ML; [5] 1ML; [7] 1ML; [9] 1FR.

Adaptive traits

Those traits noticed in this metacarpal study are listed by digit. Table 63 is a compilation by metacarpal and site with the numerical value representing the total percent of people from that site who had such things as fractures, extra bone deposits, peculiar torsion, layered entheses, etc. The "totals" in the table are the percentages compiled (sexes combined total 200%) to indicate where the greater action is represented on the bones.

By site, with the exception of Site Three, the incidences generally increase through time. Generally, the earlier sites show more damage (adaptation) on the radial bones; the later sites continue this but add ulnar traits as well. By metacarpal, the most events are registered on metacarpals in the order of: 1, 5, 2, 3, and 4. The medial, more protected bones show less damage; the peripheral, more active ones, the most.

TABLE 63

ADAPTIVE TRAITS BY SITE: SEXES COMBINED

Metacarpal	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Total
1	66%	47%	121%	62%	80%	66%	72%	53%	61%	588
2	16%	21%	71%	55%	48%	33%	66%	53%	44%	407
3	08%	30%	21%	11%	33%	25%	12%	10%	02%	152
4	00%	00%	60%	03%	04%	37%	24%	14%	11%	153
5	08%	13%	32%	59%	20%	41%	60%	91%	108%	432
Total:	98	111	305	190	185	202	232	221	226	
HEALED FRACTURES										
1	(1)	0	0	[2]	0	0	0	[2]	0	5
2	0	[2]	0	[1]	0	0	0	0	0	3
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	[1]	[1]	0	0	0	0	2
5	(1)	[2]	[1]	[1]	[1]	0	[1]	0	(1)	8
Total	2	4	1	5	2	0	1	2	1	18

Key: () = female
[] = male

Seventy traits were noted, with non-agriculturalists having more on the radial three metacarpals, the agriculturalists having the largest numbers on the two ulnar metacarpals.

Regarding healed fractures (Table 63), a similar pattern of damage prevails, with the metacarpal order being: 5, 1, 2, 4, 3--the most exposed peripheral metacarpals receiving the most damage. Of the 18 healed fractures noted, only three were in women's hands. The Site Four males had the highest fracture incidence.

Possible etiologies of adaptive traits

Some of the adaptive traits noted during data collection are interpreted here. (For definition and enumeration of conditions see beginning of Appendix B.)

<u>On the first metacarpal</u>

1-A: (Figure 48 [p.275]) The distal, radial, volar flap is formed when the tendon of Flexor Pollicis Brevis (FPB) and its accompanying sesamoid bone ride over the joint, on the way to its insertion in the proximal first phalanx. The muscle's action bends the thumb and pulls it toward the palm (Kaplan, 1965:195; Hollinshead and Jenkins, 1981:176). The bony flap (1-A) enlarges with persistent use of the Flexor as in the stretch of a pianist's thumb (Kaplan, 1965:242). In opposition, the FPB and Abductor Pollicis Brevis pull the thumb around toward the fifth digit (Kaplan, 1965:234). It is used most in fine pinch with digits two and three, whereas OPX is used with digits four and five and is the most important muscle in thumb power (Basmajian and DeLuca, 1985:301,303). FPB provides the power in holding a cup handle. The bigger the object, the less power FPB has. It is very important in gripping a dowel rod (Basmajian and DeLuca, 1985:304). It moves the stiff (extended) thumb against the tips of the second and third fingers. 1-A is seen on MC1 in all sites. The even paired extension of 1-A and 1-B is most common in Site Eight.

1-B: A portion of the FPB plus the Adductor Transverse Pollicis join and insert on the ulnar side of the first phalanx, with the sesamoid in the tendon passing over the ulnar flange on the distal end of MC1 (Hollinshead and Jenkins, 1981:176; Koebke, 1983:72). The action represented here is moving the thumb around and toward the end of fingers two and three (Gray, 1977:406). When the Adductor is added, power grip is indicated (Napier, 1956:908).

1-C: (Figure 47 [p.275]) When the articular surface of distal MC1 is flat rather than curved, flexion is limited from 90 degrees to 20 degrees--which would seem to be a disadvantage (Koebke, 1983:71). Sectional studies of the distal spongiosa of the bone show slow compression is the main stress during flexion (Koebke, 1983:72). Such flexion could possibly be the force that has flattened the distal surface of MC1. In a study of 230 male and female Europeans, 31 male Indians, and 30 Africans, many variations of the shape of this surface were found, with 10% having a flat surface (Harris and Joseph, 1949). This group was unable to hyper-extend the thumb, so the advantage of a flat distal surface might be protection against spraining the thumb, or stability in grasping large objects against stress.

1-D and 1-E: The dorsal and volar dents in the distal ends of MC1 represent attachment points for the metacarpo-phalyngeal joint capsule. 1-D would result from pulling the thumb into the palm (seen in Sites Two, Six and Seven) and 1-E from pulling the thumb way out for a large grip (seen in Sites Three and Eight).

1-G: The flared distal bone, radial and ulnar of MC1, represents the location of collateral ligaments--the straps that bind distal MC1 to its proximal first phalanx (Grant, 1959:sec.68). Enlargement represents a bony response to this part of the joint being strained. The ligament is shaped to relax for extension and contract for flexion (MacConaill and Basmajian, 1977:279). The flexed metacarpo-phalyngeal joint permits less abduction and adduction of the thumb than does the extended joint (Shipman et al., 1985:123). Evidence of repeated intense flexion

("ears") reveals limited fine precision action and increased gripping of an item toward the thumb, i.e. power grip.

1-J, 1-K, 1-L: (Figure 47 [p.275]) The carpal-metacarpal joint has been a principal focus of discussion of both evolution and function. Its form is unusual in that the two surfaces are not congruent; the curvature on the proximal MC1 is smaller than its companion on the greater multangular (Koebke, 1983:48). This permits the unusual shifting into different "gears" within the loose joint capsule, enabling the thumb to function in several planes, paraphrased as north/south (35-40 degrees), east/west (45-60 degrees) and round-and-round (Koebke, 1983:55). When extra strain is placed on this relatively free action, the bone responds with layers of support in the direction of the pull from the joint (Koebke, 1983:52). The observer, then, is confronted with bony shelves, hooks, ossified ligaments, and even repaired fractures on the proximal ends of the "saddle". Bennett's Fracture occurs when a piece of the "saddle" is broken but stays in place, the result of MC1 being pushed toward the elbow (Salter, 1983:483-484).

Second metacarpal

2-A: (Figure 49 [p.277]) The Crista Dorsalis is the line of bone that supports the origin of the First Dorsal Interosseous on the radial side and Second Dorsal Interosseous on the ulnar side of MC2. Hands using these muscles more have more prominent ridges.

2-B: This diagonal line marks the origin of First Palmar Interosseous, used to draw the index and middle fingers together. When the

muscle is frequently and intensely exercised, a larger, heavier marked area develops to support it (Susman, 1979:220).

2-C: (Figures 45 and 46 [p.273]) The second and third fingers are used in man for pinch grasping as opposed to the other primates where they may be used for weight bearing (Susman, 1979:79,215). It is the heads (distal ends) that are primarily adapted to human use. "The heads of both MC2 and 3 are characterized by axial torsion. This reflects the enhanced manipulatory role of the third finger in humans" (Susman, 1979:215).

The head is asymmetrical, with a bony beak toward the radial, volar side where the Ligamentum Palmare crosses the bone. This has nothing to do with the metacarpao-phalyngeal joint of the index, other than acting as a fulcrum for the passing of the tendon coming from the First Dorsal Interosseous (IK) to insert into the radial side of the proximal phalanx of the second digit (Kaplan, 1965:79-80; Koebke, 1983:57,65,69,74). The more the IK muscle works, the larger the bony beak to support the sesamoid bone in its tendon. Singh (1979b), however, noting radical "torsion" in the heads of MC2 and 3, and ulnar "torsion" in the heads of MC4 and 5 (5-A in this study's list of cultural adaptations), particularly the right hand, suggests it is to facilitate a more efficient grip by preventing crowding of the digits during flexion.

The new bone on the dorsal ulnar side of the "head" supports the tendon of the Extensor Indicis--specific to the index finger--that permits it to extend while fingers three, four, and five are flexed (Kaplan, 1965:68).

In short, the twisted, bony, beaked, radial, volar and bony-backed dorsal head of MC2 is testimony to considerable poking of the index and pinching with its thumb.

2-D: The volar crest reflects heavy use of the First Palmar Interosseous to pull flexed fingers two and three together.

2-G: The hole in the ERL enthesis is interpreted as evidence of an ancillary blood supply to an active muscle.

2-K: Layered bone on FCR probably reflects the same condition as layered bone on the other entheses, i.e. lack of activity of that muscle, to the point that the enthetical bone is partially resorbed. Once activity begins again, a new layer is formed. This could be interpreted as evidence of seasonal work, but the FCR shows this more often than the other entheses, sometimes as many as three and four layers. Another possible interpretation would be to see work of the FCR stopping because of damage to the tendon. This is a carefully protected tendon, entering the hand in its own sheath through the edge of the carpal tunnel (Winckler, 1979:7). The FCR, however, is innervated by the median nerve that passes through the carpal tunnel ("the traffic bottleneck in the wrist" [Moseley, 1955:100]), and is sometimes damaged by repetitive use of the finger flexors (also in that tunnel) with a frequency that does not allow for tendon recovery. The result is an inflamed, swollen package of organs in the tunnel, extreme pain, and an incapacitated hand (Shipman et al., 1985:113). The seeming maladaptation may be better considered as the natural result of turning a generalized organ into a specialized one. A layered FCR enthesis, then, may be evidence of carpal tunnel syndrome.

Third metacarpal

3-A: The volar crest is the transverse origin of the Adductor Pollicis.

3-B: A diagonal enthesis on E3B may represent extreme extension of the tendon toward the ulnar side of the hand. It was noted during data collection that in the Site Eight samples this enthesis was often located partially on the radial side of the bone, leaving a smaller portion on the dorsal surface (particularly in males--see Table 56 [p.153]). On the left side, this may represent more of an extension toward the radial side in support of the extended, stabilized bow wrist.

Fourth metacarpal

A possible explanation of changes seen on MC4 is found in work done by Susman (1979).

> The length and robusticity of the fourth metacarpal is substantially less than that of two and three. . . . In the human hand, metacarpals four and five form a functional unit that provides ancillay support in the precision grip and plays a more prominent supportive role in the power grip [emphasis added] (Susman, 1979:221).

4-A: The triangular bone deposit on the radial side of the proximal end of MC4 is the supporting area for the Second Palmar Interosseous used to draw the fourth and third fingers together. It has been traced as particularly active in tasks such as simple squeeze of a five centimeter dowel rod, lifing a hammer handle, clockwise rotation of

a screwdriver, and the spherical grip (Long et al., 1970:858). The Long et al. study on the interossei, done on the living with electronic sensors implanted in muscles, shows that the Second Palmar Interosseous is at its greatest effort when assisting in bending fingers (a) from all extended to metacarpal-phalangeal flexed, (b) from metacarpal-phalangeal flexed to only middle and distal phalanges flexed, (c) from all phalanges flexed to metacarpal-phalangeal flexed. Since this feature is prominent in Site Eight, it may have been used in working clay for pottery. One final use for the Second Palmar Interosseous may be to counter the pull of MC3 toward the radial side of the hand by the Adductor Pollicis.

4-D: Volar insertion may be for the Flexor Carpi Ulnaris (see p.187).

Fifth metacarpal

5-A: The ulnar, twisted, distal end supports a sesamoid in the Ligamentum Palmaris (Koebke, 1983:54).

5-E: The insertion site on the radial side of the proximal end of MC5 supports Third Palmar Interosseous that adducts the little finger (Hamilton, 1976:109). It also assists in flexing the proximal phalanx of the fifth digit with the second phalanx extended; it enhances opposition and works with the ODM (Kaplan, 1965:241). The same bony projection on the dorsal side supports the Fourth Dorsal Interosseous that has been read electromyographically as extremely active in clockwise motion of the flexed right hand (Landsmeer, 1979:31). This action des-

cribes holding a haft or handle tightly in the power grip. This bone deposit on MC5 is seen most prominently in the agricultural sites.

It is difficult to compare the incidence of occurance of adaptive traits between the agricultural and non-agricultural samples since there was no systematic collection of the data and no numerical control. As seen in Table 63 (p.246) and as seen in the listings of adaptive traits, there is a general increase from early to late sites, the later showing more ulnar adaptations.

APPENDIX C

PHOTOGRAPHS

Figure 26. Site One female (Eva) representative metacarpals, dorsal view. (Actual size)

Figure 27. Site One male (Eva) representative metacarpals, dorsal view. (Actual size)

Plate 6. Site One Metacarpals.

Figure 26.

Figure 27.

Figure 28. Site Two female (Three Mile) representative metacarpals, dorsal view. (Actual size)

Figure 29. Site Two male (Three Mile) representative metacarpals, dorsal view. (Actual size)

Plate 7. Site Two Metacarpals

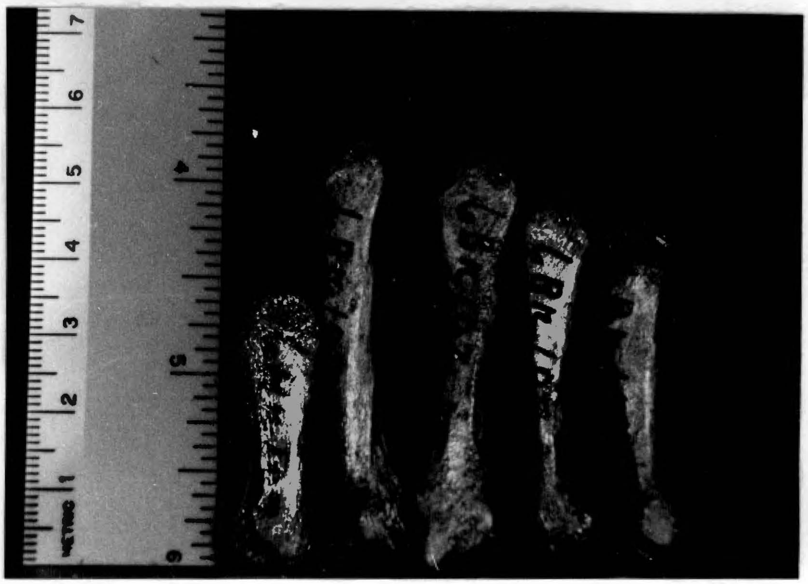


Figure 28.

Figure 29.

Figure 30. Site Six female (Cherry) representative metacarpals, dorsal view. (Actual size)

Figure 31. Site Six male (Cherry) representative metacarpals, dorsal view. (Actual size)

Plate 8. Site Six Metacarpals

Figure 30.

Figure 31.

Figure 32. Site Seven female (Ledbetter) representative metacarpals, dorsal view. (Actual size)

Figure 33. Site Seven male (Ledbetter) representative metacarpals, dorsal view. (Actual size)

Plate 9. Site Seven Metacarpals

Figure 32.

Figure 33.

Figure 34. Site Eight female (Averbuch) representative metacarpals, dorsal view. (Actual size)

Figure 35. Site Eight male (Averbuch) representative metacarpals, dorsal view. (Actual size)

Plate 10. Site Eight Metacarpals

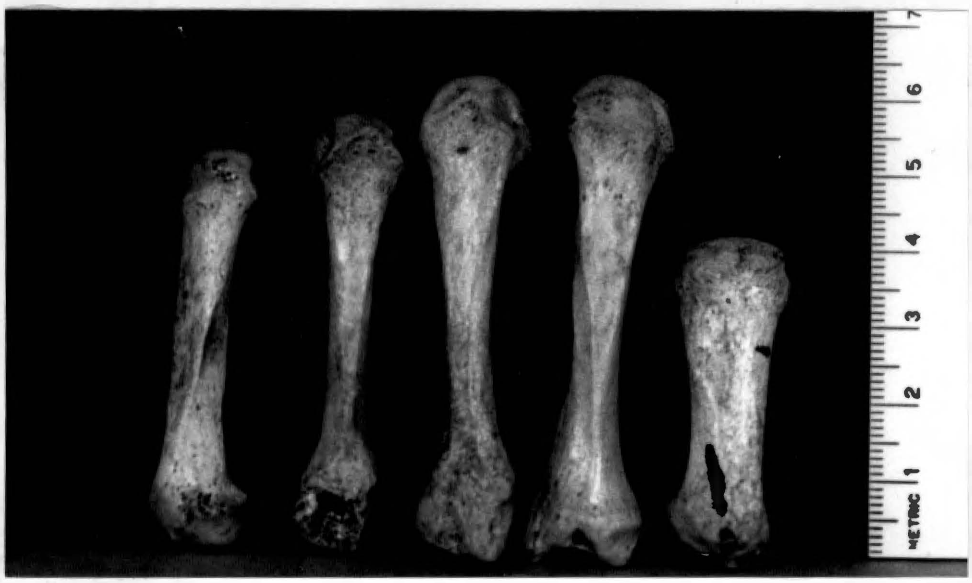


Figure 34.

Figure 35.

Figure 36. Site Nine female (Larson) representative metacarpals, dorsal view. (Actual size)

Figure 37. Site Nine male (Larson) representative metacarpals, dorsal view. (Actual size)

Plate 11. Site Nine Metacarpals

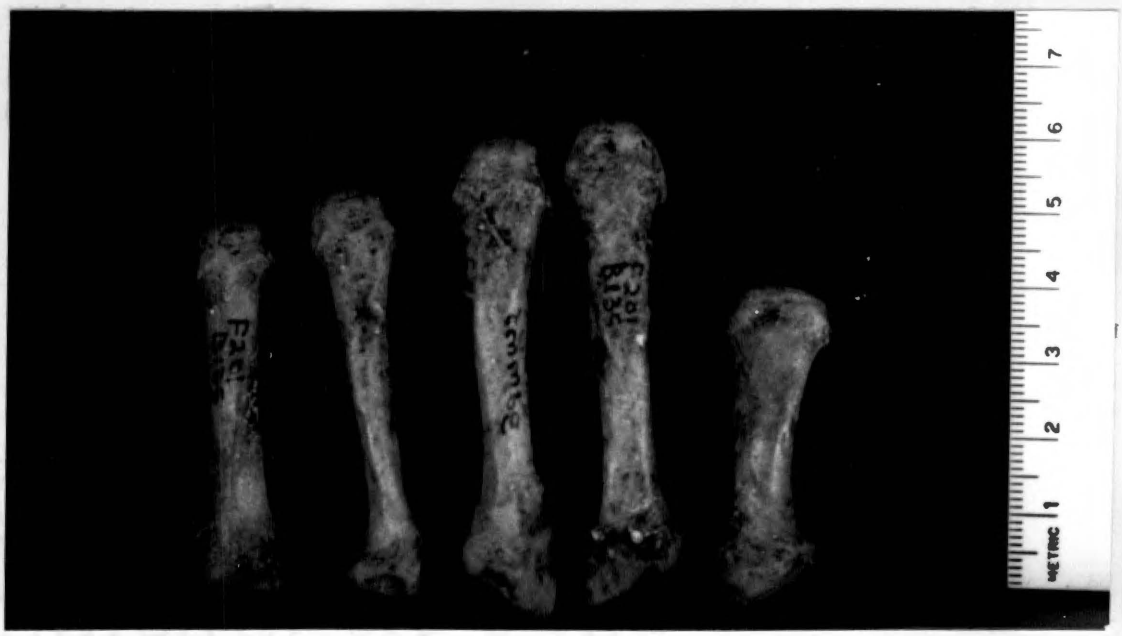


Figure 36.

Figure 37.

Figure 38. IK enthesis (First Dorsal Interosseous), left MC1, ulnar view. (Actual size)

Figure 39. ERL enthesis (Extensor Carpi Radialis Longus), left MC2, dorsal view. (Actual size)

Plate 12. IK and ERL Entheses

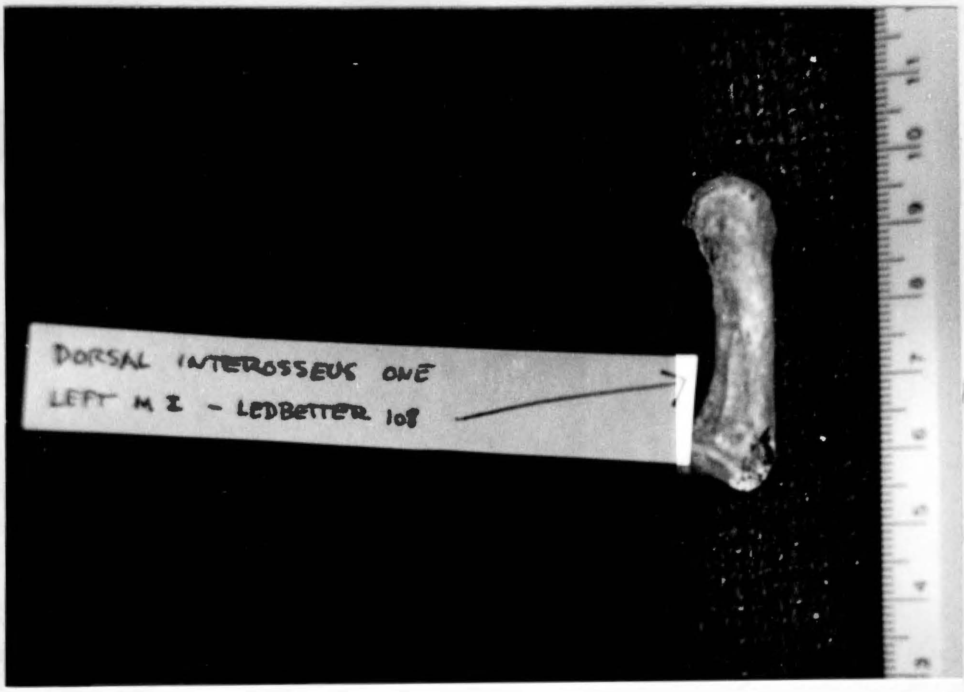


Figure 38.

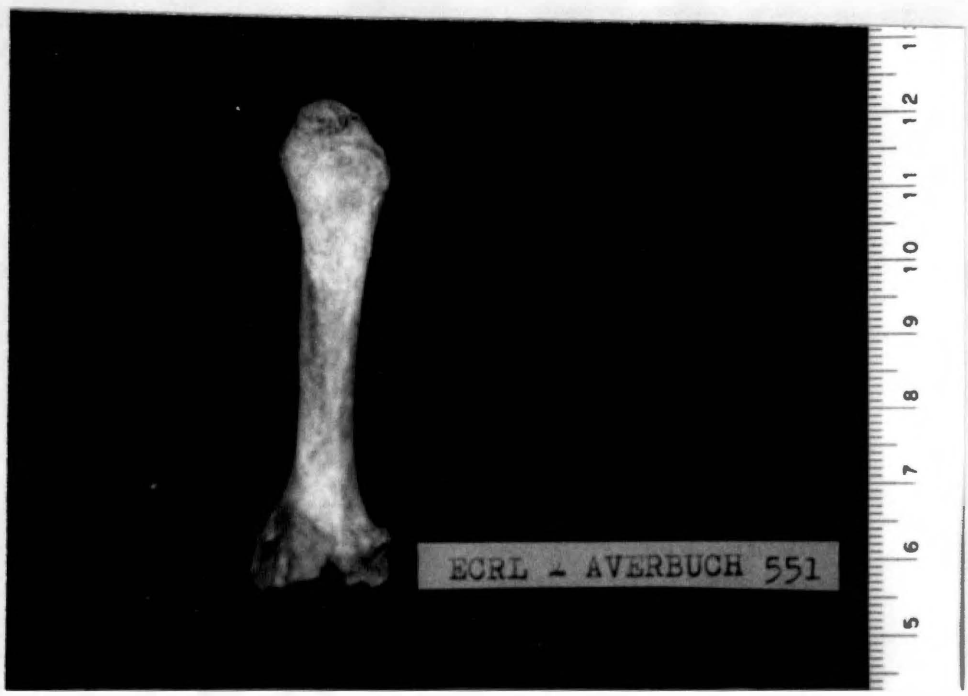


Figure 39.

Figure 40. FCR enthesis (Flexor Carpi Radialis), right MC2, volar view. (Actual size)

Figure 41. E3B (Extensor Carpi Radialis Brevis Three), left MC3, dorsal view. (Actual size)

Plate 13. FCR and E3B Entheses

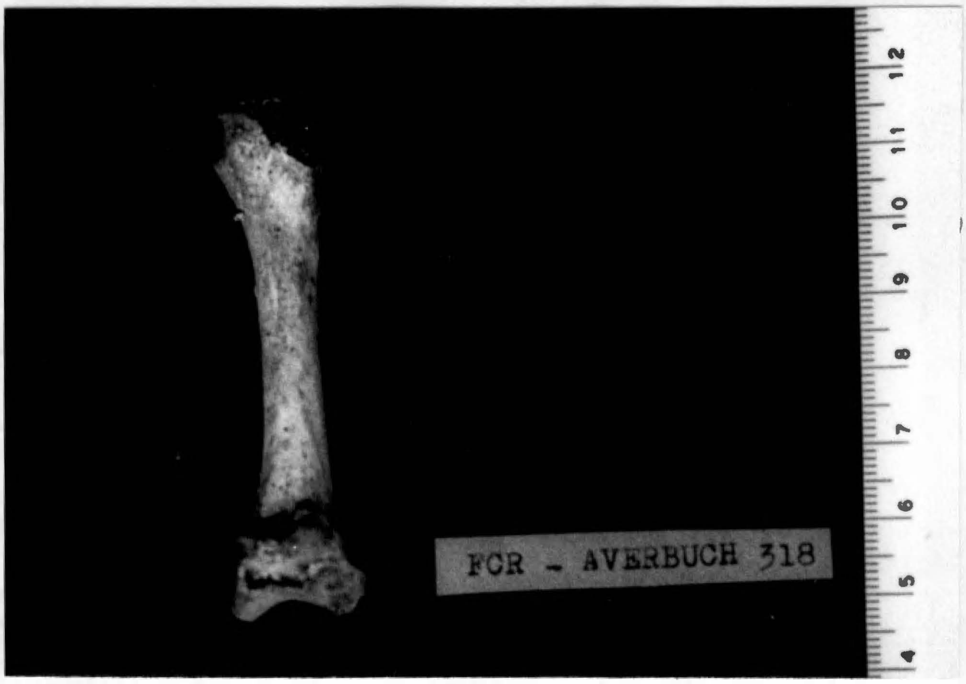


Figure 40.

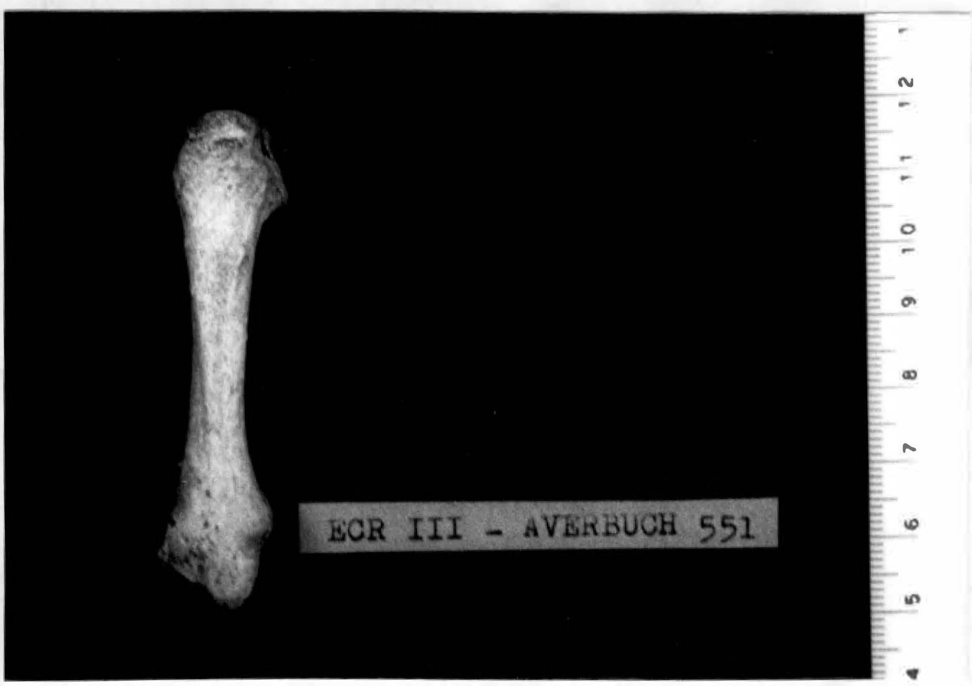


Figure 41.

Figure 42. ECU enthesis (Extensor Carpi Ulnaris), right MC5, dorsal view. (Actual size)

Figure 43. ODM enthesis (Opponens Digiti Minimi), right MC5, volar view, female. (Actual size)

Figure 44. ODM enthesis (Opponens Digiti Minimi), right MC5, volar view, male. (Actual size)

Plate 14. ECU and ODM Entheses

Figure 42.

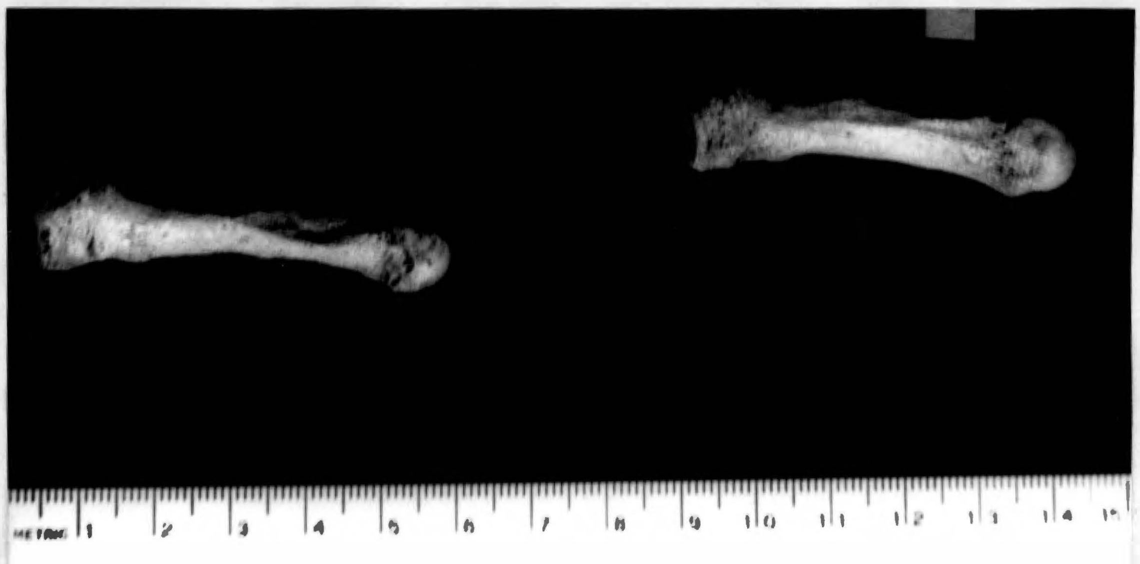


Figure 43. Figure 44.

Figure 45. Adaptive trait 2-C: bone beak on radial distal end, left MC2, radial view. (Actual size) (Note ERL on proximal radial surface.)

Figure 46. Adaptive trait 2-C: left MC2, volar view. (Actual size) (Note FCR on proximal volar surface.)

Plate 15. MC2 Adaptive Traits

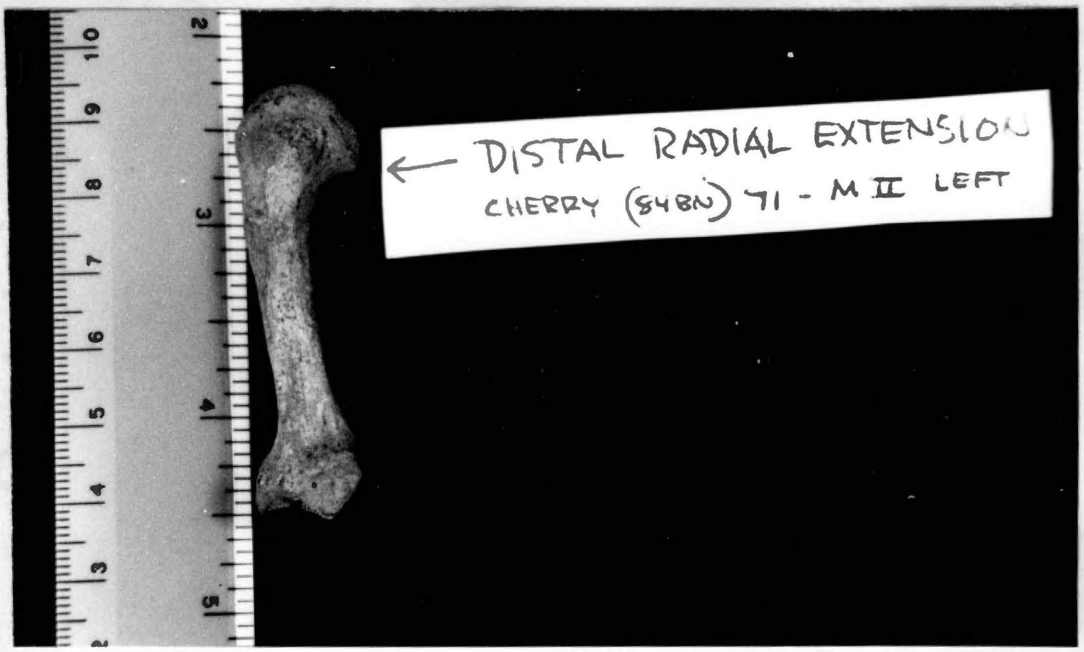


Figure 45.

Figure 46.

Figure 47. OPX enthesis (Opponens Pollicis) on MC1, radial view. (Actual size) (Note flat surface on distal end, adaptive trait 1-C; extended volar shelf on saddle, adaptive trait 1-J.)

Figure 48. Adaptive trait 1-A, radial distal bone extension, right MC1, radial view. (Actual size)

Plate 16. OPX Enthesis and MC1 Adaptive Traits

Figure 47.

Figure 48.

Figure 49. Adaptive trait 2-A, Crista Dorsalis. Right MC2, dorsal view. (Actual size) (Note hypertrophic E2B enthesis on proximal ulnar dorsal surface; very wide M-L area at mid-diaphyseal shaft.)

Plate 17. MC2 Crista Dorsalis

Figure 49.

VITA

Catherine M. Goldsmith was born in Ellsworth, Kansas on September 13, 1934. She graduated from Topeka High School in 1952 and the College of Emporia, Kansas in 1956 with a B.A. in Biology. She received the Master of Arts degree in Anthropology from the University of New Mexico in 1977, and entered the Ph.D. program in Anthropology at the University of Tennessee in 1982.

Additional studies were done at the American University of Beirut, the University of Chicago, the Spanish Language Institute, San Jose, Costa Rica, the University of Kansas, and Wichita State University.

She has taught at McPherson College, Tabor College, Hutchinson Community College, and Emporia State University.

She married Dale Goldsmith in 1959 and they have four children. They currently live in McPherson, Kansas where Dale is the Vice President for Academic Services at McPherson College and Catherine is a lecturer in Anthropology and Archeology.