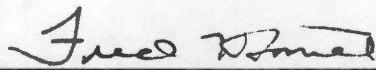


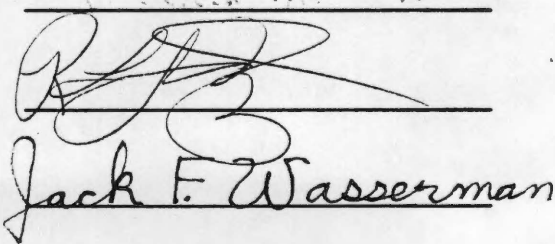
To The Graduate Council:

I am submitting herewith a dissertation written by Donna Catherine Markland Boyd entitled "A Functional Model For Masticatory-Related Mandibular, Dental, And Craniofacial Microevolutionary Change Derived From A Selected Southeastern Indian Skeletal Temporal Series." 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 Philosophy, with a major in Anthropology.



Fred H. Smith, Major Professor

We have read this dissertation
and recommend its acceptance:



Accepted for the Council:

Vice Provost
and Dean of The Graduate School

A FUNCTIONAL MODEL FOR MASTICATORY-RELATED MANDIBULAR,
DENTAL, AND CRANIOFACIAL MICROEVOLUTIONARY CHANGE
DERIVED FROM A SELECTED SOUTHEASTERN INDIAN
SKELETAL TEMPORAL SERIES

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Donna Catherine Markland Boyd

December 1988

DEDICATION

A Clifford
por afrontando las injusticias conmigo
con honor, apoyo, y amor imperecedero.
Gracias por todo.
Tu eres todo.

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use by others of raw data presented in this study must receive prior approval from the Museum and should include proper acknowledgment of their original source and the exercise of discretion and professional ethics in their interpretation and accessibility. For access to skeletal collections of Averbuch and Anderson, Drs. William M. Bass and Walter Klippel are thanked.

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ABSTRACT

In the present study, 66 metric as well as numerous morphological observations are utilized from 299 individuals representing a skeletal temporal series (Archaic, Woodland, Mississippian) from West, Middle, and East Tennessee. These groups reflect a documented subsistence shift from a relatively hard-textured, hunting and gathering Archaic to a soft-textured, Mississippian agricultural diet. Mandibular, craniofacial, and mandibular anterior dental dimensions are compared within and between these groups in order to evaluate a model of masticatory-related diachronic change in the mandibular complex.

This model proposes strong correlations between mandibular, craniofacial, and mandibular anterior dental measurements within each group. Cumulative age-related functional stress is expected to be higher in the Archaic. Across the temporal groups, gracilization in linear dimensions of the mandible, lower face, and mandibular anterior teeth is predicted, as well as change in the size and orientation of masticatory muscles. Indications of functional (masticatory-related) skeletal stress in the mandible and lower face are expected to decrease through time. It is hypothesized that these changes are the result of the documented dietary shift noted above.

Results indicate a fair amount of congruency with the model expectations. Intercorrelations between the 66 measurements are weaker than predicted; however, fairly strong relationships are noted between height of the mandible and face within both the Archaic and Mississippian. Mandibular measurement age variation is greater in the Archaic compared to the Mississippian. This difference is interpreted within the context of greater masticatory functional demands and thus cumulative stress for Archaic mandibles. Neither Archaic nor Mississippian facial dimensions vary significantly with age. Age-related dental variability is similar between the two groups.

In the between-group (temporal) comparison, reductions in several linear dimensions of the mandible, lower face, and mandibular anterior dentition are documented through time. And, masticatory muscles become less robust and more posteriorly oriented. Many manifestations of skeletal masticatory-related stress (e.g., midfacial prognathism) reduce as well. Several dimensions (e.g., total mandibular length), however, increase across the temporal span. All of these results are used in a revision of the model of masticatory-related microevolutionary mandibular and craniofacial change.

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CHAPTER 1

INTRODUCTION--STATEMENT OF PURPOSE

The goal of this study is to examine functional changes in human anatomy as they relate to changes in subsistence and other cultural factors. Effects of culture change upon the human skeleton are well-documented: etiological characteristics of many diseases have a cultural basis, as do intentional alterations of cranial and dental form. One of the most important examples of biocultural interaction, however, pertains to dietary change. Variability in subsistence (e.g., transition to agriculture) and subsistence-related technology (e.g., use of clay pottery) has resulted in dramatic impacts upon the human skeleton in many regions (see Cohen and Armelagos 1984).

For New World populations, prior research into these impacts has focused upon nutritional health changes associated with the shift from hunting and gathering to reliance upon maize agriculture. Most of these effects have been found to be detrimental in that increases in frequencies of skeletal indicators of stress (e.g., enamel hypoplasia, Harris lines, porotic hyperostosis) have been correlated with a shift to agricultural dependence. Synergistic models incorporating interactions of maize

agriculture-associated malnutrition with factors relating to increased settlement density, disease susceptibility, and decreased host resistance in New World populations have recently been developed to explain these changes (Cohen and Armelagos 1984).

Few researchers, however, have investigated the impact of adoption of agriculture upon craniofacial and mandibular morphology. In many regions, technological innovations such as the use of pottery in cooking and processing foods have influenced food texture. Transitions from a relatively hard-textured (hunting and gathering) food bolus to a well-processed soft (agricultural) one have been hypothesized (Hinton 1979, 1981a; M. Smith 1982). The impact of these cultural (dietary) factors upon the mandibular and craniofacial region has been studied in detail in only a few regions (Carlson and Van Gerven 1977; Larsen 1982, 1984; Martin et al. 1984; P. Smith et al. 1984).

Researchers who have investigated these relationships have generally noted decreased robusticity of the neuro- and splanchnocranium correlating with the dietary shift to agriculture. Reductions in linear dimensions of the mandible (length, breadth, height) and face (breadth, height, prognathism) have been documented. In short, a complex of gracilization changes particularly in the masticatory-related skeletal regions of the lower face and mandible have been observed (Carlson and Van Gerven 1977;

Larsen 1982, 1984; Martin et al. 1984). However, at present, it is not known if these changes are region-specific, or instead represent a much broader functionally adaptive and patterned response to variations in biocultural stress.

More detailed documentation of specific mandibular and craniofacial changes associated with this dietary shift is needed. And, since many of these changes are related to masticatory function, functional interrelationships between these anatomical areas must be considered in interpretations of skeletal change.

In the present study, a region-specific examination of Tennessee skeletal samples manifesting such a cultural (subsistence) change is conducted. These samples are drawn from 16 sites in West, Middle, and East Tennessee representing Archaic, Woodland, and Mississippian adaptations. Extensive archaeological and paleobotanical evidence from the Tennessee region documents the gradual in situ transition from hunting and gathering to agriculture across this 7500 year time span (Chapman and Shea 1981; Crites 1987; Yarnell and Black 1985). And, subsistence-related technological change (differences in food preparation methods and equipment) have been noted as well (Lafferty 1981).

The skeletal sample of 299 individuals from these Tennessee sites provides an excellent opportunity to

document skeletal effects of such cultural change. Since many of these changes involve the masticatory apparatus, this study will focus upon the mandibular, craniofacial, and anterior mandibular dental regions of the skeleton to elucidate more detailed variation in these areas. Sixty-six measurements in addition to numerous morphological observations are recorded from these anatomical regions. These data are then used to investigate the following specific goals of this study:

1. To outline a model of hypothesized mandibular and craniofacial gracilization. Based on previous research in other regions, this model predicts reductions in linear dimensions of the mandible and lower face with the adoption of agriculture;
2. To examine the morphological interrelationships between the mandibular, dental, and craniofacial dimensions within each skeletal (temporal) group, and to more fully document the complex functional interactions between these skeletal areas;
3. To document the precise nature of microevolutionary variability and change across this temporal series in relation to the subsistence change;
4. To compare this evidence to the previously established gracilization model;

5. To reassess the gracilization model in light of the congruency (or non-congruency) of the data to it;
6. To discuss further testing of the gracilization model.

Thus, this study will serve as a regional test of an evolutionary hypothesis predicting gracilization in linear dimensions of the mandible, lower face, and anterior mandibular dentition in response to the adoption of maize agriculture and associated subsistence technologies. Wolpoff (1976; also see Carlson and Van Gerven 1977) outlines three criteria necessary for constructing testable evolutionary hypotheses based on skeletal (or fossil) material:

1. Presence of a large skeletal sample reflecting temporal distinctiveness;
2. Knowledge of the function of the anatomical regions exhibiting change;
3. Knowledge of the ecology of the skeletal groups represented.

Control over the above three dimensions can result in a robust test of an evolutionary model.

Just such a robust test of cultural (subsistence) change upon the skeletal dimensions of the mandible and lower face is provided by the samples analyzed here. As previously mentioned, the skeletal samples are large and temporal control of them fairly secure. Functional

(theoretical) interrelationships between mandibular and craniofacial dimensions are hypothesized utilizing basic biomechanical principles and a knowledge of mandibular and craniofacial growth. These discussions are presented in Chapter 2. Examinations of the archaeological contexts of the skeletal samples, including site descriptions as well as considerations of chronology, settlement, and subsistence parameters of each temporal group, are the subject of Chapter 3. Thus, the above three criteria are fully met.

In addition, Chapter 4 details the metric and morphological dimensions recorded from these skeletal samples, as well as the methods and multivariate statistical techniques used to analyze the data. Results of the mandibular, craniofacial, and anterior mandibular dental analyses are presented in Chapters 5, 6, and 7, respectively. Interpretation of the results as well as reassessment of the gracilization model are found in the final chapter.

This study is unique for several reasons. First, although the mandible is the primary focus of this study, it will not be considered in isolation. Instead, the mandible will be discussed within the larger context of its interrelated, adjoining craniofacial structures in an attempt to better define the nature of masticatory-related change. And, although this study involves human skeletal

remains, an attempt will be made to consider the correlative soft tissue dimensions as well. The hope is that ultimately the functional (or non-functional, as the case may be) implications of microevolutionary masticatory-related change upon craniofacial and mandibular form will be determined.

Secondly, this study will involve the use of a multidisciplinary approach. Theoretical orientations from a variety of disciplinary perspectives (anatomical, anthropological, biomechanical, ontogenetic, allometric) will be utilized in an integrative interpretation of mandibular, dental, and craniofacial change across these prehistoric skeletal groups.

Another unique aspect of this study is its reexamination of several skeletal collections which were originally investigated and analyzed in some cases over 50 years ago. It is hoped that the reuse of older skeletal samples for answering new questions will be recognized as utilization (and conservation) of a valuable scientific resource.

Finally, the present investigation represents a study of one of the few well-documented temporal skeletal series in the southeastern United States. The transition from hunting and gathering to reliance on agriculture is well-illustrated in this series. Because of the quality of the archaeological and skeletal data, a unique opportunity

exists for studying masticatory-related microevolutionary change upon the mandibulofacial complex.

Thus, in this dissertation, metric and morphological dimensions of mandibular, dental, and craniofacial form are compared across a temporal series of prehistoric southeastern Indians manifesting an in situ transition from hunting and gathering to agriculture. These data are then interpreted in light of the resultant dietary change in an attempt to understand the morphological complexities of masticatory-related microevolutionary change.

CHAPTER 2

THE MANDIBULAR FUNCTIONAL COMPLEX

Introduction

The human mandible has long been a focus of scientific investigation. Even as early as 1936, morphological and metric examinations of the mandible were occurring (Morant 1936). More recent and intensive research of this area, particularly by the orthodontic community, has resulted in a wide body of data concerning mandibular structure, function, and growth dynamics. Most important has been the realization that the mandible cannot be considered in a vacuum; instead, it is part of a functional complex of interrelated orofacial features (Molnar and Ward 1977). Biggerstaff (1977:72), for example, describes the mandible as "...a complex bone with a basal core upon which related but independent, functioning units are superposed." At least five distinct units can be recognized. First is the basal bony portion forming the actual mandible body and lower portions of the ascending ramus. Much ontogenetic and anatomical evidence points to the condyle and neck of the mandible as forming a separate and somewhat independent second unit (Biggerstaff 1977), while the coronoid process and associated temporal muscle component function as a third. Interactive functioning of the masseter and medial

pterygoid muscles with the mandibular angular process (gonion) represent a distinct fourth component (Moss and Salentijn 1969). Finally, the mandibular alveolar process is separate from the above four units and exhibits a strong association with the dental complex (Biggerstaff 1977). In addition, the mental eminence has been treated by some (Biggerstaff 1977; DuBrul and Sicher 1954; Murphy 1957) as a structurally distinct mandibular segment.

These small independent, but interrelated, mandibular segments are, in turn, interacting with larger orofacial growth components. Moss (1960, 1971a, 1975; Moss and Salentijn 1969; Moss and Simon 1968; also see Koski 1968) has termed this model the "functional matrix" hypothesis--the theoretical organization of the neuro- and splanchnocranium into functional units including not only the skeletal tissues, but all of the non-skeletal elements (muscles, veins, nerves, etc.) involved in a particular function (mastication, olfaction, respiration, etc.) as well. While this theory has further implications for craniofacial growth which have not gone unchallenged (see below), its emphasis upon the interactive nature of form and function of interrelated mandibular and craniofacial segments is useful. Thus, any model of hominid mandibular morphology and change must consider the mandible within this larger (craniofacial) complex. While it is unfortunately not possible to directly study soft tissue

and muscle interactions with skeletal or fossil material, it is possible to functionally relate mandibular morphology to adjoining osteological units and to infer soft tissue effects. Just such an interpretive framework is utilized in this dissertation.

Hypothesized Mandibular Function

Muscles of Mastication

The most obvious function of the mandible is in providing movement for assistance in trituration of food during mastication. The power force necessary for such a task is supplied by the primary muscles of mastication--the temporalis, masseter, medial (internal) pterygoid, lateral (external) pterygoid, and the digastric. Each muscle's line of action on the mandible is reflected in its origin and insertion on the cranium and/or mandible. For example, the fan-shaped temporalis muscle originates from an oval area on the side of the cranium encompassing the frontal, sphenoid, and zygomatic (Shipman et al. 1985:239) (see Figure 2.1). At about the region anterior and medial to the zygomatic arch, the fibers converge and insert on the coronoid process of the mandible. The masseter originates from the inferior medial portion of the zygomatic arch, running inferiorly and posteriorly toward an insertion on the lateral gonial angle of the mandible (Cartmill et al. 1987:410-411; Shipman et al. 1985:240) (Figure 2.1). Also

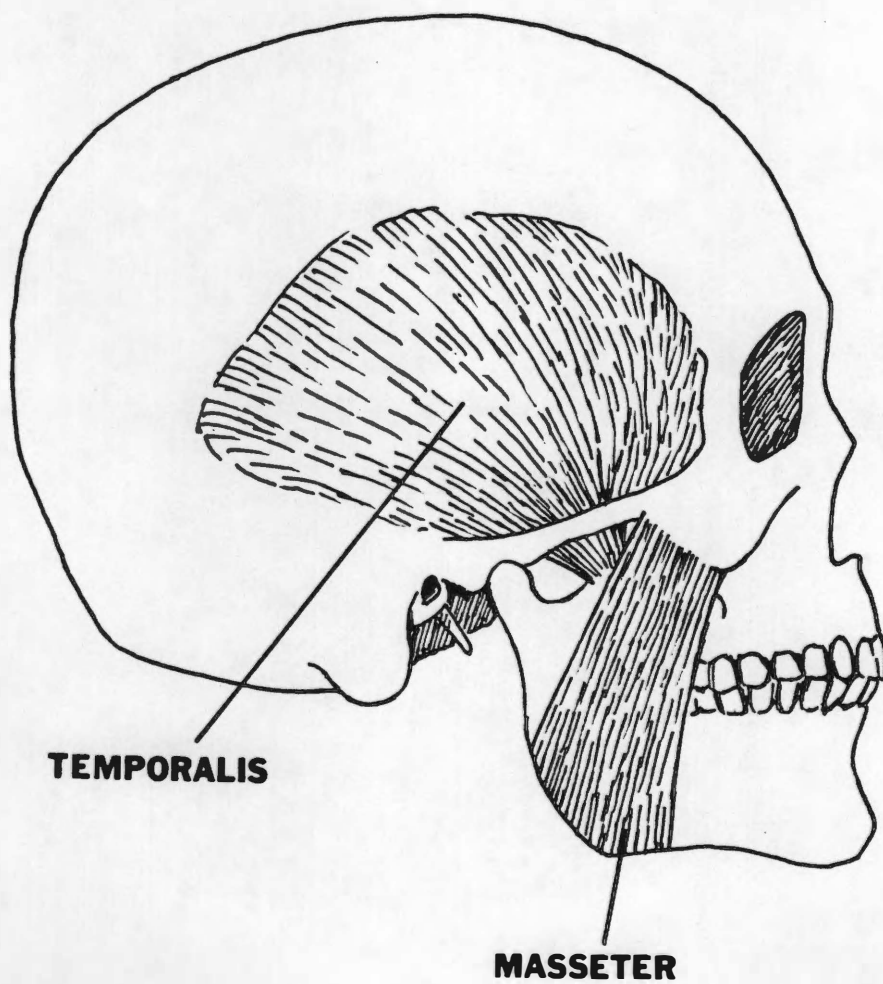


Figure 2.1. Masticatory Muscle Origins and Insertions--
Temporalis and Masseter.

inserting on the mandibular angular process (but on the medial surface) is the medial pterygoid, which arises from the lateral pterygoid plate of the sphenoid (Cartmill et al. 1987:411; Shipman et al. 1985:240) (Figure 2.2).

The above three muscles--temporalis, masseter, and medial pterygoid--have traditionally been considered the chief elevators of the mandible, instrumental in closing the jaw (Hiitemae 1978). The remaining two muscles have been characterized as depressors, operating in jaw opening. The lateral pterygoid muscle, like the medial, also arises from the area of the sphenoid and passes laterally and posteriorly toward an insertion on the mandibular condyle neck, temporomandibular joint (TMJ) capsule, and the intermediate articular disc of the condyle (Cartmill et al. 1987:411; Shipman et al. 1985:240) (Figure 2.2). Finally, the digastric originates from the region of the digastric groove near the mastoid process and follows a circuitous course beneath the cranium in the direction of the hyoid, finally ending at the internal mandibular digastric fossa (Shipman et al. 1985:242).

The traditional dichotomization of these masticatory muscles into elevators versus depressors has become much too simplistic for at least two reasons. First, all of the above mentioned muscles of mastication are functionally divisible into smaller components. Thus, as will be seen, the characterization of one entire muscle as operating

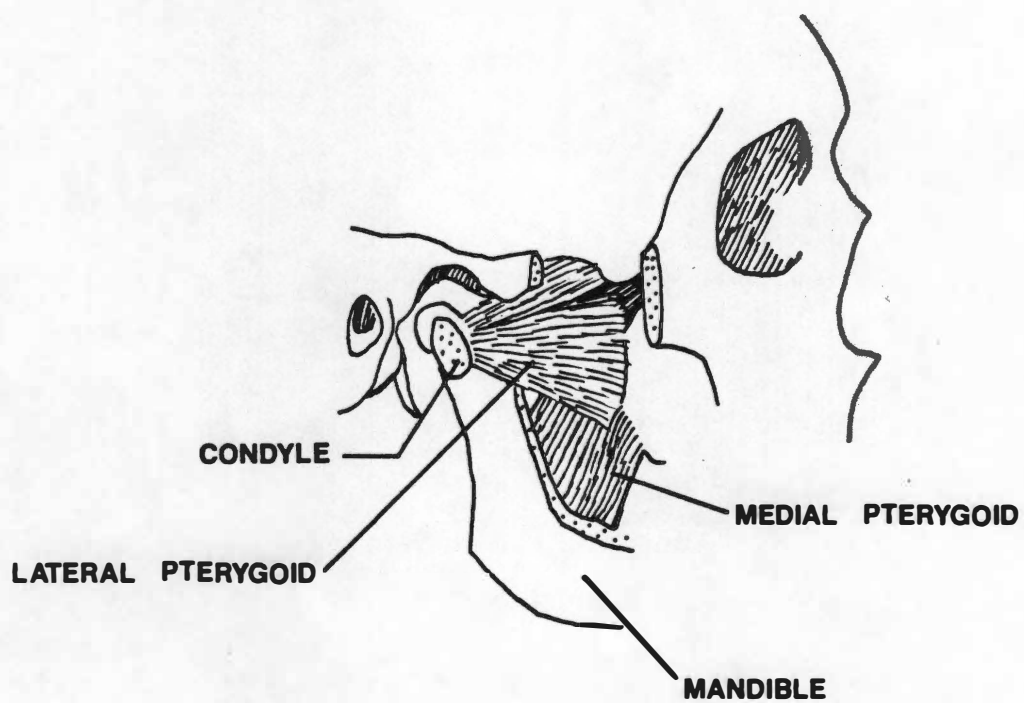


**Figure 2.2. Masticatory Muscle Origins and Insertions--
Medial and Lateral Pterygoids.**

purely as an elevator or depressor is not fully true. Second, the mandible is capable of, and manifests, additional motions beyond simply opening and closing in a single vertical plane (Kraus et al. 1975:206). Dubner et al. (1978:314) note the capacity of the mandible to move in two other dimensions: lateral and protrusive/retrusive. It is precisely the integrated action of various seemingly contradictory components of these muscles which allow the mandible to accomplish a variety of movements.

For example, the temporalis is actually divisible into anterior and posterior fibers. Anterior fibers, some of them attaching to the anterior portion of the ascending ramus, pull the mandible up, while posterior fibers allow upward and backward (retrusive) mandibular movements. In addition, Dubner et al. (1978:320) note lateral functional activity for the posterior temporalis in unilateral chewing. Møller (1976:134) identifies the temporalis muscle as primarily responsible for mandibular support in the rest position. Previous electromyographic (EMG) studies have led to the suggestion that during incisal biting, the temporalis is electrically quiet, thus, inactive. However, Hylander and Johnson (1985), in an EMG study of human and macaque (Macaca fascicularis) elevator muscles, have found significant electrical activity of both the anterior and posterior temporalis, as well as even more activity in the masseter, in incisive biting of apples.

Similarly, both a superficial and deep portion of the masseter have been recognized, resulting in overall elevation and protrusion movements of the mandible (Bacon et al. 1980; Osborn and Baragar 1985). The medial pterygoid, originating from two distinct heads (deep, superficial), also is effective in mandibular elevation, but more importantly is most involved in lateral movements.

Evidence has accumulated which supports the consideration of the lateral pterygoid as two distinct and somewhat contradictory functional units (correlating with the superior and inferior heads of that muscle) (Grant 1973a; McNamara 1973). During EMG recording of the muscle in Macaca mulatta (McNamara 1973), the superior head indicates activity during closing moments of the mandible, operating to stabilize the head of the condyle during this function. In contrast, the inferior head, in collaboration with the suprahyoid muscles, is instrumental in opening the mandible, moving the mandibular condyle anteroinferiorly as well as contralaterally (Bacon et al. 1980:727). Dissection of this muscle in the rhesus macaque and biomechanical comparison to humans (Grant 1973a) confirm the independent nature of the two heads and has led Grant (1973a) to describe them as antagonistic toward each other and representative of two separate muscles.

The digastric muscle can also be subdivided--into the anterior and posterior bellies (Cartmill et al. 1987:402),

both acting to open the mandible by depression as well as retrusion of the bone. Ahlgren (1978), through an EMG study of muscles operative in opening the human mandible, delineates the digastric muscle as the instigator of this process. Dubner et al. (1978:321), however, note that it is primarily the anterior digastric which is most active in jaw opening.

In addition, other smaller and somewhat peripheral muscles are important in jaw movement. Tongue (geniohyoid, genioglossus) as well as orofacial (infrahyoid, mylohyoid, buccinator, orbicularis oris) muscle activity during chewing and swallowing reflect the complex interaction of various craniofacial components operative during mastication and deglutition (Dubner et al. 1978:321; Moller 1976; Vitti and Basmajian 1977).

As can be seen from the above admittedly abbreviated discussion, masticatory muscle orientation and structure result in an extremely complex series of movements necessary for the masticatory process. Hiemae (1978:382), in her analytical review of mammalian masticatory muscles, states:

...when considering their mechanics in a single mammal or, more important, in the context of evolutionary change, due weight must be given to the likelihood that the proportions and internal architecture of each muscle or part thereof, have developed in relation to that muscle's optimum functional range within the envelope of motion rather than to its potential for force production in centric occlusion.

Along these same lines, Osborn and Baragar (1985) have developed a biomechanical model of jaw function delineating two separate masticatory muscle types--power versus control muscles. The superficial masseter, medial pterygoid, and (vertical) portions of the temporalis are considered power muscles, responsible for generating the main bite force and, in turn, displacing the mandible and condyle. Control muscles (deep masseter, superior head of the lateral pterygoid, oblique portions of the temporalis) act to ameliorate this displacement by serving a counteractive stabilization function preventing, for example, condylar slide. The poor moment arms of these muscular units reflect their inability to generate large occlusal forces (Osborn and Baragar 1985). Thus, Osborn and Baragar (1985:609) state: "All the jaw muscles have both power and control functions but one function usually predominates." The implication here is that these muscles are composed of independent functional units which can act accordingly. The specific functional framework in which these muscular units operate has been the subject of much controversy, and is discussed below.

The Temporomandibular Joint--The Lever Controversy

Traditional theories of mandibular function have considered the working mandible to be biomechanically analogous to a lever system, wherein the mandibular condyle

serves as a fulcrum point integrating masticatory muscle (power arm) and bite force (load arm). In this model, masticatory muscle force (provided by the medial pterygoid/masseter complex as well as portions of the anterior and posterior temporalis) is channelled through the fulcrum point of the condyle resulting in a subsequent bite force through the dentition and reaction force at the condyle (Hylander 1975:240). Most researchers have considered the mandible as analogous to a third class lever system (power arm is between fulcrum and load arm) (Kraus et al. 1975). As early as 1920, however, differing views on jaw mechanics emerged. These can be collectively referred to as non-lever hypotheses, all refuting the role of the TMJ as a fulcrum point in a lever system.

Hylander (1975) has presented an excellent summary of the lever/non-lever debate, as well as a convincing defense of the lever hypothesis. According to Hylander, non-lever enthusiasts have challenged lever models on the basis of two primary lines of evidence: actual location of the reaction force and anatomical morphology of the condylar region of the mandible. For example, Wilson (1920, 1921) maintained that all of the resultant muscle force is perpendicular to the occlusal plane, while Robinson (1946) saw this combined masticatory muscle force as passing through M1. Either way, the presence of lever-related reaction force at the condyle is denied. Secondly, it has

been claimed that due to the morphology of the tissue structure of the TMJ, this region (particularly at the mandibular fossa) is not capable of withstanding stresses expected in a lever system. Robinson (1946) viewed the presence of non-stress type synovial (vascular) tissue in the condylar region as proof of non-lever action. And, Taylor (1986) saw no evidence of mechanical stress in the TMJ (fossa) region and maintained that anatomically this region is incapable of sustaining lever-type masticatory stresses.

In defense of the lever model, Hylander (1972, 1975, 1978) as well as Picq et al. (1987) have countered the above criticisms. For example, Hylander notes that stress-bearing (avascular and dense) tissue is located in the TMJ region--not in the mandibular fossa per se, but "...between the articular tubercle of the temporal bone and that part of the mandibular condyle facing it" (Hylander 1972:209). Thus, the TMJ is perfectly capable of withstanding significant amounts of stress. Hylander (1975:236), by measuring the cross-sectional area of the condylar neck, has calculated that the theoretical quantity of reaction force which would result in the bending or breaking of the neck (supposedly the weakest part of the the condylar region) far exceeds any recorded bite force figures. Barbenel (1972:255) has used mathematical linear programming techniques to calculate theoretical load

amounts at the TMJ and concludes no upper limit on joint force exists.

In addition, Hylander (1972, 1975, 1978) maintains that, contrary to Wilson (1920, 1921) and Robinson (1946) (both of whom Hylander claims have incorrectly analyzed muscle and bite force positions), EMG studies have confirmed the presence of significant amounts of reaction force in the region of the mandibular condyle during molar biting. And, in a test involving application of incisal bite force in human subjects, Hylander (1978) has recorded EMG data reflecting both vertical and anterior mandibular force displacement. Heavy loading of the mandibular condyle and neck is indicated, supporting the hypothetical action of the condyle within a lever system during incisal biting.

In addition to EMG evidence, recent biomechanical and mathematical models of jaw function have predicted the loading of the TMJ (Barbenel 1972). Pruim et al. (1980), in considering bite force locations at the first premolar, first molar, and second molar, have calculated that the heaviest TMJ loading occurs when biting at the first premolar. In fact, Kashima (1965) has suggested that the more anterior the bite point, the greater the amount of resultant compressive strain level. In other words, TMJ compression is heaviest during incision compared to mastication. An identical conclusion is drawn by Simon

(1977) for the rat masticatory system. Groups of rats undergoing incisor removal and trimming exhibit much reduced amounts of compressive forces at the TMJ (as indicated by histological changes in the region involving, for example, thickness of the joint cartilage) compared to the control rat group. Simon suggests that the presence of external (compressive) forces at the TMJ are necessary for normal cartilaginous growth in the joint.

During unilateral biting at virtually any bite point along the tooth row, contralateral (balancing side) condylar reaction force is greater (by a factor of 2 to 1) than that seen at the ipsilateral (working) condyle (Faulkner et al. 1987; Gysi 1921; Hylander 1975; R. Smith 1978). Hylander (1975; 1977a; 1979) has suggested that the presence of a fused symphysis in some primates is possibly an adaptation for transmitting muscle force from the contralateral to ipsilateral side, thus "...maximizing occlusal force during unilateral molar (or premolar) biting by allowing a greater utilization of the balancing side musculature" (Hylander 1975:240).

R. Smith (1978) notes that lever models have been criticized because of their lack of attention toward the instantaneous center of rotation for the mandible. Moss (1972) views this point as occurring in the region of the mandibular foramen, while Grant (1973b) depicts the center as a continuous and variable path following a large curve

inferior and at times posterior (at closing) to the center of the condyle, but "...never at or near the mandibular condyle" (Grant 1973b:112). Baragar and Osborn (1984:765) have biomechanically calculated this fluctuating center of rotation:

...[it] is first located behind and below the condyle, then moves downward, and finally moves forward and upward to end in front of the condyle as the mouth opens to forward gape.

However, for the purposes of calculation of the lever model hypothesized muscle and bite force vectors, Stern (1974), Hylander (1975), and R. Smith (1978) have all noted that the instantaneous center of rotation is irrelevant, since the moments about the equilibrium center (wherever it is located) must equal zero.

Alternative models for non-lever mandibular functioning have been offered. For example, Roberts (1974) and Roberts and Tattersall (1974) hypothesize masticatory forces aligned as a couple action, resulting in an occlusal force which is absorbed by a "bilateral tripodal" area within the facial skeleton. This area theoretically encompasses the canine root, anteroinferior root of the zygomatic arch, anterior portion of the pterygoid laminae, nasal process of the maxilla, and supraorbital sections of the frontal bone (Roberts and Tattersall 1974:4). However, R. Smith (1978:342-343) correctly notes that not only are these masticatory forces (temporalis versus masseter/medial

pterygoid complex) not forming a force couple, but the proposed triangle of occlusal force dissipation is "entirely hypothetical." While Roberts' designation of occlusal stress dissipation as a major factor in craniofacial form during hominid evolution has been supported (Rak 1986; Smith and Paquette In Press; Trinkaus 1987), the theoretical absorption of all of the reaction force in the face rather than at the condyle has not (see above). And, based on orientation of these force couples, Roberts and Tattersall's (1974:9) prediction that mammals with short faces will have greater accentuation of vertical muscular units (anterior temporalis, for example), while long-faced ones will emphasize horizontally aligned muscles, is not only confusing but unsupported.

Gingerich (1971) has suggested a "link" system rather than a lever for explaining mandibular function. In this model, the jaw is a functional link between muscle and bite force. During biting, the temporalis muscle (considered by Gingerich to be the primary elevator of the mandible) can efficiently align itself at any time with any bite point along the tooth row. Thus, the condyle is not seen as serving as a fulcrum point as in the lever model. Gingerich (1971) views this as a much more efficient system due to the absence of "wasted" force at the TMJ hypothesized during level model functioning. However, Hylander (1975:231-233) notes Gingerich's omission of the

medial pterygoid and masseter from this model. Gingerich (1971) apparently considers them not to be aligned with a particular bite point and thus contributors to a reaction force at the TMJ. Therefore, Hylander (1975:233) points out that, contrary to Gingerich's stated opinion, the above scenario in reality could be considered a "lever and link" model for jaw functioning. Hylander (1975:233) also questions the validity of Gingerich's calculated bite force and mandibular movement trajectories.

Other alternative models might be considered "modified lever" ones. For example, R. Smith (1978) agrees that the lever system operates during normal mandibular elevation, but during generation of maximum masticatory force, he views the mandible as mechanically analogous to a "stationary beam or structural girder" (R. Smith 1978:347). This beam is theorized as supported at its two ends (the bite point and the articular fossa at the TMJ) during biting. Muscle forces combine into a single load distributed across the beam (including the condyle). Thus, R. Smith (1978:344) sees elevation of the mandible and generation of bite force as "...different processes, utilizing different amounts of force and perhaps requiring different structural adaptations." Interestingly, a biomechanical stress analysis by Bacon et al. (1980) involving the irradiation of human mandibles with high-intensity neutron beams to discern bone apatite crystal

orientation led these authors to an independently similar conclusion--that the mandibular body (and ramus) structurally behaves similar to a hollow beam during biting.

Thus, most researchers agree that considering the mammalian mandible a strict and simple lever system (consisting of a power and load arm and fulcrum point) is undoubtedly an oversimplification (Hylander 1972; 1975; Turnbull 1970). For example, variability in location of bite point (incisor versus molar biting), direction of tooth movements during biting, as well as side of jaw being measured (contralateral versus ipsilateral) have been found to significantly affect interpretations of mandibular function (Baragar and Osborn 1987; Gibbs et al. 1971; Hylander 1977a, 1979). In addition, demographic factors such as age and sex also result in variability (Garner and Kotwal 1973). Thus, the lever versus non-lever model for mandibular function is much more complex than is readily apparent.

However, the proven capability of the condylar region for withstanding powerful stresses, as well as the direct EMG recording of stress in this area, provide incontrovertible evidence that some amounts of reaction force are occurring at the TMJ. Thus, a lever or modified lever principle is at work at least during some phases of mandibular function. This means that variability in the

length and orientation of the power and load arms can significantly affect the effectiveness of this masticatory system. For example, a more anteriorly oriented muscle (power) arm in relation to the fulcrum results in a greater amount of force generated and delivered to the load arm. Acceptance of a lever model also means that masticatory-generated reaction force cannot be totally accounted for by occlusal bite force--significant reaction stresses are dissipated elsewhere such as the TMJ and potentially the lower face. Discussion of the evidence for and repercussions of masticatory-generated stress in the mandibular and craniofacial region are presented below.

Masticatory Function and Mandibular and Craniofacial Form

Many studies have shown a direct relationship between the functional activities associated with mastication (generation and dissipation of occlusal force) and the structural orientation of the mandible and lower face. For example, Kashima (1965) recorded electrical strain gauge resistance levels for various dimensions of the face in relation to temporalis and masseter functioning. He observed greater stress accumulation in regions of the nasal root, zygomatic, lateral ridge of the piriform aperture, and lateral orbit during masseter working, while temporalis activity correlated with stresses at the nasal root and lateral piriform aperture. In addition, he noted

tension at the inferior border of the alveolus and a "bending moment" at the supraorbital "...caused by the muscles of mastication" (Kashima 1965:66). Although this represents an early attempt to elucidate patterning between masticatory stress and orofacial structure, the methodology employed in this study (e.g., using canvas to simulate muscle activity, omitting other masticatory muscles from consideration) indicates that these results must be approached with caution.

In a more recent study, Ingervall (1974) notes a direct relationship between the height of the articular tubercle (reflecting, according to Ingervall [1974:21], the rotational path of the condyle during mandibular translation) and several facial dimensions. Cephalometric roentogram measurement comparisons of over a hundred children and fifty adults reveal a positive correlation between articular tubercle height and dimensions reflecting posterior height of the face as well as prognathism and curvature of the mandible. Negative correlations are obtained between the tubercle height and inclination of the face. Ingervall (1974:22) explains these results in terms of the variability in orientation of the lateral pterygoid muscle--a more vertical pull of the lateral pterygoid would result in a larger tubercle height, posterior height of the face, and reduced inclination of the occlusal plane, although he avoids delineating causative roles for any of

these factors. It must also be recalled from the preceeding discussion of TMJ function that varying views exist on the path of the center of instantaneous rotation of the mandible.

In a study examining the relationship between isometric bite force and selected craniofacial measurements using cephalometric radiographs of 29 female nurses, Ringqvist (1973) uses stepwise regression to discern positive correlations of incisor and molar bite force with mandibular base length, as well as anterior cranial base and maxillary lengths. A negative correlation is found between the mandibular gonial angle and bite force (larger force=smaller angle). In addition, body height (stature) also correlates well with bite force. [Interestingly, a previous comparison of isometric bite force and general body build by Linderholm and Wennström (1970) found no correlation between these two variables]. Ringqvist (1973:41) concludes:

The strong systematic correlation between bite force and the size of the mandible may be an expression of a positive correlation between the size of a bone and the size of its muscles.

Several studies point to the variation of occlusal force with regard to type and consistency of food eaten--hard-textured foods have resulted in a much greater bite force in many animals, including humans (Carlsson 1974; DeBoever et al. 1978; Hylander 1979). These differences

have, in turn, led to variation in mandibular and craniofacial form. For example, in rats, hard-textured diets have led to larger mandible and condyle dimensions (Barber et al. 1963), while soft diets have resulted in reduced masticatory muscle and overall mandibular and cranial size (Moore 1965). However, it must be cautioned that in neither of the latter two studies were allometric effects taken fully into consideration.

Weijs and Hillen (1986) have presented a multivariate study comparing computer tomography-generated cross-sectional masticatory muscle areas (masseter, medial and lateral pterygoids, and temporalis) with 17 mandibular and facial dimensions (most taken via cephalometric radiographs) of 50 adult males. Factor and principal component analyses of these data sets reveal significantly positive correlations between temporalis and masseter muscle areas and facial width measures, while mandibular length correlates with medial and lateral pterygoid as well as masseter muscle cross-sections. Although allometric influences are ruled out as causative factors (Weijs and Hillen 1986:428), specific cause/effect inferences are avoided. However, these results lead Weijs and Hillen to conclude that mandibular musculature is related to craniofacial form, and that this relationship can be "...traced back to local mechanical influences on growth sites" (Weijs and Hillen 1986:429-430).

Several authors have correlated masticatory function with craniofacial and mandibular form using human skeletal material. For example, Hinton (1979) has extensively studied the functional anatomy of the human mandibular fossa. He has conclusively shown that the depth of the mandibular fossa can be related to patterns of masticatory functional activity. In a multivariate comparison of fossa depth with craniofacial dimensions in five distinct skeletal samples (Eskimo, Australian, Southwest Amerindian, and American White and Black), he finds a significant correlation between fossa depth and measurements reflecting cranial and muscular size and robusticity within each group. In addition, orientation of masticatory muscle attachments as well as incisal and molar bite point positioning also affect fossa depth (Hinton 1979:270). Hinton concludes that there is a significant relationship between mandibular fossa and craniofacial form; however, the lack of complete agreement with his biomechanical model expectations lead him to suggest the additional influences of intrinsic genetic factors in the modification of joint form (Hinton 1979:299).

In a multivariate comparison of five human skeletal samples and 70 craniofacial dimensions, Guagliardo (1982) delineates significant age-related size and shape changes within three of these groups. These alterations include increased orbit and mastoid size and outward facial

projection as well as decreased protrusion of the subnasal area in relation to the zygomatics. Guagliardo (1982) correlates these changes with the cumulative effects of masticatory functional stress in the craniofacial region.

Factor and canonical correlation comparisons of maxillary anterior tooth root measurements (maximum length, mesiodistal and buccolingual diameters) with selected facial dimensions from a large number of prehistoric Amerindian (Arikara) individuals by Paquette (1985) has resulted in the delineation of significant patterning between the two data sets. He has found a high degree of association between anterior tooth root length and measures of vertical facial displacement (alveolar height, upper facial height). In addition, significant relationships exist between root mesiodistal diameter and dimensions reflecting subnasal prognathism. Paquette views these expanded tooth roots as reflective of masticatory stress. He concludes that a significant correlation exists between masticatory-related dental and facial form.

Similar functional relationships in mandibular, dental, and craniofacial form have been suggested for hominid fossil material. For example, F. Smith and Paquette (In Press) have postulated an adaptive model for Neandertal facial form, wherein the distinctive midfacial prognathism and elongation are related to the dissipation of heavy anterior dental stress (also see F. Smith 1983;

Trinkaus and Smith 1985). Rak (1986) and Trinkaus (1987) also view Neandertal facial morphology as an adaptive reflection of stress dissipation in conjunction with anterior dental loading, although these researchers have presented contrasting biomechanical models explaining this facial reorientation. Some researchers view much of this stress as possibly paramasticatory in nature (Brace 1962, 1964, 1967; F. Smith 1983; F. Smith and Paquette In Press). Evidence for maintenance of large sized Neandertal anterior teeth against a background of overall Middle and Upper Pleistocene dental reduction (Twisselmann 1973), as well as greater incidences of enamel chipping and fractures and heavier (differential) attrition of these teeth (Brace 1962, 1967, 1975; F. Smith 1976; Wolpoff et al. 1981) support this theory. However, it must be noted that P. Smith (1976, 1982) and Wallace (1975) offer alternative explanations involving dietary adaptive variability.

Paramasticatory stress and facial form relationships have also been explored in modern hominids. The best example of the use of teeth as tools in living populations comes from the Eskimo (see Baer [1956], Lous [1970], Mayhall [1977], Merbs [1968], and Mólnar [1972] for detailed descriptions). Hylander (1972, 1977b), in his examination of modern Eskimo craniofacial and dental morphology, considers various unique Eskimo features in the mandible, face, and dentition to be adaptive responses to

the ethnographically documented heavy vertical occlusal pressures generated by and dissipated as a result of extensive paramasticatory use of Eskimo anterior teeth. In relation to generation of heavy occlusal forces within the mandible, these features include pronounced gonial eversion (reflecting well-developed masseter and medial pterygoid muscles), robust anterior border of the ascending ramus and coronoid process (reflecting an enlarged temporalis), increased bicondylar breadth (biomechanically resulting in a power/load arm orientation shift and thus increased efficiency in hard unilateral biting), large ascending ramus breadth (relating to a more efficient anterior placement of the temporalis muscle), and a low and well-developed coronoid process (reflecting also the strong, vertical placement of the temporalis) (Hylander 1977b:143, 146-148). In addition, the presence of mandibular tori and increased mandibular height dimensions (at the symphysis, at M1, M2, etc.) reflect functional modifications for the dissipation of these heavy vertical occlusal forces (Hylander 1977b:149-155). Hylander (1977b:149) also relates Eskimo facial phenomena like the more anterior position of the anterior root of the zygoma and the zygomaxillary tuberosity to this masticatory functional adaptation.

Thus, numerous examples in the literature exist in which significant correlative relationships are seen

between mechanistic (extrinsic) masticatory function (involving force generation and stress dissipation) and mandibular and craniofacial form. These studies support a functional basis for human craniofacial form. However, attempts at inferring causation have been few and have met with varied success. One primary reason for this is the additional influence of intrinsic (genetic) factors. It becomes readily apparent that the concomitant interplay of genetically controlled craniofacial growth processes with mechanistic ones transcends the understanding of craniofacial and mandibular form in simple functional terms. A brief review of these growth processes as they relate to the mandibular and craniofacial masticatory complex follows.

Mandibular and Craniofacial Growth

Introduction

Research regarding processes and mechanisms of human mandibular and craniofacial growth has been prolific. Investigators have analyzed the topic from a variety of different perspectives using a multitude of means of measurement (see Krogh [1973] and P. Sullivan [1976] for reviews of these major trends and methods, respectively). However, for the purposes of this dissertation, only a brief review of the basic way in which the human mandible

and face grow, as well as a theoretical discussion of various craniofacial growth mechanisms, will be presented.

Growth of the Mandible

Enlow (1975a, 1975b) has summarized the major morphologic changes involved in the attainment of adult human mandibular form. First, posterior elongation of the mandibular corpus occurs in response to integration of deposition and resorption processes on various surfaces of the ascending ramus. This produces progressive posterior as well as vertical relocation of the ramus. Subsequently, the horizontal component of the ramus increases in response to functional requirements associated with the growth of the middle cranial fossa/pharynx as well as nasomaxillary complexes (including dentition). Finally, additional mandibular ramus remodelling adjusts the mandibular corpus for an optimum occlusal relationship with the maxillary corpus. Thus, the overall direction of mandibular growth as viewed from the perspective of the condyle is up and back; however, the end result of these growth forces is the displacement of the mandible inferiorly and anteriorly in conjunction with the remainder of the face (Enlow 1975a, 1975b; Enlow and Moyers 1971; Moss 1960; Wright and Moffett 1974; also see Sirianni et al. 1982 and Nanda et al. 1987 for similar mandibular growth descriptions in Macaca nemestrina and Macaca fascicularis, respectively).

However, the above-described pattern of mandibular growth is undoubtedly an oversimplification. Not only does the mandible "grow" in horizontal and vertical dimensions, but a considerable amount of rotation occurs as well. Enlow (1975b) outlines two specific types of mandibular rotation: remodelling and displacement. Remodelling processes involve resorption and deposition of bone at localized areas of the mandible (ramus, corpus) producing "angular as well as dimensional changes" in these areas (Enlow 1975b:67). Displacement, as the name implies, involves rotations of the entire mandible. In providing examples of the workings of these two rotational movements, Enlow (1975b) notes that mandibular displacement can occur as a result of a relatively more "open" or "closed" cranial base angle in relation to the cranial floor (resulting in a downward and backward displacement of the mandible or the converse). Or, displacement rotation can result from an elongated or shortened nasomaxillary and dental vertical height (resulting in a downward and backward transposition of the mandible or the opposite). Remodelling rotation primarily involves the ascending ramus and can occur to adjust the ramus and corpus in relation to the overall displacement rotations just discussed. In addition, remodelling at the ramus must orient the ramus more vertically with respect to the corpus because of continued ethmomaxillary and dental facial vertical enlargement.

This, in turn, is because vertical facial growth continues after horizontal ramal and corpus growth have ceased. Thus, in effect, continued ramal rotational remodelling must occur because of sustained facial growth (Enlow 1975b:70). Ricketts (1975) has described these rotations as resulting in a growth curve, and he has shown that by computing the radius of the arc of the curve, mandibular form and size can be predicted with a great amount of accuracy in adolescents.

As can be seen from the above discussion, one cannot possibly explain the process of mandibular growth without considering interrelated ontogenetic changes within the craniofacial complex. Thus, in the following section, some of the major trends in craniofacial growth are described. Since this represents an admittedly limited and simplistic review of this complex and oft-studied subject, the reader is referred to additional references on craniofacial growth for more detailed information (such as Enlow [1975a]).

Growth of the Midface

Once again, Enlow (1975a) and Enlow and Moyers (1971) have succinctly outlined the major sequence of human facial growth. As with mandibular growth patterning, two major types of processes occur: displacement and direct cortical drift. Growth by displacement involves the transposition of entire areas of bones away from each other, while

cortical drift is formed by depositive and resorptive interactions upon localized bone surfaces.

The traditional view of facial development envisions the anterior and inferior growth of the bones of the splanchnocranium; however, Enlow and Moyers (1971:763) term this "a misleading oversimplification." Instead, the individual bones of the face exhibit a variety of growth vectors, many occurring simultaneously. The end result is indeed a forward and downward expansion of the human face and mandible. For example, the horizontal (posterior) increase in the maxillary dental arch (via cortical drift) is accompanied by an anterior displacement of the entire nasomaxillary complex. The previously described horizontal posterior lengthening of the mandibular arch occurs at this point (also via cortical drift) as a counterbalance to the increased maxillary length. In addition, anterior displacement of the mandibular corpus matches that of the nasomaxillary complex. Inferior and anterior deposition of bone along the upper margins of the mandibular corpus results in the development of the alveolus.

Elongation of the cranial floor (particularly at the middle cranial fossa), in conjunction with inferior expansion of the brain, results in the anterior displacement of the anterior cranial fossa and entire nasomaxillary complex. Subsequent readjustment of the maxillary and mandibular corpi occurs similar to the

methods described previously. Part of this horizontal mandibular readjustment results in increases in the vertical height of the ramus. Nasomaxillary vertical dimensions also increase. Superior and posterior facial sutural growth results in increases in maxillary height, while the combined upward growth and downward displacement of several facial sutures (e.g., frontomaxillary) lead to a lowering of the palate and maxillary arch. Zygomaticotemporal and zygomaticofrontal superior sutural growth in addition to other factors result in the anteroinferior positioning of the entire zygomatic region. This, in turn, is balanced by growth of the orbital floor.

One other very important unit has yet to be discussed--the dentition. Dental elements also are part of this interrelated growth system. For example, Björk and Skieller (1972) have shown that dental eruption path and alignment (including occlusal relationships and tooth spacing) follow rotation of the mandible and face. The posterior dentition is noted as more reflective of these rotation patterns, while anterior teeth show greater influence from functional factors (for example, position of the tongue).

Moyers and Wainright (1977), in a comparison of serial casts and lateral cephalograms from a longitudinal sample of over 200 children, have found that cranial base and mandibular relative positioning were the most important

factors in the attainment of dental occlusion. In fact, they propose a feedback mechanism wherein cranial base, mandibular and nasomaxillary regions eventually adapt to the established occlusal form. Van der Linden (1970, 1975) has outlined several important craniofacial and mandibular features which affect occlusal development. He notes that the alignment of the anterior teeth in the jaws depends primarily on size and location of the apical base. Craniofacial dimensions such as height of the anterior maxilla, width of the piriform aperture (relative to canine roots), and overall form of the anterior midface significantly affect the size and location of the maxillary apical base, while the mandibular apical base is influenced by the size and shape of the mandibular lower border as well as height of the anterior mandible (Van der Linden 1975:108-109).

Thus, as can be seen, a complex set of morphogenetic interactions act in a synergistic fashion to develop the human face, dentition, and mandible. It is clear that these craniofacial, dental, and mandibular segment relationships are interdependent and that "...the nature of alignment of one part directly affects the positioning of other bony parts in quite distant locations" (Enlow and Moyers 1971:770). With such complex relationships in structure existing, it is not surprising that attempts at predicting craniofacial dimensions have met with varying

success (e.g., compare Hirschfeld and Moyers [1971] with Ricketts [1975]). In fact, Hirschfeld and Moyers (1971) state that current craniofacial growth predictions are not very accurate or successful because of the complex variables associated with the growth process. These include such factors as variation in size and scaling and timing of growth events, as well as problems in outlining vectors of growth and understanding interrelationships of craniofacial segments. However, for the purpose of this dissertation, the most important controversial question concerns the control mechanisms of craniofacial growth. More specifically, are these mechanisms primarily of an intrinsic or extrinsic nature? This is discussed briefly below.

Intrinsic versus Extrinsic Control Mechanisms of Craniofacial and Mandibular Growth

Several authors have attempted to delineate genetic (intrinsic) factors in the growth of the craniofacial complex (Harris et al. 1973; Horowitz and Osborne 1971; Hunter et al. 1970; Krogman 1967; Nakata et al. 1973, 1974). For example, Nakata et al. (1973, 1974) have used multivariate comparisons of craniofacial data from adolescent monozygotic and dizygotic twins (as well as their parents) to elucidate heritable components of the splanchnocranium. In the earlier study, six linear and two

angular craniofacial and mandibular dimensions are compared by means of multiple regression. Results denote a high heritability for all of the variables, with the twin data exhibiting greater heritability than the parent/offspring. In the later study, 33 cephalometric measurements (24 linear, nine angular) from adolescent twin pairs are compared via discriminant analysis. The authors outline nine significant heritable as well as 11 environmental functions. The extrinsic factors appear to have greater influence on localized craniofacial regions. Interestingly, hereditary components seem to be dichotomized into lower versus upper halves of the craniofacial complex. Nakata et al. (1974) conclude that multiple genetic factors influence growth processes in the superior (including maxilla) and inferior (including mandible) craniofacial regions, perhaps independently.

Significant genetic contributions to craniofacial growth have also been delineated in separate studies by Harris et al. (1973) and Hunter et al. (1970). Harris et al. (1973) compare lateral cephalogram-derived measurements (six mandibular, three maxillary) across like-sexed and unlike-sexed subadult sibling pairs as well as nonrelated pairs. Results indicate a much higher "concordance" of measurements in siblings compared to non-siblings (although it must be noted that the assessment of these complex multivariate craniofacial relationships is accomplished via

univariate [chi-square] statistics). Hunter et al. (1970) compute correlation coefficients for data representing five facial measurements from adult offspring and their parents. The authors feel that use of adult data eliminates complicating factors of growth timing and velocity. High correlation coefficients lead the authors to conclude: "...facial dimensions are largely inherited" (Hunter et al. 1970:133). Further (multiple regression) analysis indicates a stronger heritability component between father/offspring pairs, particularly in regard to mandibular dimensions.

Extrinsic control mechanisms of mandibular and craniofacial growth have been proposed by numerous authors (e.g., Graber 1975; Humphrey 1971; McNamara 1975; McNamara et al. 1975; Moss 1971b, 1975; Petrovic et al. 1975; Petrovic and Stutzmann 1977). Specifically, such diverse and extraneous factors as muscular and hormonal influences, action of applied force, and structural orientation and function of adjoining tissues have been linked to alteration of growth processes.

For example, one of the most controversial "centers" of growth is purported to be at the mandibular condyle. Considerable debate revolves around the effect of intrinsic and extrinsic factors on growth in this region. Moss (1960, 1969, 1971a) and his colleagues (Moss and Salentijn 1969; Moss and Simon 1968) have denied the independent

(genetic) control of growth potential at the condyle, and instead view this area as totally subject to compensatory, extraneous factors related to demands of the surrounding functional matrix. Transplantation studies by Koski (1968, 1977) as well as others have been used to support these conclusions--condylar cartilage transference does not result in independent and normal growth of the tissue. And, according to Koski (1968), bilateral condylectomies have no effect on "normal" growth of the mandible. In addition, the condylar cartilage is seen by the researchers as "secondary" cartilage, very unlike primary epiphyseal cartilage. This view originates from a consideration of the evolutionary derivation of this tissue from a "secondary" temporomandibular joint at the transition from reptiles to early mammals (Crompton 1963; Crompton and Parker 1978; Kermack 1972; Mills 1972). Thus, these researchers challenge the designation of the mandibular condyle as an intrinsic primary growth center responsible for the direction of subsequent mandibular growth.

In support of this contention, McNamara (1975) and McNamara et al. (1975) present results of the effect of application of extraoral force upon the splanchnocranium of Macaca mulatta. The resultant alteration in mandibular function correlates with a change in neuromuscular function. Histological examination of the TMJ region reveals an increase in masticatory muscle function

(particularly the superior head of the lateral pterygoid) in association with adaptive changes in the condylar cartilage resulting in bone deposition at the condyle. Thus, McNamara et al. (1975:225) conclude:

The structural adaptations within the mandibular condyle are usually related to changes in neuromuscular activity, particularly in the function of the lateral pterygoid muscle...

They (McNamara et al. 1975:225) also state "...condylar growth can be increased as a result of altered function." Interestingly, experiments by Petrovic et al. (1975) involving the resectioning of the lateral pterygoid in the rat are in agreement. They subsequently observe decreased condylar growth and note the muscle's primary role in the differentiation of chondroblasts from osteoblasts in the condylar cartilage. Thus, they designate this muscle as a key factor in growth regulation at the condyle, transmitting information via either biomechanical (compression, tension), chemical, or electrical signals. In reviewing this rat data, McNamara (1975:64) concludes:

...a prolonged contraction of the lateral pterygoid muscle produces acceleration of condylar growth while a reduction in contraction produces a slowing down in the growth of the condylar cartilage, thus establishing at least indirectly a relationship between muscle function and osseous or cartilaginous growth.

In humans, the effect of extrinsic factors on craniofacial growth has been reviewed by Graber (1975). He, also, notes the significance of extraoral (orthopedic) force on growth

of the face and mandible, and suggests that the magnitude and duration of such applications are key factors "...because variations can cause opposite effects" (Graber 1975:80). In addition, he identifies other extrinsic agents which can be instrumental in growth regulation, such as pressures exerted by contiguous tissues and organs (for example, capillary tissues). Moss (1971b, 1975) has pointed to the importance of neurotrophic regulators in the Central Nervous System, while Petrovic and Stutzmann (1977) suggest the action of certain hormones like testosterone in the control of craniofacial growth. Humphrey (1971) has correlated photographically-observed human fetal activity with patterns of craniofacial growth. She finds increased growth of the face and mandible after the onset of muscular reflex activity. For example, she notes a rapid proliferation of mandibular growth after the onset of jaw depressor reflexes and after a positional change in the tongue and palatal shelves. She (Humphrey 1971:1439) states:

...the action of the muscles affects the normal development of the cartilaginous and skeletal framework of both the upper facial region and the mandible through their attachments. In addition, the muscles themselves enlarge as a result of their activity, and influence the facial contours.

She concludes that muscular function is of primary importance in regulation of craniofacial growth.

Thus, the influence of extrinsic factors (such as biomechanical functional stress) upon craniofacial and

mandibular growth processes appears well-established. However, Enlow (1968), as well as Enlow and Azuma (1975) and Enlow et al. (1969, 1971), have correctly noted that direct correlations between biomechanical stress in the craniofacial region and craniofacial growth (Wolff's Law) cannot be made--areas of compression and tension due to musculoskeletal stress do not coincide with regions of bone deposition and resorption. And, muscle attachment patterns do not coincide with these areas either. Instead, Enlow (1973) suggests many different types of craniofacial control mechanisms (operating on different levels--e.g., local versus non-local) may be involved, including those relating to genetic influences as well as ph, temperature, enzymatic, nutritive, and bioelectric factors. In addition, effects from adjoining and encompassed soft tissues (e.g., brain, sense organs) may also be important considerations (Enlow 1975a).

Other authors also see an interplay of intrinsic and extrinsic growth mechanisms (Currey 1968; Hayes 1971; Meikle 1973; Proffit 1978; Van Limborgh 1970, 1972). For example, Van Limborgh (1970, 1972) sees a combination of genetic, environmental, and epigenetic ("genetically determined factors which manifest themselves by an indirect way, that is by intervention ... of influences effected by other structures") (van Limborgh 1970:148) factors operating in craniofacial growth. He believes genetic

factors play a more significant role in chondrocranial (cartilaginous) growth, while eipgenetic as well as local environmental influences are greater upon desmocranial (calvarial and facial intramembraneous) ossification.

Controversy surrounding the role of intrinsic versus extrinsic variables in craniofacial growth ultimately can be traced back to fundamental disagreements as to how the mandible and face grow. Early theories of craniofacial growth such as the shifting theory (or "Fetalisationstheorie") of Bolk (1924), in which the anterior and posterior shifting of jaw segments was seen as producing normal adult jaw form, were replaced in the 1960s and 1970s by the more fashionable functional matrix hypothesis of Moss (1960, 1969, 1971a, 1975) and colleagues (Moss and Salentijn 1969; Moss and Moss-Salentijn 1978; Moss and Simon 1968). This theory contends that functional matrices--all of the skeletal and non-skeletal (muscles, nerves, blood vessels, skin, etc.) tissues related to a particular orofacial function (mastication, respiration, deglutition, etc.)--are the primary regulators of craniofacial growth. In fact, Moss (1971a:10) states: "All skeletal tissue growth is a secondary, compensatory, and mechanically obligatory response to changes in the temporally prior demands of specific functional matrices." And, he says: "In a very real sense, functional matrices grow, and skeletal tissues respond." He concludes:

"...there is no direct genetic control of skeletal tissue growth" (Moss 1971a:10).

This can be considered the ultimate functional approach to craniofacial structure and growth and it has not gone uncriticized. Johnston (1976), in particular, has severerly critiqued and countered this growth theory on the basis of several considerations. For example, the secondary nature of condylar cartilage growth potential has recently been questioned--transplantation experiments have been viewed with cautious scrutiny by many researchers and conclusions drawn from condylectomies may not be relevant to interpretations of "normal" growth processes (see Bernabei and Johnston 1978). And, Johnston (1976) correctly notes the untestable nature of the hypothesis itself regarding the primary importance of functional spaces in craniofacial growth. Thus, Johnston (1976:160) concludes:

...it would seem a more fruitful approach to avoid dichotomies and, instead, to assume that all tissues and organs have both an 'intrinsic' ability to grow and a capacity to react, either of which may be rate-limiting for a given system, in a particular individual, at a certain time.

Meikle (1973:59) calls the attempt by many researchers to assign mutually exclusive intrinsic or extrinsic explanations for craniofacial growth control "naive". More recent theories of craniofacial growth have incorporated just such advice. "Systems theory" approaches such as the

cybernetic model developed by Petrovic and Stutzmann (1977) have placed craniofacial growth in the context of a variety of integrating mechanisms of both a biologic and mechanistic nature. And, some researchers (e.g., Hoyte 1976) have begun to look beyond the cranium into areas of the remainder of the skeleton for insights into craniofacial growth processes. Interestingly, old theories of craniofacial growth have, in some cases, experienced a revival. Biggerstaff (1977), for example, has recently used a modified shifting theory to explain the growth and development of the human chin.

Thus, in any model of human mandibular and craniofacial form, growth, and development, it must be recognized that both intrinsic (genetic) and extrinsic (biomechanical, etc.) variables may be involved. This is especially crucial in understanding change in these features through time. Previous studies of human mandibulofacial evolutionary change have addressed this problem and attempted to integrate these two dimensions. A brief discussion of some of these studies follows.

Previous Analyses of Mandibulofacial Evolutionary Change

It is well established that the posterior dentition and surrounding masticatory complex have manifested a consistent evolutionary pattern of reduction throughout the Pleistocene (F. Smith 1976; P. Smith 1982; Twiesselmann

1973; Wolpoff 1975). For example, Wolpoff (1975) has presented a comprehensive summary of Pleistocene hominid mandibular evolution. In comparison to Homo erectus, he considers European Neandertal mandibles to be reduced in terms of overall mandibular length, posterior tooth length, molar area, internal torusing system, and ascending ramus size. Wolpoff views early modern Homo sapiens mandibles as showing even more accelerated trends toward gracilization as seen in reduced corpus height and breadth, ramus height, condyle breadth, and ascending ramus breadth (Wolpoff 1975:53-55). Twiesselmann (1973) has also recorded reductions in anteroposterior dimensions of the mandible, in addition to the thickness and height of the mandibular corpus, from Australopithecus to Homo sapiens.

F. Smith (1984:190) outlines more specific changes from early Central European Neandertal mandibles (represented mainly by Krapina, but also Ochoz) to late (represented primarily by Vindija and Šipka). These include reduction of the symphyseal angle (from $> 90^\circ$ to $< 90^\circ$) and retromolar space, increased development of a trigone, and replacement of alveolar mandibular projection with more basal projection. This results in the more distinct mental eminence seen in late Neandertal and early modern human specimens from this region.

Not only have morphological reductions in robusticity been documented for Pleistocene mandibles, but changes in

orientations of certain mandibular dimensions have been noted as well. Osborn (1987) has recently conducted a biomechanical comparison of photographic tracings of selected recent as well as fossil hominid (and hominoid) mandibles. He finds a significant change in the "joint point"--the articular surface of the condyle--in terms of its height above the occlusal plane and distance behind the dentition. For example, he characterizes selected Homo erectus mandibles as having a high and posteriorly oriented joint point, with this point becoming more anterior with the emergence of early modern Homo sapiens. He relates these changes in joint point orientation to changes in biomechanical efficiency of masticatory function, and believes these modifications correlate with dietary change (although in what specific sense he does not explain).

Many of these documented Pleistocene masticatory "gracilization" trends have continued to the present. For example, P. Smith et al. (1984, 1986) have found significant reductions in corpus height, ramus width, crown length (molar and premolar), facial (nasion--prosthion) height, and bizygomatic breadth across a 12,000 year time span involving crania and mandibles from several selected Near Eastern (Levant) sites. Maximum mandibular length, corpus length, and ramus height, however, increase through time. Overall, P. Smith et al. (1984:118) note "reduced robusticity" in craniofacial morphology across the temporal

sequence, succeeded by reductions in the dentition. Frayer (1978) sees significant reductions in both the posterior and anterior dentition from the European Upper Paleolithic to the Mesolithic. Brace (1976) has found greater Post-Pleistocene dental reduction in regions of Asia which have experienced the greatest time depth of an agricultural subsistence economy (South China). He contends that development of pottery was instrumental in the production of cooked, soft-textured foodstuffs, resulting in relaxed selection for continued maintenance of large tooth size. Decreased tooth size then accrued through operation of the Probable Mutation Effect. Brace (1980) attributes similar cultural factors (in addition to others) to the decrease in dental dimensions across selected Post-Pleistocene Australian populations through time.

Moore et al. (1968) has compared six mandibular (five linear, one angular) and one mandibular dental (mesiodistal diameter of left molar) dimensions across a temporal sample consisting of Neolithic, Bronze Age, Romano-British, Anglo-Saxon, Medieval, 17th and 19th century British mandibles. A reduction in means occurs across all of the linear measurements through time, with ramus height and minimum ramus breadth manifesting the greatest change. Corpus length and symphysis height exhibit smaller reductions; however, Moore et al. (1968) note that corpus length dimensions are somewhat "erratic" in the earlier temporal

groups, presumably due to the smaller sample size. The mandibular angle (gonion) increases through time. The authors correlate these results with decreasing masticatory stress due to increasing soft consistency of the diet (e.g., refined flour) through time.

In a unique study, Carlson and Van Gerven (1977; also see Carlson 1976; Martin et al. 1984) have analyzed a temporal sequence of Post-Pleistocene Nubian groups (representing pre-agricultural, transitional hunting and gathering/agricultural, and fully agricultural adaptations) in terms of their craniofacial variability. More specifically, the authors, through a multiple discriminant comparison of 16 selected craniofacial measurements, delineate significant changes in the maxillomandibular complex across the 10,000 year time span. For example, muscles of mastication (temporalis, masseter, pterygoids) adopt more posteriorly-oriented points of origin through the temporal sequence, and the entire lower craniofacial region reduces in robusticity, becoming more infero-posteriorly located compared to the cranial vault. And, the cranial vault exhibits a trend toward increased height and decreased length through time. Tooth size also decreases over time (Greene 1972; Martin et al. 1984; also see Calgano 1986), in addition to temporomandibular joint size (Hinton and Carlson 1979). Carlson and Van Gerven (1977) explain these changes by means of an evolutionary

model relating to hypotheses involving the masticatory functional complex. They see reduced masticatory functional demands through subsequent Nubian populations (due to shifting dietary adaptations) as the primary determinant of Nubian craniofacial change. Cranial vault and tooth size changes are seen as somewhat compensatory responses to these more important masticatory-related alterations.

In the southeastern U. S. study area, Larsen (1981, 1982, 1984) has compared (primarily via univariate statistics) cranial, postcranial, and dental dimensions of over 500 individuals representing a temporal skeletal series off the Georgia coast (St. Catherine's Island). This series exhibits a well-documented dietary shift from hunting and gathering to reliance upon (maize) agriculture. Larsen has found significant reductions in size-related craniofacial dimensions like cheek height, temporalis length and height, bigonial breadth, ascending ramus height, symphysis height and thickness, and mandibular length. These reductions are more prominent in females compared to males. Female posterior tooth size also decreases; however, little variation in male dental dimensions occurs. Anterior tooth size differences across the series (for both sexes) are not significant. Postcranial reductions are also noted, and include stature differences between the pre-agricultural and agricultural

groups; however, once again, this pattern is most visible with the females. Larsen concludes that these craniofacial and dental reductions are primarily related to reductions in masticatory functional stress due to the adoption and reliance on a soft-textured agricultural diet. Factors such as decreased mechanical stress and increased nutritional stress (protein deficiency, for example) due to a more sedentary agricultural lifeway are utilized as potential explanations for postcranial reductions.

Using many of the same skeletal samples utilized in this dissertation (Eva, Cherry, Ledbetter, Toqua), Hinton (1979, 1981a) has documented the gradual reduction in temporomandibular joint size through time (Archaic--Woodland--Mississippian) in several prehistoric Tennessee Indian populations. He adopts a functional approach by relating this decrease to differences in the magnitude of force habitually transmitted to the joint during mastication. He believes this, in turn, reflects not simply dietary differences across these temporal groups, but food preparation ones as well. The transition in the Mississippian period to cooked, soft, pliable foods such as found in soups and stews (compared to hard-textured, unprocessed Archaic foods) is proposed as accounting for these TMJ morphological and metric differences.

The last three studies are unique in that they represent some of the few attempts to develop an

evolutionary model of mandibular and craniofacial gracilization based on masticatory-related functional hypotheses regarding this complex. However, greater understanding of the regional variability of this morphological complex, as well as the more precise ways in which it changes through time, are needed to develop a realistic, testable model of mandibular and craniofacial microevolutionary change.

Current Research Model

Based upon the previous theoretical discussions of mandibular and craniofacial function and growth, the complex mechanisms operating to control this growth, and the documented evidence for mandibular, dental, and craniofacial reductions in correlation with a dietary shift from a hunting and gathering to a primarily agricultural way of life, several expectations can now be expressed regarding the present regional study. First, it is anticipated that within each skeletal group (Archaic, Woodland, Mississippian), significant correlations will exist between interrelated aspects of the mandible, lower face, and mandibular anterior dentition. Thus, for example, height measures of the mandible should correlate highly with height dimensions of the face.

Secondly, it is predicted that reductions in the amount of masticatory-related functional demands across the

temporal series will result in a gradual and consistent trend toward reduction of linear dimensions in height, breadth, as well as thickness of the corpus and ascending ramus of the mandible. And, possible changes in regard to expression and orientation of the primary muscles of mastication are expected to occur--functional requirements for increased masticatory efficiency due to chewing of a hard-textured food bolus in the pre-agricultural diet are predicted to be no longer necessary in the mastication of a soft-textured Mississippian agricultural diet. Concomitant reductions and restructurings are also expected in the functionally related dimensions of the lower face. In particular, measures which have been shown in past studies to reflect masticatory stress (lower alveolar prognathism and vertical facial height, for example) are expected to reduce across the temporal series. Finally, anterior dental dimensions are expected to follow the pre-established documented trend toward reduction throughout the Holocene.

In short, a testable model can be formulated which predicts morphological and metric changes across a temporal skeletal series exhibiting a subsistence shift from hunting and gathering to agriculture. This model envisions a gradual and consistent trend toward masticatory-related gracilization of mandibular, dental, and craniofacial dimensions across the temporal skeletal series. In

addition, changes in masticatory muscle orientations and sizes are expected to occur. Skeletal manifestations of masticatory stress (alveolar prognathism, for example) are expected to reduce across the temporal series. In essence, a functional model for subsistence-related mandibular, facial, and mandibular anterior dental change through time is formulated. This model will be tested against the present skeletal data sets.

CHAPTER 3

THE SAMPLES--ARCHAEOLOGICAL CONTEXT

The Archaic Data Base

Introduction

Four sites, all located in Middle and West Tennessee, comprise the Archaic sample (Figure 3.1). Three of these four (Eva, Cherry, Ledbetter) were part of the Works Progress Administration, Tennessee Valley Authority, and University of Tennessee joint exploration of the western Tennessee Valley prior to the flooding of the Kentucky Lake Reservoir in 1941. The fourth, the Anderson site, was excavated by the Middle Cumberland Archaeological Society from 1980 to 1981. A brief description of the archaeological investigations at these sites, and a consideration of Archaic chronology, subsistence, settlement patterning, and evidence for environmental change, follow.

Poor preservation of bone at many of the sites reduced the total number of individuals which could be utilized from each site in this study. For each of the sites which were investigated in the late 1930s and early 1940s, both new and old site numbers are provided.

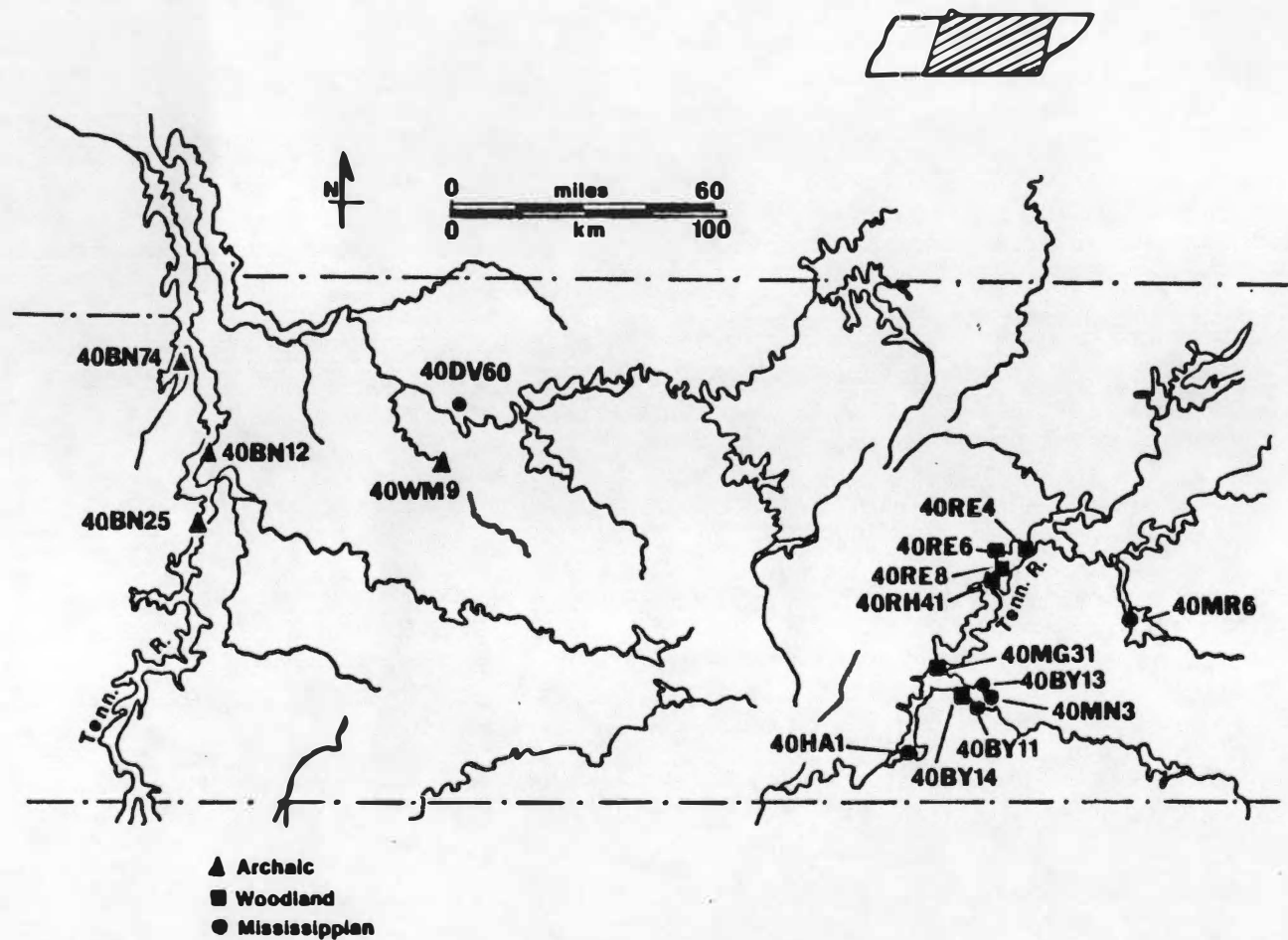


Figure 3.1. Location of Tennessee Archaic, Woodland, and Mississippian Sites Used in The Present Study.

Eva (40BN12 or 6BN12)

The Eva site was located on a broad floodplain at the right bank of Cyprus Creek roughly four miles above its confluence with the Tennessee River in Benton County, Tennessee (Lewis and Kneberg 1959:163; Lewis and Lewis 1961:1). Although the site was approximately one mile from the Tennessee River at the time of excavation, it was speculated that because of changes in the course of the Tennessee, Eva may have been directly on the bank of the river at the time of occupation (Lewis and Kneberg 1947:6). Excavations in 1940 revealed a stratigraphic sequence encompassing five distinct layers spanning the Middle and Late Archaic temporal periods. Based on this, Lewis and Kneberg (1959; Lewis and Lewis 1961) defined three chronologically separate complexes at Eva which were, in turn, components of three Archaic phases--Eva, Three Mile, and Big Sandy. Lewis and Lewis (1961:13) state:

There is little doubt that the phases represent a continuum with gradual change due to adaptation to varying ecological conditions, to internal development, and to influence from other cultural traditions.

An extensive shell midden deposit characterized the earliest Eva phase component at the site, in addition to numerous burials, hearths, and lithic and faunal remains. Three Mile phase remnants also included shell middens, burials, hearths, bone, and assorted lithic artifacts.

However, the latest occurring Big Sandy phase component was significantly lacking in mussel shell remains. Very few features were located at any of these components, and no clear evidence for storage pits or structures was found.

Although numbers vary across different sources, approximately 183 human burials were originally noted by Lewis and Kneberg (1947:7) as recovered from the various components at Eva. Of this total, only 39 could be utilized in this study. Three of the 39 (7.69%) reflect the earliest Eva phase; the majority (24 or 61.54%) are from the Three Mile phase, while 9 (23.08%) individuals are from the Big Sandy component. Three skeletons (7.69%) are indeterminate in relation to exact archaeological phase at Eva.

Cherry (40BN74 or 84BN74)

In marked contrast to the floodplain-associated Eva site, the Cherry site was rather unique in its remote upland location. It was found between Rushing Creek and a small unnamed creek, both tributaries to the Big Sandy River, approximately 0.55 miles northeast of the town of Wyly in northwestern Benton County, Tennessee (Lewis and Kneberg 1947:2; Bowen 1977:107). The site was situated roughly 0.95 miles east of the Big Sandy River (Magennis 1977:15). Investigations in 1941 revealed only one stratum approximately one and a half to two feet in depth. This

stratum produced only a scattering of shell; however, numerous postholes and pits were encountered. Some of these pits contained an abundance of midden deposits particularly in the form of faunal remains; thus, a storage function has been suggested (Lewis and Kneberg 1947:2; Magennis 1977:18). Other pits were very large (12 to 20 feet in diameter) and shallow basins, also filled with midden. Lewis and Kneberg (1947:2) have suggested that these reflect semi-subterranean houses; however, posthole patterning does not conform to this hypothesis. Many postholes formed linear and semi-circular patterns suggestive of possible windbreaks or cabanas (Bowen 1977:109).

Approximately 70 human burials were recovered from the Cherry site (Lewis and Kneberg 1947:2). Interestingly, many of these individuals were concentrated, along with an abundance of faunal debris, along the eastern portion of the site. Lewis and Kneberg (1947:2) suggest the allocation of this area possibly to refuse dump/cemetery activities. Magennis (1977), in her comparison of Middle and Late Archaic mortuary variability in the western Tennessee valley, finds no significant differences between Eva and Cherry site treatment of the dead. And, no indications of a stratified status-related social structure (as reflected by differential burial treatment) for either

site can be discerned. Twenty-one of the total number of individuals are utilized in the present analysis.

Ledbetter Landing (40BN25 or 9BN25)

Located on a slight rise between Morgan Creek and the west bank of the Tennessee River, Ledbetter Landing was about one-quarter mile below the confluence of the two bodies of water in southeastern Benton County, Tennessee (Lewis and Kneberg 1947:9). The site was investigated in 1940. Excavations unearthed two strata--one a two foot deep shell midden consisting of abundant faunal remains, and the other a burned soil, sand, and charcoal layer lacking animal remains.

One hundred and fourteen human burials were noted (Lewis and Kneberg 1947:9)--nine of which were cremations. Several of the individuals were interred with a variety of grave accompaniments--shell, copper, antler, and stone artifacts. Higgins (1982) has statistically compared mortuary characteristics of burials from Ledbetter Landing, in addition to the Cherry site and the Big Sandy component at Eva. In support of Magennis (1977), she finds a great deal of homogeneity in mortuary patterning between the sites. And, all variables indicate an egalitarian social system for this time period. Ten Ledbetter Landing individuals are utilized in the present study.

Anderson (40WM9)

In Williamson County, Tennessee, the Anderson site was found on an old channel of the Harpeth River near its intersection with a small tributary (Dowd 1981; Lindstrom and Steverson 1987:1) approximately two miles north of Franklin. Excavation of this Archaic shell midden was by six-inch arbitrary levels, reaching a maximum of eight levels in some squares. These levels produced an abundance of lithic, shell, and faunal remains, as well as 48 features including hearths and refuse-filled pits (Lindstrom and Steverson 1987:3).

Human burials recovered from this site numbered 73. An analysis of these human remains by Joerschke (1983) has resulted in a demographic profile as well as an investigation of stature and bone pathologies. Joerschke finds no evidence from any of these three parameters of substantial stress in the population. Fairly low infant mortality, comparability of long bone growth rates to other skeletal samples, and low amounts of pathological conditions (mainly involving degenerative [age-related] processes such as osteoarthritis) all support this conclusion. Approximately 12 Anderson individuals are included in the present analysis.

Thus, the Archaic skeletal sample comprises 82 individuals from four Middle and West Tennessee sites.

Since a considerable time range is being dealt with, an assessment of chronological relationships within the Archaic follows.

Archaic Site Chronology

A total of four radiocarbon dates exists from the Archaic sites discussed above:

1. Eva--bottom of Stratum IV (Eva phase component)
=5200 +/- 500 years B.C. (antler) (Lewis and Lewis 1961:13);
2. Anderson--Level 7 (deepest), Feature 38=6720 +/- 200 years B.P. or 4770 +/- 200 years B.C.
(charcoal) (Lindstrom and Steverson 1987:1);
3. Anderson--Level 6, Feature 27=6495 +/- 205 years B.P. or 4550 +/- 205 years B.C. (charcoal) (Lindstrom and Steverson 1987:1);
4. Anderson--Levels 2 and 3, Burial 73=5680 +/- 200 years B.P. or 3730 +/- 200 years B.C. (calcined deer bone and antler) (Lindstrom and Steverson 1987:1).

From a comparison of the above radiocarbon dates to Archaic chronological assessments from other areas of Tennessee (e.g., Chapman 1976, 1977, 1985), the earliest component at Eva (representing the Eva phase) appears to be early Middle Archaic in age. Estimates have placed the

beginning of this occupation at around 6000 years B.C. (Lewis and Lewis 1961:13; Magennis 1977:21).

Projectile point morphology at the second Eva phase component (Three Mile) has led Lewis and Lewis (1961) and Magennis (1977:26) to assign it a late Middle Archaic temporal designation. Although considerable mixing of deposits has resulted in the presence of a variety of Late Archaic lithics, Middle Archaic points such as Eva I and II, Morrow Mountain I, Sykes, Big Sandy, and Cyprus Creek II predominate and have led Magennis (1977:26) to suggest a date range of between 5000 and 3000 years B.C. for this occupation. This is precisely the time period at which the Anderson site is estimated to have been occupied (4700 - 3700 years B.C.) (Lindstrom and Steverson 1987:1).

The final (latest) component at Eva--representing the Big Sandy phase--is Late Archaic in age. Once again, projectile point form (straight-stemmed, corner notched) supports this contention. Estimates for the duration of this occupation period in the Little Tennessee River valley approximate 3000 - 1200 years B.C. (Chapman 1985:146). Habitations at Cherry and Ledbetter Landing (Bowen 1975, 1977, 1979; Lewis and Kneberg 1959) are thought to be coeval with the Late Archaic Big Sandy phase at Eva.

Thus, the Archaic skeletal sample utilized in this study reflects a Middle and Late Archaic temporal series spanning approximately 5000 years. However, it must be

noted that only three individuals originate from the earliest Eva phase occupation; therefore, the majority of the skeletons are late Middle and Late Archaic. Notwithstanding the rather long time period represented, the subsistence and settlement strategies employed by these inhabitants evince a great deal of homogeneity. A discussion of these aspects of the Archaic follows.

Archaic Settlement, Subsistence, and Environmental Change

Using archaeological trait lists from the first three sites discussed above, as well as other Archaic sites within the Kentucky Lake Reservoir inundation zone, Lewis and Kneberg (1959) have compared the western Tennessee valley Archaic to that in other regions in the Middle South (Kentucky, Alabama, and Georgia). The result is the division of the Archaic into two "traditions"--Midcontinent and Eastern. The Midcontinent one contains all three components represented at the Eva site as well as Cherry and other sites in the Kentucky region (e.g., Indian Knoll), while the Eastern tradition involves Ledbetter Landing and other sites within the Ledbetter, Stallings Island, Lauderdale, Kays Landing, and Waldon phases. This distinction is based on such "key" traits as attitude toward dogs (careful burial with or apart from humans) and notching of projectile points (Lewis and Kneberg 1959:174).

However, Lewis and Kneberg (1959:173) note:

Long-continued association of peoples of the two traditions in the same region resulted in gradual obliteration of distinctions in culture, and in development of a single, more uniform area tradition.

Cole (1975a) has analyzed skeletal representatives of the Midcontinent (Eva, Three Mile, and Indian Knoll) and Eastern (Kays Landing, Perry) traditions in the Midsouth to test the biological implications of this cultural division. In a statistical comparison of eight craniofacial variables from these individuals, no genetic dichotomization in the samples is indicated. She suggests that the Eastern/Midcontinent Archaic separation may be strictly a cultural rather than a biological distinction.

Later investigators such as Bowen (1975, 1977, 1979) have discarded these cultural distinctions within the Middle South. Instead, recent research has focused upon the nature of Archaic adaptation in the region with an emphasis on the environment as well as settlement and subsistence patterning. For example, Bowen (1977) hypothesizes an Archaic settlement and subsistence model quite different from that proposed earlier. Contrary to Lewis and Lewis (1961), he interprets differences in site location (mainstream vs. upland), shell content (abundant vs. scarce), and feature presence (pits, postholes) between Ledbetter Landing and Cherry not as cultural distinctions but ecological variants of perhaps the same cultural group.

Thus, he challenges their contention that Archaic groups were primarily sedentary, year-round inhabitants of the same site. Instead, he formulates a seasonal round model, suggesting that the Cherry site represents an autumn, winter, and early spring occupation with a focus on plant food gathering and hunting, while Ledbetter Landing reflects a more temporary summer habitation emphasizing riverine resources (Bowen 1977:115, 117). He (Bowen 1977: 117) concludes:

Due to the sites' closeness to one another (ca. 20 to 25 miles) and homogeneity in artifact morphology ..., it is suggested that both assemblages (9BN25 and 84BN74) were produced by the same population or segments thereof, or two culturally related units.

Examinations of Eva artifact assemblages by Winters (1969) have led him to delineate functional artifact categories possibly reflecting different occupational activities. He suggests that strata reflecting the originally designated Big Sandy and Three Mile phases indicate possible base camps, while the lower stratum (Eva phase) suggests a hunting camp. Magennis (1977:34), in her summary comparison of Eva and Cherry site archaeological configurations, allocates differences in these two sites (in relation to site location and storage pit and structure presence or absence) to variability in site function. Once again, a riverine, shell-oriented exploitation of the

floodplain site (Eva) contrasts with the hunting and gathering emphasis at the upland Cherry site.

Archaic settlement analyses in the Middle Tennessee valley (Amick 1984; Bowen 1979; Faulkner and McCollough 1974) reveal similar patterning. Bowen's (1979) review of site distribution within the Normandy Reservoir in the upper Duck River valley leads him to conclude that Late Archaic inhabitants of this region were occupying a transitional ecological zone strategically placed between the floodplain and the uplands in order to capitalize on the diversity of resources represented by these ecozones. Once again, a partially nomadic seasonal round model is promulgated.

Amick (1984), in a comparison of seven Middle and Late Archaic lithic assemblages from sites within the central Duck River Basin in Middle Tennessee, suggests important differences between the two temporal periods in terms of organizational strategies. Lithic raw material variability as well as other factors indicate a higher degree of residential mobility within the Middle Archaic as well as technology reflecting greater expediency (for example, less craft specialization). In contrast, Late Archaic lithic assemblages form a pattern denoting a decrease in the frequency of residential mobility accompanied by an increase in logistical mobility. And, increases in technological specialization reflect a less expedient

approach to tool manufacture. In short, "egalitarianism decreases as political and social organization increases in complexity and integration" (Amick 1984:266). Amick believes stresses associated with population pressure (related to environmental change in the Middle Archaic hypsithermal) to be important factors in this strategic difference.

Subsistence data relating to plant utilization in the Middle and Late Archaic in the southeast has recently been summarized by Yarnell and Black (1985). In a survey of numerous reports on southeastern sites containing floral remains, they compile statistics regarding nut and seed as well as cultigen quantities across the Archaic and Woodland and outline general trends in the use of these remnants. In the Middle and Late Archaic, hickory nut appears to be the most important plant food source in the Tennessee region; however, other nuts such as acorn and walnut are also prevalent (Yarnell and Black 1985:97, 100; see also Chapman and Shea 1981). Nut counts from western Tennessee valley sites such as Ledbetter Landing support this finding (Bowen 1979:143).

Seed utilization in the form of small grains (maygrass, knotweed, chenopod, amaranth, and various legumes), greens (polkweed, purslane), and fleshy fruits (grape, persimmon, honey locust, cherry, plum, hackberry, sumac, bramble, and maypop) are relatively rare in

occurrence in the Tennessee region until Late and Terminal Archaic temporal periods (Yarnell and Black 1985:101-103). First evidence of cultigen use in the southeast occurs in Middle and East Tennessee in the Late and Terminal Archaic time periods--from the Tellico Reservoir, dates of 2500 years B.C. are obtained for early squash remains, 1300 years B.C. for bottle gourd, and 2000 years B.C. for maygrass (Chapman and Shea 1981). In the nearby Watts Bar Reservoir in southeast Tennessee, early sunflower has been dated to 900 years B.C. (Brewer 1973).

Faunal data from these same time periods in Tennessee are poorly represented and reported. For example, Chapman (1985:151) notes the virtual absence of faunal remains from the Late Archaic in the lower Little Tennessee River valley due to poor bone preservation. In the western Tennessee valley, Lewis and Lewis (1961:17, 20) designate mammal bone, in particular that of deer, as the most frequent faunal remain found throughout the three Eva components. However, it must be noted that modern faunal analyses employing different analytical techniques (such as calculation of MNI) might produce varying results.

Interestingly, Lewis and Lewis (1961:20) note a decrease in deer bone frequency from the Eva to the Three Mile phase. They hypothesize from this a reduction in the deer population during Three Mile phase times due perhaps to the warming and drying effects of the Altithermal and/or

overexploitation of this resource by the human inhabitants. They also use environmental change to explain the disappearance of mussel shell within the final Big Sandy component at Eva. The end of the Altithermal by this time (and the onset of the cooler Medithermal period) is thought to result in increased precipitation and water levels and thus more inaccessible shell resources. Alternatively, Lewis and Lewis (1961:20) also suggest that a change in the course of the Tennessee River could have been responsible for this shell variability. While recent sediment core pollen analyses from two Middle Tennessee sites do provide support for the presence of a possible Altithermal warming and drying trend from 6000 to 3000 years B.C. (Chapman 1985:149; Delcourt 1979), the impact of such an environmental change upon faunal resources in upland or floodplain regions of Middle and West Tennessee is unknown.

Thus, as stated above, faunal data reflecting the importance of this food source to Archaic inhabitants are limited. It can only be inferred from the wide availability of animal resources in the region at this time and from tool technology and probable functions, that these foods were utilized, but to what extent remains speculative. In addition, the great quantities of mussel shell at most of these sites reflect the relatively great importance of this food source in the Middle and Late Archaic.

For the purposes of this dissertation, more important than what was eaten in the Middle and Late Archaic was how the material was prepared (or not) (see Brace 1977). This, of course, can only be inferred from such indirect sources as ethnohistoric analogies or paleofecal analyses. M. Smith (1982:68) has provided an excellent review of such Archaic paleofecal evidence. She concludes that the documented large degree of indigestible floral and faunal fragments in the Archaic diet indicates minimal preparation of food remains. Thus, rough-textured and relatively unprocessed food resources characterize the Archaic food bolus. The rather ubiquitous presence of manos and metates at most Tennessee Archaic sites (for example, the Anderson site [Lindstrom and Steverson 1987]), as well as the presence of parching and charring of many Tennessee Archaic paleobotanical remains, suggest at least some processing of plant food remains (Chapman 1985:147). And, the cave context for much of the paleofecal data cannot be considered to reflect normal food processing modes. As for mussel shell, Trinkley (1985:117) hypothesizes a steaming activity pattern from a shell ring midden from the Early Woodland Lighthouse Point site in South Carolina. It cannot be ascertained from the western and Middle Tennessee valley Archaic sites, given the nature of archaeological recovery there, if their method of shell preparation was similar. In sum, while at least some processing of Archaic

foodstuffs (hickory nuts, for example) must have occurred for ingestion to be possible, overall the amount of Archaic food processing appears to have been minimal. A relatively hard-textured food bolus is thus indicated for the Archaic.

Archaic Summary

A relatively nomadic hunting and gathering settlement and subsistence model has been proposed by several researchers for Middle and Late Archaic inhabitants of the Middle and western Tennessee valley. This model involves optimal utilization of food resources from a variety of ecozones, possibly on a seasonal basis. Dietary items most likely to have been of importance in this exploitation include nut crops and riverine shell deposits, as well as mammals such as white-tailed deer. Seed exploitation begins in the Late or Terminal Archaic. Preparation of these food items for consumption appears to have been slight to minimal. Thus, mastication of a rather hard-textured food bolus is indicated for the Archaic inhabitants.

The Woodland Data Base

Introduction

Skeletal remains from six sites, all located within Bradley, Meigs, Rhea, and Roane counties of East Tennessee, form the Woodland sample (Figure 3.1: page 62). Two of these--Candy Creek and Hiwassee Island--were primarily

explored as part of WPA, TVA, and the University of Tennessee's joint investigation of the Chickamauga Reservoir inundation impact area from 1936 to 1939 at the time of the construction of Chickamauga Dam (Lewis and Kneberg n.d.a., 1941). The four remaining sites (all mounds) were partially excavated in 1940 and 1941 by representatives from the same parties listed above due to inundation impact assessment associated with the Watts Bar Reservoir (Cole 1975b). Only one of the six site areas has been formally described and interpreted (Hiwassee Island--Lewis and Kneberg 1946); thus, the author relied on original field notes and secondary summaries for reviews of the other five sites. Once again, both new and old site numbers are presented.

Candy Creek (40BY14 or 17BY14)

Located on the left bank of Candy Creek at its confluence with the Hiwassee River, the Candy Creek site was excavated from January to April, 1939 (Lewis and Kneberg n.d.a., 1941). The site is described as a small village area located on a restricted table of land about five feet higher in elevation than the surrounding topography (Lidberg n.d.). Much evidence of soil erosion and flooding is noted. A test trench directed through this table of land revealed no visibly inherent stratification; thus, further excavations were in arbitrary six-inch

levels. Approximately 17 features were located--most of these were fire or midden pits; however, one feature is described as evincing a possible postmold pattern (Lidberg n.d.). Very little shell or non-human bone were present.

The wide presence of limestone-tempered ceramic sherds has prompted Lewis and Kneberg (1941:32-33) to assign the primary occupation at this site to the Woodland temporal period. The Candy Creek Phase is readily distinguishable from the later Hamilton Phase on the basis of certain ceramic wares--greater frequencies of sand-tempered as well as limestone-tempered stamped ceramics are more common at Candy Creek Phase components (Schroedl and Boyd 1986). However, the presence of several shell-tempered whole vessels in association with a few Candy Creek site burials suggests Mississippian use of the site as well.

While the Candy Creek site is inundated at full pool levels of the Chickamauga Reservoir, pool fluctuation allowed the visitation of the area by the author in March of 1986 (Boyd 1986a). No ceramic remains were noted; however, an abundance of lithic debitage, fire-cracked rock, projectile points, and a possible intact aboriginal feature were observed. Approximately 100 burials were originally located at Candy Creek, the majority being very fragmentary. Only nine of these are utilized in the present study, all of which represent the Woodland occupation at the site.

Hiwassee Island (40MG31 or 42MG31, 46MG31)

This large island, originally located at the confluence of the Hiwassee and Tennessee Rivers in Meigs County, Tennessee (seven miles south of Dayton), actually contained over a hundred archaeological regions. Only two of these units (Units 42 and 46) are considered in the present study. Investigation of this island began early: J. W. Emmert, representing the Bureau of American Ethnology (under the direction of Cyrus Thomas [1894]), was one of the first to explore the island in 1885. Twenty-four mounds were identified on the island at this time. In 1914 and 1915, Clarence B. Moore conducted partial excavations of the area (Moore 1915), including Unit 46. In 1922, M. R. Harrington published a monograph focusing primarily on his activities at Hiwassee Island. He identified 16 mounds, excavating two of these fully and two others partially. However, his excavations did not include the two mounds used in this study. In addition, he also excavated the village area at the upper end of the island. As a result of this work, Harrington (1922:143-144) allocated three separate occupation regions to three distinct cultural groups--the early "Round Grave" people utilizing crude soapstone vessels, an unnamed later group without these same vessels (but with "unsophisticated" pottery wares and a tendency toward partial cremation of

their dead), and a third "Cherokee" group manifesting celts, triangular projectile points, and assorted bone implements.

From April, 1937 to April, 1939, this island was investigated jointly by TVA, WPA, and the University of Tennessee. At this time, only six mounds (five conoidal and one truncated) were readily recognizable as such. Also present were numerous small shell middens, a large habitation midden area, and a supposed artificial pond (Lewis and Kneberg 1946:1, 2).

Unit 42 was located opposite the Hiwassee River mouth (approximately one-quarter mile from shore) and measured eight feet high and 55 feet in diameter (Lewis and Kneberg 1946:23). Three mound construction phases were present, in addition to abundant mussel shell and 78 human burials. Forty-three of these burials were attributable to the earliest Hamilton Focus, while two belonged to the later Dallas component, 23 were historic, and ten were unidentifiable as to temporal context. In this study, three individuals are utilized from this unit, all of which represent the earliest Hamilton component.

Unit 46, also reflecting three mound construction phases, was similar in diameter to Unit 42, but its height of 9.6 feet made it the tallest conical mound remaining at the time of this excavation (Lewis and Kneberg 1946:24). One hundred and twenty-five human burials were recovered

from this unit, of which 117 were attributable to the Hamilton component. Two of these Hamilton-associated individuals are utilized in this study.

Three components are attributed to Hiwassee Island by Lewis and Kneberg (1946). The earliest (Late Woodland) Hamilton component is found at the majority of the conoidal burial mounds as well as numerous small midden areas. The later Hiwassee Island component exhibits many structure patterns and assorted midden deposits and is an Early Mississippian manifestation, while the final Dallas component also contains structures and the village deposits at the head of the island (Lewis and Kneberg 1946:34) and is considered Late Mississippian in temporal affiliation.

Alford (40RE4 or 10RE4)

Located in an apparent cluster of mounds on the R. H. Alford Farm, this area was about two miles south of Kingston in Roane County, Tennessee. This particular mound comprised part of a group of five mounds about 3000 feet from the Tennessee River, while five others were found closer to the water (about 600 feet) (Cole 1975b:43; Walker n.d.a.). While brief excavations by Moore (1915) focused on the mound group closest to the river, in 1940 all of the remaining mounds were surveyed by Walker (n.d.a.). Unit 10 was excavated at this time.

Five construction phases were defined for the mound at Unit 10. And, 28 human burials were noted as inclusive to

these layers, with the majority occurring in the third and fourth construction stages (Cole 1975b:45; Walkner n.d.a.). Only one of these individuals could be included in the present study. Based on recent dating of southeastern ceramic artifacts (Kimball 1985; Lafferty 1981; Schroedl et al. 1985), the presence of limestone-tempered plain ceramics in the mound fill suggests a Late Woodland date for this mound.

Wilson (40RE6 or 23RE6)

Seven mounds were located on land owned by Dr. Charles Wilson approximately a mile from Rockwood Landing on a bluff overlooking the west bank of the Tennessee River. Although the mounds were noted by Moore (1915), formal excavation of them did not occur until late 1940 and early 1941 (Burroughs n.d.).

Unit 23 was a mound exhibiting three construction phases. Unstemmed as well as stemmed projectile points, conch columellae, shell beads, and limestone- and grit-tempered ceramics were found throughout the mound fill (Burroughs n.d.; Cole 1975b:46-47). In addition, 19 human burials were recovered from the mound--17 from the earliest Phase A and one each from Phases B and C. Only two of these individuals are included in the present study.

Montgomery (40RE8 or 78RE8)

Seven mounds and a village area were situated on the Montgomery Farm eight miles southwest of Rockwood in Roane County, Tennessee. The archaeological areas were located on the right bank of the Tennessee River at the head of Half Moon Island (Nash n.d.a.). In the early 1940s, three of the seven mounds were formally excavated, in addition to portions of the Mississippian village midden area.

Unit 78 was separated from the remainder of the Montgomery mounds because of its placement on a crest of an upland terrace. It was approximately 1000 feet from the village area and measured 50 to 60 feet in diameter and 12 feet high (Nash n.d.a.). Profiled excavations revealed four distinct construction phases. Ceramics in association with all of the mound fill were limestone-tempered. In addition, chipped and smoothed celt, lithic, and faunal remains were noted. Twenty-three human burials were recovered from this mound (Nash n.d.a.). Only one of these could be utilized in the present study.

Hampton Place (40RH41 or 86RH41, 89RH41)

Three and a half to four miles south of the confluence of White Creek with the Tennessee River in Rhea County, Tennessee, five mounds and a village area were located on Hampton Farm (Walker n.d.b.). Only one of the mounds (Unit 89) and the village area (Unit 86) are discussed here.

Unit 86 represents a stratified Woodland and Mississippian village site approximately three-quarters of a mile northeast of the five mounds. Located on a high terrace on the right (west) bank of the Tennessee River, the unit was 800 feet north of the Mississippian village component represented at Unit 85. Excavations from 1940 to 1941 in six-inch arbitrary levels revealed a fairly large village area (175 feet east/west diameter) with heavy shell deposits. Mississippian and Late Woodland strata were mixed and occurred primarily in the plowzone. The Early Woodland (Stratum II) deposit was separated from the above mixture by a sterile Stratum I. Numerous postmolds were identified in this Early Woodland stratum; however, no structure patterns could be discerned. Artifacts recovered from this deposit included quartz-tempered cord wrapped dowl-impressed ceramics, steatite bowl fragments, hematite, projectile points, and ground stone. In addition, mussel shell was fairly abundant. Twenty-four human burials were associated with the Early Woodland component, all of which were pit burials. Three of these are used in this study.

Unit 89 was one of five Woodland mounds situated on a high bluff above a broad floodplain on the right (west) bank of the Tennessee River (Walker n.d.b.). This mound was the largest of the group, with limestone slabs covering the sides. While it was recorded by Moore (1915), formal investigations did not occur until 1941 (Walker n.d.b.).

However, WPA labor difficulties prevented these excavations from being completed. Three arbitrary mound levels were assigned: A, B, and C; however, little difference could be distinguished between them. Limestone-tempered ceramics were found in the soil deposits. A total of nine burials was located--only one could be included in this study.

Woodland Site Chronology and Settlement

Of the six aforementioned Woodland sites, only one--Unit 86 of the Hampton site--represents an Early Woodland occupation. One other site--Candy Creek--reflects a Middle Woodland manifestation in the form of the Candy Creek Phase (Lewis and Kneberg 1941). No radiocarbon dates exist from either site; however, Candy Creek/Connestee Phase component dates from the nearby Icehouse Bottom site as well as the Westmoreland Barber site in Southeast Tennessee and Garden Creek Mound Number 2 in North Carolina (Chapman and Crites 1987; Keel 1976; Kimball 1985), along with other archaeological data, have led some researchers to suggest a date range of between A.D. 350 and 700 (Schroedl and Boyd 1987:138) for the Middle Woodland period in East Tennessee. Early Woodland is projected at 1000 years B.C. to A.D. 350 for the same area (Lafferty 1981).

Settlement data for the East Tennessee Early and Middle Woodland are lacking. Lewis and Kneberg (1941:30) describe Candy Creek Phase populations as "semi-sedentary"

due to the absence of associated structures. However, numerous circular pits (with and without fire-cracked rock) in relation to this culture suggest the widespread presence of cooking and storage activities. And, circular structures are noted for other Upper Valley cultures (to which Candy Creek is assigned) (Lewis and Kneberg 1946). Circular and rectangular structures are noted at the temporally similar Garden Creek Mound Number 2 in North Carolina (Keel 1976).

Chronological and settlement data for the remainder of the Woodland sites are even more scarce. These sites belong to what has generally been referred to as the Late Woodland Hamilton culture by Lewis and Kneberg (1946) or burial mound complex by Schroedl and Boyd (1986, 1987). Only a single radiocarbon date exists from these sites--a date of A.D. 1020 +/- 150 years was obtained from the Alford mound deposits (Crane and Griffin 1961:114). Based on other radiocarbon dates from the nearby McDonald mounds (Schroedl 1973) as well as from 40RE124 (Schroedl 1978a), Schroedl and Boyd (1987:140) assign a date of between A.D. 700 and 1200 to the Hamilton mortuary complex.

Thus, the integrity of the Late Woodland Hamilton "culture" as defined by Lewis and Kneberg (1946) has been severely called into question (Schroedl 1978a; Schroedl and Boyd 1986, 1987). Radiocarbon dates from Hamilton mounds (Schroedl 1978a) clearly indicate that this burial pattern

was used by Late Woodland and Early Mississippian cultures. Because no residential characteristics (structures, features, etc.) have been directly associated with these burial mounds, the phenomenon must be considered a burial complex and not the remains of a distinct culture. For this reason, the skeletal samples from the previously discussed "Late Woodland" mounds used in this study may originate from Late Woodland or Early Mississippian time periods and may crosscut several cultural groups in a restricted geographic region.

Cole (1975b), utilizing two of the mounds discussed in this dissertation (Alford and Wilson) in addition to 12 other Hamilton mounds in East Tennessee, delineates important patterning with regard to this mortuary complex. Through a statistical comparison of over 50 burial characteristics, she notes the consistent geographic spatial clustering of these mounds as well as alignment of burial orientation (e.g., with the sun or river). She isolates 17 variables which were common to most of these mounds (such as mode of interment, mound fill and burial covering types, grave good associations, etc.) and feels that these dimensions best characterize the Late Woodland Hamilton complex. However, the variability with respect to these features leads her to suggest "...the possibility that distinct Hamilton groups rather than a single, uniform

Late Woodland culture may have existed in East Tennessee" (Cole 1975b:87).

Helmkamp (1985:152) describes Late Woodland Hamilton biosocial organization in East Tennessee as "...partitioned into numerous small-scaled socio-political organizations" with "...highly impermeable boundaries at intervals averaging about twelve kilometers" and with a high degree of "local (intra-organizational) integration." He sees a very close evolutionary relationship between these Late Woodland organizational strategies and those seen in the Early and Middle Mississippian of the same area. In fact, he attributes much of the East Tennessee Mississippian period social organization to a Late Woodland in situ origin.

Woodland Subsistence

Due to the absence of abundant shell or other faunal remains at the Candy Creek site, Lewis and Kneberg (1941:30) propose that the gathering of wild plants was the most important subsistence activity of this Middle Woodland group. In contrast, large amounts of mussel shell were recorded from the majority of the Hamilton mounds. Lewis and Kneberg (1941:30) infer the importance of riverine resources for these inhabitants, in addition to the gathering of plants. Absence of floral data from any of these sites makes these statements speculative at best.

More recent investigations of subsistence economies at

other Woodland sites in the Tennessee area have produced more substantial information. In Yarnell and Black's (1985) review of the literature concerning paleobotanical remains in the region, they note continued high frequencies of nutshell remains (hickory, walnut, acorn) throughout the Woodland in East Tennessee contexts; however, a small, gradual decline in these resources (particularly walnut) occurs from late Middle Woodland to late Late Woodland.

Seed plant utilization increases substantially in the Woodland period compared to the Archaic. Early cultigens previously discussed (squash, gourd, sunflower) which appear in the southeastern paleobotanical record in the Late and Terminal Archaic continue to be of importance throughout the Woodland period of East Tennessee. And, for the first time, other cultigens such as corn begin to appear. An Accelerated Mass Spectrometry date of a maize kernal from the Icehouse Bottom site in the Tellico Reservoir of East Tennessee produced a date of 1775 +/- 100 years B.P. (or A.D. 175) (Chapman and Crites 1987:352). Other radiocarbon dates from corn-containing contexts at this site indicate an average date of A.D. 439 +/-75 years (Chapman and Shea 1981). The above dates represent the earliest evidence for the occurrence of maize in the southeast (Chapman and Crites 1987; Yarnell and Black 1985). However, extensive utilization of these cultigens apparently does not occur until the Mississippian time

period. Other (non-cultigen) seed plants such as those of small grains (knotweed, for example), greens (pokeweed, purslane), and fleshy fruits (grape, persimmon) continue to be of great importance throughout the Woodland period of East Tennessee (Yarnell and Black 1985). Similar patterns in plant food utilization have been noted by Crites (1985, 1987) for Middle Tennessee.

Few faunal remains were recovered from any of the Woodland sites used in this study. However, faunal data from other East Tennessee Woodland sites indicate a continued use of such resources as white-tailed deer, squirrel, raccoon, eastern box as well as softshell turtle, fish like freshwater drum, and assorted avians (Cridlebaugh 1981; Schroedl 1978b).

The most important innovation in the Woodland period of Tennessee, however, was the adoption of clay pottery for use in food processing. Radiocarbon dates ranging from 1000 to 700 years B.C. from Swannanoa Phase crushed quartz ceramics from the Phipps Bend site in East Tennessee (Lafferty 1981:500, 506) represent some of the earliest pottery in the Tennessee region. Limestone-tempered pottery appears slightly later in this region (700 to 600 years B.C.). The use of pottery results in a more efficient food processing technology primarily because foods can now be cooked or boiled at higher temperatures for much longer periods of time (Braun 1983; Munson 1988).

Munson (1988:13) notes a 10-25% caloric gain associated with the boiling of animal products into soups. In addition, undesirable (e.g., poisonous) or peripheral (e.g., oils) food substances can be extracted from the primary food substrate. Munson (1988) views the adoption in the Early Woodland of clay pottery as a primary factor in the development of larger and more sedentary groups in the Midwest and regions of Eastern North America at this time. For the present research, this very significant technological innovation results in greater processing of food substances. In short, a softer-textured food bolus is indicated for the Woodland period.

Woodland Summary

Very little settlement information exists pertaining to the Early, Middle and particularly Late Woodland skeletal samples utilized in this dissertation. In fact, the validity of the distinctiveness of Late Woodland Hamilton as a culture has been challenged. The presence of primarily mortuary-related information with regard to the Late Woodland Hamilton era in East Tennessee must lead one to entertain the possibility that this represents a mortuary complex (and not a culture) extending possibly into the Early Mississippian and involving perhaps more than one cultural group.

Available subsistence information supports the

continued use of nut crops such as hickory and acorn, but with the gradual replacement of these by seed crops by the Late Woodland. And, evidence for early cultigens such as maize begins to accrue, although extensive reliance on such foods does not occur until the Mississippian. The most important change, however, is a technological one--the documented adoption of clay pottery. All of these factors result in a softer-textured Woodland food bolus compared to the Archaic.

The Mississippian Data Base

Introduction

Six sites--one in Middle and the remainder in East Tennessee--form the Mississippian skeletal sample used in the present study (Figure 3.1: page 62). Four of the six (Mouse Creek, Rymer, Ledford Island, and Dallas) were first formally investigated from 1936 to 1939 as a result of impact assessment related to the construction of Chickamauga Dam and Reservoir (Lewis and Kneberg n.d.a., 1941). The other two sites (Toqua and Averbuch) have been studied more recently; however, both the quantity and quality of information available from all of these sites are impressive. Both old and new site numbers are listed for the older sites.

Ledford Island (40BY13 or 16BY13)

Located on the southern end of a large island in the Hiwassee River approximately one and a half miles downstream from the mouth of North Mouse Creek in Bradley County, Tennessee, the Ledford Island site was investigated in 1938 and 1939. The site was roughly 2300 feet from the area of Candy Creek. Excavations at this time revealed a village area containing 16 structures, numerous hearths and burned clay regions, and an open plaza area notably devoid of cultural material (L. Sullivan 1986:278, 281-283). In addition, a palisade and parallel ditch were located around the southern and western end of the site; however, it is not known whether these were contemporaneous with each other (L. Sullivan 1986:283-286).

Lewis and Kneberg (n.d.a., 1941) have identified two components at this site. A small Candy Creek component (Middle Woodland) was overlain by a much more extensive Late Mississippian Mouse Creek Phase occupation. However, more recent analyses of Ledford Island lithic remains has led L. Sullivan (1986:289) to delineate small Early, Middle, and Late Archaic components as well. In addition, the Woodland ceramics from this site may reflect Middle Woodland Connestee and late Early Woodland Long Branch Phase as well as Candy Creek Phase occupations. No

features could be assigned to any of the Archaic or Woodland components.

Approximately 468 human burials were recovered from the site. Eighty-nine of these were clustered in a probable cemetery area to the northeast of the village region (L. Sullivan 1986:293). Many of the remaining individuals were found in association with village structure floors (Boyd 1984:14). Thirty-five Ledford Island individuals are included in the present study. All of these originate from the Mouse Creek Phase component at the site.

Ledford Island is not completely inundated by the Chickamauga Reservoir at full pool. Visitation of the site by the author in March of 1986 revealed abundant lithic, ceramic, and faunal remains, including additional human bone (Boyd 1986a:46-48).

Rymer (40BY11 or 15BY11)

The Rymer site was located on a high river terrace overlooking the south bank of the Hiwassee River one mile above its confluence with South Mouse Creek in Bradley County, Tennessee. The area originally encompassed three Hamilton mounds in addition to the Late Mississippian village component--approximately one-half mile separated these two regions (L. Sullivan 1986:261). Excavation of the village area in 1937 and 1938 revealed over 20

structures in addition to numerous other features such as hearths and midden deposits. While the main component of the Rymer village is attributable to the Late Mississippian Mouse Creek Phase, L. Sullivan (1986:271), on the basis of projectile point morphology, notes the presence of small Archaic and Woodland occupations as well. However, no features could be assigned to either of these latter components.

One hundred and sixty-eight burials were located at the Rymer site (L. Sullivan 1986:272). Most of these were in association with village structures. Of this total, only 17 could be used in the present study. All represent the Late Mississippian occupation at the site.

Mouse Creek (40MN3 or 3MN3, 4MN3)

Located in McMinn County, this site was about one mile downstream from Rymer on the north bank of the Hiwassee River. In 1938, excavations concentrated on two distinct units (3 and 4) at the site. Approximately 1000 feet separated these units, with no cultural debris observed between them. Ethnographic records denote the presence of considerable flooding and erosional activity in this region; however, it cannot be ascertained whether two separate occupations are represented by these units or just one (Lewis and Kneberg 1941; L. Sullivan 1986:237).

The north unit (4MN3) excavations produced approximately 11 structures in addition to numerous

hearths, storage pits, and a palisade (L. Sullivan 1986:240, 243-244). Eighty-five burials were excavated from this unit (L. Sullivan 1986:259)--only two of these could be included in the present study. Lewis and Kneberg (n.d.a.), based on the presence of limestone-tempered ceramics, suggest the existence of a Late Woodland Hamilton component at this unit. In addition, L. Sullivan (1986:245, 259) notes the presence of Middle and Late Archaic projectile points to the west and southwest of the unit; however, again, no definite feature associations could be made. The primary occupation at the unit is the Late Mississippian Mouse Creek Phase, and it is this component from which the individuals used in the present study are derived.

Investigations at the southern unit (3MN3) also revealed 11 definite structures and numerous hearths and pit features. In addition, the remains of a Late Woodland Hamilton mound and associated borrow areas were located in the south-central portion of the the excavated unit (L. Sullivan 1986:253-254). Small Late Archaic and Early Mississippian (Hiwassee Island) occupations were also identified at this unit; however, the major component is that of the Late Mississippian Mouse Creek Phase (L. Sullivan 1986:260). Eighty-one burials were recovered from this unit (L. Sullivan 1986:260). Of this total, only three (from the Late Mississippian component) could be

included in this study. Skeletal remains from the Mouse Creek site, in addition to Rymer and Ledford Island, have been described by Boyd (1984).

The three aforementioned sites, all located within three miles of each other in the Chickamauga Reservoir of Southeast Tennessee, have been used by previous researchers (Lewis and Kneberg n.d.a., 1941) to define the Mouse Creek Phase. This phase has, in the past, been seen as distinctly separate from the other Late Mississippian sites to be discussed next--Dallas and Toqua representing the Dallas Phase and Averbuch reflecting the Middle Cumberland culture.

Dallas (40HA1 or 7HA1, 8HA1)

Also in the Chickamauga Reservoir, this site was on the east (left) bank of the Tennessee River at its confluence with Maddux Branch opposite the foot of Dallas Island. Two units were represented at the site--Unit 7 encompassed the village area, while Unit 8 was the mound to the south of the village. Excavations from November, 1936 to March, 1937 unearthed approximately 20 structures, numerous hearths, cache pits, and other cultural remains, as well as evidence for a fortification structure surrounding the village area (Nash n.d.b.). Nash (n.d.b.:3) identified three distinct strata from each unit, with the primary occupation level (Stratum II) evidencing abundant shell-tempered ceramic remains. Four distinct

mound stages were noted, with remnants of a structure located on the Primary Mound area (Nash n.d.b.).

Approximately 278 individuals were recovered from this site, of which 117 were from the village area. Thirty-eight Dallas skeletons are included in the present Mississippian sample--16 from Unit 7 and 22 from Unit 8. All reflect the Late Mississippian occupation at the site.

Toqua (40MR6)

The Toqua site was originally investigated in 1884 by John W. Emmert, under the direction of Cyrus Thomas of the Bureau of American Ethnology (Thomas 1894). At this time, two substructure Mississippian mounds as well as a village area were tested. The site was again visited in the 1930s by George D. Barnes, a commercial collector (Polhemus 1987). However, it was not until 1975 through 1977 that extensive and formal investigation of Toqua occurred as a result of the impending inundation by the Tellico Reservoir. The site was located on the south bank of the Tennessee River about four and a half miles east of Vonore, Tennessee. It was a multicomponent site, exhibiting several periods of aboriginal occupation (Archaic through Mississippian); however, the Late Mississippian Dallas Phase component was the most extensive and was the focus of the more recent investigations.

Excavation of Mound A to the west of the site revealed

nine construction phases, while that of Mound B to the east identified two. Numerous structures and other features, as well as a plaza and palisade, characterized the Toqua village area. Approximately 477 human burials representing 500 individuals were recovered as a result of these later excavations. These have been extensively described by Parham (1982). Only fourteen of these skeletons could be used in the present analysis, all representing the Late Mississippian occupation at the site.

Averbuch (40DV60)

Averbuch represents the largest formally investigated Middle Cumberland site and skeletal series to date. Situated on the southern portion of a hill 300 meters east of Drake Branch in Davidson County, Tennessee, it was located between the Nashville Basin and Highland Rim of Middle Tennessee (Berryman 1981; Reed 1984). The site was systematically tested and excavated from 1975 through 1978 by the University of Tennessee and the Tennessee Division of Archaeology as a result of impact mitigation from construction of a subdivision.

Excavations at the site revealed a Mississippian village area and three associated cemeteries. Abundant cultural remains were recovered (see Klippel and Bass 1984); however, it was estimated that because of construction, over 30% of the site had already been destroyed (Berryman 1981:8). A total of 887 individuals

was recovered from Averbuch--many of these were from stone-lined graves. These have been extensively described by Berryman (1981, 1984) and Eisenberg (1986), while all other aspects of the site have been presented by Klippel and Bass (1984). Eighty-six Averbuch skeletal individuals are included in the present study. All are representative of the Late Mississippian temporal period.

Mississippian Site Chronology and Settlement

All of the previously discussed Mississippian sites belong to the Late Mississippian temporal period of Middle and East Tennessee. Chronological dating information for the three Mouse Creek Phase sites (Ledford Island, Rymer, and Mouse Creek) is rare due to the time at which these sites were excavated. Lewis and Kneberg (1941) have proposed a rather late date (after A.D. 1540--contact period) for the phase based partially on the presence of a small number of European trade items in the archaeological collections from the sites. However, a recently obtained date from a paraffin-decontaminated wood sample from Ledford Island produced a dendrocalibrated date range of A.D. 1420 - 1470 (L. Sullivan 1986:125-126). This, in addition to other archaeological data, has led L. Sullivan (1986:127) to suggest a temporal span of A.D. 1400 to 1600 for the Mouse Creek Phase. The Ledford Island site probably represents the longest occupation, thereby

temporally overlapping with the Rymer and Mouse Creek site time periods; however, it cannot be determined if these latter two sites are contemporaneous (L. Sullivan 1986:510). The presence of Spanish trade items, as well as a radiocarbon date of A.D. 1530 +/- 98 years (corrected) from a standing charred wall post from a structure at the supposed Mouse Creek Phase town of Hampton Place (40HA146) at Moccasin Bend in Chattanooga, Tennessee (McCollough and Bass 1983; McCollough and Alexander 1987), suggest similar dates for the Mouse Creek Phase.

Similarly, dating of the Dallas site is problematic--no absolute dates exist. Lewis and Kneberg (1941, 1946) have viewed the Dallas Phase [Focus] as immediately preceeded by the Hiwassee Island Phase [Focus]. Subsequent radiocarbon dating of other Dallas Phase sites has supported this sequence (Hatch 1976), although the "replacement" model of Lewis and Kneberg regarding Dallas and Hiwassee Island Phases has not received support. These radiocarbon dates have led some researchers (Hatch 1976; Parham 1982; L. Sullivan 1986) to suggest date ranges of about A.D. 1200 to 1600 for the Dallas Phase. Recent radiocarbon dates from the Toqua site support this temporal span. Six Dallas Phase dates from this site range from 605 +/- 120 years B.P. (A.D. 1345) for Structure 14 on the initial construction stage of Mound A to 280 +/- 105 years B.P. (A.D. 1670) for the latest structure just beneath the

plowzone on the summit of Mound A (Kimball 1985:288; Tellico C14 Dates on file, Frank H. McClung Museum, Knoxville, Tennessee).

The Middle Cumberland culture is believed to date to between A.D. 1200 and 1400 (Berryman 1981:3; also see Broster 1988). Radiocarbon dating at Averbuch, in addition to analyses of archaeological remains from the site, have placed the Averbuch site in the 14th century A.D. (Klippel and Bass 1984).

L. Sullivan (1986, 1987) has recently documented settlement as well as mortuary patterning within and between the three Mouse Creek Phase sites. Households containing single family groups appear to be the primary cohesive entity in Mouse Creek Phase society. In terms of status and rank, the Mouse Creek Phase does not conform to the traditional chiefdom model of Late Mississippian sociopolitical organization in the Southeast--status differentiation was based primarily on age and sex and perhaps personal merit. L. Sullivan (1986:506) notes that the social organization exhibited by the more egalitarian historic Cherokee and Creek form a better analogy for the Mouse Creek Phase. She hypothesizes that, of the three Mouse Creek Phase sites, Ledford Island was perhaps the most prominent. The presence of the plaza, council house, and cemetery area denotes the importance of this site in Mouse Creek Phase society. She suggests the possibility

that "...the Rymer and Mouse Creek sites represent outlying settlements of the same social and political entity" (L. Sullivan 1986:511).

In contrast, the Dallas Phase has been characterized as a ranked, chiefdom-level society, involving a greater amount of ascribed rather than achieved status (Hatch 1976; Parham 1982; Polhemus 1987). For example, Hatch and Willey (1974) have found significant differences in Dallas Phase (representing several Dallas sites in East Tennessee) male stature estimates correlating with status indicators. High status males (as measured by proximity to mound as well as number and type of artifact associations), in general exhibit higher stature compared to lower status ones. The female pattern is more equivocal.

In addition, trace element comparisons of high (mound associated) and low status Dallas subadults by Hatch and Geidel (1983) delineate greater amounts of plant (corn?) material in the low status diet, while the diet of higher status subadults reflects a greater balance of vegetable and meat sources. Comparisons of transverse lines as well as cortical bone thicknesses across different Dallas status groups reveal similar patterning (Hatch et al. 1983). Non-mound males manifest greater amounts of subadult transverse lines (and thus stress) than higher (mound) status males. And, cortical bone is thinner (implying less strenuous physical activity) in higher status Dallas

individuals. These results not only strongly suggest the effect of social organization upon biological parameters, but reinforce the presence of strong social patterning at Dallas Phase sites (Hatch et al. 1983). However, at Toqua, Parham (1982) could find no biological evidence for this kind of status differentiation--there are no discernible differences in mortality, pathology occurrence, stature, or nutritional indicators (e.g., porotic hyperostosis) across the status groups. He concludes that status at Toqua may have been achieved rather than ascribed.

Klippel and Reed (1984) note the position of the Averbuch site as somewhat aberrant in spatial location in comparison to other Middle Cumberland (and Dallas Phase) sites. Unlike these more mainstream, floodplain-associated areas (see Broster 1988), Averbuch represents an alternative site choice which reflects optimal utilization of fertile phosphate-enriched soils. Jolley (1983), however, views the presence of substantial salt springs and subsequent associated animal resources as well as an extensive trail network "hub" as primary factors in settlement density in the Late Mississippian Nashville Basin area.

As can be seen from the previous discussion, the six Mississippian sites (and the three "cultures" to which they have been designated) exhibit numerous similarities with each other. Temporally, all of the Late Mississippian site

samples utilized in this dissertation may be roughly contemporaneous. And, five of these sites are in close geographic proximity to each other. Because of these similarities in temporal and spatial affinities, many questions have been raised regarding the genetic and ethnic relationships between the three cultural groups they represent. For example, Lewis and Kneberg (n.d.a., 1941, 1946), on the basis of variability with regard to Dallas and Mouse Creek Phase ceramics, architectural and mortuary patterning as well as community plan, deny an association between the Mouse Creek and Dallas Phase populations. Instead, they hypothesize a Middle Cumberland origin, and thus, affiliation, for the Mouse Creek Phase. More recent analyses of biological (Boyd 1984, 1986b) as well as archaeological (L. Sullivan 1986) dimensions involving these samples have not supported this hypothesis. Evidence for a genetic or ethnic relationship between Mouse Creek and Dallas Phase individuals is increasing (Boyd 1984, 1986b; Boyd and Boyd 1987; Schroedl 1986).

Thus, three possible scenarios can be proposed regarding ethnic relationships between these three cultural groups, particularly those of Mouse Creek and Dallas. First is the potentiality that Mouse Creek and Dallas do represent distinct cultural groups living contemporaneously but maintaining their own cultural uniqueness. Given the increasing biological and archaeological data regarding

relationships between these two skeletal samples (Boyd 1984, 1986b; Boyd and Boyd 1987), this seems unlikely.

Secondly, Mouse Creek Phase settlements may represent more hinterland, frontier occupations subsumed within the larger Dallas Phase organizational strategy. Finally, it has been proposed that perhaps Mouse Creek occupations represent, in some areas, the collapse of Dallas Phase societies (Schroedl 1986) and potential antecedents to the later occurring historic Cherokee. Helmkamp's (1985) model for East Tennessee biosocial organization in the Mississippian period can be seen as support for this idea--the increase in social integration as well as boundary permeability throughout the Mississippian may have necessarily resulted in a decline in status differentiation due partially to the increased inability of high ranking members to control the ranking system. Further consideration of this problem is beyond the scope of this dissertation.

Mississippian Subsistence

As far as can be determined, subsistence economies of the three Late Mississippian cultures discussed above were similar (Klippel and Bass 1984; Schroedl 1986:129). Wild plant foods as well as local fauna (like white-tailed deer, assorted birds and fish) continue to be gathered and hunted (Bogan 1982). Exploitation of early cultigens (such as

squash, gourd, and sunflower) originating in the Terminal Archaic and Woodland periods of Tennessee continues, and, in fact, increases within the Mississippian. And, new cultigens such as beans and particularly maize begin to dominate Mississippian subsistence economies. Thus, diets within this temporal period begin to focus on agricultural foodstuffs, with a concomitant reduction in nutshell resources (Chapman and Shea 1981; M. Smith 1982).

Buikstra et al. (1988), in a comparison of stable carbon isotope values from a diachronic sequence of human skeletons from the Nashville Basin of Middle Tennessee (including Averbuch), have found a dramatic rise in positive $\delta^{13}\text{C}$ estimates correlating with the onset of the Mississippian period. They attribute this pattern to increased maize dependence in this region and characterize this dietary shift as rapid and intensive; however, the presence of possible non-dietary factors in carbon isotope analyses (for example, variability in carbon isotope values across different environmental conditions or maize types) is yet to be clarified.

Although regional variability in terms of Mississippian subsistence exploitation of agricultural cultigens has been documented (Masters 1987; Milner 1982), perhaps most important for the present research is the continued use of clay pottery in food processing. The Mississippian use of shell as a tempering agent results in better bonding with

clay and a harder and more resistant vessel wall (Bronitsky and Hamer 1986). This allows heating at greater temperatures for longer periods of time. M. Smith (1982:70-72) reviews ethnographic sources which detail extensive preparation of food resources in the southeastern contact period. If ethnographic analogies between these proto-historic and historic groups are accepted, then processing techniques ranging from the boiling of corn into a meal soup to the shredding and pounding of meats before cooking are suggested (see Swanton 1948). In short, M. Smith (1982) hypothesizes a soft-textured food bolus as dominating the Late Mississippian Tennessee diet.

Biological research supports this contention. For example, M. Smith (1982, 1986, 1987) has compared oral morphology of Archaic (involving the Cherry, Eva, and Anderson sites) and Mississippian (Toqua) skeletal remains. She has found significant increases in number and locations of dental caries in combination with a substantial decrease in attrition rates through time. And, antemortem molar tooth loss increases substantially across the temporal samples. Smith attributes these patterned changes to subsistence-related differences across these groups--large amounts of unprocessed foods result in high Archaic attrition levels, while intensive reliance upon maize agriculture in the Mississippian period results in greater caries and periodontal disease leading to molar tooth loss.

The decrease in tooth size documented across these Tennessee populations from the Archaic to Mississippian periods (Hinton et al. 1980; F. Smith et al. 1980) taken with evidence for decreased temporomandibular joint and interstitial wear facet sizes (Hinton 1981a) all support the pattern of decreased masticatory stress related to adoption and increased dependence upon a soft-textured agricultural diet. Thus, M. Smith (1982:72) states:

It appears that the variable which has altered the most between the diets of the two samples [Tennessee valley Archaic and Mississippian], apart from the inclusion of the primary domesticates in the latter sample, is the amount of food processing which is performed on the plant food before it is ingested.

Mississippian Summary

The Mississippian skeletal data base includes individuals from six sites reflecting three Late Mississippian cultural manifestations in Middle and East Tennessee. While ethnic and genetic relationships between these cultures are poorly understood, it is felt that the close geographic and temporal similarities as well as comparable ecological adaptations justify the compilation of data from these groups. Similarities in settlement as well as subsistence patterning across the groups support this contention. Documented dietary changes occurring in the Late Mississippian groups primarily involve increased reliance upon agricultural cultigens, particularly maize. However, the greatest change is purported to be in the

texture of the food bolus. Increased technological processing of the food items, such as occurs with use of shell-tempered clay pottery, results in a soft-textured Mississippian food bolus.

The Temporal Series

Table 3.1 summarizes the chronological time period encompassed by the Tennessee skeletal populations utilized in this dissertation. These skeletal remains represent a temporal series covering a period of over 7500 years. This series manifests a dietary shift from a primarily hunting and gathering to an agricultural subsistence economy. While no direct evidence exists supporting a genetic relationship between these Archaic, Woodland, and Mississippian populations, absence of reliable data suggesting large-scale migration of populations into the area (resulting in significant culture change) makes an assumption of continuous predominantly in situ cultural development reasonable. Previous migration models (e.g., Lewis and Kneberg 1946) have not been substantiated by current analyses (Schroedl and Boyd 1987). While it is unreasonable to assume strict genetic continuity over the entire 7500 years (e.g., gene flow must have occurred), it is argued here that in spite of a possible lack of genetic continuity, the functional model for subsistence-related mandibular and craniofacial change can still be tested.

Table 3.1. Summary of Chronology for The Tennessee Archaic, Woodland, and Mississippian Sites Used in The Present Study.

Time Period	Dates
Late Mississippian	A.D. 1200-1600
Late Woodland/ Early Mississippian (Hamilton Complex)	A.D. 700-1200
Middle Woodland	A.D. 350-700
Early Woodland	1000 B.C.-A.D. 350
Late Archaic	3000-1000 B.C.
Middle Archaic	6000-3000 B.C.

Given the geographic and ecological similarities and temporal continuity of the skeletal samples, as well as the extensive documentation in the Tennessee region of gradual subsistence change (replacement of wild nut and seed crops by cultigens), it is unlikely that genetic or ethnic variation would mimic the functional subsistence-related predictions of the present model. In other words, even if these skeletal samples do not reflect a strict temporal series in the genetic sense, functional adaptation in response to documented subsistence change in the restricted geographic (and ecologically similar) region considered should be observable and measurable.

CHAPTER 4

ANALYTICAL METHODS AND PROCEDURES

Introduction

From the 16 previously discussed Tennessee Indian sites, a total of 299 skeletonized individuals was analyzed. Of this total, 82 (27.42%) are representative of Archaic (pre-agricultural), 22 (7.36%) are Woodland or Late Woodland/Early Mississippian (incipient agricultural), and 195 (65.22%) reflect fully Mississippian (intensive agricultural) temporal groups. Both morphologic as well as metric data are collected from these samples. Precedent to this, however, is an evaluation of the age and sex status of the remains--variability in researcher determination of age and sex across the different skeletal samples makes a consideration of criteria used necessary. This chapter addresses these issues, in addition to the particular statistical methods used in data analysis.

Age and Sex Determination

Previous research has shown morphologic and metric variation to exist in the mandible and lower facial region with respect to age (Buschang et al. 1986; Carlson et al. 1978; Guagliardo 1982; Harris et al. 1977; Hinton 1981b; Morant 1936), sex, and race (Harris et al. 1977; Kile

1983). Since all of the present skeletal remains are homogeneous with respect to race, only age and sex will be discussed. All of the skeletal remains utilized in this study had been analyzed by previous investigators with reference to the determination of age and sex. McClung Museum skeletal individuals (which include all except Averbuch and Anderson) were first studied by Lewis and Kneberg (n.d.b.) in the 1930s and 1940s as a result of WPA-associated reservoir projects. Burial cards on file at McClung Museum reflect their demographic assessments. A previous test comparison (involving a 5% random sample selected from Ledford Island, Rymer, and Mouse Creek individuals) by the author delineated significant discrepancies in these older age and sex determinations and those performed recently by the author (Boyd 1984:31-33). More recently, however, a reanalysis of all of these McClung Museum remains has begun as part of a recuration effort headed by Dr. Maria O. Smith. At the time of this study, this project was still ongoing. Thus, the author relied both on this information (where available) as well as her own judgements regarding age and sex of the remains. In the case of Averbuch and Anderson, the author was fortunate to be able to consult Berryman (1981, 1984) and Joerschke (1983), respectively, for confirmation of age and sex determinations of skeletal remains from these two sites.

Aging Considerations

Only adult (roughly 18 years and older) skeletal remains are considered in this analysis. This status is judged by the presence of unification of the epiphyses and diaphyses of the majority of long bones (excepting clavicle) and eruption of the third molars, if present. Since dental attrition is a coded variable used in later analyses, it is not also used as an aging criterion. For the purposes of further analyses, only general adult age categories are necessary; therefore, individuals are promulgated into age categories of 18-29, 30-44, and 45+. Thus, young, middle and old adult age categories are established.

Factors influential in the author's judgement of age include consideration of morphological attributes of the pubic symphysis (McKern and Stewart 1957; Todd 1920, 1921), as well as other degenerative changes such as degree of vertebral osteoarthritic lipping (Stewart 1958), lowering and broadening of the five lumbar vertebrae (Ericksen 1976, 1978a, 1978b), and degree of pre-mortem dental loss. On rare occasions when no appropriate postcranial elements are present, ectocranial as well as endocranial suture closure comparisons to McKern and Stewart (1957:28-30) and Todd and Lyon (1924:345, 351, 357) are made with caution. While this aging technique has been found to exhibit significant

variability (Brooks 1955; Singer 1953:56), more stringent application of the basic suture closure premise has led to a resurgence of this method in the forensic field (Baker 1984; Meindl and Lovejoy 1985).

Sexing Considerations

While small sample sizes, particularly of the pre-agricultural group, preclude the statistical analysis of the data separately with regard to sex (sex was centered in these cases), visual observation of trends with respect to sex is made. Morphologic observations of dimensions of both the innominate and cranium are significant in the judgement of sex. The length of the pubic portion, width of the sub-pubic angle (Bass 1987:200), width of the sciatic notch, degree of build-up of bone upon the sacro-iliac articular surface (Bass 1987:202), presence of a ventral arc or sub-pubic concavity, width of the medial aspect of the ischio-pubic ramus (Phenice 1969:298-300), and shape of the pre-auricular groove (Houghton 1974:381) are all important innominate features considered. Cranial traits noted include browridge size (Bass 1987:81; Keen 1950:69-70), upper eye orbit border shape (dull versus sharp), amount of muscle markings (Bass 1987:81), shape of chin (square versus round) (Bass 1987:81), mastoid process size, and overall appearance (robust versus gracile) (Bass 1987:81; Keen 1950:68-70; Krogman and İşcan 1986).

Curvature of the sacrum (Bass 1987:206) as well as femoral head diameter as compared to Thieme and Schull (1957:249) are used as supplemental sex indicators.

Other Morphological Observations Noted

Franz Weidenreich, in his detailed monograph dealing with the Sinanthropus pekinensis mandibles (1936), was one of the first researchers to present extensive descriptions of non-metric characteristics of the human mandible. This study, along with Larnach and Macintosh's (1971) review of eastern Australian aborigine mandibles and Wolpoff's (1975) comprehensive summary of mandibular features important throughout hominid evolution, serve as the basis for the present non-metric assessment.

Figure 4.1 presents a listing of the various morphological features noted from the mandibular samples analyzed here. There is no question that the assessment of many of these characteristics is subjective. Comparative data outlining feature variability within other mandibular samples are rare. Furthermore, the existence of identifiably patterned variability of many of these traits as well as usefulness of this information in delineating meaningful differences in skeletal form have not gone unquestioned (e.g., see Rightmire 1972; Zegura 1975). Nevertheless, it is primarily because of this dearth of knowledge and comparative data surrounding non-metric

Symphysis Contour
Digastric Fossa Form
Sublingual Fossa Development
Submaxillary Fossa Development
Genial Spine Development
Mandibular Torus Form
Mental Eminence Development
Submental Notch Development
Gnathal Projection
Anterior Marginal Tubercle Development
Mylohyoid Ridge Development
Mylohyoid Sulcus Morphology
Dental Arcade Form
Mandibular Notch Morphology
Gonial Eversion or Inversion Degree

Figure 4.1. Morphological Observations Recorded From The Mandible.

mandibular variation that these features are recorded and explored here.

In addition to the morphologic characteristics noted in Figure 4.1, general impressions regarding origins, pathways, and insertions of the major muscles of mastication on the mandible and cranium are also noted (see Figures 2.1 and 2.2: pages 12, 14). Particular emphasis is placed upon the variability of these anatomical structures with regard to the orofacial masticatory functional complex.

Because the presence of both intentional (including fronto-occipital, lambdoidal, and occipital) and unintentional (post-mortem warping) cranial deformation has been found to significantly affect cranial morphological and metric assessments (Berryman and Owsley 1984), this variable is also noted in the present study. Incidences of cranial deformation (whether due to cradleboarding practices or post-depositional factors) in the Mississippian period samples are widespread. This variable is coded on a simple ordinal-level scale of increasing severity ranging from 1 (absent) through 4 (most severe), regardless of cause.

Traditional differences in attrition rates between populations have been explained primarily in terms of diet. For example, Lavelle (1970), in a comparison of maxillary and mandibular attrition rates across modern as well as

19th century British, Anglo-Saxon, West African, and Australian aborigine dentitions, notes a low attrition rate in the two British samples. This difference is attributed to dietary differences between the groups. However, Molnar (1968a, 1971), McKee and Molnar (1988), as well as Wolpoff (1971a), have all pointed to the variability inherent in tooth wear development and have outlined many factors contributing to the process besides diet (e.g., tooth size, position, and angulation, cusp morphology, enamel thickness, sexual dimorphism, etc.). Age appears to be of primary importance in dental wear variation. Thus, causative agents of human dental attrition are numerous. However, the relationship of diet and dental attrition remains a significant research question to be explored. In this study, dental attrition is coded on an ordinal scale following that originally defined by Molnar (1968b) and later modified by Hinton (1979) and Guagliardo (1982:38-40). Figure 4.2 illustrates the coding format. According to Guagliardo (1982:40):

Category 1 teeth may show some polishing of enamel at points of occlusion, but no exposure of dentin. Category 2 incisors and canines vary from a pin-point or thin line of visible dentin to a stage where even a casual glance discloses the fact of dentin exposure....Classification of Category 3 anterior teeth is quite subjective, but becomes easy and replicable through experience. Dentin exposure is quite pronounced, but plenty of enamel is still present, and the crown as a whole cannot yet be described as a "nub".... Anterior teeth of Category 4 are little more than nubs with little and sometimes no enamel apparent.

INCISORS AND
CANINES

WEAR
CATEGORY

MOLARS

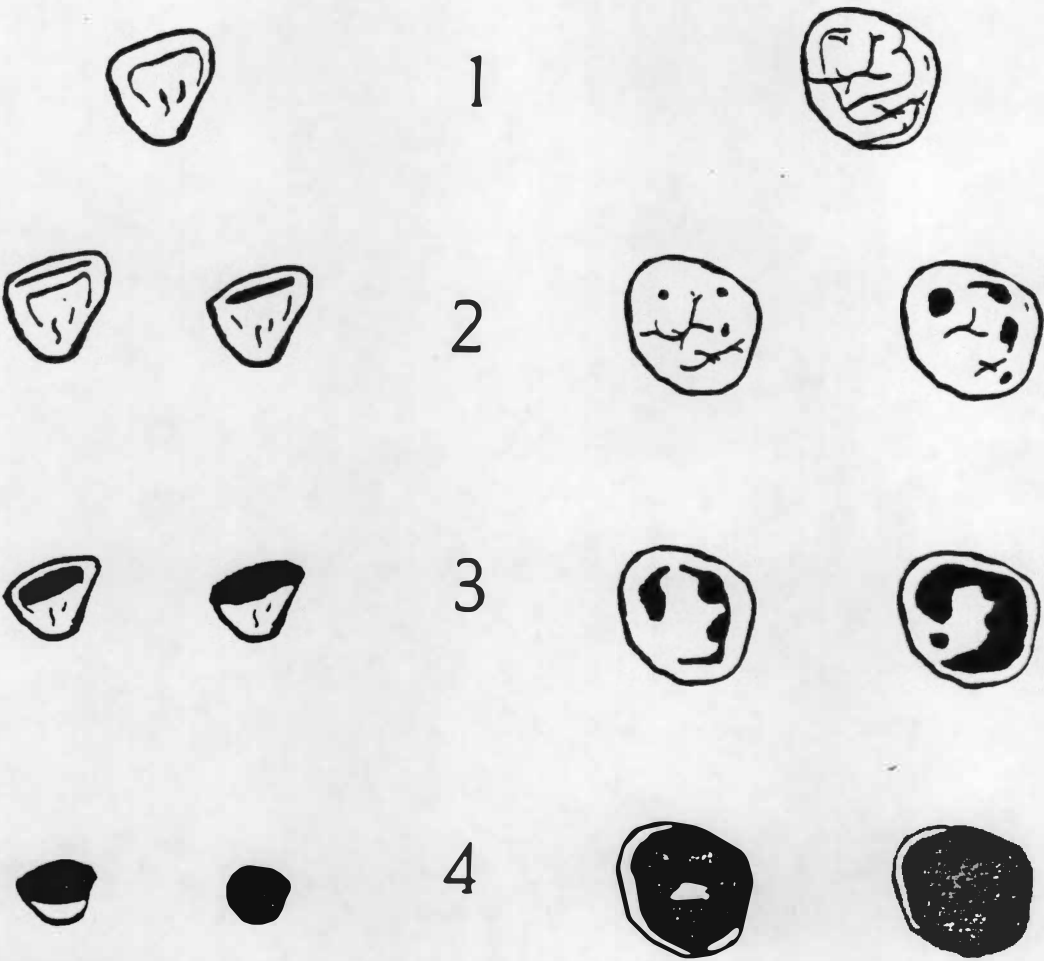


Figure 4.2. Dental Attrition Scoring System (from Guagliardo 1982:39).

Only anterior mandibular teeth are scored for dental attrition. Only one attrition score exists for each individual, due to the averaging of the overall appearance of all the incisors and canines present in each mandible.

Several researchers (Brothwell 1959; Hillson 1979; Mandel 1979; Mayhall 1970, 1977) have noted an increase in caries with a cultural shift to a more modern agricultural-based diet. Visual observations of caries and abscess incidences are recorded across the Archaic, Woodland, and Mississippian skeletal groups.

Finally, the last morphological feature to be noted is that of degree of preservation. Since only well-preserved specimens were selected for inclusion in this study, the particular focus of this variable is identification of degree and location of skeletal reconstruction. These renovations, are, for the most part, the product of previous researchers; however, in a few instances, the reconstruction of mandibles and/or faces was made by the author. A code of 1, indicating the absence of any restructuring of the mandible or face, is fairly rare for these samples. Codes of 2 and 3, denoting slight but reliable amounts of reconstruction in the face and mandible, respectively, are more common. A code of 4 indicates small degrees of restoration in both. In no case, however, are gross and tenuous reconstructions of the

craniofacial and mandibular regions accepted for inclusion in this study.

Metric Variables Coded

A total of 66 metric observations is recorded for each individual in this analysis--36 are mandibular and 25 are facial. In addition, five measurements are taken from each available anterior mandibular tooth for which mandibular dimensions are also obtained. Measurements are, for the most part, restricted to regions of the mandible and lower face for two reasons. First, measurements are selected for inclusion in this study to reflect mandibular and orofacial structural and functional variability with regard to the masticatory complex. And, limiting measurements to lower regions of the face and mandible has been found in previous studies to ameliorate biasing metric effects of cranial deformation (Berryman and Owsley 1984).

A listing of the metric variables recorded, including variable code names, is located in Appendix A. Definitions of these measurements can also be found in this appendix. A sliding dial caliper measuring to the nearest 0.1 millimeter is used for the majority of the measurements; however, coordinate and spreading calipers as well as a goniometer and radiometer are also utilized.

Fourteen of the 66 measurements are unconventional ones uniquely designed by the author and Dr. Fred H. Smith.

These consist of mandibular radii and projections and are meant to align many mandibular dimensions with an independent reference point. All are taken in relation to the bicondylar axis--a projected horizontal chord stretched from one condyle to the other. In the present study, a 2.80 millimeter thick dowl is extended across the maximum superior bicondylar breadth distance (Figure 4.3). Measurements are taken from the particular mandibular point (such as infradentale inferius) straight back to this line. Projections are taken via the sliding caliper, while the radii requires the coordinate caliper.

Two other measurements are also taken via unconventional means. Symphyseal angle is measured by a portable hand-held goniometer placed against the mandible while resting on a horizontal plane (in this case, a very thin [0.80 millimeter] piece of cardboard) (Figure 4.3). And, coronoid process angle deflection is noted by the superimposition of a protractor horizontally across the posterior tooth row. A vertical dowl is placed in front of this protractor and in line with the coronoid process. The angle of flare is thus read from the coincidence of dowl with protractor (Figure 4.3). As will be seen in the next section, success with both of these latter methods must be considered tentative.

For dimensions involving symmetry, all measurements are taken from the left side; however, when the left side

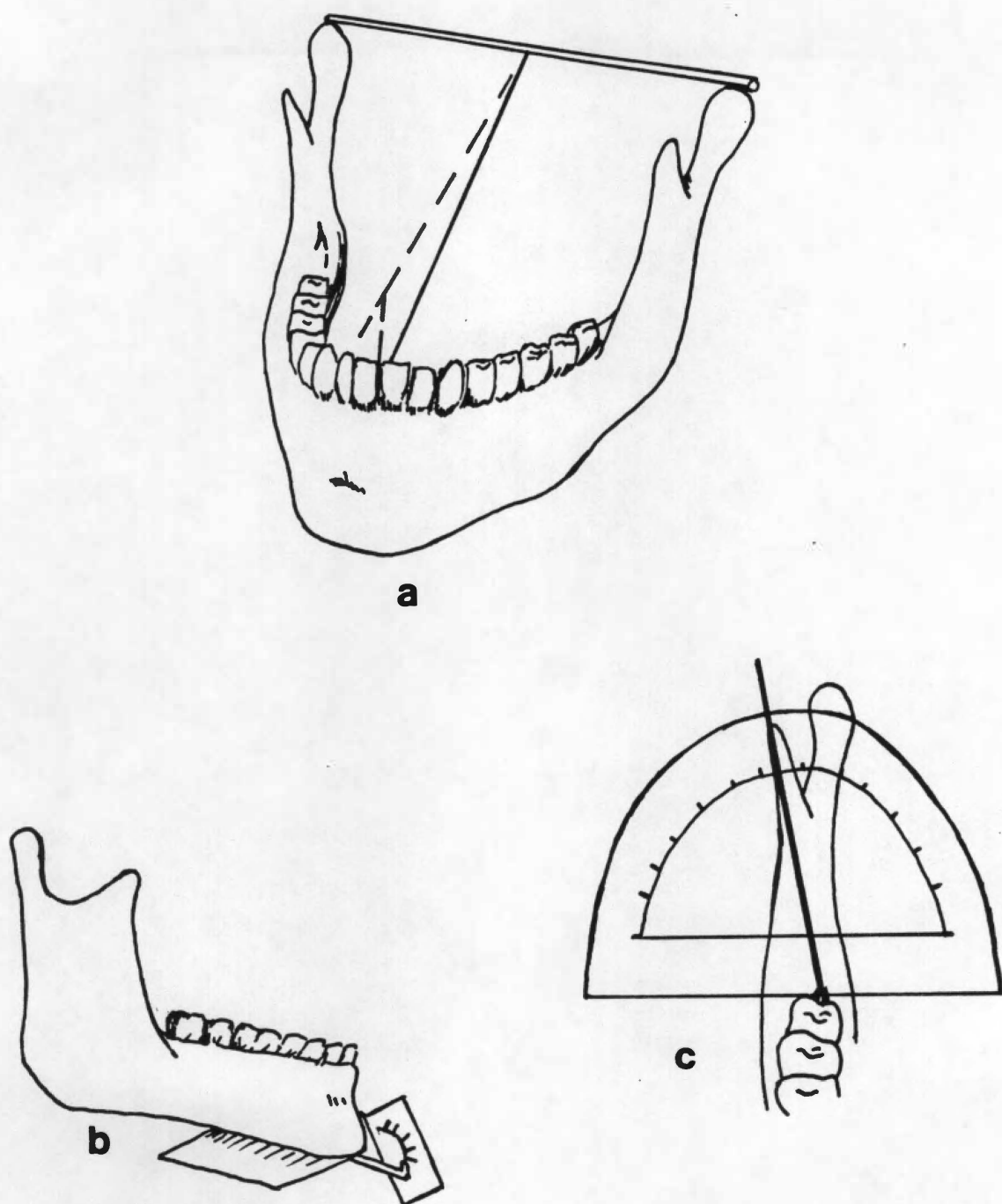


Figure 4.3. Illustration of Selected Measurement Methods:
 (a) Mandibular radius and projection;
 (b) Symphyseal angle; (c) coronoid process
 angle.

is missing or damaged, the right side is used. Only readily replicable measurements are taken--no dimensions are estimated. All measurements are taken by the author.

Throughout the measurement process, two individuals serve as the control specimens. All 66 measurements are taken from Control #1 after each 50 individual interval; thus, approximately seven sets of measurements pertain to this control specimen. Control #2 is measured more infrequently (after about every 100 individuals)--three sets of measurements apply here. In addition, teeth from Control #2 are measured at specified intervals similar to those described for Control #1--six sets of values are collected for the dental measurements. In this way, replicability, reliability, and precision of all of these measurements can be objectively assessed.

Data Analysis

Poor preservation of Tennessee Woodland period skeletal remains and the resultant small Woodland sample size preclude the use of the Woodland data in the majority of statistical analyses. Visual comparison of Woodland data means to those of the other temporal groups is performed. Multivariate statistical comparison of the mandibular, craniofacial, and dental dimensions with respect to temporal group (Archaic versus Mississippian) is accomplished via correlation and canonical correlation

analyses as well as multiple analysis of variance (MANOVA). However, first, univariate statistics (means, standard deviations) for all of the measurements are generated, control specimens are analyzed to assess error potential, some measurements are deleted due to small sample sizes or high error, and missing values are estimated. A discussion of all of these aspects of data analysis follows.

Descriptive Statistics

Means, standard deviations, minimum and maximum data range, and the sample sizes upon which these statistics are calculated, are first generated for all of the mandibular and facial measurements. This is accomplished via the PROC MEANS method of SAS (SAS Institute, Inc. 1985). These data are located in Appendix B and are arranged by separate sex for each temporal group (including Woodland). Similar descriptive statistics for the tooth measurements can be found in Appendix C.

Control Specimens

To assess the error potential inherent in the previously described measurements, the control specimen data are first also subjected to SAS PROC MEANS (SAS Institute, Inc. 1985) per individual. Using the mean estimates ($\bar{x}$) and the standard deviations (s), coefficients of variation (CV) are then calculated for all 66 measurements for the two control specimens separately

(Control Specimen #1=seven sets of measurements; Control Specimen #2=three sets of measurements) based on the following equation: $CV = s/\bar{x} \times 100$. Since coefficients of variation express "sample variability independent of mean size" (Thomas 1976:83), high CV values for particular measurements suggest, in this case, high measurement errors. Table 4.1 outlines a ranking of all of the 61 mandibular and facial measurements in terms of their coefficients of variation for Control Specimen #1. Rankings for the more infrequently measured Control Specimen #2 are, for the most part, similar and are not presented here. Tooth control specimen coefficients of variation for the five dental dimensions (involving six sets of measurements) are shown in Table 4.2.

Based upon these rankings, five measurements are judged to have unacceptable amounts of error. Symphyseal angle, coronoid process angle, infratemporal fossa length and width, and symphysis width (alveolar) are thus removed from further statistical analyses. Measurements of alveolar height, zygomatic arch thickness, condyle thickness, coronoid process radius and projection, and pogonion/gnathion also exhibit rather high CVs for Control Specimen #1, but not Control Specimen #2. These dimensions are not deleted.

In addition to the five measurements noted above, others are also omitted. Three measures of overall

Table 4.1. Control Mandibular and Facial Measurements
Ranked In Order of Greatest Error (Based
on Coefficients of Variation--CV).^a

Measurement	CV	Measurement	CV
CPA	13.57	PBR	1.16
IFL	10.17	PLB	1.15
AVH	10.14	SSR	1.14
ZAT	7.82	TMB	1.04
SWA	7.63	TML	1.04
IFW	6.58	PBP	0.99
CDT	5.78	GBP	0.97
CPR	5.76	CMP	0.92
CPP	5.15	IBR	0.87
PGN	4.74	EZP	0.79
SMA	4.51	ZRS	0.74
CDH	3.97	BGB	0.71
CTR	3.73	IDR	0.67
CSH	3.12	FMR	0.67
MBR	2.80	EIS	0.66
ART	2.79	CDW	0.65
CPT	2.31	GNR	0.61
SWB	2.30	NAR	0.54
PLL	2.20	ZMR	0.51
WMH	2.13	CPH	0.50
SMH	2.04	GMA	0.46
PTP	2.02	PRR	0.38
BCN	2.00	XCB	0.38
IBP	1.98	FRC	0.35
CTP	1.61	XCL	0.33
EUP	1.51	ARB	0.30
PTR	1.50	BBH	0.28
UFH	1.44	BZB	0.28
PTL	1.32	CPG	0.21
ARH	1.31	BCB	0.09
MBP	1.30		

^aMeasurement definitions may be found in Appendix A.

Table 4.2. Control Anterior Mandibular Tooth Measurements
Ranked In Order of Greatest Error (Based on
Coefficients of Variation--CV).^a

Measurement	CV
ROL - right lateral incisor	5.87
RMD - right lateral incisor	3.14
ROL - right canine	3.01
RMD - left central incisor	2.87
ROL - left central incisor	2.49
RMD - left lateral incisor	2.25
ROL - left lateral incisor	2.08
CMD - right canine	2.05
CMD - left central incisor	1.88
CBL - right canine	1.84
RMD - right canine	1.65
ROL - right central incisor	1.47
RMD - right central incisor	1.44
RBL - right central incisor	1.35
CMD - right lateral incisor	1.35
CBL - left central incisor	1.32
CBL - right central incisor	1.30
CBL - right lateral incisor	1.24
RBL - left central incisor	1.05
RBL - right canine	1.01
CMD - left lateral incisor	0.95
RBL - right lateral incisor	0.80
CMD - right central incisor	0.77
CBL - left lateral incisor	0.76
RBL - left lateral incisor	0.64

^aMeasurement definitions may be found in Appendix A.

cranial form (maximum cranial length, breadth, and basion-bregma height) are dropped from further statistical analyses because of the aforementioned biasing effects of cranial deformation on many of the Mississippian individuals. And, nine mandibular and facial measurements (palate length and breadth, bizygomatic breadth, bicondylar breadth, condyle width, gnathion radius, infradentale radius, eminence point/upper molar point, and lower molar point/bicondylar projection) are deleted due to inadequate sample sizes. Thus, only 44 mandibulofacial attributes (30 mandibular, 14 facial) are utilized in further analyses. All five dental measurements (crown mesiodistal and buccolingual diameters, root length, root mesiodistal and buccolingual diameters) are used in the analyses reported here.

Missing Value Estimation--Stepwise Regression

The everpresent nemesis of any multivariate analysis centers around missing values for certain measurements. This problem in the present study proved no less challenging. Many alternatives exist which can partially ameliorate this situation--ranging from using group means for particular missing measurements to estimating these values based on pre-existing data. In the present study, the latter method is judged to be more accurate.

Stepwise regression is an exploratory approach to

multivariate regression which operates to isolate the particular independent variables which are most important in predicting a "best fit" model equation (SAS Institute, Inc. 1982:101). Many methods are available which implement PROC STEPWISE; however, the Maximum R-square Improvement approach (MAXR) (SAS Institute, Inc. 1985) to stepwise regression is judged to be the most appropriate for this analysis. MAXR sequentially explores the best one variable model, best two-variable model, etc., in order to produce the best model fit based on the number of variables desired (SAS Institute, Inc. 1982:102). In this study, PROC STEPWISE with the MAXR option is used to estimate missing data via regression. Approximately 48 values are estimated utilizing 29 different regression equations and a total of 15 measurements. These equations are calculated separately as to temporal group and sex. In no case are more than two of the 44 utilizable mandibular and facial measurements estimated for a particular individual. In sum, the number of estimated values is less than 1% of the total data set--thus, minimal to no biasing effects from missing value projection are anticipated.

Correlation Analysis

The CORR procedure of SAS (SAS Institute, Inc. 1979:173) produces Pearson's correlation coefficients (product-moment and weighted product-moment) between two

sets of variables. These variable sets are usually considered criterion and predictor variables. The correlation coefficient measures the strength of the relationship between them (Hair et al. 1979:32). Correlation coefficients of +1 indicate a perfect (and positive) predictive association between the variables, while negative values suggest inverse relationships. Coefficients near zero imply no relationship between the variables (Hair et al. 1979:32).

In the present study, correlation coefficients are generated in three instances:

1. To explore the interrelationships between the 30 mandibular measurements;
2. To assess the intercorrelation of the 14 facial dimensions;
3. To investigate the intercorrelation of the five mandibular anterior dental measures.

Thus, PROC CORR is applied to three separate data sets (mandibular, facial, and dental) with a primarily exploratory goal of elucidating interrelationships within the various variable sets. In addition, these analyses are performed separately as to temporal group (Archaic versus Mississippian) and then compared. In all cases, variables are centered on respective sex means (via PROC STANDARD of SAS [SAS Institute, Inc. 1985]) and combined.

Canonical Correlation Analysis

Canonical correlation is a powerful multivariate technique useful in exploring the statistical interrelationships between two sets of variables. When one set of variables is considered dependent and the other set independent, the method can be employed in the prediction of these multiple dependent variables from the multiple independent ones (Hair et al. 1979:180). However, the technique can also simply determine the magnitude of relationship (if any) between two variable sets. PROC CANCORR (SAS Institute, Inc. 1985) accomplishes this by deriving maximum linear combinations (canonical variables) from each variable set which successively form optimum canonical functions or correlations. These canonical correlations can be tested for the overall significance of the relationship. Thus, each canonical function consists of two variates, representing the two variable sets (Hair et al. 1979:183). Correlation coefficients (or loadings) are useful in interpreting these variates:

Just as with factor analysis, these coefficients reflect the importance of the original variables in deriving the canonical variates. Thus, the larger the coefficient the more important it is in deriving the canonical variates (Hair et al. 1979:183).

While methodological intricacies of canonical correlation analysis are well-established, interpretation

of the results is still somewhat tenuous. Hair et al. (1979:191-192) have outlined several important limitations of the technique. For example, the derived canonical correlation relates to the variance shared by the linear combinations of the variable sets, not the original variables themselves. Also, canonical loadings and especially weights tend to be somewhat "sample-specific"--that is, some degree of instability occurs across different data sets. And, small weights or loadings for a particular variable can reflect the overall unimportance of the measurement in the particular relationship; however, this may also mean that the variable was "partialled out of the relationship because of a high degree of multicollinearity" (Hair et al. 1979:189). Thus, many researchers suggest the use of caution in the interpretation of canonical correlation results. Even so, when approached with such care, this technique can be very effective in delineating relationships between two sets of multiple variables.

In this analysis, canonical correlation is used to examine the following relationships:

1. the mandibular versus the face measurements;
2. the mandibular versus the anterior teeth variables;
3. the face versus the anterior teeth variables.

These procedures are performed separately as to temporal group. Sexes are combined and centered (means=0) by

the PROC STANDARD technique of SAS (SAS Institute, Inc. 1985).

Regression--Multiple Analysis of Variance (MANOVA)

The analysis of variance approach to regression (ANOVA) is a statistical technique designed to study the relationships between one dependent metric and one or more independent non-metric variables. PROC GLM (SAS Institute, Inc. 1985) implements this method by partitioning the total sum of squares ($SSTO$ =total variation) associated with the dependent variable into the sum of squares due to regression (SSR) and due to residual (SSE) (Neter and Wasserman 1974:77).

Multiple analysis of variance (MANOVA) relates several metric dependent (response) variables to a set of non-metric independent (predictor) variables. MANOVA is unique in that it treats the dependent measures as vectors rather than individual responses, and it uses the sum of squares cross-product (SSCP) matrices (rather than just sum of squares) in its calculations. This technique evaluates the presence of differences in these mean vectors (Hair et al. 1979:127)--a Wilk's Lambda statistic is provided which tests the overall significance of this relationship. An advantage of MANOVA is that it "...allows simultaneous testing of all the variables and considers the various interrelationships among them" (Hair et al. 1979:145).

Thus, intercorrelation among dependent variables is accounted for by MANOVA. Assumptions preceeding the use of this technique include a normally distributed residual variance which should be equal among cells and a low correlation among cell observations (assumed when from randomly sampled groups). Even when these assumptions are not met, MANOVA and ANOVA have been found to be very robust techniques (Hair et al. 1979:132).

In this analysis, the 44 metric mandibulofacial measurements as well as the five dental ones are considered to be dependent variables. A one-way MANOVA is first used to test the relationship between all of the craniofacial, mandibular, and dental measurements with respect to the three age categories (independent categorical variables). This is done to assess the effect of possible functional age-related stress on mandibular and craniofacial masticatory-related dimensions previously found to be significant in research by Guagliardo (1982).

A one-way MANOVA is also used to test the null hypothesis that no differences exist between the measurement centroid means with regard to the temporal groups (also independent variables). In other words, MANOVA tests the hypothesis that no difference exists between Archaic and Mississippian sample individuals in regard to the mandibular and facial measurements under investigation. A similarly designed one-way MANOVA is

also applied to the anterior mandibular tooth dimensions in relation to temporal group. In all cases, variables are centered on respective sex means by PROC STANDARD (SAS Institute, Inc. 1985). Thus, these MANOVAs represent combined, but centered sex analyses.

Controlling Allometric Influences--Femur Length and Geometric Body Scaling

One major potential bias in any investigation of multivariate change in skeletal dimensions through time is the effect of body size. For example, it is entirely conceivable that observed reductions in craniofacial, dental, and mandibular variables through time are attributable to decrease in body size across this time span rather than to masticatory-related functional factors. Just such a phenomenon has been documented by Oleksiak (1987) concerning Upper Pleistocene early modern Homo sapiens sapiens tooth and body size. Thus, in the present study, some method of assessing body size differences across the temporal groups is needed. One such technique is a comparison of femur length means.

Maximum femur lengths were measured and recorded by the author for the Archaic sites of Eva, Cherry, and Ledbetter, and the Mississippian site of Dallas. These values are then compared to published femur length means from the Archaic Anderson site (Joerschke 1983) as well as

the Mississippian sites of Toqua (Parham 1982), Averbuch (Berryman 1981), Ledford Island, Rymer, and Mouse Creek (Boyd 1984). These femur mean length comparisons (including standard deviations and sample sizes) are presented (by sex) in Table 4.3. Little differences exist between Tennessee site Archaic and Mississippian femur lengths. In six separate T-tests comparing male and female Archaic (Eva, Cherry, and Ledbetter combined mean femur lengths) with Mouse Creek Phase (Ledford Island, Mouse Creek, Rymer sites), Dallas Phase (Toqua and Dallas sites) and Averbuch male and female mean femur lengths, only the Archaic versus Averbuch male comparison exhibits significant differences ($t=3.25$; $df=150$) at the 0.05 level. Berryman (1981:143) notes that Averbuch males manifest one of the highest recorded femur length means of any prehistoric Amerindian group. Thus, it does not appear that overall body size (at least in regard to femur length) changed across this temporal span.

However, a better control of allometric influences can be accomplished by use of a geometric body scaling statistical program in which the raw data undergo a logarithmic transformation. The program used in the present study is similar to one used by Mosimann and James (1979) and Darroch and Mosimann (1985), as modified by Anthony Falsetti at the University of Tennessee, Knoxville. This program does not remove allometric influences, but instead

Table 4.3. A Comparison of Tennessee Archaic and Mississippian Site Maximum Femur Lengths.^a

Site	$\bar{x}$	Female S.D.	n	$\bar{x}$	Male S.D.	n
<u>Archaic</u>						
Anderson ^b	40.27	2.20	7	43.93	1.93	6
Eva	40.27	2.10	21	43.56	1.99	24
Cherry	41.33	2.22	10	43.92	2.63	12
Ledbetter	42.08	2.23	5	44.06	1.29	11
<u>Mississippian</u>						
Ledford						
Island ^c	40.82	1.78	41	44.38	2.37	39
Rymer ^c	41.56	1.39	15	44.63	1.37	21
Mouse Creek ^c	41.24	2.15	9	44.72	1.66	8
Toqua ^d	41.50	1.78	37	44.31	1.75	43
Averbuch ^e	42.30	1.79	73	44.81	1.81	105
Dallas	41.25	1.73	22	44.45	1.68	35

^aMeasurements are in centimeters.

^bJoerschke (1983)

^cBoyd (1984)

^dParham (1982)

^eBerryman (1981)

controls body size across the temporal groups. While Corruccini (1987) believes that linearly transformed data sets do not "cancel out" size effects, he (Corruccini 1987:292) states:

...procedures such as Mosimann and James' (1979) while aiming not to produce statistically uncorrelated size and shape (but geometrically meaningful definitions thereof), do lead easily and naturally to adjusting shape vectors for lesser correlation with size over defined segments of the sample range.

In the present study, each measurement variable is divided by the total variable set mean. These data are then logarithmically transformed and used in MANOVA analyses identical to the ones previously described (mandibular measurements versus temporal group; facial dimensions versus temporal group; dental measures versus temporal group). These corrected MANOVA results are then compared to the uncorrected MANOVAs to assess allometric-related dimensional size changes and distinguish these changes from shape-related ones.

Summary

Both morphological as well as metric (univariate, multivariate) dimensions are recorded and compared across the temporal data sets. The Multiple Analysis of Variance (MANOVA) approach to regression is used to assess the variability of these mandibular, facial, and dental measurements with respect to temporal group (Archaic,

Mississippian). Body size variation is controlled via the use of a geometric body scaling program which logarithmically standardizes the groups with respect to body size. Thus, primarily shape differences across these temporal groups are isolated.

Before assessing the between-group multivariate variability, however, an exploration of the within-group intercorrelation of measurements is accomplished via Correlation and Canonical Correlation analyses. And, within-group MANOVAs are performed to assess the differences in craniofacial, dental, and mandibular dimensions with regard to age. In this way, biasing effects of functional age-related masticatory changes may be isolated.

CHAPTER 5

RESULTS--MANDIBLE

Introduction

Although previous chapters have emphasized the interrelatedness of the mandibular, craniofacial, and dental dimensions within the masticatory-associated mandibular complex, for simplification, presentation of results of the analyses discussed in the preceeding chapter must be subdivided. Thus, discussion of the results follows a logical pattern--in this chapter, data are presented concerning intercorrelation as well as within- and between-group variability of the mandibular dimensions, while in Chapters 6 and 7 the focus is primarily upon regions of the lower face and mandibular anterior dentition, respectively. However, it must be stressed that these dimensions are interrelated and these interconnections are discussed more fully in Chapter 8.

Intercorrelation of Mandibular Measurements

As mentioned in Chapter 4, the PROC CORR technique is performed separately by temporal group. The results are presented accordingly.

Archaic

Partial results of the correlation analysis for the 30 mandibular measurements, representing skeletal samples ranging from approximately 79 to 82 Archaic individuals, can be found in Table 5.1. As expected, the highest correlation coefficients exist between the complementary mandibular radii and projections. For example, the correlation coefficient between infradentale inferius/bicondylar radius and projection (IBR and IBP, respectively) is quite high--0.95233. Interestingly, all but one of these measures exhibit high correlations strictly with each other or dimensions of total or posterior tooth row length (TML, PTL). The exception relates gonion/bicondylar projection (GBP) to ascending ramus height (ARH). Thus, the majority of these measures express in varying degrees the length and projection of the mandible.

The remainder of the dimensions manifest much lower correlation coefficients. Most height (CDH--condyle height, CPH--corpus height, SMH--symphyseal height) and width/thickness (CPT--corpus thickness, BGB--bigonial breadth, ART--ascending ramus thickness, CDT--condyle thickness, SWB--symphysis width, basal) variables correlate highly among themselves, respectively. And, dimensions of the coronoid process (CSH, CMP, CPG) are fairly strongly correlated with each other. Interesting, however, is the

Table 5.1. Highest Correlation Coefficients (via PROC CORR) Among Archaic Mandibular Dimensions.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
BCN	PTL	0.31205	IBP	0.29038	TML	0.27030
CPH	SMH	0.57939	PBP	0.46641	CPG	0.44398
CPT	SWB	0.63903	ART	0.54631	BGB	0.41795
CDH	GBP	0.29560	CPP	0.29330	CPG	0.27410
BGB	CPT	0.41795	CMP	0.37214	SWB	0.32439
CPG	GBP	0.70435	ARH	0.69394	CMP	0.61122
ART	CPT	0.54631	SWB	0.42913	CDT	0.38591
ARB	CTR	0.62777	CTP	0.55633	IBP	0.50409
ARH	GBP	0.71810	CPG	0.69394	GMA	-0.65265
TML	PTL	0.92001	PBR	0.90348	PBP	0.85123
PTL	TML	0.92001	PBR	0.87269	IBR	0.86742
IBR	IBP	0.95233	PTR	0.87355	PTL	0.86742
PBR	PBP	0.95402	TML	0.90348	PTL	0.87269
CPR	CPP	0.92657	CTR	0.81707	CTP	0.77057
PTR	IBR	0.87355	PTP	0.86448	PBR	0.82360
MBR	PBR	0.84491	PBP	0.82659	PTR	0.80862
CTR	CTP	0.91004	CPR	0.81707	CPP	0.81042
IBP	IBR	0.95233	PBR	0.86316	PBP	0.86040
PBP	PBR	0.95402	IBP	0.86040	TML	0.85123
CPP	CPR	0.92657	CTR	0.81042	CTP	0.75390
PTP	PTR	0.86448	IBP	0.82467	IBR	0.81645
CTP	CTR	0.91004	CPR	0.77057	CPP	0.75390
GBP	ARH	0.71810	CPG	0.70435	PBP	0.50751
PGN	ARB	0.23941	CTP	0.22156	PTL	0.21319
CDT	SWB	0.42320	ART	0.38591	CPT	0.33224
GMA	ARH	-0.65265	CPG	-0.46888	TML	0.39237
CSH	CMP	0.46245	CPG	0.45760	CPR	-0.25858
CMP	CPG	0.61122	PBP	0.52913	IBP	0.47476
SMH	CPH	0.57939	PBP	0.41148	PTL	0.40337
SWB	CPT	0.63903	CPH	0.44132	ART	0.42913

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and correlation coefficient, respectively;
M2, C2 = the second highest measurement and correlation coefficient, respectively;
M3, C3 = the third highest measurement and correlation coefficient, respectively.

association of bicanine width (BCN) with measures of the length of the mandible (PTL, IBP, TML), although it must be noted that these correlations are rather low (0.31 and below). And, gonial angle (GMA) exhibits a high negative correlation with measures of the height of the ascending ramus (ARH, CPG).

Mississippian

Table 5.2 lists similar data for approximately 192 to 195 Mississippian mandibles. When compared to that of the Archaic, the correlative pattern is very similar. Once again, mandibular radii and projections correlate highly with one another and measures of the length and projection of the mandible. And, various height variables show high correlations amongst themselves. Width measures also exhibit fairly strong intercorrelations. Bicanine width (BCN) manifests the same association with length and projection of the mandible (IBR, PBP), while gonial angle (GMA) shows an even higher inverse relationship with ascending ramus height.

Thus, in both Archaic and Mississippian samples, a strong relationship exists between the various length and projection measures of the mandible. The majority of the remainder of the measurements reflect various height and breadth dimensions of the lower jaw.

Table 5.2. Highest Correlation Coefficients (via PROC CORR) Among Mississippian Mandibular Dimensions.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
BCN	IBR	0.33444	PBP	0.31864	PTR	0.31104
CPH	SMH	0.70009	PBP	0.55165	PBR	0.53592
CPT	SWB	0.52246	ARB	0.43607	CDT	0.31397
CDH	GBP	0.42235	CTP	0.41296	CTR	0.38075
BGB	BCN	0.26051	GMA	0.21745	PBR	0.20415
CPG	GBP	0.61864	GMA	-0.55516	CMP	0.51915
ART	CPT	0.30259	SWB	0.22947	CMP	0.22483
ARB	CTR	0.54256	CTP	0.54053	CPT	0.43607
ARH	GBP	0.77641	GMA	-0.73297	CPG	0.62157
TML	PBR	0.84942	PBP	0.79817	PTL	0.79476
PTL	TML	0.79476	IBR	0.74942	PTR	0.72290
IBR	IBP	0.95533	PTR	0.86283	PBR	0.84118
PBR	PBP	0.95788	TML	0.84942	IBR	0.84118
CPR	CPP	0.89226	CTP	0.81519	CPR	0.81043
PTR	PTP	0.92685	MBR	0.87128	IBR	0.86283
MBR	PTR	0.87128	PTP	0.84423	PBR	0.80176
CTR	CTP	0.94054	CPP	0.81278	CPR	0.81043
IBP	IBR	0.95533	PTR	0.84569	PTP	0.83999
PBP	PBR	0.95788	PBP	0.81793	IBP	0.81346
CPP	CPR	0.89226	CTP	0.82187	CTR	0.81278
PTP	PTR	0.92685	MBR	0.84423	IBP	0.83999
CTP	CTR	0.94054	CPP	0.82187	CPR	0.81519
GBP	ARH	0.77641	CPG	0.61864	GMA	-0.47419
PGN	ART	0.21801	PTL	0.20465	ARB	0.16529
CDT	ARB	0.41809	ARH	0.38064	GBP	0.34836
GMA	ARH	-0.73297	CPG	-0.55516	GBP	-0.47419
CSH	CPG	0.47629	CMP	0.47480	BGB	0.17310
CMP	CPG	0.51915	CSH	0.47480	MBR	0.45080
SMH	CPH	0.70009	PBR	0.52368	PBP	0.50820
SWB	CPT	0.52246	PBR	0.32408	PBP	0.30548

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and correlation coefficient, respectively;
M2, C2 = the second highest measurement and correlation coefficient, respectively;
M3, C3 = the third highest measurement and correlation coefficient, respectively.

Within-Group (Age) Variability

Before a consideration of change in mandibular measurements through time can be investigated, the effect of age biases on these measurements must be explored. This aspect is discussed below.

Archaic

MANOVA partial results for the age versus mandibular measurement comparison for the Archaic individuals are presented in Table 5.3. Only the dimensions which exhibit differences with regard to age at the 0.05 level are listed. As can be seen, there is a significant overall difference in the Archaic mandibular dimensions with respect to the age categories--the Wilks' Criterion F value of 1.60 results in a probability value ($> F$) of 0.007. Several measurements contribute to this relationship. These include dimensions of the thickness of the corpus (CPT), breadth of the ascending ramus (ARB) and mandibular dental arch (BCN), as well as height of the condyle (CDH) and overall length of the mandible (IBR, IBP). If one examines the means for these measurements with respect to the age categories, it is noted that all of these dimensions decrease from young to old age, with one important exception. Female condyle height experiences a substantial increase across these age categories.

Table 5.3. MANOVA (Significant Variables Only) Comparison Among Age Classes For Archaic Mandibular Dimensions.^a

Measurement ^b	R-Square	F Value	Probability > F
BCN	0.14	3.91	0.01
CPT	0.12	3.25	0.03
CDH	0.13	3.74	0.01
ARB	0.17	4.98	0.00
IBR	0.10	2.81	0.04
IBP	0.10	2.68	0.05

^aWilks' Criterion=0.107; F=1.60; Probability > F=0.007; Degrees of Freedom: Model=3; Error=72; Corrected Total=75; n=76.

^bMeasurement definitions may be found in Appendix A.

Mississippian

Similar MANOVA comparisons are generated for Mississippian mandibular measurements with respect to age. Table 5.4 summarizes these results. There is no significant overall relationship between the two variable sets (Wilks' Criterion Probability > F value=0.398); however, the measure of condyle thickness (CDT) is the only one of the 30 mandibular dimensions to show significant variation--it increases in both males and females with advancing age.

Thus, there are significant age-related overall differences in Archaic mandibular dimensions, but not Mississippian ones. Implications for this patterning are discussed further in Chapter 8.

Between-Group (Temporal) Variability

Archaic versus Mississippian

Results of the between-group (uncorrected for body size) MANOVA comparison of the mandibular measurements and the two temporal groups (Archaic and Mississippian) are summarized in Table 5.5. A Wilks' Criterion of 0.445 and associated F value of 9.69 (significant at the 0.0001 level) clearly allow the rejection of the null hypothesis of no differences between Archaic and Mississippian mandibular dimensions. Approximately 18 of the original 30

Table 5.4. MANOVA (Significant Variables Only) Comparison Among Age Classes For Mississippian Mandibular Dimensions.^a

Measurement ^b	R-Square	F Value	Probability > F
CDT	0.07	4.72	0.00

^aWilks' Criterion=0.578; F=1.04; Probability > F=0.398; Degrees of Freedom: Model=3; Error=184; Corrected Total=187; n=188.

^bMeasurement definitions may be found in Appendix A.

Table 5.5. MANOVA (Significant Variables Only) Comparison Of Mandibular Measurements Between Archaic and Mississippian Samples.^a

Measurement ^b	R-Square	F Value	Probability > F
BCN	0.07	21.42	0.00
CPH	0.04	11.75	0.00
ART	0.11	31.89	0.00
ARH	0.05	12.72	0.00
TML	0.11	33.09	0.00
PTL	0.03	7.13	0.01
IBR	0.07	20.30	0.00
PBR	0.11	31.42	0.00
CPR	0.06	16.39	0.00
PTR	0.02	6.64	0.01
MBR	0.02	6.16	0.01
IBP	0.03	8.79	0.00
PBP	0.06	16.29	0.00
CPP	0.04	10.30	0.00
GMA	0.10	28.71	0.00
CMP	0.11	32.86	0.00
SMH	0.21	68.97	0.00
SWB	0.04	9.87	0.00

^aWilks' Criterion=0.445; F=9.69; Probability > F=0.0001; Degrees of Freedom: Model=1; Error=262; Corrected Total =263; n=264.

^bMeasurement definitions may be found in Appendix A.

mandibular measurements manifest this variability. Eight of these are mandibular radii and projections. In addition, total mandibular length and posterior tooth row length (TML and PTL, respectively) also are significantly different across the temporal groups. Other dimensions showing change include two relating to the mandibular symphysis (SMH--symphysis height and SWB--symphysis width, basal), two concerning height and thickness of the ascending ramus (ARH and ART), and another reflecting height of the corpus (CPH). Finally, coronoid point/lower molar point (CMP), bicanine width (BCN), and gonial angle (GMA) also manifest significant differences.

More important than merely the establishment of significant differences is the documentation of a pattern in these data. It can be seen from a review of these measurement means by group and sex in Table 5.6 that such an identifiable pattern exists. All of the separate sex mean comparisons exhibit the same pattern of change. Fourteen of the 18 variables increase from the Archaic to the Mississippian. Most of these are measures of the total length and projection of the mandible; however, it should be noted that projection and radius of the coronoid process (CPP and CPR, respectively) decrease. In addition, ascending ramus height (ARH) and symphysis width, basal (SWB) also decrease through time. Measures of height (CPH, SMH) as well as width/thickness (BCN, ART) of the mandible

Table 5.6. Means and Sample Sizes of Significantly Different (via MANOVA) Mandibular Dimensions From Archaic and Mississippian Females and Males.^a

Measure- ment ^b	<u>Archaic</u>				<u>Mississippian</u>			
	Female		Male		Female		Male	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
BCN	18.23	39	18.84	42	19.43	94	19.59	101
CPH	30.25	40	33.16	42	31.66	94	33.92	100
ART	10.63	40	11.18	42	11.54	94	12.07	101
ARH	54.82	39	61.59	42	52.32	94	58.69	101
TML	97.18	39	101.02	42	100.97	93	105.13	101
PTL	87.08	39	90.55	42	88.71	93	92.14	101
IBR	86.31	38	89.36	42	89.35	93	92.26	100
PBR	93.89	38	98.67	42	97.43	93	102.58	101
CPR	31.97	38	31.97	41	29.99	93	30.68	101
PTR	80.08	38	83.02	42	82.13	93	84.64	101
MBR	60.62	37	63.95	42	62.28	92	65.46	101
IBP	88.67	38	92.46	42	90.62	93	94.21	100
PBP	98.59	38	104.15	42	101.12	93	106.99	101
CPP	33.13	38	33.19	41	31.59	93	32.39	101
GMA	117.90	40	115.40	42	122.94	94	119.58	101
CMP	44.03	39	50.61	39	47.91	92	53.10	100
SMH	31.34	40	32.95	42	34.04	94	36.58	101
SWB	13.75	40	15.05	42	13.40	94	14.12	101

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

increase from the Archaic to the Mississippian, along with the dimension of gonial angle (GMA).

Woodland

Before conclusive statements about changes in mandibular measurements through time can be made, Woodland mandibles must be considered. As previously mentioned, small Woodland sample sizes preclude the use of statistical analysis and interpretation for this data set. However, visual inspection of the means and standard deviations for those dimensions which exhibit variability from the Archaic to the Mississippian may provide additional insight into the presence of identifiable patterning in these measurements through time. Table 5.7 lists such data. When compared to the previous table (Table 5.6) containing Archaic and Mississippian means for the same measurements, almost all of the Woodland mandibular dimensions fit within the pre-established pattern of increase or decrease from Archaic to Mississippian. Interestingly, the two main exceptions involve similar measurements (CPR, CPP) for the same sex (female).

Before these results can be accepted with confidence, however, a final cause for error or bias must be investigated. The possibility that some of the above-described differences relate to allometric variation

Table 5.7. Means, Standard Deviations, and Sample Sizes of Selected Mandibular Dimensions From Woodland Females and Males.^a

Measurement ^b	Female			Male		
	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n
BCN	19.50	0.82	8	19.10	2.29	15
CPH	31.84	2.20	9	33.81	2.65	16
ART	12.00	2.77	9	12.59	1.23	16
ARH	52.44	5.46	9	58.69	4.74	16
TML	101.44	5.90	9	104.19	4.90	16
PTL	90.67	5.66	9	92.12	4.18	16
IBR	89.55	4.75	9	91.62	3.22	16
PBR	97.78	5.12	9	101.25	3.66	16
CPR	32.78	3.38	9	30.87	4.06	16
PTR	83.55	3.91	9	85.31	3.94	16
MBR	63.00	3.12	9	64.37	3.84	16
IBP	90.91	5.53	9	93.39	3.41	16
PBP	101.57	4.91	9	105.56	3.84	16
CPP	34.13	3.77	9	32.19	3.85	16
GMA	122.55	7.42	9	117.94	5.96	16
CMP	44.81	2.58	9	50.64	5.54	16
SMH	33.33	2.90	9	34.75	3.10	15
SWB	13.73	0.69	9	14.53	1.26	16

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

between Archaic and Mississippian individuals exists. This question is explored in the next section.

Geometric Body Scaling

The 30 mandibular measurements from the two temporal groups (Archaic and Mississippian) are subjected to logarithmic transformation (controlling body size across the groups) via the previously described geometric body scaling statistical program. A MANOVA comparison identical to the one described above investigating the variation of these measurements with regard to temporal group is then performed. Partial results showing only the mandibular measurements which are significantly different across time are presented in Table 5.8. As can be seen when compared to Table 5.5, there are virtually no differences in results when body size is controlled. The only change is the addition of one measurement (CSH--coronoid process height), which, in the uncorrected MANOVA comparison, is significant only at the 0.0505 level. This dimension significantly increases from the Archaic to the Mississippian. Thus, allometric factors do not appear to be important across this temporal span in relation to these mandibular measurements.

Summary

Both within- and between-group analyses are conducted upon the mandibular data. Within each temporal group

Table 5.8. MANOVA (Significant Variables Only) Comparison Of Logarithmic Mandibular Dimensions Between Archaic and Mississippian Samples (Body Size Differences Controlled).^a

Measurement ^b	R-Square	F Value	Probability > F
BCN	0.08	22.02	0.00
CPH	0.05	13.03	0.00
ART	0.11	32.71	0.00
ARH	0.05	12.98	0.00
TML	0.11	33.90	0.00
PTL	0.03	7.26	0.01
IBR	0.07	21.08	0.00
PBR	0.11	32.13	0.00
CPR	0.06	15.47	0.00
PTR	0.03	7.00	0.01
MBR	0.02	6.40	0.01
IBP	0.03	9.16	0.00
PBP	0.06	16.89	0.00
CPP	0.03	9.45	0.00
GMA	0.10	29.08	0.00
CSH	0.01	4.04	0.04
CMP	0.12	34.98	0.00
SMH	0.21	71.18	0.00
SWB	0.03	9.54	0.00

^aWilks' Criterion=0.434; F=9.76; Probability > F=0.0001; Degrees of Freedom: Model=1; Error=262; Corrected Total =263; n=264.

^bMeasurement definitions may be found in Appendix A.

(Archaic, Mississippian), correlation analyses indicate strong relationships between many mandibular dimensions. For example, high correlations exist between the various length and projection measures of the mandible. Height variables correlate fairly highly together, as do width/thickness mandibular measurements. Overall, the pattern of Archaic mandibular intercorrelations is very similar to that seen in the Mississippian. With regard to age variability, however, the two temporal groups differ. MANOVA comparisons indicate that Archaic mandibular dimensions vary significantly with age--corpus thickness, bicanine width, ascending ramus breadth, and overall length of the mandible decrease significantly with increasing age, while condyle height increases. However, overall, Mississippian mandibular dimensions do not vary with age.

Between-group MANOVA analyses reveal that a majority (18/30) of the utilized mandibular measurements exhibit significant differences across the temporal groups. Surprisingly, 14 of these increase from the Archaic to the Mississippian. For example, in comparison to Archaic mandibles, Mississippian lower jaws increase in length and projection. In addition, the symphysis and corpus are higher and width at bicanine and thickness at the ascending ramus greater in Mississippian mandibles. However, height of the ramus, thickness of the base of the symphysis, and radius and projection of the coronoid process decrease

through time. Visual inspection of Woodland means for these same dimensions corroborates these patterns. When the MANOVAs are performed on mandibular dimensions logarithmically transformed (body size controlled across the temporal groups), very similar results are obtained. Thus, allometric biases do not appear to be contributing to the patterns observed.

It is primarily the focus of the next chapter to delineate changes in craniofacial dimensions across this time span. In addition, correlations between these craniofacial and mandibular measurements will be explored, and age-related craniofacial variability will be investigated.

CHAPTER 6

RESULTS--THE LOWER FACE

Introduction

Similar analyses conducted in the previous chapter for the mandibular dimensions (such as intercorrelation, within- and between-group measurement variation) are presented here for the 14 measures of the lower face. In addition, the relationship between these mandibular and facial variables is explored.

Intercorrelation of Facial Measurements

Correlation matrices are generated for the facial measures of each temporal group via the PROC CORR technique. Discussion of these results follows.

Archaic

Table 6.1 lists the three highest correlation coefficients obtained for each Archaic facial dimension. As can be seen, the highest correlations are between the various radii of the face--prosthion, subspinale, nasion, zygomaxillare, and frontomolare (PRR, SSR, NAR, ZMR, and FMR, respectively). These radii reflect measures of the projection of the lower and midface. Dimensions of the height of the face (AVH--alveolar height, UFH--upper facial

Table 6.1. Highest Correlation Coefficients (via PROC CORR) Among Archaic Facial Dimensions.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
AVH	UFH	0.60997	EIS	0.47800	WMH	0.28759
UFH	AVH	0.60997	EIS	0.52144	WMH	0.25020
WMH	EIS	0.35158	AVH	0.28759	EZP	0.27712
ZAT	FRC	0.15457	TMB	0.13817	ZMR	-0.13538
ZRS	EZP	0.52664	ZMR	0.42572	SSR	0.31555
EZP	ZMR	0.72939	SSR	0.63634	ZRS	0.52664
EIS	PRR	0.57588	EZP	0.54768	NAR	0.52988
TMB	NAR	0.38239	FMR	0.30574	FRC	0.29685
PRR	SSR	0.72739	NAR	0.59687	EIS	0.57588
NAR	SSR	0.70083	PRR	0.59687	FMR	0.55414
SSR	PRR	0.72739	NAR	0.70083	EZP	0.63634
ZMR	EZP	0.72939	SSR	0.61502	FMR	0.59950
FMR	SSR	0.63150	ZMR	0.59950	NAR	0.55414
FRC	TMB	0.29685	NAR	0.26528	SSR	0.22125

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and canonical correlation, respectively;
M2, C2 = the second highest measurement and canonical correlation, respectively;
M3, C3 = the third highest measurement and canonical correlation, respectively.

height, WMH--cheek height) are all fairly correlated with one another. And, finally, measures of the breadth and projection of the lateral (zygomatic) facial region (ZRS, EZP, ZMR) correlate fairly highly together.

Mississippian

As expected, the same correlative patterns can be discerned in the correlation coefficients between Mississippian facial dimensions (Table 6.2). The facial radii manifest the highest correlations with each other, while heights of the face (AVH, UFH, WMH) and dimensions reflecting breadth and projection of the lateral face (ZRS, EZP, ZMR) are correlated highly among themselves as well.

In sum, while minor differences exist, the within-group facial correlation pattern for Archaic and Mississippian individuals is the same. The 14 facial dimensions reflect the height, breadth, and projection of the lower and midface in each temporal group.

Correlations Between Facial and Mandibular Dimensions

Archaic

In Table 6.3, partial results of the canonical correlation (CANCORR) comparison of Archaic mandibles and faces are presented. The Wilks' Criterion F value of 1.46 (and Probability > F value of 0.0042) allows the rejection

Table 6.2. Highest Correlation Coefficients (via PROC CORR) Among Mississippian Facial Dimensions.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
AVH	UFH	0.62560	PRR	0.50042	EIS	0.49201
UFH	AVH	0.62560	PRR	0.55602	EIS	0.45113
WMH	UFH	0.22920	FRC	0.22067	FMR	0.18184
ZAT	TMB	0.26885	ZRS	0.23578	WMH	0.17300
ZRS	EZP	0.56751	EIS	0.41404	ZMR	0.39818
EZP	ZMR	0.79952	ZRS	0.56751	EIS	0.55025
EIS	PRR	0.69898	EZP	0.55025	AVH	0.49201
TMB	ZAT	0.26885	ZRS	0.21611	FRC	-0.11995
PRR	SSR	0.83893	EIS	0.69898	ZMR	0.66372
NAR	FMR	0.74052	SSR	0.72750	ZMR	0.64822
SSR	PRR	0.83893	NAR	0.72750	ZMR	0.63894
ZMR	EZP	0.79952	PRR	0.66372	FMR	0.65931
FMR	NAR	0.74052	SSR	0.52384	PRR	0.51569
FRC	UFH	0.36374	NAR	0.36289	PRR	0.27879

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and canonical correlation, respectively;
M2, C2 = the second highest measurement and canonical correlation, respectively;
M3, C3 = the third highest measurement and canonical correlation, respectively.

Table 6.3. Within-group CANCERR Comparison Statistics
For Archaic Site Mandibular Versus Facial
Dimensions.^a

Statistic	Value	F	DF	Prob>F
Wilks' Criterion	0.0000	1.461	420	0.0042
Pillai's Trace	9.5180	1.416	420	0.0009
Hotelling-Lawley Trace	119.1361	1.459	420	0.0252
Roy's Greatest Root	54.7514	36.501	30	0.0001

^aBased on 51 observations.

of the null hypothesis that no significant relationship exists between mandibular and facial dimensions in Archaic individuals. Other measures of the significance of the relationship (such as Pillai's Trace, Hotelling-Lawley Trace, and Roy's Greatest Root) concur. Canonical correlation likelihood ratios and associated F and Probability > F values for the first five canonical functions (Table 6.4) reveal that only the first canonical function is significant at the 0.05 level.

A squared canonical correlation estimates the amount of shared variance between the canonical variates. In this case, a value of 0.98 (Table 6.4) indicates a very high amount of shared variance (98%). Another measure of shared variance between variables is a redundancy index.

According to Hair et al. (1979:187), it is:

...the equivalent of computing the squared multiple correlation coefficient between the total predictor set and each variable in the criterion set, and then averaging these squared coefficients to arrive at an average R^2 .

The redundancy index can be calculated as follows: $R \times VED$, where $VED = \sum L$ or sum of dependent variable squared canonical loading/the number of variables. Or, the REDUNDANCY option of SAS PROC CANCORR (SAS Institute, Inc. 1985) can be specified and similar statistics generated. The latter approach is used in this analysis. Redundancy calculations for the amount of shared (raw) variance between the mandibular and facial data sets for the first

Table 6.4. Within-group Summary Statistics For CANCORR Comparison of Archaic Site Mandibular Versus Facial Dimensions For The First Five Canonical Functions.^a

Func- tion	Corre- lation	Corre- lation ²	Eigenvalue Raw	Cum. ^b	Likelihood Ratio	F	Prob>F
1	0.9909	0.9820	54.75	0.46	0.0000	1.46	0.0042
2	0.9834	0.9671	29.42	0.71	0.0000	1.22	0.0852
3	0.9467	0.8963	8.64	0.78	0.0000	1.03	0.4306
4	0.9426	0.8885	7.97	0.85	0.0000	0.96	0.6267
5	0.9084	0.8252	4.72	0.89	0.0000	0.86	0.8395

^aBased on 51 observations.

^bCum.=Cumulative.

canonical function indicate that roughly 8% of the variance of the mandibular variables can be explained by the facial canonical variables. A similar value exists between facial variables and mandibular canonical variables.

If one looks at the canonical structure comparing the mandibular measurements with the canonical variables of the face for the first canonical function (Table 6.5), it can be seen that measures of the height of the mandible are reflected most strongly. The highest correlation coefficient of 0.5706 for symphysis height (SMH) and the similarly large coronoid process/gonion (CPG) correlation of 0.4952 and corpus height (CPH) correlation coefficient of 0.4741 support this pattern. Canonical correlations between the facial measurements and canonical variables of the mandible for the first canonical function (Table 6.6) also denote strong involvement of height (AVH--alveolar height) as well as projection (EIS--eminence point/infradentale superius) and width (ZAT--zygomatic arch thickness) dimensions of the lateral midface.

In sum, CANCORR comparisons indicate that there is a significant correlation between Archaic mandibles and faces at the 0.05 level. This relationship primarily involves fairly high correlations of measures of the height of the mandible with height of the lower face, as well as projection of the lateral midface.

Table 6.5. Canonical Correlation Structure Comparison of Archaic Mandibular Measurements and Canonical Variables of The Face.

Mandibular Measurement ^a	Canonical Face Variable
BCN	0.1055
CPH	0.4741
CPT	0.3194
CDH	-0.0923
BGB	0.2864
CPG	0.4952
ART	0.3950
ARB	0.1984
ARH	0.1272
TML	0.1577
PTL	0.2069
IBR	0.3703
PBR	0.2627
CPR	-0.1640
PTR	0.2630
MBR	0.2372
CTR	-0.1265
IBP	0.3725
PBP	0.2844
CPP	-0.1691
PTP	0.3124
CTP	-0.1470
GBP	0.3727
PGN	0.0533
CDT	0.2018
GMA	-0.0008
CSH	0.0092
CMP	0.3611
SMH	0.5706
SWB	0.2437

^aMeasurement definitions may be found in Appendix A.

Table 6.6. Canonical Correlation Structure Comparison of Archaic Facial Measurements and Canonical Variables of The Mandible.

Facial Measurement ^a	Canonical Mandibular Variable
AVH	0.5366
UFH	0.3267
WMH	0.1080
ZAT	0.5125
ZRS	0.2647
EZP	0.1467
EIS	0.4476
TMB	0.3483
PRR	0.0799
NAR	0.1205
SSR	-0.0883
ZMR	-0.0316
FMR	-0.1539
FRC	0.2884

^aMeasurement definitions may be found in Appendix A.

Mississippian

Similar CANCELL statistics are presented in Tables 6.7 through 6.11 for Mississippian mandibles and faces. The Wilks' Criterion F value of 1.56 (and Probability > F estimate of 0.0001) (Table 6.7) indicates there is a significant relationship between mandibles and faces within this temporal group. Other measures of the significance of the relationship (Pillai's Trace, Hotelling-Lawley Trace, Roy's Greatest Root) concur. F approximations (and Probability > F values) for canonical correlation likelihood ratios (Table 6.8) indicate that two canonical functions are significant at the 0.05 level. Squared canonical correlation estimates of 0.86 for the first canonical function and 0.77 for the second canonical function indicate fairly large amounts of shared variance between these variable sets. Raw redundancy statistics (Table 6.9) indicate that for the first canonical function, approximately 0.2235 or 22% of the variance of the mandibular measurements can be explained by the facial canonical variables. With the addition of the second significant canonical function, this shared variance estimate (CAN1 and CAN2) increases to 26% (0.2640). Conversely, for CAN1, approximately 20% (0.1982) of the facial measurement variance is attributable to the mandibular canonical variables. This increases to 24%

Table 6.7. Within-group CANCERR Comparison Statistics For Mississippian Site Mandibular Versus Facial Dimensions.^a

Statistic	Value	F	DF	Prob>F
Wilks' Criterion	0.00010	1.561	420	0.0001
Pillai's Trace	5.89329	1.405	420	0.0001
Hotelling-Lawley Trace	17.41536	1.789	420	0.0001
Roy's Greatest Root	6.01159	11.622	30	0.0001

^aBased on 89 observations.

Table 6.8. Within-group Summary Statistics For CANCELL
Comparison of Mississippian Site Mandibular
Versus Facial Dimensions For The First Five
Canonical Functions.^a

Func- tion	Corre- lation	Corre- lation ²	Eigenvalue		Likelihood Ratio	F	Prob>F
			Raw	Cum. ^b			
1	0.9259	0.8574	6.01	0.34	0.0001	1.56	0.0001
2	0.8750	0.7657	3.27	0.53	0.0007	1.30	0.0021
3	0.7938	0.6302	1.70	0.63	0.0032	1.13	0.1081
4	0.7528	0.5667	1.31	0.71	0.0087	1.04	0.3598
5	0.7322	0.5361	1.15	0.77	0.0202	0.96	0.6309

^aBased on 89 observations.

^bCum.=Cumulative.

Table 6.9. Mississippian Mandibular Versus Facial Canonical Correlation Raw Redundancy Statistics For The First Two Canonical Functions.

Measurement Class	Mandibular Canonical Variable Shared Variance	Facial Canonical Variable Shared Variance
<u>CAN1</u>		
Mandible	0.2606	0.2235
Face	0.1982	0.2311
<u>CAN2</u>		
Mandible	0.0529	0.0405
Face	0.0445	0.0582
<u>CAN1 and CAN2</u>		
Mandible	0.3136	0.2640
Face	0.2427	0.2893

Table 6.10. Canonical Correlation Structure Comparison of Mississippian Mandibular Measurements and Canonical Variables of The Face.

Mandibular Measurement ^a	Canonical Face Variable	
	CAN1	CAN2
BCN	0.2027	0.0524
CPH	0.6962	-0.0858
CPT	0.3081	-0.0475
CDH	0.2365	0.0575
BGB	-0.0469	0.0180
CPG	0.4294	0.3015
ART	0.0407	0.0874
ARB	0.4126	0.2338
ARH	0.3751	0.1118
TML	0.5547	0.1118
PTL	0.6517	0.0269
IBR	0.6417	0.2733
PBR	0.6026	0.2553
CPR	0.2782	0.2593
PTR	0.6658	0.2704
MBR	0.5991	0.2202
CTR	0.2933	0.3428
IBP	0.6169	0.3124
PBP	0.6028	0.2479
CPP	0.1908	0.2690
PTP	0.6780	0.2558
CTP	0.2920	0.3306
GBP	0.3728	0.0859
PGN	0.0802	0.1248
CDT	0.3041	0.1353
GMA	-0.1212	0.0027
CSH	-0.0735	0.2346
CMP	0.4100	0.1733
SMH	0.6972	-0.2405
SWB	0.1988	0.0901

^aMeasurement definitions may be found in Appendix A.

Table 6.11. Canonical Correlation Structure Comparison of Mississippian Facial Measurements and Canonical Variables of The Mandible.

Facial Measurement ^a	Canonical Mandibular Variable	
	CAN1	CAN2
AVH	0.6179	-0.3717
UFH	0.6055	-0.0691
WMH	0.3018	0.0067
ZAT	0.1322	-0.0703
ZRS	0.3358	0.4276
EZP	0.3071	0.4467
EIS	0.5280	0.0314
TMB	-0.0246	-0.0509
PRR	0.7118	0.0726
NAR	0.3607	0.2206
SSR	0.4269	0.1058
ZMR	0.4507	0.3223
FMR	0.4675	0.0576
FRC	0.4344	0.2486

^aMeasurement definitions may be found in Appendix A.

(0.2427) with the addition of CAN2. Thus, within the Mississippian, there is a fairly strong correlation between metric dimensions of the mandible and face. A closer look at the particular variables involved in this relationship follows.

CAN1. Table 6.10 contains the canonical structure comparison of Mississippian mandibular measurements and facial canonical variables for the two significant canonical functions. For CAN1, high correlations exist for several mandibular height measurements. For example, the highest coefficients are for corpus and symphysis heights (CPH=0.6962; SMH=0.6972). Also loading highly are some of the measures of mandibular length and projection (PTP, PTR, PTL). Facial measurements correlating highly with mandibular canonical variables for CAN1 (Table 6.11) reflect height (AVH--alveolar height; UFH--upper facial height) and projection (PRR--prosthion radius) measures of the face. Thus, for the first canonical function (accounting for the majority of the shared variance), significant correlation between Mississippian mandibles and faces involves height (and secondly, length) of the mandible and height and projection of the lower face.

CAN2. Canonical correlation structure comparisons between Mississippian mandibular dimensions and facial canonical variables for the second canonical function

(Table 6.10, see CAN2) reveal high correlations involving measures of the length of the mandible, particularly at the coronoid process (CTP, CTR, CPG). Facial measurement and mandibular canonical variable correlation comparisons for CAN2 (Table 6.11) involve high loadings on dimensions of breadth and projection of the midface (EZP, ZRS, ZMR). And, a fairly high negative value exists for alveolar height (AVH=-0.3717).

Therefore, there is a significant relationship between Mississippian mandibular and facial dimensions. This correlation primarily relates height of the mandible with height of the face and lower facial projection. Secondly, length of the mandible correlates highly with projection and breadth of the lateral midface. Now that an understanding of the association of mandibular and facial dimensions in each temporal group has been obtained, analyses of within-group differences across these measurements with respect to age follow.

Within-Group (Age) Variability

Just as with the mandible, within-group MANOVAs are performed for all 14 craniofacial measurements with regard to the three age categories. Results are presented by temporal group.

Archaic

In the MANOVA comparison of Archaic facial dimensions and age, no facial measurements are found to significantly vary with the different age categories. The overall Wilks' Criterion F value of 1.07 and associated Probability > F value of 0.3793 corroborate these results. However, it must be cautioned that Archaic sample sizes in this comparison are less than ideal.

Mississippian

Table 6.12 summarizes results of the MANOVA comparison of Mississippian facial dimensions and age. As can be noted from the Wilks' Criterion F value and associated probability level, there is no overall relationship between Mississippian facial measurements and the age categories; however, measures of height of the face (alveolar, upper facial, frontal chord) do show significant variation with age--all increase with increasing age.

Thus, overall, neither Archaic nor Mississippian facial dimensions exhibit significant variability with respect to age. However, Mississippian individuals do show significantly greater facial height with advancing age.

Table 6.12. MANOVA (Significant Variables Only) Comparison Among Age Classes For Mississippian Cranio-facial Dimensions.^a

Measurement ^b	R-Square	F Value	Probability > F
AVH	0.07	3.35	0.04
FRC	0.07	3.37	0.04
UFH	0.06	3.03	0.05

^aWilks' Criterion=0.649; F=1.28; Probability > F=0.1777; Degrees of Freedom: Model=2; Error=87; Corrected Total=89; n=90.

^bMeasurement definitions may be found in Appendix A.

Between-Group (Temporal) Variability

Archaic versus Mississippian

Results of the facial measurement MANOVA comparisons (uncorrected for body size) between the Archaic and Mississippian temporal groups are presented in Table 6.13. Once again, only the facial dimensions which manifest significant differences at the 0.05 level are listed. The Wilks' Criterion F value of 13.04 (and associated probability value of 0.0001) indicates a very strongly significant difference between Archaic and Mississippian faces. Nine of the total 14 facial variables contribute to this diversity. All three of the height measures of the face (alveolar, upper facial, and cheek height) are involved in this relationship, in addition to several dimensions reflecting midfacial prognathism (subspinale, zygomaxillare radii) and breadth/projection (transmeatal breadth, zygomatic root point/zygomaticotemporal suture, eminence point/zygomatic root point, eminence point/infradentale superius).

Table 6.14 lists original means and standard deviations (separate sex) for these significantly different facial measurements. It can be seen that both height and projection of the overall face (AVH, UFH, WMH, EIS, TMB) increase from the Archaic to the Mississippian. However,

Table 6.13. MANOVA (Significant Variables Only) Comparison Of Craniofacial Measurements Between Archaic and Mississippian Samples.^a

Measurement ^b	R-Square	F Value	Probability > F
AVH	0.28	56.01	0.00
UFH	0.28	56.19	0.00
WMH	0.13	20.54	0.00
ZRS	0.18	31.46	0.00
EZP	0.15	25.99	0.00
EIS	0.05	8.27	0.01
TMB	0.11	17.40	0.00
SSR	0.09	13.75	0.00
ZMR	0.19	32.72	0.00

^aWilks' Criterion=0.414; F=13.04; Probability > F=0.0001; Degrees of Freedom: Model=1; Error=142; Corrected Total=143; n=144.

^bMeasurement definitions may be found in Appendix A.

Table 6.14. Means and Sample Sizes of Significantly Different (via MANOVA) Facial Dimensions From Archaic and Mississippian Females and Males.^a

Measure- ment ^b	<u>Archaic</u>				<u>Mississippian</u>			
	Female		Male		Female		Male	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
AVH	17.28	27	18.59	36	21.25	75	21.90	75
UFH	64.44	25	69.47	36	70.81	53	73.57	55
WMH	21.48	28	23.74	38	23.17	71	24.87	67
ZRS	35.42	25	36.83	34	31.83	48	34.23	51
EZP	51.19	25	53.06	36	48.56	48	49.66	53
EIS	96.58	25	100.07	36	99.35	48	101.85	52
TMB	163.17	24	167.17	36	166.98	47	171.90	53
SSR	91.35	23	92.94	35	88.46	46	90.06	50
ZMR	69.56	23	72.54	35	66.98	46	67.73	52

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

lateral and central midfacial prognathism and projection (as reflected by zygomaxillare [ZMR] and subspinale [SSR] radii, zygomatic root point/zygomaticotemporal suture [ZRS], and eminence point/zygomatic root point [EZP]) decrease through time.

Woodland

Once again, sampling problems restrict an evaluation of Woodland craniofacial morphology to a purely descriptive venture. Table 6.15 lists Woodland means and standard deviations for the above-discussed facial measurements showing change across the Archaic and Mississippian. Again, most of the Woodland means corroborate the previously discerned pattern of change. A few exceptions (EIS, TMB, SSR males) manifest close proximities to Archaic means and exhibit standard deviations great enough (for example, SSR=5.11) and sample sizes small enough to make conclusive interpretations tenuous.

Geometric Body Scaling

Table 6.16 presents results of the between-group MANOVA comparison of logarithmically-transformed craniofacial dimensions with temporal group (Archaic versus Mississippian). As can be seen when compared with the uncorrected Table 6.13 (page 184), MANOVA results are the same when body size is controlled across these temporal groups. Thus, as with the mandibular temporal comparison,

Table 6.15. Means, Standard Deviations, and Sample Sizes of Selected Facial Dimensions From Woodland Females and Males.^a

Measurement ^b	Female			Male		
	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n
AVH	20.10	1.71	6	21.19	3.59	12
UFH	67.75	2.49	4	69.16	5.33	7
WMH	22.15	1.97	6	24.67	2.54	7
ZRS	32.17	4.25	3	35.03	3.89	6
EZP	48.17	2.89	3	50.94	2.45	7
EIS	97.20	5.52	3	99.12	2.09	6
TMB	164.67	5.51	3	164.50	1.76	6
SSR	89.00	4.00	3	93.17	5.11	6
ZMR	65.67	3.51	3	69.33	3.61	6

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

Table 6.16. MANOVA (Significant Variables Only) Comparison Of Logarithmic Craniofacial Dimensions Between Archaic and Mississippian Samples (Body Size Differences Controlled).^a

Measurement ^b	R-Square	F Value	Probability > F
AVH	0.30	60.83	0.00
UFH	0.29	57.80	0.00
WMH	0.13	20.85	0.00
ZRS	0.18	31.77	0.00
EZP	0.15	26.03	0.00
EIS	0.06	8.38	0.00
TMB	0.11	17.21	0.00
SSR	0.09	13.85	0.00
ZMR	0.18	32.10	0.00

^aWilks' Criterion=0.410; F=12.27; Probability > F= 0.0001; Degrees of Freedom: Model=1; Error=142; Corrected Total=143; n=144.

^bMeasurement definitions may be found in Appendix A.

allometric factors do not appear to be a major determinant of these metric changes through time.

Summary

Correlation analyses of facial dimensions within both the Archaic and the Mississippian indicate strong correlations between the various projection measures (e.g., prosthion, nasion, subspinale, zygomaxillare, frontomalare radii) of the lower and midface. In addition, height variables of the face (such as alveolar, upper facial, and cheek heights) correlate highly with each other, as do dimensions expressing the breadth and projection of the lateral face (e.g., zygomatic root point/zygomaticotemporal suture, eminence point/zygomatic root point). Thus, the intercorrelative pattern of Archaic and Mississippian facial measurements is very similar.

Canonical correlation comparisons between facial and mandibular dimensions within both the Archaic and Mississippian show similar patterning across the temporal groups. In the Archaic, there is significant correlation between mandibular and craniofacial dimensions, primarily centering around height measures of both, in addition to lateral midfacial projection. Mississippian mandibular and facial measurements also exhibit significant correlations, involving height measures of the mandible and face as well

as lower facial projection, and secondly, mandibular length and midfacial projection dimensions.

Age does not prove to be of significance with regard to either Archaic or Mississippian within-group craniofacial variability. However, Mississippian facial height does increase with advancing age.

In the between-group multivariate MANOVA comparison, nine of the total 14 facial dimensions exhibit significant variability across the Archaic and Mississippian time periods. Facial height (such as alveolar, upper facial, cheek) as well as overall projection (eminence point/infradentale superius, transmeatal breadth) measures significantly increase from the Archaic to the Mississippian. However, central and lateral midfacial prognathism and projection dimensions (such as zygomaxillare and subspinale radii, zygomatic root point/zygomaticotemporal suture, and eminence point/zygomatic root point) decrease across the temporal span. Visual inspection of Woodland means for these same dimensions generally supports this pattern. As with the mandibular data, craniofacial measurements logarithmically transformed (body size controlled across the temporal span) yield identical MANOVA results when compared with the uncorrected craniofacial MANOVA analysis.

CHAPTER 7

RESULTS--ANTERIOR MANDIBULAR DENTITION

Introduction

While the two previous chapters have been concerned with the interrelationships among the 44 mandibular and craniofacial variables as well as change in these measurements through time, the focus of the present chapter is upon the five dental dimensions recorded from the mandibular lateral and central incisors and canine. As with the mandibular and craniofacial analyses, intercorrelation of dental variables among themselves is first explored. Then, the relationships between these measurements and the mandibular and facial ones are investigated. Within-group age variability is evaluated by a MANOVA comparison of dental dimensions across the three age categories for the Mississippian period samples. While small sample sizes do not permit this same within-group MANOVA comparison of age categories and Archaic temporal group dental measures, Archaic site age-related dental variability is assessed by visual comparison of dental means across the three age categories. Finally, a between-group MANOVA analysis is performed to discern possible differences in these dental dimensions across time. These results are then compared to MANOVAs based on

logarithmically-transformed dental data to elucidate potential allometric biases.

Intercorrelation of Anterior Mandibular Dental Dimensions

SAS PROC CORR (SAS Institute, Inc. 1985) is applied to the anterior mandibular dental data and correlation matrices are generated by temporal group.

Archaic

In Table 7.1, the three highest correlation coefficients are listed for each dental variable from each Archaic tooth measured. As expected, root lengths for the lateral (LROL) and central (MROL) incisor teeth are highly correlated with each other; however, canine root length (CROL) does not fit this pattern. This measurement is associated, instead, with lateral and central incisor buccolingual dimensions of the root. Also somewhat expected is the relationship between the root and crown regions for the buccolingual dimensions within each tooth--all three teeth show this high correlative pattern. While buccolingual measurements correlate highly among themselves within each tooth, mesiodistal variables correlate highly between teeth. For example, the mesiodistal measurement for the lateral incisor root (LRMD) is highly related to the same measure from the central incisor root (MRMD) (and vice versa). The one exception, however, is the canine. For this tooth, high correlations exist between the canine

Table 7.1. Highest Correlation Coefficients (via PROC CORR) Among Archaic Anterior Mandibular Teeth.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
<u>Lateral Incisor</u>						
LROL	MROL	0.67796	CROL	0.60716	LCMD	0.41588
LRMD	MRMD	0.74939	CRMD	0.71773	CCMD	0.60350
LRBL	LCBL	0.86973	CRBL	0.73279	MRBL	0.72751
LCMD	CCMD	0.60344	MCMD	0.54370	CRMD	0.45376
LCBL	LRBL	0.86973	MCBL	0.73653	CRBL	0.72783
<u>Central Incisor</u>						
MROL	LROL	0.67796	CROL	0.47517	CRBL	0.34596
MRMD	LRMD	0.74939	CCMD	0.60684	MRBL	0.57979
MRBL	MCBL	0.83804	LRBL	0.72751	LCBL	0.72404
MCMD	LCMD	0.54370	CCMD	0.50876	CROL	-0.42149
MCBL	MRBL	0.83804	CCMD	0.78008	LCBL	0.73653
<u>Canine</u>						
CROL	LRBL	0.69873	MRBL	0.69805	LCBL	0.66287
CRMD	CRBL	0.78159	LRMD	0.71773	CCBL	0.70315
CRBL	CCBL	0.93380	CRMD	0.78159	LRBL	0.73279
CCMD	MCBL	0.78008	MRBL	0.65327	MRMD	0.60684
CCBL	CRBL	0.93380	CRMD	0.70315	LCBL	0.69213

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and correlation coefficient, respectively;
M2, C2 = the second highest measurement and correlation coefficient, respectively;
M3, C3 = the third highest measurement and correlation coefficient, respectively.

mesiodistal and buccolingual root dimensions (CRMD--CRBL) as well as between the canine mesiodistal and central incisor buccolingual crown variables (CCMD--MCBL).

Mississippian

High correlation coefficients for each mandibular anterior Mississippian dental dimension are presented in Table 7.2. Once again, root lengths between all teeth are highly correlated (including the canine). And also, as with Archaic teeth, root and crown buccolingual measurements are closely related within each tooth. Similarly, mesiodistal Mississippian dental variables mimic the Archaic pattern in that they highly correlate with similar mesiodistal variables from different teeth. Again, the exception is the canine, in which the root mesiodistal dimension (CRMD) correlates highly with the root buccolingual measure (CRBL) of the same tooth.

Thus, intercorrelation patterns among various mandibular anterior dental variables are very similar between Archaic and Mississippian individuals. Both manifest a high degree of correlation between the various root lengths. Root and crown buccolingual measures of the same tooth are highly correlated with each other, as are mesiodistal dimensions between different teeth. The next section entails an examination of how these dental

Table 7.2. Highest Correlation Coefficients (via PROC CORR) Among Mississippian Anterior Mandibular Teeth.

Measure- ment ^a	Correlation Coefficients ^b					
	M1	C1	M2	C2	M3	C3
<u>Lateral Incisor</u>						
LROL	MROL	0.63049	CROL	0.60954	LRBL	0.32755
LRMD	MRMD	0.49470	LCMD	0.39085	CRBL	0.38788
LRBL	LCBL	0.86658	MRBL	0.68046	MCBL	0.62252
LCMD	MCMD	0.61730	CCMD	0.47935	LRMD	0.39085
LCBL	LRBL	0.86658	MCBL	0.73012	MRBL	0.65722
<u>Central Incisor</u>						
MROL	LROL	0.63049	CROL	0.45963	LRBL	0.30938
MRMD	LRMD	0.49470	CRMD	0.43558	LRBL	0.34463
MRBL	MCBL	0.80784	LRBL	0.68046	LCBL	0.65722
MCMD	LCMD	0.61730	CCMD	0.36442	CROL	-0.21244
MCBL	MRBL	0.80784	LCBL	0.73012	LRBL	0.62252
<u>Canine</u>						
CROL	LROL	0.60954	MROL	0.45963	CCBL	0.30619
CRMD	CRBL	0.64445	CCBL	0.54911	MRBL	0.49705
CRBL	CCBL	0.86701	CRMD	0.64445	MRBL	0.62939
CCMD	LCMD	0.47935	CRMD	0.42908	MCMD	0.36442
CCBL	CRBL	0.86701	LCBL	0.57395	CRMD	0.54911

^aMeasurement definitions may be found in Appendix A.

^bM1, C1 = the first highest measurement and correlation coefficient, respectively;
M2, C2 = the second highest measurement and correlation coefficient, respectively;
M3, C3 = the third highest measurement and correlation coefficient, respectively.

variables relate to the previously discussed mandibular and facial ones.

Correlations Between Anterior Mandibular Teeth and Mandibular and Facial Dimensions

The SAS PROC CANCORR (SAS Institute, Inc. 1985) method is applied to the dental data set in the following manner in order to examine the relationship between the mandibular lateral and central incisors and canine and the previously discussed mandibular and craniofacial variables:

1. Mandibular versus Lateral Incisor Measurements;
2. Mandibular versus Central Incisor Measurements;
3. Mandibular versus Canine Measurements;
4. Facial versus Lateral Incisor Measurements;
5. Facial versus Central Incisor Measurements;
6. Facial versus Canine Measurements.

This format is followed because of the limitation of small dental sample sizes--the number of cases in which an Archaic individual manifests all five dental dimensions from all three teeth, for example, precludes the combination of all three teeth for statistical interpretation. In addition, the restricted dental sample size necessitates the reduction of the total mandibular (from 30 to 15) and craniofacial (from 14 to 10) variables utilized. Measurement candidates for deletion are those which, from the previously conducted correlation

procedures, were found to be somewhat redundant and superfluous (IBR and IBP in relation to total mandibular length, for example).

Archaic

Mandible. In the canonical correlation comparison between the lateral incisor and mandibular dimensions, a Wilks' Criterion F value of 1.100 and associated probability estimate of 0.33 do not allow the rejection of the null hypothesis of no significant relationship between Archaic mandibular and lateral incisor measurements. A squared canonical correlation of 0.65 reflects the amount of shared variance between the two variable sets. Raw redundancy statistics for the first canonical function show that roughly 12% (0.1158) of the raw variance of the mandibular measurements can be explained by the dental canonical variables, while 17% of the dental measurement raw variance is attributable to the mandibular canonical variables.

Similarly, the Wilks' Criterion F value of 1.476 and associated probability estimate of 0.08 for the mandible versus central incisor comparison indicates no significant mandible/central incisor relationship. The squared canonical correlation estimate of shared variance is 0.91. Raw

redundancy shared variance estimates range from seven to 11%.

A canine versus mandible CANCELL Wilks' Criterion F value of 1.293 and associated probability estimate of 0.17 also denote no significant relationship between these variable sets. The squared canonical correlation estimate for shared variance is 0.81. Raw redundancy statistics for the first canonical function indicate that approximately 7% (0.0687) of the variance of the mandibular dimensions can be explained by the dental canonical variables, while roughly 22% (0.2175) of the dental measurement variance is explained by the mandibular canonical variables.

Thus, in all of the above analyses, no overall significant relationships are elucidated between Archaic mandibular and anterior mandibular dental dimensions. A consideration of Archaic facial and anterior mandibular dental variable correlations follow.

Face. A face versus lateral incisor Wilks' Criterion F value of 1.109 and associated probability estimate of 0.35 indicate no significant relationship between these data sets. Raw shared variance (redundancy analysis) calculations between the face and lateral incisor dimensions approximate 10%, while the squared canonical correlation estimate is 0.75.

Central incisor versus face CANCELL results also do not support an Archaic face/anterior mandibular dentition

relationship. The Wilks' Criterion F value of 1.627 yields a probability estimate of 0.13. The squared canonical correlation value approximates 0.96. Only 10% (0.0977) of the raw variance of the facial measurements can be explained by the dental canonical variables; however, roughly 20% (0.1992) of the raw variance of the central incisor measurements is explainable by the facial canonical variables.

A Wilks' Criterion F value of 1.520 and associated probability measure of 0.11 designate the absence of a significant overall relationship between craniofacial and canine variables. Raw redundancy statistics for the first canonical function indicate that 17% (0.1711) of the raw variance of the facial measurements may be explained by the dental canonical variables. Approximately 12% of the raw variance of the dental measurements is attributable to the facial canonical variables. The squared canonical correlation value is 0.91.

Thus, within the Archaic, no significant overall relationships are found between dental (anterior mandibular lateral and central incisors and canine) and mandibular or craniofacial variables. In other words, the selected dental variables have little predictive power in relation to the mandibular and facial variables.

Mississippian

Mandible. CANCELL comparisons between mandibular and lateral incisor variables indicate no significant relationship between these data sets (Wilks' Criterion F value=1.263; probability estimate=0.08). Redundancy analysis calculations for the amount of raw shared variance between the two variable sets range only from 3 to 8%, while the squared canonical correlation estimate of shared variance approximates 0.32.

Table 7.3 presents partial canonical correlation results for the mandible versus mandibular central incisor comparison. The Wilks' Criterion F value of 1.583 and associated probability estimate of 0.003 denote a significant relationship between the two variable sets. Other measures testing the relationship (such as Pillai's Trace, Hotelling-Lawley Trace, and Roy's Greatest Root) also indicate significance at the 0.05 level. Canonical correlation statistics in Table 7.4 (including Probability > F) designate two canonical functions as significant. Squared canonical correlation estimates of shared variance approximate 0.31 for CAN1 and 0.27 for CAN2. Redundancy statistics in Table 7.5 indicate that only approximately 1% (0.0151) of the raw variance of the mandibular measurements can be explained by the central incisor canonical variables

Table 7.3. Within-group CANCELL Comparison Statistics For
Mississippian Site Mandibular Central Incisor
Versus Facial Dimensions.^a

Statistic	Value	F	DF	Prob>F
Wilks' Criterion	0.27796	1.583	75	0.0030
Pillai's Trace	1.11493	1.607	75	0.0021
Hotelling-Lawley Trace	1.48318	1.550	75	0.0044
Roy's Greatest Root	0.45006	2.520	15	0.0040

^aBased on 100 observations.

Table 7.4. Within-group Summary Statistics For CANCELL
Comparison of Mississippian Site Mandibular
Central Incisor Versus Mandibular Dimensions
For The Five Canonical Functions.^a

Func- tion	Corre- lation	Corre- lation ²	Eigenvalue		Likelihood	F	Prob>F
			Raw	Cum. ^b	Ratio		
1	0.5571	0.3104	0.45	0.30	0.2780	1.58	0.0030
2	0.5220	0.2725	0.37	0.56	0.4030	1.49	0.0186
3	0.4809	0.2312	0.30	0.76	0.5540	1.38	0.0775
4	0.4289	0.1840	0.22	0.91	0.7207	1.23	0.2223
5	0.3418	0.1169	0.13	1.00	0.8831	1.01	0.4445

^aBased on 100 observations.

^bCum.=Cumulative.

Table 7.5. Mississippian Mandibular Central Incisor Versus Mandible Canonical Correlation Raw Redundancy Statistics For The First Two Canonical Functions.

Measurement Class	Central Incisor Canonical Variable Shared Variance	Mandibular Canonical Variable Shared Variance
<u>CAN1</u>		
Central Incisor	0.4829	0.1499
Mandible	0.0151	0.0486
<u>CAN2</u>		
Central Incisor	0.2485	0.0677
Mandible	0.0253	0.0929
<u>CAN1 and CAN2</u>		
Central Incisor	0.7315	0.2176
Mandible	0.0404	0.1415

for the first canonical function. When CAN2 is added, the amount of shared variance between these two data sets increases to 4% (0.0404--CAN1 and CAN2). The raw variance of the central incisor measurements explained by the mandibular canonical variables approaches 15% (0.1499) for CAN1 and 22% (0.2176) for CAN1 and CAN2. This difference in raw redundancy estimates of shared variance is most likely due to the greater number of mandibular dimensions compared to the dental ones.

The canonical structures involved in this predictive relationship are found in Tables 7.6 and 7.7. For the first canonical function containing correlations between mandibular measurements and central incisor canonical variables (Table 7.6--CAN1), ascending ramus thickness (ART=0.3561) and symphyseal breadth, basal (SWB=0.1613) exhibit the highest positive correlations, while height measures of the mandible (ARH=-0.1774; CPH=-0.1875; CDH=-0.1579) manifest fairly high negative correlations. Correlation structure comparisons between the central incisor measurements and the mandibular canonical variables for the first canonical function (Table 7.7--CAN1) isolate root length (MROL=0.4412) and, secondly, mesiodistal crown diameter (MCMD=0.3020) as important dental dimensions involved in the correlative relationship.

For the second canonical function, mandibular measurement versus central incisor canonical variable

Table 7.6. Canonical Correlation Structure Comparison of Mississippian Mandibular Measurements and Canonical Variables of The Mandibular Central Incisor.

Mandibular Measurement ^a	Canonical Central Incisor Variable	
	CAN1	CAN2
BCN	-0.0806	-0.1543
CPH	-0.1875	0.2234
CPT	0.0515	0.0633
CDH	-0.1579	0.1081
BGB	-0.0945	0.1113
CPG	-0.0772	0.0867
ART	0.3561	0.0033
ARB	0.0605	0.1276
ARH	-0.1774	0.2802
TML	0.0990	0.1443
IBR	0.0170	0.1276
CDT	0.0884	0.1641
GMA	0.1335	-0.1027
SMH	0.0776	0.2071
SWB	0.1613	0.1806

^aMeasurement definitions may be found in Appendix A.

Table 7.7. Canonical Correlation Structure Comparison of Mississippian Mandibular Central Incisor Measurements and Canonical Variables of The Mandible.

Central Incisor Measurement ^a	Canonical Mandibular Variable	
	CAN1	CAN2
MROL	0.4412	0.2189
MRMD	0.2339	-0.1343
MRBL	0.2386	0.2379
MCMD	0.3020	-0.3897
MCBL	0.2122	0.2385

^aMeasurement definitions may be found in Appendix A.

comparisons (Table 7.6--CAN2) show that mandibular height measures have the highest positive correlations (ARH=0.2802; CPH=0.2234). For the central incisor measurement/mandibular canonical variable comparison (Table 7.7--CAN2), mesiodistal crown diameter exhibits a high negative correlation (MCMD=-0.3897).

In sum, the first canonical function structure involves high loadings for mandibular thickness (ART, SWB) and central incisor root variables, with mandibular heights showing a high negative correlation. The second canonical function involves high positive loadings for mandibular height and a negative value for central incisor mesiodistal crown diameter.

Table 7.8 lists partial canonical correlation results for the comparison between Mississippian mandibular and mandibular canine variables. The Wilks' Criterion F value of 1.554 and associated probability estimate of 0.0042 indicate a significant relationship between these two data sets. Pillai's Trace, Hotelling-Lawley Trace, and Roy's Greatest Root statistics agree. Canonical correlation statistics (Table 7.9) isolate the first canonical function as responsible for this relationship. A squared canonical correlation estimate for shared variance between the two variable sets approaches 0.40 (0.3980). Raw redundancy calculations indicate that only approximately 1% (0.0098) of the variance of the mandibular measurements can be

Table 7.8. Within-group CANCELL Comparison Statistics
For Mississippian Site Mandibular Canine Ver-
sus Mandibular Dimensions.^a

Statistic	Value	F	DF	Prob>F
Wilks' Criterion	0.29143	1.554	75	0.0042
Pillai's Trace	1.03483	1.496	75	0.0077
Hotelling-Lawley Trace	1.49691	1.605	75	0.0023
Roy's Greatest Root	0.66125	3.791	15	0.0001

^aBased on 102 observations.

Table 7.9. Within-group Summary Statistics For CANCORR Comparisons of Mississippian Site Mandibular Canine and Mandibular Dimensions For The Five Canonical Functions.^a

Func- tion	Corre- lation	Corre- lation ²	Eigenvalue		Likelihood Ratio	F	Prob>F
			Raw	Cum. ^b			
1	0.6309	0.3980	0.66	0.44	0.2914	1.55	0.0042
2	0.5641	0.3182	0.47	0.75	0.4841	1.90	0.1805
3	0.4188	0.1754	0.21	0.90	0.7101	0.71	0.8182
4	0.3159	0.0998	0.11	0.97	0.8611	0.55	0.9569
5	0.2082	0.0434	0.04	1.00	0.9566	0.35	0.9697

^aBased on 102 measurements.

^bCum.=Cumulative.

explained by the dental canonical variables, while only about 2% (0.0169) of the variance of the dental measurements is explainable by the mandibular canonical variables. Table 7.10 contains the correlation structure between the mandibular measurements and the canonical variables of the canine dimensions for the first canonical function. Condyle height ($CDH=-0.3159$) and corpus thickness ($CPT=-0.2409$) exhibit fairly high negative correlations. Correlations between the canine measures and the canonical variables of the mandibular dimensions (Table 7.11) isolate mesiodistal diameter of the crown ($CCMD=0.3528$) and, secondly, root ($CRMD=0.2642$) as important dental contributors to this relationship.

Thus, in the Mississippian, there is a significant overall relationship between both the central incisor and canine in regard to the mandibular dimensions. Correlation between the lateral incisor and mandible is not significant.

Face. Table 7.12 presents Mississippian canonical correlation statistic summaries for the separate comparisons of all three teeth with the craniofacial dimensions. As can be seen by looking at the Wilks' Criterion F values and associated probability estimates, none of the teeth exhibit a significant relationship with the facial dimensions at the 0.05 level. Very low raw

Table 7.10. Canonical Correlation Structure Comparison of Mississippian Mandibular Measurements and Canonical Variables of The Mandibular Canine.

Mandibular Measurement ^a	Canonical Canine Variable
BCN	0.0679
CPH	-0.1616
CPT	-0.2409
CDH	-0.3159
BGB	-0.0178
CPG	0.1450
ART	0.0862
ARB	-0.0512
ARH	-0.1068
TML	-0.0688
IBR	0.0763
CDT	-0.1175
GMA	-0.0690
SMA	0.0978
SWB	-0.0709

^aMeasurement definitions may be found in Appendix A.

Table 7.11. Canonical Correlation Structure Comparison of Mississippian Mandibular Canine Measurements and Canonical Variables of The Mandible.

Canine Measurement ^a	Canonical Mandibular Variable
CROL	-0.0155
CRMD	0.2642
CRBL	-0.1366
CCMD	0.3528
CCBL	0.0390

^aMeasurement definitions may be found in Appendix A.

Table 7.12. Canonical Correlation Summary Statistics For Mississippian Mandibular Anterior Tooth Versus Face Comparison.

Comparison ^a	Wilks' F	Prob. > F	CAN CORR ²	Raw Redundancy	n
Lateral I* Face	0.821	0.7918	0.35	1--6%	53
Central I* Face	1.149	0.2567	0.41	1--13%	50
Canine* Face	1.042	0.4129	0.40	4%	49

^aI=Incisor.

redundancy statistics and shared canonical correlations indicate small amounts of shared variance between the variable sets.

In sum, within the Mississippian, no significant overall relationships between the lower face and the mandibular anterior dentition are found. This situation parallels that seen in the Archaic.

Within-Group (Age) Variability

Small tooth sample sizes from the Archaic skeletal remains preclude the statistical exploration of within-group Archaic dental variability with regard to age. However, visual comparison of dental means across age categories is possible. Mississippian within-group variation involving the relationship between the mandibular anterior dental dimensions and the three age categories is assessed statistically. These results are presented below.

Archaic

Tables 7.13 and 7.14 present comparisons of mandibular anterior dental variable means with respect to the three age categories for Archaic females and males, respectively. As can be seen, sample sizes for the older aged individuals are small. Generally, however, lateral incisor root lengths tend to decrease, while central incisor and canine root lengths increase with increasing age. Mesiodistal diameters of the root of all three teeth show a mixed

Table 7.13. Comparison of Female Archaic Mandibular Anterior Tooth Means and Sample Sizes With Respect to Age.^a

Measure- ment ^b	18-29 years		30-44 years		45+ years	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
<u>Lateral Incisor</u>						
LROL	14.78	12	14.10	4	-	0
LRMD	3.80	14	3.88	4	-	0
LRBL	5.96	14	6.00	4	-	0
LCMD	6.07	14	5.43	4	-	0
LCBL	6.10	14	6.18	4	-	0
<u>Central Incisor</u>						
MROL	12.77	9	13.07	3	-	0
MRMD	3.40	10	3.77	3	-	0
MRBL	5.39	10	5.87	3	-	0
MCMD	5.14	10	4.53	3	-	0
MCBL	5.65	10	5.77	3	-	0
<u>Canine</u>						
CROL	16.42	6	17.83	6	14.80	1
CRMD	4.87	6	5.35	6	5.00	1
CRBL	7.13	6	7.43	6	7.40	1
CCMD	6.83	6	6.68	6	6.20	1
CCBL	7.28	6	7.47	6	7.30	1

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

Table 7.14. Comparison of Male Archaic Mandibular Anterior Tooth Means and Samples Sizes With Respect To Age.^a

Measure- ment ^b	18-29 years		30-44 years		45+ years	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
<u>Lateral Incisor</u>						
LROL	15.02	9	13.98	6	15.00	3
LRMD	4.13	9	3.83	8	3.60	3
LRBL	6.03	9	6.08	8	6.13	3
LCMD	5.93	9	5.68	8	5.33	3
LCBL	6.08	9	6.16	8	6.17	3
<u>Central Incisor</u>						
MROL	13.16	8	13.78	6	12.20	1
MRMD	3.63	8	3.46	7	2.70	1
MRBL	5.56	8	5.73	7	4.90	1
MCMD	4.73	8	4.70	7	3.60	1
MCBL	5.56	8	5.87	7	5.10	1
<u>Canine</u>						
CROL	18.89	7	18.96	8	19.80	3
CRMD	5.66	7	5.79	8	5.33	3
CRBL	7.69	7	8.10	8	7.47	3
CCMD	7.11	7	6.99	8	6.40	3
CCBL	7.81	7	8.19	8	7.53	3

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

pattern of variation, while mesiodistal crown diameters decrease slightly with older individuals. Most buccolingual diameters tend to increase with advancing age.

Mississippian

Table 7.15 presents summary statistics from three separate MANOVA comparisons of Mississippian mandibular anterior dental measurements with the age categories. As can be noted from an analysis of the overall Wilks' Criterion F values and associated probabilities, both the lateral and central mandibular incisors vary significantly (at the 0.05 level) with age. These relationships primarily involve mesiodistal dental diameters (of the root in the lateral incisor and crown in both the lateral and central incisors) as well as root length (for the central incisor). A comparison of female and male dental means across the Mississippian age categories reveals that, for the most part, the mesiodistal diameters of the root and crown decrease with increasing age, while root length increases with older individuals.

In sum, the increase in central incisor root length and decrease in mesiodistal diameters of the lateral and central incisor with increasing age in the Mississippian appear to generally support the age-related dental variability patterning observed for the Archaic. However, small Archaic dental sample sizes prohibit further

Table 7.15. MANOVA (Significant Variables Only) Comparison Among Age Classes For Mississippian Anterior Mandibular Dental Dimensions.

Measurement ^a	R-Square	F Value	Probability > F
<u>Lateral Incisor</u> ^b			
LRMD	0.10	4.09	0.01
LCMD	0.14	6.43	0.00
<u>Central Incisor</u> ^c			
MROL	0.13	4.99	0.00
MCMD	0.27	11.98	0.00

^aMeasurement definitions may be found in Appendix A.

^bWilks' Criterion F=3.19; Probability > F=0.0001; n=118.

^cWilks' Criterion F=4.49; Probability > F=0.0001; n=103.

tooth/age variability comparisons between these temporal groups.

Between-Group (Temporal) Variability

Archaic versus Mississippian

MANOVA summary results for mandibular anterior dental measurements exhibiting significant variability (at the 0.05 level) across the Archaic and Mississippian temporal groups are presented in Table 7.16. For the lateral incisor, both the root and crown buccolingual dimensions manifest significant differences through time. The Wilks' Criterion F value of 2.34 and associated probability measure of 0.0444 indicate that there is a significant (at the 0.05 level) overall difference in these lateral incisor metrics with regard to the two temporal groups.

Mandibular central incisor (Table 7.16) variables which are different across the temporal groups also include the buccolingual root measure; in addition, root length and the mesiodistal crown dimension are also involved. An F value of 3.78 for the Wilks' Criterion and associated probability estimate of 0.0032 allow the rejection of the null hypothesis of no overall variability between Archaic and Mississippian central incisor dimensions.

Table 7.16 also contains similar data for the mandibular canine. A significant difference in Archaic and Mississippian canine dimensions is evident at the 0.05

Table 7.16. MANOVA (Significant Variables Only) Comparison of Mandibular Anterior Dental Dimensions Between Archaic and Mississippian Samples.

Measurement ^a	R-Square	F Value	Probability > F
<u>Lateral Incisor</u> ^b			
LRBL	0.04	6.66	0.01
LCBL	0.03	4.57	0.03
<u>Central Incisor</u> ^c			
MROL	0.03	3.99	0.05
MRBL	0.07	9.72	0.00
MCMD	0.03	4.48	0.04
<u>Canine</u> ^d			
CROL	0.03	4.16	0.04
CCMD	0.03	4.62	0.03

^aMeasurement definitions may be found in Appendix A.

^bWilks' Criterion=0.928; F=2.34; Probability > F=0.0444; Degrees of Freedom: Model=1; Error=155; Corrected Total=156; n=157.

^cWilks' Criterion=0.870; F=3.78; Probability > F=0.0032; Degrees of Freedom: Model=1; Error=130; Corrected Total=131; n=132.

^dWilks' Criterion=0.875; F=3.78; Probability > F=0.0032; Degrees of Freedom: Model=1; Error=136; Corrected Total=137; n=138.

level (Wilks' Criterion F value=3.78; Probability > F=0.0032). Two of the five total dental variables contribute to this relationship--root length and the mesiodistal dimension of the crown.

Thus, all three mandibular anterior teeth show significant differences across the Archaic and Mississippian. This variability is related to measures of root length, root and crown buccolingual and crown mesiodistal diameters. In order to obtain a clearer assessment of the pattern of these differences, a review of the original means and standard deviations across each temporal group is in order.

Table 7.17 presents such a reexamination for Archaic and Mississippian females and males. Both measurements involved in mandibular lateral incisor variability (LRBL, LCBL) decrease across these groups. Mandibular central incisor variables show a mixed pattern--the root buccolingual diameter decreases, while root length and crown mesiodistal diameter increase. Both measurements of the canine which are involved in the significant variation for this tooth increase from the Archaic to the Mississippian. An alternative mode of describing these results reveals the presence of an important pattern--root lengths and crown mesiodistal diameters increase, while root and crown buccolingual measures decrease across these temporal groups.

Table 7.17. Means and Sample Sizes of Significantly Different (via MANOVA) Mandibular Anterior Tooth Measurements From Archaic and Mississippian Females and Males.^a

Measure- ment ^b	<u>Archaic</u>				<u>Mississippian</u>			
	Female		Male		Female		Male	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
<u>Lateral Incisor</u>								
LRBL	5.97	18	6.05	21	5.76	62	5.90	57
LCBL	6.12	18	6.13	21	5.95	62	5.99	56
<u>Central Incisor</u>								
MROL	12.84	12	13.35	15	13.21	49	13.85	54
MRBL	5.50	13	5.59	16	5.27	49	5.34	54
MCMD	5.00	13	4.64	16	5.00	49	5.09	54
<u>Canine</u>								
CROL	16.95	13	19.07	18	17.88	55	19.44	52
CCMD	6.71	13	6.94	18	6.92	55	7.19	52

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

Woodland

Sample sizes for Woodland tooth data are extremely small; thus, only a non-statistical, impressionistic appraisal of the congruence of the Woodland tooth data with the pattern outlined above can be made. Table 7.18 contains Woodland means and standard deviations (and sample sizes) for the above-discussed significant dental variables for males only (female sample sizes are too small for consideration). Only one tooth comprises the canine male sample; thus, this tooth is excluded also. Of the remaining dimensions, it can be seen that the buccolingual root diameters of the lateral (LRBL) and central (MRBL) incisors do appear to fall within the pattern of reduction through time. Central incisor root length and crown mesiodistal diameter also fit the previously established example of increase from the Archaic to the Mississippian; however, the Woodland increase is even greater than that seen in the equivalent Mississippian dimensions. Finally, the lateral incisor buccolingual crown diameter mean for the three Woodland males does not fit the previous pattern of reduction through time. However, it must be reiterated that sample size limitations for Woodland dental data must breed caution in the interpretation of any of the above comparisons.

Table 7.18. Means, Standard Deviations, and Sample Sizes of Selected Mandibular Anterior Tooth Dimensions From Woodland Males.^a

Measurement ^b	$\bar{x}$	S.D.	n
<u>Lateral Incisor</u>			
LRBL	6.03	0.15	3
LCBL	6.20	0.10	3
<u>Central Incisor</u>			
MROL	14.07	0.98	3
MRBL	5.40	0.62	4
MCMD	5.43	0.47	3

^aMeasurements are in millimeters.

^bMeasurement definitions may be found in Appendix A.

Geometric Body Scaling

Just as with the mandibular and craniofacial data, the mandibular anterior dental measurements are subjected to the logarithmic geometric body scaling transformation described previously to control body size differences across the two temporal (Archaic and Mississippian) groups. Table 7.19 presents the results of the MANOVA comparison between the three mandibular teeth and temporal group based on these corrected data. When this table is compared to the uncorrected MANOVA results of Table 7.16 (page 220), it can be seen that the results are identical. Thus, once again, allometric variability across this time span does not appear to be an important consideration in explaining the nature of the metric changes.

Summary

As with the mandibular and craniofacial data sets, the intercorrelative patterns between dental dimensions for the Archaic and Mississippian are very similar. Within both the Archaic and Mississippian, high correlations exist between various root length dimensions of the mandibular anterior dentition. And, root and crown buccolingual measures of the same tooth and mesiodistal diameters of different teeth strongly correlate together.

In the CANCELL comparison of anterior mandibular

Table 7.19. MANOVA (Significant Variables Only) Comparison Of Logarithmic Mandibular Anterior Dental Dimensions Between Archaic and Mississippian Samples (Body Size Differences Controlled).

Measurement ^a	R-Square	F Value	Probability > F
<u>Lateral Incisor</u> ^b			
LRBL	0.04	6.11	0.01
LCBL	0.03	4.11	0.04
<u>Central Incisor</u> ^c			
MROL	0.03	4.43	0.04
MRBL	0.06	8.97	0.00
MCMD	0.03	4.14	0.04
<u>Canine</u> ^d			
CROL	0.03	4.60	0.03
CCMD	0.03	4.62	0.03

^aMeasurement definitions may be found in Appendix A.

^bWilks' F=1.97; Probability > F=0.0734; n=157.

^cWilks' F=3.76; Probability > F=0.0039; n=132.

^dWilks' F=3.59; Probability > F=0.0045; n=138.

dental measurements and mandibular variables, none of the three teeth exhibit overall significant (at the 0.05 level) relationships with the Archaic mandibles. Mississippian mandibles do show significant correlations with dimensions involving the central incisor and canine. These correlations involve height and thickness dimensions of the mandible with root length and crown and root mesiodistal diameters. Craniofacial comparisons with these anterior dental dimensions indicate no significant overall correlations between either Archaic or Mississippian faces and anterior mandibular teeth.

Within-group age variability with respect to the dental dimensions can only be statistically investigated (via MANOVA) with regard to the Mississippian period. Age is seen to be a significant factor with regard to dental variability for the central and lateral incisors, involving decreases in mesiodistal root and crown diameters and increases in root length with advancing age. Similar (although somewhat variable) non-statistical observations are noted for Archaic dental dimensions with regard to the three age categories.

Between-group (temporal) MANOVA analyses reveal clear evidence for a significant (0.05 level) reduction in buccolingual diameters of the root of the central and lateral incisors through time. In addition, lateral incisor crown buccolingual diameter also decreases from the

Archaic to the Mississippian. Root length as well as mesiodistal crown variables for the central incisor and canine increase across these temporal groups. Although sample sizes are very small, visual inspection of Woodland male dental means and standard deviations generally supports these patterns. As with the mandibular and craniofacial data, allometric variability is not a contributing factor involved in these metric changes.

CHAPTER 8

EVALUATION AND INTERPRETATION

Introduction

At the end of Chapter 2 of this dissertation, several expectations were outlined regarding the nature of the present data comparisons. For example, it was predicted that, because of the previously discussed complex functional interrelationships of the mandible, lower face, and anterior mandibular dentition, high correlations would be found between measurements from these data sets. In regard to variation in these dimensions across the temporal skeletal series, a model involving masticatory-related gracilization in the mandibulofacial and dental region was formulated. In this model, it was predicted that because of the dietary shift from a hard-textured (Archaic hunting and gathering) food bolus to a soft-textured (Mississippian agricultural) one, reductions in linear dimensions of the mandible and face (height, length, breadth) would occur. In addition, anterior mandibular dental dimensions were expected to decrease. Possible changes in orientation and size of masticatory muscles were also theorized. In short, the present data were utilized in a test of this model of masticatory-related mandibular, craniofacial, and dental

change through time. It is now time to assess the correspondence of the results presented in the three preceeding chapters with predictions generated from this model.

Intercorrelation of Measurements

As noted in Chapter 6, significant correlations exist between craniofacial and mandibular dimensions within both the Archaic and Mississippian samples. There are significant correlations between Archaic height measures of the mandible and height of the lower face as well as lateral midfacial breadth and projection. Significant Mississippian correlations relate mandibular height dimensions with lower facial height and projection; secondly, length of the mandible correlates fairly highly with projection and breadth of the lateral midface.

Significant correlations are noted in Chapter 7 between anterior mandibular dental and mandibular measurements. These associations are significant at the 0.05 level in only two instances, both involving the Mississippian period samples--mandible versus central incisor and mandible versus canine. Interestingly, when the actual canonical structures denoting variables involved in these relationships are examined, it can be seen that both of these instances involve fairly high correlations between mandibular thickness and height measures and root

length or crown or root mesiodistal diameter. For example, fairly high correlations exist between the mandibular dimensions of ascending ramus thickness, height, symphyseal breadth (basal), and corpus height with central incisor root length and mesiodistal crown diameter. For the mandibular canine, condyle height and corpus thickness correlate fairly strongly (and negatively) with mesiodistal crown and root diameters. Thus, significant intercorrelation relationships are noted between height and thickness measures of the mandible and mesiodistal diameters of the root and crown as well as root length.

The above intercorrelation pattern between dental and craniofacial variables corroborates to some extent similar findings by Paquette (1985) and Smith and Paquette (In Press) in relation to maxillary anterior dental and facial dimensional relationships. Within the prehistoric Arikara population, they find (through a canonical correlation analysis) high correlations between craniofacial measurements reflecting vertical displacement (height) of the face (alveolar, upper facial heights) as well as prognathism of the lower face (subnasal, canine radii) with mesiodistal diameter as well as length of the anterior maxillary tooth roots. They conclude that a significant relationship exists between anterior tooth size and vertical facial displacement and lower facial prognathism (Paquette 1985:89).

Given the previously discussed documentation of functional integration of mandibular, craniofacial, and mandibular anterior dental dimensions within the masticatory-related mandibular complex, why are not the intercorrelative relationships between the mandibulofacial and dental variables stronger? It is the author's belief that complex intrinsic (genetic) craniofacial variability (discussed in Chapter 2) may be a complicating factor--the statistical analyses performed here measure phenotypic rather than genetic variation. The well known conservative nature of the dentition also understandably would result in rather weak associations between dental and craniofacial dimensions.

Within-Group (Age) Variability

Within the Archaic, several mandibular dimensions vary significantly with respect to age. Width and thickness measurements (corpus thickness, bicanine width, ascending ramus breadth) as well as length of the mandible decrease with increasing age, while condyle height increases. No correlations are noted for Archaic facial dimensions and the three age categories. Age-related mandibular anterior tooth changes could not be statistically assessed, but central incisor and canine root lengths appear to increase, while mesiodistal diameters show a somewhat mixed pattern

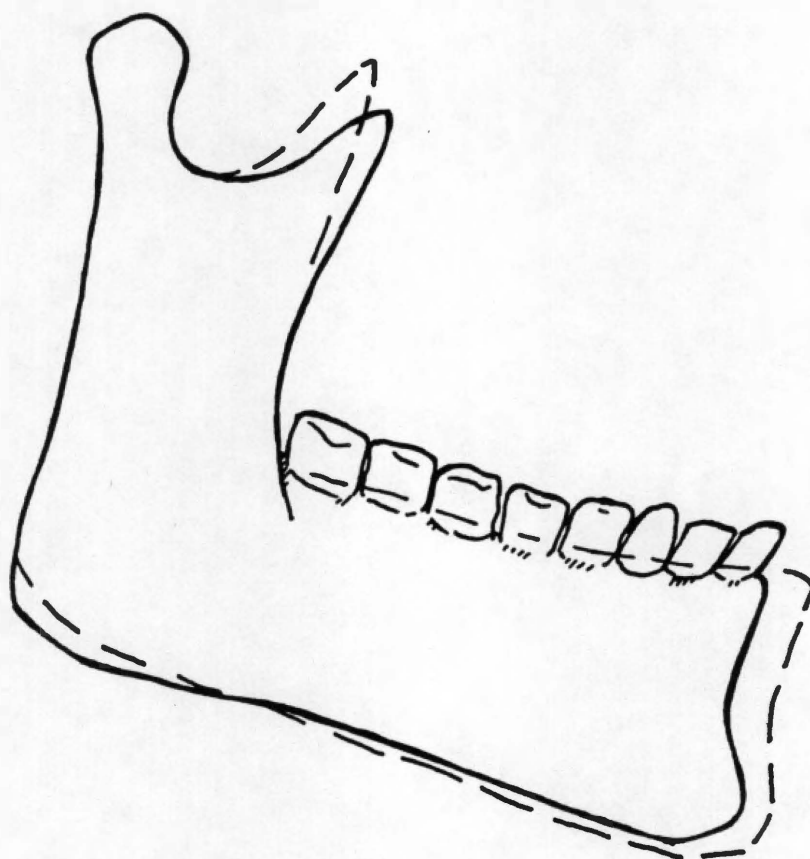
of variation with increasing age. Buccolingual diameters tend to increase with older individuals.

The Mississippian within-group correlations with age reveal different patterning. Overall mandible/age as well as face/age relationships are not significant at the 0.05 level; however, condyle thickness as well as facial height are greater in older individuals. Dental/age relationships are similar to those noted for the Archaic.

These results, particularly the differences between Archaic and Mississippian mandibular measurements with regard to age, form an important pattern. Guagliardo (1982) relates age-associated changes in the cranium to accumulation of increased amounts of masticatory functional stress. Thus, in this study, the differences in Archaic and Mississippian mandibles noted above are potentially interpretable in terms of functional occlusal force differences between the two temporal groups. Greater amounts of masticatory force in Archaic mandibles possibly led to more severe accumulation of age-related skeletal stress in these mandibles, compared to those of the Mississippian.

Between-Group (Temporal) Variability

Figure 8.1 illustrates the metric changes occurring across the Archaic and Mississippian mandibular samples. Well over half (28/44--corrected MANOVA) of the total



— ARCHAIC

- - MISSISSIPPIAN

Figure 8.1. Illustration of Mandibular Metric Changes Occurring Across The Archaic and Mississippian Samples.

selected mandibular and craniofacial dimensions compared across the Archaic and Mississippian skeletal series exhibit significant (0.05 level) differences. As expected, several of these dimensions of the mandible and lower face decrease across this time period. These include measurements reflecting prognathism of the midface (subspinale and zygomaxillare radii) as well as ascending ramus height and symphysis width at the base. And, buccolingual diameters of the root and crown of the mandibular lateral incisor and root of the central incisor significantly reduce in size through time.

However, contrary to expectations, the majority of the dimensions which show change through time (15/19 mandibular; 5/9 facial--corrected MANOVA) increase from the Archaic to the Mississippian. These measurements involve reflections of length (total mandibular and posterior tooth row lengths, infradentale inferius/bicondylar radius and projection, pogonion/bicondylar radius and projection, P3/bicondylar radius, lower molar point/bicondylar radius), height (symphysis, corpus, and coronoid process heights, coronoid process/lower molar point), width (bicanine width), and thickness (ascending ramus thickness) of the mandible as well as height (alveolar, upper facial, cheek) of the lower face. In addition, root lengths as well as mesiodistal crown diameters of the mandibular central

incisor and canine increase significantly (0.05 level) across the temporal span.

These results at first glance do not appear to fit the pre-established model of masticatory-related mandibular and craniofacial gracilization through time at all. In fact, the converse seems to be happening. Control of allometric variables throughout this study rules out body size differences as a possible explanation. And, visual comparison of Woodland means to these Archaic and Mississippian dimensions corroborates the pattern of consistent and gradual increases through time. Given the previously documented dietary shift from a hard- to soft-textured food bolus through time, an increase in linear dimensions of the mandible, lower face, and anterior mandibular dentition appears to refute the gracilization model. However, when these results are more closely examined in light of the previously discussed principles of masticatory function, some very interesting patterns emerge. These are discussed below.

Heavy Occlusal Force Generation and Masticatory Efficiency

There are several ways in which a masticatory system can be made more "efficient" in terms of generating and dissipating heavier amounts of occlusal force. In his examination of the Eskimo masticatory system, Hylander (1972:222) notes that increased mechanical efficiency

results from an increase in the length of the power (masticatory muscle) arm or a decrease in the length of the load (dental arch) arm. An increased power arm length can be accomplished by moving the masticatory muscles more anterior in relation to the lever-hypothesized fulcrum at the TMJ. Increasing the size and robusticity of the muscles also results in a greater power arm. A shortened load arm can result when the teeth are moved closer to the condyle (fulcrum). If one examines more closely the results of the between-group (temporal) multivariate comparisons, it can be seen that all of the above reorientations characterize Archaic mandibles and lower faces in contrast to those of Mississippian individuals. These aspects are discussed below.

Masticatory Muscle Size. Hinton (1979:119) provides measurements and methods which estimate masticatory muscle size. The distance from zygomatic root point to zygomaticotemporal suture (ZRS) approximates the size of the masseter. As can be seen in Table 6.13 and 6.14 (pages 184-185), this dimension is significantly larger in Archaic faces compared to Mississippian ones at the 0.05 level. Hinton (1979:119) also cites zygomatic arch thickness (ZAT) as reflective of masseter size. In this study, there is little difference in female zygomatic arch thickness, but male ZAT measurements decrease from Archaic to Mississippian (although not enough to be significant at the

0.05 level). Hinton (1979:119) notes that the multiplication of these two measurements (ZRS x ZAT) provides an estimate of masseter cross-sectional area. In the present study, an Archaic female cross-sectional masseter area of 161.51 mm^2 is substantially greater than the 147.69 mm^2 estimate for Mississippian females. The same pattern can be observed for the males (Archaic male masseter cross-sectional area= 192.62 mm^2 ; Mississippian= 175.26 mm^2). Thus, for both Archaic males and females, cross-sectional areas and overall sizes of the masseter are larger compared to the Mississippian.

Similar patterning can be noted for the temporalis muscle. Hinton (1979:119) notes that measurements concerning the infratemporal fossa (length, width) reflect size of the temporalis. Infratemporal fossa length (IFL) multiplied by width (IFW) approximates the cross-sectional area of the temporalis. Unfortunately, these two measurements were not included in the multivariate statistical comparison; however, their means (see Appendix B) can be statistically compared across the Archaic and Mississippian time periods. T-test comparisons of the means indicate that the female IFL mean is significantly (at the 0.05 level) larger than that of the Mississippian (Archaic= 33.71 mm ; Mississippian= 32.44 mm ; $t=1.90$, $df=70$). The Archaic male IFL dimension mean (35.06 mm) is also significantly larger than the mean for the same Mississippian measurement

(32.89 mm) ($t=3.06$, $df=82$). A similar significant relationship is discerned for the IFW mean male comparison (Archaic=25.40 mm; Mississippian=24.29 mm; $t=2.27$, $df=77$); however, the female IFW sample size is not large enough for statistical analysis.

When means from these two dimensions (IFL, IFW) are multiplied to arrive at temporalis cross-sectional area estimates, once again, differences can be seen. The male Archaic cross-sectional temporalis area of 890.52 mm² is substantially greater than the Mississippian area estimate (798.90 mm²). Because of the slightly larger Mississippian female IFW mean, the female cross-sectional temporalis areas are more similar (Archaic=761.17 mm²; Mississippian=769.15 mm²). Thus, it can be stated that, at least for the males, Archaic temporalis muscle size and cross-sectional area, as with the masseter, are greater in the Archaic in comparison to the Mississippian. Table 8.1 presents an adaptation of two tables from Hinton (1979:214, 215) comparing the cross-sectional areas of the Archaic and Mississippian temporalis and masseter muscles with five populations analyzed by Hinton. It can be seen that in almost all cases, the Archaic data falls between the traditionally heavily stressed masticatory systems of the Eskimo and Australian aborigine and the less stressed agriculturally based Southwestern Amerindian group representing Western Pueblo populations of circa A.D. 1280

Table 8.1. Comparison of Masseter and Temporalis Cross-sectional Muscle Areas Across Several Human Populations.^a

Muscle	Human Population Muscle Area ^b						
	Eskimo	Aust. Abor.	Archa-ic	Mississippian	SW Amer.	Am. White	Am. Black
<u>Masseter^c</u>							
Female	164.4	172.0	161.5	147.7	145.4	132.8	142.7
Male	219.7	223.1	192.6	175.3	178.3	162.6	184.4
<u>Temporalis^d</u>							
Female	839.6	785.9	761.2	769.1	707.9	606.0	704.3
Male	946.7	920.5	890.5	798.9	808.5	734.1	801.2

^aAdapted from Tables 9.3 and 9.4 (pages 214-215) of Hinton (1979);

^bAust. Abor.=Australian aborigine; Archaic and Mississippian=samples collected for the present study; SW Amer.=Southwestern U.S. Amerindians; Am. White and Am. Black=modern American White and Black populations;

^cmasseter area=(in mm²) zygomatic root point/zygomaticotemporal suture X zygomatic arch thickness;

^dtemporalis area=(in mm²) infratemporal fossa length x width.

to 1600 (Hinton 1979). The Mississippian areas fall closer to the Southwestern Amerindian agricultural group.

Masticatory Muscle Orientation. Not only are Archaic masticatory muscles more robust than Mississippian ones, they are located more anterior in relation to the hypothesized condylar fulcrum than Mississippian masticatory muscles. For example, Hinton (1979:120) designates the measurement from eminence point to zygomatic root point (in this study, EZP) as reflective of the anterior extent of the masseter. As can be seen from Tables 6.13 and 6.14 (pages 184-185), this dimension is significantly larger in Archaic faces compared to Mississippian ones at the 0.05 level. In other words, Archaic masseter muscles are positioned more anterior in relation to the fulcrum and bite points compared to Mississippian masseter orientation.

In addition, Hinton (1979:120) notes that the distance from the most superior point on the head of the mandibular condyle (condylion) to the most anterior convex point on the coronoid process (coronoid point) represents the moment or power arm of the temporalis muscle. In the present study, the measurements of CTR and CTP (coronoid point radius and projection) as well as CPR and CPP (cornoid process radius and projection) are designed to approximate this distance. As can be seen in Tables 5.5 and 5.6 (pages

154, 156), while almost all of the significantly different (0.05 level) linear length measures of the mandible are smaller in Archaic mandibles compared to Mississippian ones, the only two which are significantly larger are CPR and CPP--coronoid process radius and projection. And, if one compares the means for CTR and CTP across the Archaic and Mississippian (Appendix B), one can see that these length dimensions are also larger in male and female Archaic mandibles (excepting CTR for males), although not enough to be significant at the 0.05 level. This means that, compared to Mississippian mandibles, Archaic mandibles manifest a longer and more anterior positioning of the temporalis muscle in relation to the temporomandibular joint.

Hylander (1972:227) notes for his heavily masticatory-stressed Eskimos that a low and robust coronoid process reflects a robust temporalis muscle which is reoriented more vertically in relation to the occlusal plane. This rearrangement results in an increased vertical mandibular force generation potential (Hylander 1972:227). In the present study, it is very interesting to note that both measures of coronoid process height (coronoid process/lower molar point--CMP, coronoid process height--CPH, corrected MANOVA) are significantly (at the 0.05 level) smaller in the Archaic and increase in the Mississippian.

Thus, for both the masseter and temporalis muscles,

the greater size and more anterior placement in the Archaic reflect essentially a longer and more powerful muscle (power) arm in relation to load arm. The significantly greater lateral and lower midfacial Archaic prognathism (as reflected by subspinale and zygomaxillare radii) (Tables 6.13 and 6.14, pages 184-185) reflect this rearrangement.

At the same time, it can be seen that the load arm within Archaic mandibles is reduced compared to the Mississippian situation. It is very interesting to note that eight of the 19 mandibular dimensions which show significant (0.05) variability from the Archaic to the Mississippian (Tables 5.5, 5.6 and 5.8:pages 154, 156, 160) reflect various anterior and overall length measures of the body of the mandible. All of these (excepting CPP and CPR, discussed previously) are smaller in the Archaic. This means that within the Archaic, the dental arch (load arm) is closer to the fulcrum point at the condyle compared to Mississippian mandibles.

Further evidence for this pattern can be gleaned by an analysis of mandibular and maxillary incisor and molar bite point locations. Hinton (1979:120) defines the distance from condylion to lower molar point as reflective of the mandibular molar bite point, while condylion to infradentale inferius represents the mandibular incisal bite point. In this study, lower molar point/bicondylar radius (MBR) and infradentale inferius/bicondylar radius

(IBR) approximate the molar and incisal bite point distances for the mandible, respectively. For the maxilla, Hinton's (1979:120) eminence point/upper molar point (EUP) reflects the maxillary molar bite point, while eminence point/infradentale superius (EIS) denotes the incisal bite point. Both of these measurements are used in the present study. As can be seen from Tables 5.5, 5.6, 6.13, and 6.14 (pages 154, 156, 184-185), dimensions of MBR, IBR, and EIS are significantly (at the 0.05 level) different in the Archaic compared to the Mississippian--all are smaller. The measurement of EUP was unfortunately not included in the multivariate comparison due to reduced sample size, but a comparison of Archaic and Mississippian means (Appendix B) shows that the female Archaic mean is smaller than the Mississippian one (although not statistically so as indicated by a T-test). The male means are more similar.

Thus, in effect, Archaic power (muscle) arm is larger and more anteriorly positioned relative to the fulcrum and occlusal plane, while the load (bite point) arm is shorter compared to the Mississippian. This is further illustrated by computation of muscle/bite point ratios. Hinton (1979:211) devises measurement ratios of temporalis/incisal bite point, temporalis/molar bite point, masseter/incisal bite point, and masseter/molar bite point for the mandible as well as the maxilla. In the present study, similar ratios are devised, with the dimension of coronoid point

radius (CTR) approximating the temporalis muscle arm and eminence point/zygomatic root point (EZP) the masseter muscle arm. Mandibular and maxillary bite points are as defined above (MBR, IBR, EUP, EIS). Table 8.2 presents ratios denoting temporalis and masseter muscle arms in relation to incisal and molar mandibular and maxillary bite force distances for Archaic and Mississippian females. As can be seen, in all instances, Archaic muscle to bite point ratios are larger than Mississippian ones. Table 8.3 shows a similar pattern for the male comparison--all but one ratio are larger in the Archaic. Measurement ratios for temporalis/molar maxillary bite point (CTR/EUP) are the same. Thus, there is no question that the temporalis and masseter muscle power arms are located much more anterior in relation to molar and incisal bite points in the Archaic compared to the Mississippian.

In sum, assuming a lever model for mandibular function and a fulcrum point at the condyle, increased masticatory efficiency is evident when the load arm (dental arch) is shortened in combination with a lengthened and more anterior power (muscle) arm. This is precisely the situation with Archaic mandibles and it is proposed here that this is an adaptive measure for generating large amounts of occlusal force. Mississippian mandibles manifest smaller and more posteriorly located masticatory

Table 8.2. Comparison of Archaic and Mississippian Female Muscle and Bite Point Ratios.

Ratio ^a	Archaic	Mississippian
<u>Temporalis</u>		
CTR/MBR	0.66	0.62
CTR/IBR	0.46	0.43
CTR/EUP	0.68	0.65
CTR/EIS	0.42	0.39
<u>Masseter</u>		
EZP/MBR	0.84	0.78
EZP/IBR	0.59	0.54
EZP/EUP	0.87	0.81
EZP/EIS	0.53	0.49

^aMeasurement definitions may be found in Appendix A.

Table 8.3. Comparison of Archaic and Mississippian Male Muscle and Bite Point Ratios.

Ratio ^a	Archaic	Mississippian
<u>Temporalis</u>		
CTR/MBR	0.64	0.62
CTR/IBR	0.45	0.44
CTR/EUP	0.66	0.66
CTR/EIS	0.41	0.40
<u>Masseter</u>		
EZP/MBR	0.83	0.76
EZP/IBR	0.59	0.54
EZP/EUP	0.86	0.81
EZP/EIS	0.53	0.49

^aMeasurement definitions may be found in Appendix A.

muscles, combined with longer dental arches. The result is less capability for generating heavy occlusal biting force.

Stress Dissipation

Concomitant with this occlusal force capability differential is a necessity for mechanisms allowing dissipation of resultant masticatory stress. Many of these adjustments are, in fact, seen in Archaic mandibles. For example, Hylander (1975) notes that the more narrow dental arch is an adaptive response for withstanding heavy amounts of vertical incisal biting. It can be seen in Tables 5.5 and 5.6 (pages 154, 156) that bicanine width (BCN) is indeed significantly (at the 0.05 level) smaller in Archaic mandibles compared to Mississippian ones. And, Hylander (1977c) suggests that reduced length of the dental arch is related to heavy amounts of dental attrition (and, therefore, masticatory stress). Reduced dental occlusal heights also result. The reduced lengths of the anterior and overall Archaic mandibular corpus have already been noted. Archaic dental attrition rates, as will be discussed later, were high.

Hinton (1979:120) notes that large symphyseal breadth dimensions act to "counter torsion resulting from heavy unilateral molar chewing". Tables 5.5, 5.6 and 5.7 (pages 154, 156, 158) reveal that symphyseal width at the base (SWB) is indeed significantly (at the 0.05 level) larger in

Archaic mandibles and undergoes a steady reduction through the Woodland and Mississippian.

Finally, Ringqvist (1973) correlates a small gonial angle with the generation of a large bite force. Tables 5.5 and 5.6 (pages 154, 156) show that this measure is significantly (at the 0.05 level) smaller in Archaic mandibles compared to Mississippian ones. Interestingly, the previous correlation analysis investigating the interrelationships of the mandibular measurements (Chapter 5) shows a high negative (inverse) correlation between gonial angle and ascending ramus height. And, as can be seen in Tables 5.5 and 5.6 (pages 154, 156), while gonial angle significantly increases through the temporal span, ascending ramus height experiences a significant decrease.

Many studies (e.g., Paquette 1985; Rak 1986; F. Smith 1983, 1984, 1985; Smith and Paquette In Press; Trinkaus 1987) have illustrated the role of lateral and lower midfacial prognathism in the dissipation of heavy occlusal forces. And, as already mentioned, measures used in this dissertation to reflect this prognathism (subspinale and zygomaxillare radii) manifest a significant (0.05 level) pattern of decrease from the Archaic to the Mississippian. Other facial prognathism measures like frontomale (male and female), nasion (males and females), and prosthion (males) radii also show decreases across the Archaic/

Mississippian temporal span (see Appendix B), although not enough to be significant at the 0.05 level.

Hylander (1972:251) and Hinton (1979:216) both cite the presence of large vertical height measures of the mandible and face as adaptive responses for the dissipation of heavy occlusal force. In fact, many researchers have noted this pattern (e.g., Corruccini et al. [1985] for rural Kentucky populations; Larsen [1981, 1982, 1984] for St. Catherine's Island). However, in looking at the results of this dissertation (Tables 5.5, 5.6, 6.13, 6.14; pages 154, 156, 184-185), it can be seen that with only one exception (ascending ramus height), all of the height measures of the mandible (corpus, symphyseal heights) and face (alveolar, upper facial, and cheek heights) which are significantly (0.05 level) different across the temporal span are smaller in the Archaic and increase by the Mississippian period. At present, it is unknown why this increase in vertical craniofacial and mandibular height occurs, but one potential clue lies in an analysis of mandibular anterior dental change through time.

Anterior Dental Change

As expected, several mandibular anterior dental dimensions (lateral incisor root and crown buccolingual diameters, central incisor buccolingual diameter of the root) decrease across the temporal span. Wolpoff (1971b)

has suggested that tooth area (length x breadth) is perhaps a better indication of tooth size than individual length or breadth measures alone. Table 8.4 presents crown and root tooth area calculations (buccolingual x mesiodistal diameters) for the mandibular lateral incisor, central incisor, and canine across the Archaic and Mississippian. Most of these tooth areas decrease across the temporal span. F. Smith et al. (1980:84) suggest that buccolingual dental dimensions are less affected by attrition and thus are more indicative of genetic tooth size. As can be seen in Tables 7.16 and 7.17 (pages 220, 222), these dimensions significantly reduce through time. This agrees with previous research by Hinton et al. (1980), M. Smith (1982), and F. Smith et al. (1980) (involving many of these same skeletal samples) denoting a gradual reduction in the anterior dentition through time.

Contrary to expectations, however, is the increase in some dental dimensions. And, interestingly, the particular tooth measures which increase illustrate an important pattern. Tables 7.16 and 7.17 (pages 220, 222) reveal that central incisor and canine root lengths and mesiodistal diameters of the crown show the significant (0.05 level) increases. In fact, these very dimensions were shown to have a high canonical correlation with measures of vertical facial and mandibular height in the Mississippian (see Chapter 7, pages 204, 210). Thus, both the height of the

Table 8.4. Comparison of Anterior Mandibular Crown and Root Dental Areas Between Archaic and Mississippian Samples.

Tooth Measurement	<u>Archaic Area^a</u>		<u>Mississippian Area^a</u>	
	Female	Male	Female	Male
<u>Lateral Incisor</u>				
Crown	36.29	35.37	35.64	35.76
Root	22.80	23.72	21.89	22.66
<u>Central Incisor</u>				
Crown	28.40	26.31	27.50	28.25
Root	19.14	19.51	17.71	18.42
<u>Canine</u>				
Crown	49.45	55.03	51.00	56.44
Root	37.18	44.32	36.21	43.24

^aArea measurements are in square millimeters.

face and mandible and the root length and mesiodistal crown diameters of the anterior mandibular dentition (at least the central incisor and canine) are increasing in unison across the Archaic/Mississippian transition. Whether the teeth are responding to the increased facial height or vice versa is not known, but given the traditionally conservative nature of the dentition, the former seems more likely. The question of causation, however, still remains. But it must be cautioned that mesiodistal dental dimensions are more susceptible to attrition effects (F. Smith et al. 1980). Thus, the observed smaller Archaic mesiodistal dental dimensions may be a consequence of the documented extensive Archaic dental attrition.

While Henneberg (1988) has noted a microevolutionary trend toward decrease of cranial vault size throughout the Holocene, it is interesting to note that Carlson and Van Gerven (1977) see an overall increase in cranial vault height across their Nubian temporal sequence. These authors describe this change as secondary and compensatory in relation to the more important masticatory muscle changes (more posterior origins and attachments, for example) occurring through time. Although not included in the multivariate statistical comparison of the present study due to possible biasing effects of Mississippian period cranial deformation, the measure of overall cranial vault height (basion/bregma height--BBH) does exhibit a

significant increase in both females and males across the Archaic/Mississippian transition. The relationship between the increases in cranial and facial height through time across the present skeletal samples requires further investigation.

Trends in Non-Metric Observations

As expected, non-metric skeletal indications of masticatory muscle robusticity are noted for Archaic mandibles and lower faces. For example, the temporal line is often more pronounced on Archaic crania compared to Mississippian ones. And, the region of mandibular gonion is equally more robust in the Archaic. Gonial eversion is much more frequent for Archaic mandibles, accompanied by thickening and at times crenulation of the entire gonial region. And, in a few cases, these reinforcements are combined with a unique incurvature of the posterior and inferior mandibular corpus directly anterior to gonion. These phenomena are much less common for Mississippian mandibles, with full gonial inversion more frequent. While Moss and Simon (1968) and Bacon et al. (1980) see the degree of gonial eversion/inversion as an age-related factor (eversion is more common in older individuals) and Larnach and Macintosh (1971) view it as a sex indicator (eversion is more common in males), Hylander (1972:188) regards lateral flaring of the mandibular gonion as a

functional adaptation for increased masseter muscle size and, thus, generation of heavy occlusal force. The previously discussed attachments of the masseter and internal pterygoid masticatory muscles on the lateral and medial gonial surfaces of the mandible, respectively, support this last contention.

Also as expected, dental attrition is much more severe for Archaic mandibles compared to Mississippian ones. Dental caries and abscesses are more frequent in the Mississippian mandibles. These results agree with previous dental research on many of these same skeletal samples by M. Smith (1982), as well as many other temporal studies examining the skeletal effects of a dietary (hunting and gathering to agriculture) shift on the oral health status of aboriginal populations (e.g., see the majority of research studies summarized in Cohen and Armelagos [1984]).

Other non-metric observations (see Figure 4.1: page 120), however, do not appear to be patterned across the temporal groups. Morphological dimensions such as mylohyoid ridge and sulcus, sublingual, submaxillary, and digastric fossae, genial spine, submental notch, and mandibular foramen development exhibit variability both within and between the Archaic, Woodland, and Mississippian skeletal samples. The previously documented variation in these non-metric traits across human populations has already been discussed.

Summary

Both morphological and metric skeletal dimensions are utilized in an investigation of mandibular, craniofacial, and anterior mandibular dental variability across a Tennessee temporal series. This series exhibits a clear and gradual transition from a hard-textured (hunting and gathering) Archaic to a soft-textured (agricultural) Mississippian diet. The following changes are the most important ones delineated across the time span:

1. Increases in mandibular overall length and projection as well as height (symphysis, corpus), thickness at the ascending ramus, and bicanine width;
2. Decreases in mandibular coronoid process and coronoid point radii and projections as well as ascending ramus height and symphyseal breadth (basal);
3. Increases in facial height measures (upper facial, alveolar, cheek);
4. Decreases in lower and lateral midfacial projection;
5. Increases in mandibular anterior dental mesiodistal diameters and root lengths;
6. Decreases in mandibular anterior dental areas and buccolingual diameters.

The majority of the above changes have been explained in the context of functional differences in masticatory-related adaptations in the mandibular, dental, and craniofacial regions of Archaic and Mississippian individuals. For example, across this temporal series, the following functional adaptations have been documented:

1. Reductions in masticatory muscle size and robusticity;
2. Adoptions of more posterior points of masticatory muscle attachments relative to the TMJ and occlusal plane;
3. Decreased length of power (muscle) arm in conjunction with an increased length of load (dental arch) arm;
4. Decreased muscle/bite point ratios;
5. Reductions in adaptive mechanisms for masticatory stress dissipation.

These differences are seen as reflective of variability in the functional demands of the two masticatory systems in terms of occlusal force generation and dissipation. Dietary change is viewed as the primary reason for the documented mandibular, craniofacial, and dental differences noted in this study.

Revision of the Model of Masticatory-Related Mandibular and Craniofacial Change

It is clear from the previous discussion of the results of this dissertation that a model of masticatory-related mandibular, dental, and craniofacial gracilization resulting from a shift from a hard- to a soft-textured diet through time is much too simplistic. While many of the changes documented across the Archaic and Mississippian data sets indeed do involve reductions in masticatory muscle robusticity and size, facial prognathism, and dental size, other differences are more complex. These involve functional reorientations of muscle and bite point positions leading to increased masticatory (occlusal force generation) efficiency. Other changes relate to heavy masticatory stress dissipation. Thus, size of linear dimensions alone cannot be assumed to reflect dietary-related functional variability in the human mandible, dentition, and lower face. For example, measurements reflecting positioning of masticatory muscles in relation to the rest of the face and mandible, length of power and load arms, and occlusal stress dissipation must also be considered in any analysis of diachronic functional change in the mandibular complex.

Thus, for documented archaeological transitions from a

hard-textured hunting and gathering diet to a more heavily processed soft agricultural one, revised expectations can be generated. It is predicted that in addition to decreased robusticity of muscles of mastications (as reflected by their skeletal correlates), these muscles will adopt more posterior points of attachment through time. In addition, lower and midfacial prognathism is expected to reduce. Bite points (molar, incisal) will be more anterior in relation to the muscle arms and the condyle through time. Skeletal adaptations to withstanding heavy occlusal forces and the stresses which result (as seen in a small bicanine width, low coronoid process, and thickened symphysis breadth at the base in the present study) are predicted to be no longer needed in a soft-textured subsistence situation.

The above discussion does not, however, explain how these morphological and metric changes occur. Given the previously discussed complex craniofacial and mandibular functional interrelationships and growth-regulating mechanisms, there is little doubt that an interplay of genetic and mechanistic factors is at work. It is suggested here that the decrease in heavy occlusal force necessity with the adoption of a soft-textured Mississippian agricultural diet results in a concomitant reduction in the functional demands on the Mississippian masticatory complex both in terms of occlusal force generation and dissipation. These

reduced functional energy demands, in turn, can lead to relaxed selection in terms of the structural skeletal correlates of this no-longer-needed adaptation. Thus, masticatory-related functional change in the mandible and lower face can become incorporated into the genome, resulting in microevolutionary change in the mandibular functional complex through time.

Testing The Model

The functional model of microevolutionary mandibular and craniofacial change in relation to the dietary shift presented above is directly testable. Other temporal skeletal series exhibiting similar dietary shifts from hard- to soft-textured diets should exhibit comparable (but not necessarily identical) changes. Some skeletal and muscular alterations reflecting reduced masticatory force generation and stress dissipation requirements are expected to occur across the dietary shift. However, as this study has shown, the human masticatory apparatus is extremely complex. Thus, a variety of adaptational adjustments can occur as a result of changing diet and food texture.

Finally, it is recommended that a functional approach (utilizing measurements which illustrate these complex interrelative relationships) to the delineation of masticatory-related diachronic change be considered. While there is no doubt that functional approaches cannot (and

should not) be used to explain all morphological changes in skeletal dimensions across time, investigation of adaptive, functional relationships between many skeletal dimensions (particularly those involved in mastication) can provide insight into the mechanisms of this observed variability. Many of the documented differences in Archaic and Mississippian mandibular and craniofacial morphology delineated in this dissertation are not understandable otherwise.

REFERENCES CITED

REFERENCES CITED

Ahlgren, Johan

1978 Relationship between integrated EMG and tension in opening of the mandible. In James H. Perryman (editor): Oral Physiology and Occlusion. New York: Pergamon Press, pp. 41-54.

Amick, Daniel S.

1984 Lithic Raw Material Variability in the Central Duck River Basin: Reflections of Middle and Late Archaic Organizational Strategies. M.A. Thesis, The University of Tennessee, Knoxville.

Bacon, G. E., P. J. Bacon, and R. K. Griffiths

1980 Orientation of apatite crystals in relation to muscle attachment in the mandible. Journal of Biomechanics 13:725-729.

Baer, P.

1956 The relation of the physical character of the diet to the periodontium and periodontal disease. Oral Surgery 9:839-843.

Baker, Ronald K.

1984 The Relationship of Cranial Suture Closure and Age Analyzed in a Modern Multi-Racial Sample of Males and Females. M.A. Thesis, The University of California, Callerton.

Baragar F. A. and J. W. Osborn

1984 A model relating patterns of human jaw movement to biomechanical constraints. Journal of Biomechanics 17:757-767.

Baragar, F. A. and J. W. Osborn

1987 Efficiency as a predictor of human jaw design in the sagittal plane. Journal of Biomechanics 20:447-457.

Barbenel, J. C.

1972 The biomechanics of the temporomandibular joint: A theoretical study. Journal of Biomechanics 5:251-256.

Barber, Charles G., Larry J. Green, and Gerald J. Cox

1963 Effects of the physical consistency of diet on the condylar growth of the rat mandible. Journal of Dental Research 42:848-851.

- Bass, William M.
1987 Human Osteology: A Laboratory and Field Manual, 3rd edition. Columbia, Missouri: Special Publication of the Missouri Archaeological Society, Number 2.
- Bernabei, Raymond L. and Lysle E. Johnston
1978 The growth in situ of isolated mandibular segments. American Journal of Orthodontics 73:24-35.
- Berryman, Hugh 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, The University of Tennessee, Knoxville.
- Berryman, Hugh E.
1984 The Averbuch skeletal series: A study of biological and social stress at a Late Mississippian period site from Middle Tennessee. In Walter E. Klippel and William M. Bass (editors): Averbuch: A Late Mississippian Manifestation In The Nashville Basin, Volume I, Observations. Report Submitted to the National Park Service.
- Berryman, Hugh E. and Douglas W. Owsley
1984 Effects of artificial cranial deformation on cranio-facial dimensions: Implications for measurement selection. In Walter E. Klippel and William M. Bass (editors): Averbuch: A Late Mississippian Manifestation In The Nashville Basin, Volume I, Observations. Report Submitted to the National Park Service, I.
- Biggerstaff, Robert H.
1977 The biology of the human chin. In Albert A. Dahlberg and Thomas M. Graber (editors): Orofacial Growth and Development. The Hague: Mouton, pp. 71-87.
- Björk, A. and V. Skieller
1972 Facial development and tooth eruption. American Journal of Orthodontics 62:339-383.
- Bogan, Arthur E.
1982 Archaeological evidence of subsistence patterns in the Little Tennessee valley. Tennessee Anthropologist 7:38-50.
- Bolk, L.
1924 Die Entstehung des Menschenkinnes. Ein Beitrag zur Entwicklungsgeschichte des Unterkiefers. Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam, Tweede Sectie 23.

- Bowen, William R.
1975 Late Archaic Subsistence and Settlement in the Western Tennessee Valley: A Reevaluation. M.A. Thesis, The University of Tennessee, Knoxville.
- Bowen, William R.
1977 A reevaluation of Late Archaic subsistence and settlement patterns in the western Tennessee valley. Tennessee Anthropologist 2:101-120.
- Bowen, William R.
1979 The Late Archaic in the upper Duck River valley. Tennessee Anthropologist 4:140-159.
- Boyd, Donna C.
1984 A Biological Investigation of Skeletal Remains From The Mouse Creek Phase and A Comparison With Two Late Mississippian Skeletal Populations From Middle and East Tennessee. M.A. Thesis, The University of Tennessee, Knoxville.
- Boyd, Donna C.
1986a A Survey and Assessment of Extant Data Pertaining to Prehistoric Cultural Resources of the Chickamauga Reservoir. Report Submitted to the Tennessee Valley Authority, Norris, Tennessee.
- Boyd, Donna C.
1986b A comparison of Mouse Creek phase to Dallas and Middle Cumberland culture skeletal remains. In Janet E. Levy (editor): Skeletal Analysis in Southeastern Archaeology. Raleigh, North Carolina: North Carolina Archaeological Council Publication Number 24, pp. 103-126.
- Boyd, Donna C. and C. Clifford Boyd, Jr.
1987 Biocultural Relationships Between Three Late Mississippian Groups: Mouse Creek, Dallas, and Middle Cumberland. Paper presented at the 44th Annual Meeting of the Southeastern Archaeological Conference, Charleston, South Carolina.
- Brace, C. Loring
1962 Cultural factors in the evolution of the human dentition. In M. F. Ashley Montagu (editor): Culture and the Evolution of Man. New York: Oxford University Press, pp. 343-354.
- Brace C. Loring
1964 The fate of the classic Neanderthals: A consideration of hominid catastrophism. Current Anthropology 5: 3-43.

- Brace, C. Loring
1967 Environment, tooth form, and size in the Pleistocene. *Journal of Dental Research* 46:809-816.
- Brace, C. Loring
1975 Comment on Wallace: Did La Ferrassie I use his teeth as a tool? *Current Anthropology* 16:396-397.
- Brace, C. Loring
1976 Tooth reduction in the Orient. *Asian Perspectives* 19:203-219.
- Brace, C. Loring
1977 Occlusion to the anthropological eye. In J. A. McNamara, Jr. (editor): *The Biology of Occlusal Development. Craniofacial Growth Series, Monograph Number 7.* Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 179-210.
- Brace, C. Loring
1980 Australian tooth-size clines and the death of a stereotype. *Current Anthropology* 21:141-162.
- Braun, David P.
1983 Pots as tools. In James A. Moore and Arthur S. Keene (editors): *Archaeological Hammers and Theories.* New York: Academic Press, pp. 107-134.
- Brewer, Andrea J.
1973 Analysis of floral remains from the Higgs site (40L045). In Major C. R. McCollough and Charles H. Faulkner (editors): *Excavation of the Higgs and Doughty Sites, I-75 Salvage Archaeology. Miscellaneous Paper Number 12.* Knoxville: Tennessee Archaeological Society, pp. 141-144.
- Bronitsky, Gordon and Robert Hamer
1986 Experiments in ceramic technology: the effects of various tempering materials on impact and thermal shock-resistance. *American Antiquity* 51:89-101.
- Brooks, S. T.
1955 Skeletal age at death: the reliability of cranial and pubic age indicators. *American Journal of Physical Anthropology* 13:567-589.
- Broster, John B.
1988 Burial patterns for the Mississippian period in Middle Tennessee. *Tennessee Anthropologist* 13:1-15.

Brothwell, D. R.

1959 Teeth in earlier human populations. Proceedings of the Nutrition Society 18:59-65.

Buikstra, Jane E., William Autry, Emanuel Breitburg, Leslie Eisenberg, and Nikolaas van der Merwe

1988 Diet and health in the Nashville basin: Human adaptation and maize agriculture in Middle Tennessee. In Brenda V. Kennedy and Genevieve M. LeMoine (editors): Diet and Subsistence: Current Archaeological Perspectives. Proceedings of the 19th Annual Conference, Chacmool. Calgary: The Archaeological Association of the University of Calgary, pp. 243-259.

Burroughs, Carroll A.

n.d. Unpublished field report, 23RE6. M.S. on file, Frank H. McClung Museum. Knoxville: The University of Tennessee.

Buschang, P. H., R. Tanguay, A. Demirjian, L. LaPalme, and H. Goldstein

1986 Sexual dimorphism in mandibular growth of French-Canadian children 6 to 10 years of age. American Journal of Physical Anthropology 71:33-37.

Calgano, James M.

1986 Dental reduction in post-Pleistocene Nubia. American Journal of Physical Anthropology 70:349-363.

Carlson, David S.

1976 Patterns of morphological variation in the human midface and upper face. In James A. McNamara, Jr. (editor): Factors Affecting The Growth of The Midface. Craniofacial Growth Series, Monograph Number 6. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 277-299.

Carlson, David S., James A. McNamara, Jr., and Douglas H. Jaul

1978 Histological analysis of the growth of the mandibular condyle in the rhesus monkey (Macaca mulatta). American Journal of Anatomy 151:103-118.

Carlson, David S. and Dennis P. Van Gerven

1977 Masticatory function and post-Pleistocene evolution in Nubia. American Journal of Physical Anthropology 46:495-506.

Carlsson, Gunnar E.

1974 Bite force and chewing efficiency. In Y. Kawamura (editor): Frontiers of Oral Physiology, Volume I. Basel: Karger, pp. 265-292.

- Cartmill, Matt, William L. Hylander, and James Shafland
1987 Human Structure. Cambridge, Massachusetts: Harvard University Press.
- Chapman, Jefferson
1976 The Archaic period in the lower Little Tennessee River valley: The radiocarbon dates. Tennessee Anthropologist 1:1-12.
- Chapman, Jefferson
1977 Archaic Period Research in The Lower Little Tennessee River Valley. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 18.
- Chapman, Jefferson
1985 Archaeology and the Archaic period in the southern ridge-and-valley province. In Roy S. Dickens, Jr. and H. Trawick Ward (editors): Structure and Process in Southeastern Archaeology. University, Alabama: The University of Alabama Press, pp. 137-153.
- Chapman, Jefferson, and Gary D. Crites
1987 Evidence for early maize (Zea mays) from the Ice-house Bottom site, Tennessee. American Antiquity 52: 352-354.
- Chapman, Jefferson, and Andrea B. Shea
1981 The archaeobotanical record: Early Archaic period to contact in the lower Little Tennessee River valley. Tennessee Anthropologist 6:61-84.
- Cohen, Mark N. and George J. Armelagos (editors)
1984 Paleopathology At The Origins of Agriculture. Orlando, Florida: Academic Press.
- Cole, Patricia E.
1975a Archaic populations of the Middle South: A multivariate analysis. Tennessee Archaeologist 31:87-97.
- Cole, Patricia E.
1975b A Synthesis and Interpretation of The Hamilton Mortuary Pattern in East Tennessee. M.A. Thesis, The University of Tennessee, Knoxville.
- Corruccini, Robert S.
1987 Shape in morphometrics: comparative analyses. American Journal of Physical Anthropology 73:289-303.

- Corruccini, R. S., L. D. Whitley, S. S. Kaul, L. B. Flander, and C. A. Morrow
 1985 Face height and breadth relative to dietary consistency and oral breathing in two populations (North India and U.S.). *Human Biology* 57:151-161.
- Crane, H. R. and James B. Griffin
 1961 University of Michigan radiocarbon dates VI. *American Journal of Science Supplement* 33:105-125.
- Cridlebaugh, Patricia
 1981 The Icehouse Bottom Site: 1977 Excavations. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 35.
- Crites, Gary D.
 1985 Middle Woodland Paleoethnobotany of The Eastern Highland Rim of Tennessee: An Evolutionary Perspective on Change in Human-Plant Interaction. Ph.D. Dissertation, The University of Tennessee, Knoxville.
- Crites, Gary D.
 1987 Human-plant mutualism and niche expression in the paleoethnobotanical record: A Middle Woodland example. *American Antiquity* 52:725-740.
- Crompton, A. W.
 1963 The evolution of the mammalian jaw. *Evolution* 17:431-439.
- Crompton, A. W. and Pamela Parker
 1978 Evolution of the mammalian masticatory apparatus. *American Scientist* 66:192-201.
- Currey, J. D.
 1968 The adaptations of bones to stress. *Journal of Theoretical Biology* 20:91-106.
- Darroch, J. and J. E. Mosimann
 1985 Canonical and principal components of shape. *Biometrika* 72:241-252.
- DeBoever, J. A., W. D. McCall, Jr., S. Holden, and M. M. Ash
 1978 Functional occlusal forces: an investigation by telemetry. *Journal of Prosthetic Dentistry* 40:326-333.
- Delcourt, Hazel
 1979 Late Quaternary vegetation history of the Eastern Highland Rim and adjacent Cumberland Plateau of Tennessee. *Ecological Monographs* 49:255-280.

- Dowd, John T.
1981 The Anderson site (40WM9). Tennessee Anthropological Newsletter 6:1-2.
- Dubner, Ronald, Barry J. Sessle, and Arthur T. Storey
1978 The Neural Basis of Oral and Facial Function.
New York: Plenum Press.
- DuBrul, E. Lloyd and Harry Sicher
1954 The Adaptive Chin. Springfield, Illinois: Charles C. Thomas.
- Eisenberg, Leslie E.
1986 Adaptation In A "Marginal" Mississippian Population From Middle Tennessee: Biocultural Insights From Paleopathology. Ph.D. Dissertation, New York University.
- Enlow, Donald H.
1968 Wolff's law and the factor of architectonic circumstance. American Journal of Orthodontics 54:803-822.
- Enlow, Donald H.
1973 Growth and the problem of the local control mechanism. American Journal of Anatomy 136:403-406.
- Enlow, Donald H.
1975a Handbook of Facial Growth. Philadelphia: W. B. Saunders Company.
- Enlow, Donald H.
1975b Rotations of the mandible during growth. In James A. McNamara, Jr. (editor): Determinants of Mandibular Form and Growth. Craniofacial Growth Series, Monograph Number 4. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp 65-76.
- Enlow, Donald H. and Mitsuo Azuma
1975 Functional growth boundaries in the human and mammalian face. In Daniel S. Bergsma (editor): Morphogenesis and Malformation of Face and Brain. Birth Defects: Original Article Series, Volume 11, The National Foundation, March of Dimes, pp. 217-230.
- Enlow, Donald H., Takayuki Kuroda, and Arthur B. Lewis
1971 The morphological and morphogenetic basis for craniofacial form and pattern. Angle Orthodontist 41: 161-188.

- Enlow, Donald H. and Robert E. Moyers
1971 Growth and architecture of the face. *Journal of the American Dental Association* 82:763-774.
- Enlow, Donald H., Robert E. Moyers, W. Stuart Hunter, and James A. McNamara, Jr.
1969 A procedure for the analysis of intrinsic facial form and growth: an equivalent-balance concept. *American Journal of Orthodontics* 56:6-23.
- Ericksen, M. F.
1976 Some aspects of aging in the lumbar spine. *American Journal of Physical Anthropology* 45:575-580.
- Ericksen, M. F.
1978a Aging in the lumbar spine II. L1 and L2. *American Journal of Physical Anthropology* 48:241-246.
- Ericksen, M. F.
1978b Aging in the lumbar spine III. L5. *American Journal of Physical Anthropology* 48:247-250.
- Faulkner, Charles H. and Major C. R. McCollough
1974 Excavations and Testing, Normandy Reservoir Salvage Project: 1972 Seasons. Normandy Archaeological Project, Volume 2. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 12.
- Faulkner, M. G., D. C. Hatcher, and A. Hay
1987 A three-dimensional investigation of temporomandibular joint loading. *Journal of Biomechanics* 20: 997-1002.
- Freyer, David W.
1978 The Evolution of the Dentition in Upper Paleolithic and Mesolithic Europe. Lawrence, Kansas: The University of Kansas, Publications in Anthropology, Number 10.
- Garner, L. D. and N. S. Kotwal
1973 Correlation study of incisive biting forces with age, sex, and anterior occlusion. *Journal of Dental Research* 52:698-702.
- Gibbs, Charles H., Theodore Messerman, James B. Reswick and Harry J. Derda
1971 Functional movements of the mandible. *Journal of Prosthetic Dentistry* 26:604-620.
- Gingerich, P. D.
1971 Functional significance of mandibular translation in vertebrate jaw mechanics. *Postilla* 152:3-10.

- Graber, T. M.
1975 Extrinsic control factors influencing craniofacial growth. In James A. McNamara, Jr. (editor): Control Mechanisms in Craniofacial Growth. Craniofacial Growth Series, Monograph Number 3. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 75-100.
- Grant, Philip G.
1973a Lateral pterygoid: two muscles? American Journal of Anatomy 138:1-9.
- Grant, Philip G.
1973b Biomechanical significance of the instantaneous center of rotation: the human temporomandibular joint. Journal of Biomechanics 6:109-113.
- Greene, D. L.
1972 Dental anthropology of early Egypt and Nubia. Journal of Human Evolution 1:315-324.
- Guagliardo, Mark Frances
1982 Craniofacial Structure, Aging and Dental Function: Their Relationships in Adult Human Skeletal Series. Ph.D. Dissertation, The University of Tennessee, Knoxville.
- Gysi, Alfred
1921 Studies on the leverage problem of the mandible. Dental Digest 27:74-84; 184-190; 203-208.
- Hair, Joseph F., Jr., Rolph E. Anderson, Ronald L. Tatham, and Bernie J. Grablowski
1979 Multivariate Data Analysis: With Readings. Tulsa, Oklahoma: Petroleum Publishing Company.
- Harrington, M. R.
1922 Cherokee and Earlier Remains on Upper Tennessee River. In F. W. Hodge (editor): Indian Notes and Monographs. New York: Museum of the American Indian, Heye Foundation Publication 24:1-321.
- Harris, James E., Charles J. Kowalski, Frances A. LeVasseur, Carlos E. Nasjleti, and Geoffrey F. Walker
1977 Age and race as factors in craniofacial growth and development. Journal of Dental Research 56:266-274.
- Harris, James E., Charles J. Kowalski, and Sheldon S. Watnick
1973 Genetic factors in the shape of the craniofacial complex. Angle Orthodontist 43:107-111.

- Hatch, James W.
1976 Status in Death: Principles of Ranking in Dallas Culture Mortuary Remains. Ph.D. Dissertation, Pennsylvania State University.
- Hatch, James W. and Richard A. Geidel
1983 Tracing status and diet in prehistoric Tennessee. *Archaeology* 36:56-59.
- Hatch, James W. and Patrick S. Willey
1974 Stature and status in Dallas society. *Tennessee Archaeologist* 30:107-131.
- Hatch, James W., Patrick S. Willey, and Edward E. Hunt, Jr.
1983 Indicators of status-related stress in Dallas society: transverse lines and cortical thickness in long bones. *Midcontinent Journal of Archaeology* 8:49-71.
- Hayes, Richard C.
1971 The application of an index to determine genetic and environmental contributions to dentofacial growth in twins and siblings (Abstract). *American Journal of Orthodontics* 60:418-419.
- Helmkamp, Richard Criss
1985 Biosocial Organization and Change in East Tennessee Late Woodland and Mississippian. Ph.D. Dissertation, Purdue University.
- Henneberg, Maciej
1988 Decrease of human skull size in the Holocene. *Human Biology* 60:395-405.
- Hiiemae, Karen N.
1978 Mammalian mastication: A review of the activity of the jaw muscles and the movements they produce in chewing. In P. M. Butler and K. A. Joysey (editors): *Development, Function and Evolution of Teeth*. London: Academic Press, pp. 359-398.
- Higgins, Katherine French
1982 The Ledbetter Landing Site: A Study of Late Archaic Mortuary Patterning. M.A. Thesis, The University of Tennessee, Knoxville.
- Hillson, S. W.
1979 Diet and dental disease. *World Archaeology* 11: 147-162.

- Hinton, Robert Julian
1979 Influence of Dental Function on Form of the Human Mandibular Fossa. Ph.D. Dissertation, The University of Michigan.
- Hinton, Robert Julian
1981a Temporomandibular joint size adaptations in prehistoric Tennessee indians. Tennessee Anthropologist 6:89-111.
- Hinton, Robert Julian
1981b Changes in articular eminence morphology with dental function. American Journal of Physical Anthropology 54:439-455.
- Hinton, Robert Julian and David S. Carlson
1979 Temporal changes in human temporomandibular joint size and shape. American Journal of Physical Anthropology 50:325-334.
- Hinton, Robert Julian, Maria Ostendorf Smith, and Fred H. Smith
1980 Tooth size changes in prehistoric Tennessee indians. Human Biology 52:229-245.
- Hirschfeld, William J. and Robert E. Moyers
1971 Prediction of craniofacial growth: The state of the art. American Journal of Orthodontics 60:435-444.
- Horowitz, Sidney and Richard Osborne
1971 The genetic aspects of craniofacial growth. In Robert E. Moyers and Wilton M. Krogman (editors): Craniofacial Growth in Man. Oxford: Pergamon Press, pp. 183-192.
- Houghton, Philip
1974 The relationship of the pre-auricular groove of the ilium to pregnancy. American Journal of Physical Anthropology 41:381-390.
- Howells, W. W.
1973 Cranial Variation in Man: A Study By Multivariate Analysis of Patterns of Difference Among Recent Human Populations. Papers of the Peabody Museum, Vol. 67. Cambridge: Harvard University.

Hoyte, D. A. N.

1976 Growth of the face and jaws compared with the rest of the skeleton. In D. F. G. Poole and M. V. Stack (editors): The Eruption and Occlusion of Teeth. Proceedings of the 27th Symposium of the Colston Research Society, University of Bristol. London: Butterworths, pp. 31-51.

Humphrey, Tryphena

1971 Development of oral and facial motor mechanisms in human fetuses and their relation to craniofacial growth. Journal of Dental Research 50:1428-1440.

Hunter, W. Stuart, Daniel R. Balbach, and Donald E. Lamphiear

1970 The heritability of attained growth in the human face. American Journal of Orthodontics 58:128-134.

Hylander, William L.

1972 The Adaptive Significance of Eskimo Craniofacial Morphology. Ph.D. Dissertation, The University of Chicago.

Hylander, William L.

1975 The human mandible: lever or link? American Journal of Physical Anthropology 43:227-242.

Hylander, William L.

1977a In vivo bone strain in the mandible of Galago crassicaudatus. American Journal of Physical Anthropology 46:309-326.

Hylander, William L.

1977b The Adaptive Significance of Eskimo Craniofacial Morphology. In Albert A. Dahlberg and Thomas M. Graber (editors): Orofacial Growth and Development. The Hague: Mouton, pp. 129-169.

Hylander, William L.

1977c Morphological changes in human teeth and jaws in a high-attrition environment. In Albert A. Dahlberg and Thomas M. Graber (editors): Orofacial Growth and Development. The Hague: Mouton, pp. 301-330.

Hylander, William L.

1978 Incisal bite force direction in humans and the functional significance of mammalian mandibular translation. American Journal of Physical Anthropology 48: 1-8.

Hylander, William L.

1979 Mandibular function in Galago crassicaudatus and Macaca fascicularis: An In vivo approach to stress analysis of the mandible. *Journal of Morphology* 159:253-296.

Hylander, William L. and Kirk R. Johnson

1985 Temporalis and masseter muscle function during incision in macaques and humans. *International Journal of Primatology* 6:289-322.

Ingervall, Bengt

1974 Relation between height of the articular tubercle of the temporomandibular joint and facial morphology. *Angle Orthodontist* 44:15-24.

Joerschke, Bonnie 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, The University of Tennessee, Knoxville.

Johnston, Lysle E., Jr.

1976 The functional matrix hypothesis: Reflections in a jaundiced eye. In James A. McNamara, Jr. (editor): *Factors Affecting Growth of the Midface*. Craniofacial Growth Series, Monograph Number 6. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 131-168.

Jolley, Robert L.

1983 Mississippian adaptations to the Middle Cumberland drainage of Central Tennessee. *Midcontinent Journal of Archaeology* 8:73-90.

Kashima, T.

1965 Morphological significance of human skull based upon masticatory stress distribution. *Bulletin of the Tokyo Dental College* 6:43-67.

Keel, Bennie C.

1976 *Cherokee Archaeology: A Study of the Appalachian Summit*. Knoxville: The University of Tennessee Press.

Keen, J. A.

1950 A study of the difference between male and female skulls. *American Journal of Physical Anthropology* 8: 65-79.

Kermack, K. A.

1972 The origin of mammals and the evolution of the temporomandibular joint. *Proceedings of the Royal Society of Medicine* 65:389-392.

Kile, Dorn P.

1983 Multivariate Discriminant Function Analyses of The Mandible in American Caucasoid and American Negroid Populations. M.A. Thesis, The University of Tennessee, Knoxville.

Kimball, Larry R. (editor)

1985 The 1977 Archaeological Survey: An Overall Assessment of The Archaeological Resources of Tellico Reservoir. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 40.

Klippel, Walter E. and William M. Bass (editors)

1984 Averbuch: A Late Mississippian Manifestation in The Nashville Basin, Volume I, Observations; Volume II, Descriptions. Report Submitted to the National Park Service.

Klippel, Walter E. and Ann Reed

1984 Locational analysis of the Late Mississippian sites in the Nashville Basin: Chapter 2. In Walter E. Klippel and William M. Bass (editors): Averbuch: A Late Mississippian Manifestation in The Nashville Basin, Volume I, Observations. Report Submitted to the National Park Service.

Koski, Kalevi

1968 Cranial growth centers: facts or fallacies? American Journal of Orthodontics 54:566-583.

Koski, Kalevi

1977 The role of the craniofacial cartilages in the postnatal growth of the craniofacial skeleton. In Albert A. Dahlberg and Thomas M. Graber (editors): Orofacial Growth and Development. The Hague: Mouton, pp. 9-34.

Kraus, Bertram S., Ronald E. Jordan, and Leonard Abrams

1975 Dental Anatomy and Occlusion: A Study of The Masticatory System. Baltimore: The Williams and Wilkins Company.

Krogman, Wilton Marion

1967 The role of genetic factors in the human face, jaws and teeth: A review. Eugenics Review 59:165-192.

Krogman, Wilton Marion

1973 Forty years of growth research and orthodontics. American Journal of Orthodontics 63:357-365.

- Krogman, Wilton Marion and M. Y. Işcan
1986 The Human Skeleton in Forensic Medicine (Second Edition). Springfield, Illinois: Charles C. Thomas.
- Lafferty, Robert H., III
1981 The Phipps Bend Archaeological Project. Research Series Number 4. University of Alabama: Office of Archaeological Research.
- Larnach, S. L. and N. W. G. Macintosh
1971 The Mandible in Eastern Australian Aborigines. The Oceania Monographs Number 17.
- Larson, Clark Spencer
1981 Skeletal and dental adaptations to the shift to agriculture on the Georgia Coast. Current Anthropology 22:422-423.
- Larsen, Clark Spencer
1982 The Anthropology of St. Catherines Island 3. Prehistoric Human Biological Adaptation. New York: Anthropological Papers of the American Museum of Natural History 57, pp. 157-276.
- Larson, Clark Spencer
1984 Health and disease in prehistoric Georgia: The transition to agriculture. In Mark N. Cohen and George J. Armelagos (editors): Paleopathology At The Origins of Agriculture. Orlando, Florida: Academic Press, pp. 367-392.
- Lavelle, C. L. B.
1970 Analysis of attrition in adult human molars. Journal of Dental Research 49:822-828.
- Lewis, Thomas M. N. and Madeline Kneberg
n.d.a. The Chickamauga Basin Report. Unpublished Draft Manuscript On File, Frank H. McClung Museum. Knoxville: The University of Tennessee.
- Lewis, Thomas M. N. and Madeline Kneberg
n.d.b. Manual of Field and Laboratory Techniques Employed by the Division of Anthropology, University of Tennessee, Knoxville, Tennessee. Unpublished Draft Manuscript On File, Frank H. McClung Museum. Knoxville: The University of Tennessee.
- Lewis, Thomas M. N. and Madeline Kneberg
1941 The Prehistory of the Chickamauga Basin in Tennessee: A Preview. Tennessee Anthropology Papers, No. 1.

- Lewis, Thomas M. N. and Madeline Kneberg
1946 Hiwassee Island: An Archaeological Account of Four Tennessee Indian Peoples. Knoxville: The University of Tennessee Press.
- Lewis, Thomas M. N. and Madeline Kneberg
1947 The Archaic Horizon in Western Tennessee. Record Extension Series, Tennessee Anthropological Papers 2, Vol. 23. Knoxville: The University of Tennessee.
- Lewis, Thomas M. N. and Madeline Kneberg
1959 The Archaic culture in the Middle South. American Antiquity 25:161-183.
- Lewis, Thomas M. N. and Madeline Kneberg Lewis
1961 Eva: An Archaic Site. Knoxville: The University of Tennessee Press.
- Lidberg, Charles
n.d. Unpublished field report, 17BY14. M.S. on file, McClung Museum. Knoxville: The University of Tennessee.
- Linderholm, Håkan and Arne Wennström
1970 Isometric bite force and its relation to general muscle force and body build. Acta Odontologica Scandinavica 28:679-689.
- Lindstrom, Bruce and Kenneth W. Steverson
1987 Lithic artifacts from the Anderson site, 40WM9. Tennessee Anthropologist 12:1-50.
- Lous, Inger
1970 The Masticatory system used as a tool. American Dental Association Dental Abstracts 15:457-458.
- Magennis, Ann
1977 Middle and Late Archaic Mortuary Patterning: An Example From the Western Tennessee Valley. M.A. Thesis, The University of Tennessee, Knoxville.
- Mandel, Irwin D.
1979 Dental caries. American Scientist 67:680-688.
- Martin, Debra L., George J. Armelagos, Alan H. Goodman and Dennis P. Van Gerven
1984 The effects of socioeconomic change in prehistoric Africa: Sudanese Nubia as a case study. In Mark N. Cohen and George J. Armelagos (editors): Paleopathology At The Origins of Agriculture. Orlando, Florida: Academic Press, pp. 191-214.

Masters, Cathie L.

1987 Dental Pathologies and Attrition of Some Prehistoric Eastern Great Plains Groups: Implications For Subsistence. M.A. Thesis, The University of Nebraska, Lincoln.

Mayhall, John T.

1970 The effect of culture change upon the Eskimo dentition. Arctic Anthropology 7:117-121.

Mayhall, John T.

1977 Cultural and environmental influences on the Eskimo dentition. In Albert A. Dahlberg and Thomas M. Graber (editors): Orofacial Growth and Development. The Hague: Mouton, pp. 215-227.

McCollough, Major C. R. and Quentin R. Bass

1983 Moccasin Bend, Chattanooga's First National Historic Landmark: Investigation of the Value of its Archaeological and Historical Contents as a Public Resource. Chattanooga: Chattanooga Regional Anthropological Association.

McCollough, Major C. R. and Lawrence S. Alexander

1987 Dating results for two sixteenth-century Spanish contact towns in Chattanooga, Tennessee. Chattanooga Regional Anthropological Association Chainmail 1.

McKee, Jeffrey and Stephen Molnar

1988 Measurements of tooth wear among Australian aborigines: II. Intrapopulational variation in patterns of dental attrition. American Journal of Physical Anthropology 76:125-136.

McKern, Thomas W. and T. Dale Stewart

1957 Skeletal Age Changes in Young American Males, Analyzed From the Standpoint of Identification. Natick, Massachusetts: Headquarters Quartermaster Research and Development Command, Technical Report EP-45.

McNamara, James A., Jr.

1973 The independent functions of the two heads of the lateral pterygoid muscle. American Journal of Anatomy 138:197-205.

McNamara, James A., Jr.

1975 The role of muscle and bone interaction during craniofacial growth. In James A. McNamara, Jr. (editor): Control Mechanisms in Craniofacial Growth. Craniofacial Growth Series, Monograph Number 3. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 51-74.

McNamara, James A., Jr., Thomas G. Connelly, and M. Christine McBride

1975 Histological studies of temporomandibular joint adaptations. In James A. McNamara, Jr. (editor): Determinants of Mandibular Form and Growth. Craniofacial Growth Series, Monograph Number 4. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 209-227.

Meikle, Murray C.

1973 The role of the condyle in the postnatal growth of the mandible. American Journal of Orthodontics 64:50-62.

Meindl, Richard S. and C. Owen Lovejoy

1985 Ectocranial suture closure: A revised method for the determination of skeletal age at death based on the lateral-anterior sutures. American Journal of Physical Anthropology 68:57-66.

Merbs, Charles F.

1968 Anterior tooth loss in Arctic populations. Southwestern Journal of Anthropology 24:20-32.

Mills, J. R. E.

1972 Evolution of mastication. Proceedings of The Royal Society of Medicine 65:392-396.

Milner, George Robert

1982 Measuring Prehistoric Levels of Health: A Study of Mississippian Period Skeletal Remains From the American Bottom, Illinois. Ph.D. Dissertation, Northwestern University, Evanston, Illinois.

Møller, Eigild

1976 Human muscle patterns. In Barry J. Sessle and Alan G. Hannam (editors): Mastication and Swallowing: Biological and Clinical Correlates. Toronto: University of Toronto Press, pp. 128-144.

Molnar, Stephen

1968a Mechanical simulation of human chewing motions. Journal of Dental Research 47:559-563.

Molnar, Stephen

1968b Experimental studies of human tooth wear: II. American Journal of Physical Anthropology: 28:361-368.

Molnar, Stephen

1971 Sex, age, and tooth position as factors in the production of tooth wear. American Antiquity 36: 182-188.

- Molnar, Stephen
1972 Tooth wear and culture: A survey of tooth functions among some prehistoric populations. *Current Anthropology* 13:511-526.
- Molnar, Stephen and Steven C. Ward
1977 On the hominid masticatory complex: Biomechanical and evolutionary perspectives. *Journal of Human Evolution* 6:557-568.
- Moore, Clarence B.
1915 Aboriginal sites on Tennessee River. *Journal of The Academy of Natural Sciences of Philadelphia, Second Series*, 16:169-428.
- Moore, W. J.
1965 Masticatory function and skull growth. *Journal of Zoology* 146:123-131.
- Moore, W. J., C. L. B. Lavelle, and T. F. Spence
1968 Changes in the size and shape of the human mandible in Britain. *British Dental Journal* 125:163-169.
- Moore-Jansen, Peer H. and Richard L. Jantz
1986 A Computerized Skeletal Data Bank For Forensic Anthropology. Knoxville: Department of Anthropology, The University of Tennessee.
- Morant, G. M.
1936 A biometric study of the human mandible. *Biometrika* 28:84-122.
- Mosimann, J. E. and F. C. James
1979 New statistical methods for allometry with application to Florida redwinged blackbirds. *Evolution* 33: 444-459.
- Moss, Melvin L.
1960 Functional analysis of human mandibular growth. *The Journal of Prosthetic Dentistry* 10:1149-1159.
- Moss, Melvin L.
1969 The primary role of functional matrices in facial growth. *American Journal of Orthodontics* 55:566-577.
- Moss, Melvin L.
1971a Functional cranial analysis and the functional matrix. In Hughlett L. Morris (editor): *Patterns of Orofacial Growth and Development: Proceedings of the Conference*. Washington D.C.: American Speech and Hearing Association Report 6, pp. 5-18.

- Moss, Melvin L.
1971b Neurotrophic processes in orofacial growth.
Journal of Dental Research 50:1492-1494.
- Moss, Melvin L.
1972 The non-existent hinge axis. American Institute
of Oral Biology Annual Meeting, pp. 59-63.
- Moss, Melvin L.
1975 New studies of cranial growth. In Daniel S. Bergsma
(editor): Morphogenesis and Malformation of Face and
Brain. Birth Defects Article Series, Volume 11. The
National Foundation of the March of Dimes, pp. 283-295.
- Moss, Melvin L. and Letty Salentijn
1969 The primary role of functional matrices in facial
growth. American Journal of Orthodontics 55:566-577.
- Moss, Melvin L. and Letty Moss-Salentijn
1978 The muscle-bone interface: An analysis of a morph-
ological boundary. In David S. Carlson and James A. Mc-
Namara, Jr. (editors): Muscle Adaptation in the Cranio-
facial Region. Craniofacial Growth Series, Monograph
Number 8. Ann Arbor, Michigan: Center for Human Growth
and Development, The University of Michigan, pp. 39-71.
- Moss, Melvin L. and Mark R. Simon
1968 Growth of the human mandibular angular process: A
functional cranial analysis. American Journal of Physi-
cal Anthropology 28:127-138.
- Moyers, Robert E. and Robert L. Wainright
1977 Skeletal contributions to occlusal development.
In James A. McNamara, Jr. (editor): The Biology of Oc-
clusal Development. Craniofacial Growth Series, Mono-
graph Number 7. Ann Arbor, Michigan: The Center for Hu-
man Growth and Development, The University of Michigan,
pp. 89-111.
- Munson, Patrick J.
1988 Late Woodland settlement and subsistence in temp-
oral perspective. In Richard W. Yerkes (editor): Inter-
pretations of Culture Change in The Eastern Woodlands
During The Late Woodland Period. Columbus, Ohio: Ohio
State University Occasional Papers Number 3, pp. 7-16.
- Murphy, Thomas
1957 The chin region of the Australian aboriginal
mandible. American Journal of Physical Anthropology
15:517-535.

Nakata, Minoru, Pao-lo Yu, Bailey Davis, and Walter E. Nance

1973 The use of genetic data in the prediction of craniofacial dimensions. *American Journal of Orthodontics* 63:471-480.

Nakata, Minoru, Pao-lo Yu, Bailey Davis, and Walter E. Nance

1974 Genetic determinants of cranio-facial morphology: A twin study. *Annals of Human Genetics, London* 37:431-443.

Nanda, Ravindra, Robert M. Baume, Kazuo Tanne, and Junji Sugawaria

1987 Longitudinal study of craniofacial growth in Macaca fascicularis. *American Journal of Physical Anthropology* 73:215-225.

Nash, Charles

n.d.a. Unpublished field report, 78RE8. M.S. on file, McClung Museum. Knoxville: The University of Tennessee.

Nash, Charles

n.d.b. Unpublished field report, 7HA1, 8HA1. M.S. on file, McClung Museum. Knoxville: The University of Tennessee.

Neter, J. and W. Wasserman

1974 *Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Design*. Homewood, Illinois: Richard D. Irwin, Inc.

Oleksiak, Debra Ann

1987 Body Size and Dental Scaling of Upper Pleistocene Human Populations: A Test of the Paramasticatory Hypothesis. Ph.D. Dissertation, State University of New York, Binghamton.

Olivier, Georges

1969 *Practical Anthropology*. Springfield, Illinois: Charles C. Thomas.

Osborn, J. W.

1987 Relationship between the mandibular condyle and the occlusal plane during hominid evolution: Some of its effects on jaw mechanics. *American Journal of Physical Anthropology* 73:193-207.

- Osborn, J. W. and F. A. Baragar
1985 Predicted pattern of human muscle activity during clenching derived from a computer assisted model: Symmetric vertical bite forces. *Journal of Biomechanics* 18:599-612.
- Paquette, Steven P.
1985 Patterns of Variation in The Permanent Maxillary Anterior Tooth Roots: A Different Approach to The Problem of Anterior Dental Reduction During The Transition From Archaic to Modern Homo sapiens. M.A. Thesis, The University of Tennessee, Knoxville.
- Parham, Kenneth R.
1982 A Biocultural Approach to The Skeletal Biology of The Dallas People From Toqua. M.A. Thesis, The University of Tennessee, Knoxville.
- Petrovic, Alexandre G. and Jeanne J. Stutzmann
1977 Further investigations into the functioning of the peripheral "comparator" of the servosystem (respective positions of the upper and lower dental arches) in the control of the condylar cartilage growth rate and of the lengthening of the jaw. In James A. McNamara, Jr. (editor): *The Biology of Occlusal Development. Craniofacial Growth Series, Monograph Number 7.* Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 255-291.
- Petrovic, Alexandre G., Jeanne J. Stutzmann, and Claudine L. Oudet
1975 Control processes in the postnatal growth of the condylar cartilage of the mandible. In James A. McNamara, Jr. (editor): *Determinants of Mandibular Form and Growth. Craniofacial Growth Series, Monograph Number 4.* Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 101-153.
- Phenice, Terrell W.
1969 A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology* 30: 297-302.
- Picq, Pascal G., J. Michael Plavcan, and William L. Hylander
1987 Nonlever action of the mandible: the return of the hydra. *American Journal of Physical Anthropology* 74: 305-307.

Polhemus, Richard (editor)

1987 The Toqua Site--40MR6: A Late Mississippian Dallas Phase Town. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 41.

Proffit, William R.

1978 The facial musculature in its relation to the dental occlusion. In David S. Carlson and James A. McNamara, Jr. (editors): Muscle Adaptation In The Craniofacial Region. Craniofacial Growth Series, Monograph Number 8. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 73-89.

Pruim, G. J., H. J. de Jongh, and J. J. ten Bosch

1980 Forces acting on the mandible during bilateral static bite at different bite force levels. Journal of Biomechanics 13:755-763.

Rak, Yoel

1986 The Neanderthal: A new look at an old face. Journal of Human Evolution 15:151-164.

Reed, Ann

1984 The environmental setting: Chapter 1. In Walter E. Klippel and William M. Bass (editors): Averbuch: A Late Mississippian Manifestation in The Nashville Basin, Volume I, Observations. Report Submitted to the National Park Service.

Ricketts, Robert M.

1975 Mechanisms of mandibular growth: a series of inquiries on the growth of the mandible. In James A. McNamara, Jr. (editor): Determinants of Mandibular Form and Growth. Craniofacial Growth Series, Monograph Number 4. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 77-100.

Rightmire, G. P.

1972 Cranial measurements and discrete traits compared in distance studies of African Negro skulls. Human Biology 44:263-276.

Ringqvist, Margareta

1973 Isometric bite force and its relation to dimensions of the facial skeleton. Acta Odontologica Scandinavica 31:35-42.

Roberts, David

1974 The etiology of the temporomandibular joint dysfunction syndrome. American Journal of Orthodontics 66:498-515.

- Roberts, David and Ian Tattersall
1974 Skull form and the mechanics of mandibular elevation in mammals. *American Museum Novitates* 2536:1-9.
- Robinson, Marsh
1946 The temporomandibular joint: theory of reflex controlled nonlever action of the mandible. *Journal of the American Dental Association* 33:1260-1271.
- SAS Institute, Inc.
1979 SAS User's Guide: 1979 Edition. Raleigh, North Carolina: SAS Institute, Inc.
- SAS Institute, Inc.
1982 SAS User's Guide: Statistics, 1982 Edition. Cary, North Carolina: SAS Institute, Inc.
- SAS Institute, Inc.
1985 SAS User's Guide: Statistics. Version 5. Cary, North Carolina: SAS Institute, Inc.
- Schroedl, Gerald F.
1973 Radiocarbon dates from three burial mounds at the McDonald site in East Tennessee. *Tennessee Archaeologist* 29:3-11.
- Schroedl, Gerald F.
1978a Excavations of The Leuty and McDonald Site Mounds in The Watts Bar Nuclear Plant Area. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 22.
- Schroedl, Gerald F.
1978b The Patrick Site (40MR40), Tellico Reservoir, Tennessee. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 25.
- Schroedl, Gerald F.
1986 Toward an explanation of Cherokee origins in East Tennessee. In David G. Moore (assembler): *The Conference on Cherokee Prehistory*. Swannanoa, North Carolina: Warren Wilson College, pp. 122-138.
- Schroedl, Gerald F., R. P. Stephen Davis, Jr., and C. Clifford Boyd, Jr.
1985 Archaeological Contexts and Assemblages at Martin Farm. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 39.

- Schroedl, Gerald F. and C. Clifford Boyd, Jr.
1986 Late Woodland Culture in East Tennessee. Paper presented at the 43rd Annual Meeting of the Southeastern Archaeological Conference, Nashville, Tennessee.
- Schroedl, Gerald F. and C. Clifford Boyd, Jr.
1987 Mississippian origins in East Tennessee. In Richard A. Marshall (editor): The Emergent Mississippian: Proceedings of the Sixth Mid-South Archaeological Conference. Mississippi State University: Cobb Institute of Archaeology, Occasional Papers, 87-01, pp. 137-148.
- Shipman, Pat, Alan Walker, and David Bichell
1985 The Human Skeleton. Cambridge, Massachusetts: Harvard University Press.
- Simon, Mark R.
1977 The role of compressive forces in the normal maturation of the condylar cartilage in the rat. *Acta Anatomica* 97:351-360.
- Singer, R.
1953 Estimation of age from cranial suture closure. *Journal of Forensic Medicine* 1:52-59.
- Sirianni, J. E., A. L. Van Ness, and D. R. Swindler
1982 Growth of the mandible in adolescent pigtailed macaques (Macaca nemestrina). *Human Biology* 54: 31-44.
- Smith, Fred H.
1976 The Neandertal Remains From Krapina: A Descriptive and Comparative Study. Knoxville: The University of Tennessee, Department of Anthropology, Report of Investigations, Number 15.
- Smith, Fred H.
1983 Behavioral interpretations of changes in craniofacial morphology across the archaic-modern Homo sapiens transition. In Erik Trinkaus (editor): The Mousterian Legacy: Human Biocultural Change in the Upper Pleistocene. BAR International Series, Number 164, pp. 141-163.
- Smith, Fred H.
1984 Fossil hominids from the Upper Pleistocene of Central Europe and the origin of modern Europeans. In Fred H. Smith and Frank Spencer (editors): The Origins of Modern Humans: A World Survey of the Fossil Evidence. New York: Alan R. Liss, pp. 137-209.

Smith, Fred H.

1985 Continuity and change in the origin of modern Homo sapiens. Zeitschrift für Morphologie und Anthropologie 75:197-222.

Smith, Fred H. and Steven P. Paquette

In Press The adaptive basis of Neandertal facial form, with some thoughts on the nature of modern human origins. In Erik Trinkaus (editor): Biocultural Emergence of Modern Humans in The Late Pleistocene. Cambridge, Massachussets: Cambridge University Press.

Smith, Fred H., Maria O. Smith, and Robert J. Hinton

1980 Evolution of tooth size in the prehistoric inhabitants of the Tennessee valley. In P. Willey and Fred H. Smith (editors): Skeletal Biology of Aboriginal Populations in the Southeastern United States. Knoxville: Tennessee Anthropological Association Miscellaneous Paper Number 5, The University of Tennessee, pp. 81-103.

Smith, Maria Ostendorf

1982 Patterns of Association Between Oral Health Status and Subsistence: A Study of Aboriginal Skeletal Populations From The Tennessee Valley Area. Ph.D. Dissertation, The University of Tennessee, Knoxville.

Smith, Maria Ostendorf

1986 Caries frequency and distribution in the Dallas skeletal remains from Toqua (40MR6), Monroe County, Tennessee. Tennessee Anthropologist 11:145-155.

Smith, Maria Ostendorf

1987 Pattern of antemortem tooth loss between selected aboriginal populations of the Tennessee Valley area. Tennessee Anthropologist 12:128-138.

Smith, Patricia

1976 Dental pathology in fossil hominids: What did Neanderthals do with their teeth? Current Anthropology 17:149-151.

Smith, Patricia

1982 Dental reduction: Selection or drift? In Bjorn Kurten (editor): Teeth: Form, Function, and Evolution. New York: Columbia University Press, pp. 366-379.

Smith, Patricia

1984 Archaeological and skeletal evidence for dietary change during the Late Pleistocene/Early Holocene in the Levant. In Mark N. Cohen and George J. Armelagos (editors): Paleopathology At The Origins of Agriculture. Orlando, Florida: Academic Press, pp. 101-136.

- Smith, Patricia, Ofer Bar-Yosef, and Andrew Sillen
1984 Archaeological and skeletal evidence for dietary change during the Late Pleistocene/Early Holocene in the Levant. In Mark N. Cohen and George J. Armelagos (editors): *Paleopathology at The Origins of Agriculture*. Orlando, Florida: Academic Press, pp. 101-136.
- Smith, Patricia, Yochanan Wax, Fanny Adler, Uri Silberman, and Gady Heinie
1986 Post-Pleistocene changes in tooth root and jaw relationships. *American Journal of Physical Anthropology* 70:339-348.
- Smith, Richard J.
1978 Mandibular biomechanics and temporomandibular joint function in primates. *American Journal of Physical Anthropology* 49:341-350.
- Stern, Jack T.
1974 Comment on Grant's "Biomechanical Significance of the Instantaneous Center of Rotation: The Human Temporomandibular Joint". *Journal of Biomechanics* 7:109.
- Stewart, T. Dale
1958 The rate of development of vertebral osteoarthritis in American Whites and its significance in skeletal age identification. *The Leech* 28:144-151.
- Sullivan, Lynne Anne Peters
1986 *The Late Mississippian Village: Community and Society of the Mouse Creek Phase in Southeastern Tennessee*. Ph.D. Dissertation, The University of Wisconsin, Milwaukee.
- Sullivan, Lynne Anne Peters
1987 The Mouse Creek Phase household. *Southeastern Archaeology* 6:16-29.
- Sullivan, P. G.
1976 The measurement of jaw growth. In D. F. G. Poole and M. V. Stack (editors): *The Eruption and Occlusion of Teeth*. Proceedings of the 27th Symposium of the Colston Research Society, University of Bristol. London: Butterworths, pp. 52-57.
- Swanton, John R.
1948 *The Indians of The Southeastern United States*. Bureau of American Ethnology Bulletin 137 (reprinted 1979 by Smithsonian Institution Press).

- Taylor, R. M. S.
1986 Nonlever action of the mandible. *American Journal of Physical Anthropology* 70:417-421.
- Thieme, F. P. and W. J. Schull
1957 Sex determination from the skeleton. *Human Biology* 29:242-273.
- Thomas, Cyrus
1894 Report on the Mound Explorations of the Bureau of Ethnology. Washington, D. C.: Twelfth Annual Report of The Bureau of American Ethnology.
- Thomas, David Hurst
1976 *Figuring Anthropology: First Principles of Probability and Statistics*. New York: Holt, Rhinehart, and Winston.
- Todd, T. Wingate
1920 Age changes in the pubic bone. I: The male white pubis. *American Journal of Physical Anthropology* 3: 285-334.
- Todd, T. Wingate
1921 Age changes in the pubic bone. II: The pubis of the white female. IV: The pubis of the female white-negro hybrid. *American Journal of Physical Anthropology* 4:1-70.
- Todd, T. Wingate and D. W. Lyon, Jr.
1924 Endocranial suture closure, its progress and age relationship, part I: Adult males of white stock. *American Journal of Physical Anthropology* 7:325-384.
- Trinkaus, Erik B.
1987 The Neandertal face: evolutionary and functional perspectives on a recent hominid face. *Journal of Human Evolution* 16:429-443.
- Trinkaus, Erik B. and Fred H. Smith
1985 The fate of the Neandertals. In Eric Delson (editor): *Ancestors: The Hard Evidence*. New York: Alan R. Liss, pp. 325-333.
- Trinkley, Michael B.
1985 The form and function of South Carolina's Early Woodland shell rings. In Roy S. Dickens, Jr. and H. Trawick Ward (editors): *Structure and Process in Southeastern Archaeology*. University, Alabama: The University of Alabama Press, pp. 102-118.

- Turnbull, W. D.
1970 Mammalian masticatory apparatus. *Fieldiana: Geology* 18.
- Twisselmann, F.
1973 Evolution Des Dimensions et De La Forme De La Mandibule, Du Palais et Des Dents De L'Homme. *Annales De Paléontologie: Vertébrés* 59. Paris: Masson et Cie.
- Van der Linden, Frans P. G. M.
1970 Interrelated factors in the morphogenesis of teeth, the development of the dentition and craniofacial growth. *Schweizerische Monatsschrift für Zahnheilkunde* 80:518-526.
- Van der Linden, Frans P. G. M.
1975 Control mechanisms regulating the development of the dentition. In James A. McNamara, Jr. (editor): *Control Mechanisms in Craniofacial Growth. Craniofacial Growth Series, Monograph Number 3.* Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 101-114.
- Van Limborgh, Jan
1970 A new view on the control of the morphogenesis of the skull. *Acta Morphologica Neerlandico-Scandinavica* 8:143-160.
- Van Limborgh, Jan
1972 The role of genetic and local environmental factors in the control of postnatal craniofacial morphogenesis. *Acta Morphologica Neerlandico-Scandinavica* 10:37-47.
- Vitti, Mathias and John V. Basmajian
1977 Integrated actions of masticatory muscles: Simultaneous EMG from eight intramuscular electrodes. *The Anatomical Record* 187:173-190.
- Walker, Wendell C.
n.d.a. Unpublished field report, 10RE4. M.S. on file, Frank H. McClung Museum. Knoxville: The University of Tennessee.
- Walker, Wendell C.
n.d.b. Unpublished field report, 86RH41, 89RH41. M.S. on file, Frank H. McClung Museum. Knoxville: The University of Tennessee.
- Wallace, John A.
1975 Did LaFerrassie I use his teeth as a tool? *Current Anthropology* 16:393-401.

Weidenreich, Franz

1936 The Mandibles of Sinanthropus Pekinensis: A Comparative Study. *Palaeontologica Sinica* Vol. 7, Fascicle 3.

Weijs, W. A. and B. Hillen

1986 Correlations between the cross-sectional area of the jaw muscles and craniofacial size and shape.

American Journal of Physical Anthropology 70:423-431.

Wilson, G. H.

1920 The anatomy and physics of the temporomandibular joint. *Journal of the National Dental Association* 7: 414-420.

Wilson, G. H.

1921 The anatomy and physics of the temporomandibular joint. *Journal of the National Dental Association* 8: 236-241.

Winters, H. D.

1969 The Riverton Culture. Springfield: Illinois State Museum, Reports of Investigation, Number 13.

Wolpoff, Milford H.

1971a Interstitial wear. *American Journal of Physical Anthropology* 34:205-228.

Wolpoff, Milford H.

1971b A functional measure of tooth size. *Southwestern Journal of Anthropology* 27:279-286.

Wolpoff, Milford H.

1975 Some aspects of human mandibular evolution. In James A. McNamara, Jr. (editor): *Determinants of Mandibular Form and Growth*. Craniofacial Growth Series, Monograph Number 4. Ann Arbor, Michigan: Center for Human Growth and Development, The University of Michigan, pp. 1-64.

Wolpoff, Milford H.

1976 Evolutionary aspects of hominid tooth reduction and early hominid dental variation. In P. Tobias and Y. Coppens (editors): *Les Plus Anciens Hominides*. Paris: Centre Nationale de la Recherche Scientifique, pp. 318-406.

Wolpoff, Milford H., Fred H. Smith, Mirko Malez, J. Rad-ovčić, and D. Rukavina

1981 Upper Pleistocene human remains from Vindija Cave, Croatia, Yugoslavia. *American Journal of Physical Anthropology* 54:499-545.

- Wright, Donald M. and Benjamin C. Moffett, Jr.
1974 The postnatal development of the human temporo-
mandibular joint. American Journal of Anatomy 141:
235-250.
- Yarnell, Richard A. and M. Jean Black
1985 Temporal trends indicated by a survey of Archaic
and Woodland plant food remains from southeastern North
America. Southeastern Archaeology 4:93-106.
- Zegura, S. L.
1975 Taxonomic congruence in Eskimoid populations.
American Journal of Physical Anthropology 43:271-284.

APPENDICES

APPENDIX A

Coding Format and Measurement Definitions

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
Mandibular Dimensions		
SMH	Symphysis Height	- maximum distance from gnathion (the meeting point of the inferior border of the median plane) to the infradental point (the highest point of the alveolar margin between the two medial incisors) (Olivier 1969:189).
SWB	Symphysis Width (Basal)	- the horizontal distance between lateral and mesial aspects of the corpus at the inferior border of the symphysis.
SWA	Symphysis Width (Alveolar)	- the horizontal distance between the lateral and mesial aspects of the corpus at infradentale inferius.
BCB	Bicondylar Breadth	- the maximal breadth taken between the most lateral parts of the condyles (Olivier 1969:185).
BGB	Bigonial Breadth	- the distance from gonion to gonion (the point of intersection between the posterior tangent to the ascending ramus and the inferior tangent to the border of the bone on that side) (Olivier 1969:186).
BCN	Bicanine Breadth	- the maximum diameter between the canines at the midpoint of the alveolus (Paquette 1985:48).
CPH	Corpus Height	- the vertical distance from the inferior border of the mandibular corpus to a point on the alveolus between P4 and M1.
CPT	Corpus Thickness	- the horizontal distance between the lateral and mesial aspects of the corpus between P4 and M1.

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
CDH	Condyle Height	- the maximum projected vertical distance from the tangent to the lateral aspect of the mandibular notch to the tip of the condyle.
CDT	Condyle Thickness	- the maximum horizontal distance between the lateral and mesial aspects of the mandibular condyle.
CDW	Condyle Width	- the maximum horizontal distance between the anterior and posterior aspects of the mandibular condyle.
TML	Total Mandibular Length	- the distance of the anterior margin of the chin from a center point on a projected straight line placed along the posterior border of the two gonial/mandibular angles (Moore-Jansen and Jantz 1986:64).*
PTL	Posterior Tooth Row Length	- on a projected straight line, the distance from the gonial angle to the perpendicular at the point of proximal P3.*
ARH	Ascending Ramus Height	- the distance from gonion to the upper part of the condyle measured along the posterior part of the bone (Olivier 1969:186).*
ART	Ascending Ramus Thickness	- the maximum horizontal distance between the mesial and lateral aspects of the ramus, measured at a point perpendicular to the occlusal plane.
ARB	Ascending Ramus Breadth	- the minimal distance between the anterior and posterior margins, measured perpendicular to the height (Olivier 1969:187).
CPG	Coronoid Process to Gonion	- the maximum distance between the tip of the coronoid process and gonion.
PGN	Pogonion to Gnathion	- the maximum distance from pogonion to gnathion.

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
CSH	Coronoid Process Height	- the maximum distance from a tangent drawn from the mandibular notch to the most superior point on the coronoid process.
CMP	Coronoid Process/Lower Molar Point	- the maximum vertical distance from the most superior aspect of the coronoid process to the lower molar point on the same side of the mandible.

Mandibular Radii and Projections

IBR	Infradentale inferius/Bicondylar Radius	- the perpendicular to the bicondylar axis from infradentale inferius.*
IBP	Infradentale inferius/Bicondylar Projection	- the projected straight-line distance from infradentale inferius to the bicondylar axis.*
PBR	Pogonion/Bicondylar Radius	- the perpendicular to the bicondylar axis from gnathion.*
PBP	Pogonion/Bicondylar Projection	- the projected straight-line distance from gnathion to the bicondylar axis.*
CPR	Coronoid Process/Bicondylar Radius	- the perpendicular to the bicondylar axis from the coronoid process.*
CPP	Coronoid Process/Bicondylar Projection	- the projected straight-line distance from the coronoid process tip to the bicondylar axis.*
PTR	P3/Bicondylar Radius	- the perpendicular to the bicondylar axis from the midpoint of the lateral alveolus to mandibular P3.*
PTP	P3/Bicondylar Projection	- the projected straight-line distance from the midpoint of the lateral alveolus at mandibular P3 to the bicondylar axis.*
MBR	Lower Molar Point/Bicondylar Radius	- the perpendicular to the bicondylar axis from the lower molar point.*

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
MBP	Lower Molar Point/Bicondylar Projection - the projected straight-line distance from the lower molar point to the bicondylar axis.*	
CTR	Coronoid Point/Bicondylar Radius - the perpendicular to the bicondylar axis from the coronoid point.*	
CTP	Coronoid Point/Bicondylar Projection - the projected straight-line distance from the coronoid point to the bicondylar axis.*	
GBR	Gonion/Bicondylar Radius - the perpendicular to the bicondylar axis from gonion.*	
GBP	Gonion/Bicondylar Projection - the projected straight-line distance from gonion to the bicondylar axis.*	

Mandibular Angles

SMA	Symphyseal Angle - the most acute angle between the horizontal plane (the inferior tangent to the inferior border of the bone) and that of the chin (the tangent to the mental eminence, starting from the infradental point) (Olivier 1969:189).
GMA	Gonial (Mandibular) Angle - the angle formed by the inferior border of the corpus and the posterior border of the ramus (Moore-Jansen and Jantz 1986:65).
CPA	Coronoid Process Angle - the angle formed by the deflection of the coronoid process in relation to the dental arch.

Facial Dimensions

AVH	Alveolar Height - the distance from nasospinale (or subspinale) to alveolare (infradentale superius) (Paquette 1985:48).
UFH	Upper Facial Height - the distance from nasion to alveolare (or infradentale superius) (Bass 1987:75).

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
WMH	Cheek Height	- the minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, mesial to the masseter attachment, on the left side (Howells 1973:180).
BZB	Bizygomatic Breadth	- the maximum breadth across the zygomatic arches, wherever found, perpendicular to the median plane (Howells 1973:173).
PLL	Palate Length	- the distance between orale (the median point of a line tangent to the posterior alveolar border of the median incisors) to staphylion (the median point of the notches in the posterior border of the palate (Bass 1987:79).
PLB	Palate Breadth	- the maximum interproximal breadth of the palate between M1 and M2 (Paquette 1985:48).
ZAT	Zygomatic Arch Thickness	- the horizontal distance from the lateral to the medial border of the zygomatic arch directly posterior to the zygomaticotemporal suture (Hinton 1979:108).
ZRS	Zygomatic Root Point/Zygomaticotemporal Suture	- the distance from the most anterior extension of the zygomatic arch at the point where it merges into the maxilla (ZRP) to the suture joining the zygomatic process of the maxilla and the zygomatic process of the temporal bone (ZTS). Approximates the length of masseter origin (Hinton 1979:108, 117).
IFL	Infratemporal Fossa Length	- the maximum distance measured along the long axis of the infratemporal fossa, oriented perpendicular to infratemporal fossa width (Hinton 1979:108).
IFW	Infratemporal Fossa Width	- the distance between the medial surface of the zygomatic arch and the infratemporal crest, perpendicular to the sagittal plane (Hinton 1979:108).

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
EZP	Eminence Point/Zygomatic Root Point - the distance from the point of maximum convexity on the articular tubercle (EP) to the most anterior extension of the zygomatic arch at the point where it merges into the maxilla (ZRP) (Hinton 1979:108, 115, 117).	
EUP	Eminence Point/Upper Molar Point - the distance from the point of maximum convexity on the articular tubercle (EP) to the intersection of the maxillary alveolar border and the distal surface of the first maxillary molar (UMP) (Hinton 1979:115, 117-118).	
EIS	Eminence Point/Infradentale Superius - the distance from the point of maximum convexity on the articular tubercle (EP) to the most anterosuperior interdental point on the alveolar arch between the maxillary central incisors (IS) (Hinton 1979:115-116, 118).	
XCL	Maximum Cranial Length - the maximum distance from glabella to opisthocranion (Bass 1987:62).	
XCB	Maximum Cranial Breadth - the maximum cranial breadth perpendicular to the median sagittal plane (above the supramastoid crests) (Howells 1973:172).	
BBH	Cranial (Basion/Bregma) Height - the distance from basion to bregma (Bass 1987:62).	
TMB	Transmeatal Breadth - the maximum breadth from one external auditory meatus to the other.	

Facial Radii and Chords

PRR	Prosthion Radius - the perpendicular to the transmeatal axis from prosthion (Howells 1973:183).*
GNR	Gnathion Radius - the perpendicular to the transmeatal axis from gnathion.*
NAR	Nasion Radius - the perpendicular to the transmeatal axis from nasion (Howells 1973:183).*

<u>Code</u>	<u>Measurement</u>	<u>Definition</u>
SSR	Subspinale Radius - the perpendicular to the transmeatal axis from subspinale (Howells 1973:183).*	
ZMR	Zygomaxillare Radius - the perpendicular to the transmeatal axis from the left zygomaxillare anterior (Howells 1973:184).*	
FMR	Frontomalare Radius - the perpendicular to the transmeatal axis from the left frontomalare anterior (Howells 1973:183).*	
IDR	Infradentale Radius - the perpendicular to the transmeatal axis from infradentale inferius.*	
FRC	Frontal Chord - the direct distance from nasion to bregma, taken in the midplane and at the external surface (Howells 1973:181).*	

Dental Dimensions

ROL	Root Length - the distance from the cemento-enamel junction to the apex.
RMD	Root Mesiodistal Diameter - the maximum diameter of the root mesiodistally.
RBL	Root Buccolingual Diameter - the maximum diameter of the root buccolingually.
CMD	Crown Mesiodistal Diameter - the maximum diameter of the crown mesiodistally.
CBL	Crown Buccolingual Diameter - the maximum diameter of the crown buccolingually.
LROL, LRMD, LRBL, LCMD, LCBL=Lateral Incisor Dimensions	
MROL, MRMD, MRBL, MCMD, MCBL=Central Incisor Dimensions	
CROL, CRMD, CRBL, CCMD, CCBL=Canine Dimensions	

*denotes measurements taken to the nearest millimeter; all other measurements are taken to the nearest tenth of a millimeter.

APPENDIX B

Descriptive Statistics--Mandibular and Craniofacial Dimensions

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=1 SEX=1 -----						
SMH	40	31.3450000	3.13499274	23.9000000	38.0000000	0.49566588
Shb	40	13.7525000	1.35873008	11.2000000	16.8000000	0.21483409
ShA	35	5.2857143	0.66456652	3.9000000	6.4000000	0.11317740
BCA	39	16.2307692	1.73450293	11.5000000	20.7000000	0.27854339
CPH	40	30.2500000	2.55393111	24.5000000	36.5000000	0.40381196
CPT	40	11.7850000	1.66372304	9.0000000	15.9000000	0.26305771
CDH	39	14.7717949	2.23794416	11.0000000	19.5000000	0.35835787
CDa	33	16.6636364	1.78434663	15.9000000	22.5000000	0.31148527
BCB	31	117.6560645	6.47824048	105.7000000	136.3000000	1.24434872
BGB	39	93.0744672	6.71111331	79.2000000	109.2000000	1.07463818
CPG	40	56.2175000	3.91492132	49.4000000	66.8000000	0.61900341
APT	40	10.6775000	1.06264969	8.1000000	12.4000000	0.16801967
ARB	40	32.5005000	2.47676046	26.0000000	38.8000000	0.39192960
ARM	39	54.8205128	4.47726300	45.0000000	66.0000000	0.71693586
TML	39	97.1794872	4.67135448	88.0000000	106.0000000	0.78004100
PTL	39	87.0769231	4.17627771	78.0000000	93.0000000	0.66873964
IBK	38	86.3157895	4.47277206	77.0000000	96.0000000	0.72557944
PBK	38	93.8947368	4.65903713	85.0000000	102.0000000	0.78823991
CPA	38	31.4736842	3.29197913	22.0000000	39.0000000	0.53402953
PTK	38	80.0789474	4.62822612	71.0000000	88.0000000	0.75089475
MBK	37	60.6216216	4.23834167	52.0000000	71.0000000	0.69678730
CTA	38	40.1578947	3.30050214	34.0000000	49.0000000	0.53541215
IBP	38	86.6657895	4.28636803	81.1000000	97.1000000	0.69534356
PBP	38	96.5921053	5.03304655	88.3000000	106.8000000	0.81646796
CPP	38	33.1342105	3.37763014	23.0000000	40.5000000	0.53981289
PTP	38	83.1868421	4.25366934	75.0000000	91.0000000	0.69652239
MRP	37	65.6162162	4.07332198	58.0000000	72.7000000	0.66965001
CTP	38	41.1078947	3.45650941	33.8000000	49.6000000	0.56104431
CBP	38	55.9842105	3.78085693	48.9000000	65.4000000	0.61333598
PCN	40	11.9300000	1.99309063	6.4000000	15.5000000	0.31513530
CDT	39	4.8743590	0.67350412	8.0000000	11.8000000	0.13987260
SFA	40	76.3000000	6.80196050	66.0000000	92.0000000	1.07548439
GFA	40	117.9000000	5.05761675	106.0000000	130.0000000	0.79967942
AVH	27	17.2814815	2.37309228	13.0000000	22.7000000	0.45670182
UFH	25	64.4440000	4.27542201	52.0000000	71.0000000	0.85508440
MMH	28	21.4785714	1.65335957	18.5000000	26.5000000	0.31245559
PLL	12	47.1750000	2.00096568	44.5000000	52.0000000	0.57762904
PLB	25	34.5660000	2.89694092	33.6000000	44.1000000	0.57938818
ZAT	25	4.5560000	0.67582049	3.4000000	6.3000000	0.13516410
ZRS	25	35.4160000	2.51688961	29.5000000	40.0000000	0.50337792
IFL	24	33.7125000	2.62915303	30.1000000	39.4000000	0.53667361
IFW	18	22.5833333	2.53127496	18.5000000	27.7000000	0.59662723
EZP	25	51.1920000	3.11152696	46.0000000	58.9000000	0.62230539
EUP	23	56.7304348	2.62478232	51.5000000	63.5000000	0.59005040
EIS	25	96.5840000	3.68913721	87.5000000	102.4000000	0.73782744
XCL	28	176.2857143	4.73643485	166.0000000	185.0000000	0.89510300
XCB	27	135.1111111	4.50071219	127.0000000	143.0000000	0.86616247
BBH	12	134.7500000	5.73662511	125.0000000	147.0000000	1.66598338
	24	163.1666667	6.95742748	149.0000000	176.0000000	1.42017894
PRK	23	97.3478261	4.28112473	83.0000000	103.0000000	0.89267705
GNK	21	111.7619048	4.54667851	102.0000000	119.0000000	0.99260303
NAK	23	91.3913043	2.79185716	85.0000000	98.0000000	0.58214246
SSK	23	91.3478261	2.83819238	86.0000000	96.0000000	0.59180402
ZMK	23	65.5652174	3.18241777	63.0000000	76.0000000	0.66483106
FMK	23	76.4130435	3.47606156	70.0000000	82.0000000	0.72480894
IDR	21	101.3809524	3.20115625	95.0000000	109.0000000	0.69855698
FRC	25	107.0360000	4.22695574	98.8000000	116.4000000	0.84579115
B7b	22	130.0303636	5.78623535	123.0000000	144.0000000	1.23362952
CSH	40	12.3000000	2.10786075	8.7000000	17.1000000	0.33328205
CMP	39	44.0262051	4.41176350	36.8000000	53.4000000	0.70644755
CPA	40	39.5750000	6.73257485	28.0000000	53.0000000	1.06451355

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GPCUP=1 SEX=2 -----						
SMH	42	32.4523810	3.43945813	24.0000000	39.3000000	0.53071991
SWB	42	15.0460000	1.36296842	12.5000000	18.3000000	0.21031059
SWA	39	5.0435297	0.63816682	4.1000000	7.0000000	0.13421411
BCN	42	16.8404762	1.73163669	14.1000000	21.3000000	0.26719734
CPH	42	33.1642857	3.12260222	25.4000000	39.9000000	0.48182798
CPT	42	13.1023810	1.75339227	10.4000000	16.8000000	0.27055430
CDH	42	15.1119048	2.07684122	10.5000000	19.0000000	0.32046356
CDW	38	21.0578947	1.90271947	16.0000000	25.0000000	0.30866186
BCB	35	125.2942857	4.06973629	117.1000000	135.4000000	0.78932950
BCE	41	106.5195122	6.88313953	87.4000000	118.0000000	1.07496579
CPG	41	63.7756096	5.12266389	51.6000000	75.6000000	0.80002881
APT	42	11.1833333	1.58756088	8.4000000	13.5000000	0.24105229
ARB	41	33.4268293	2.71145542	27.4000000	41.8000000	0.42345882
ARM	42	61.5952381	5.25013135	49.0000000	77.0000000	0.81011286
TML	42	101.0238095	5.58520736	89.0000000	111.0000000	0.86181621
PTL	42	90.5476190	4.67062633	81.0000000	99.0000000	0.72069329
IBH	42	84.3571429	5.45411650	78.0000000	101.0000000	0.84158845
PBK	42	98.6666667	5.31755797	89.0000000	108.0000000	0.82051701
CPR	41	31.9756096	3.20536897	26.0000000	39.0000000	0.50059453
PTH	42	83.0238095	5.01941642	72.0000000	93.0000000	0.77451277
MBK	42	63.4523810	4.48820884	53.0000000	73.0000000	0.69254566
CTK	41	40.0829248	3.18150141	34.0000000	48.0000000	0.49686704
IBP	42	92.4571429	4.47222249	81.0000000	101.0000000	0.76723059
PBP	42	104.1547619	5.34621828	95.0000000	113.6000000	0.82493339
CPP	41	33.1902439	3.21572736	26.3000000	39.4000000	0.50221224
PTP	42	87.5928571	5.02944466	78.6000000	99.5000000	0.77606016
PBP	39	70.6000000	4.36872859	63.0000000	81.6000000	0.69955644
CTP	41	42.3768293	3.21418920	35.2000000	50.3000000	0.50197202
GBP	42	61.4238095	4.48018997	47.5000000	70.3000000	0.69130832
PGN	42	12.4809524	1.92787487	8.8000000	16.5000000	0.29747755
CDT	42	10.6023810	1.10683109	9.0000000	13.4000000	0.17109635
SMA	42	72.4761905	8.78257170	51.0000000	86.0000000	1.35516023
GMA	42	115.4047619	6.27833977	102.0000000	127.0000000	0.96876870
AVH	36	16.5916667	3.33204142	12.1000000	24.5000000	0.55534024
UFH	36	64.4750000	5.13066147	57.0000000	79.3000000	0.85510024
MMH	38	23.7368421	2.04944568	19.5000000	27.7000000	0.33246399
PLL	23	46.0521734	3.52882540	41.0000000	53.8000000	0.73581096
PLB	32	40.2875000	2.60282105	34.7000000	45.0000000	0.46011810
ZAT	36	5.2277778	0.69389629	3.6000000	6.7000000	0.11564938
ZRS	34	36.8323529	2.91960153	31.0000000	43.5000000	0.50070753
IFL	34	35.0647059	2.66797873	30.6000000	42.4000000	0.45755458
IFW	33	25.4030303	2.05616221	20.0000000	30.0000000	0.35793190
EZP	36	53.0611111	3.46527903	43.5000000	62.3000000	0.57754650
EUP	30	61.4700000	3.59888872	54.9000000	68.3000000	0.65706418
ETS	36	106.0722222	4.53214620	90.4000000	107.7000000	0.75535770
XCL	39	174.0769231	5.93998323	164.0000000	191.0000000	0.95115855
XCB	39	136.0769231	4.57904044	126.0000000	150.0000000	0.73323329
BBH	26	139.0769231	5.54200741	125.0000000	150.0000000	1.08687707
TMB	36	167.1666667	4.64325746	159.0000000	178.0000000	0.80720958
PRR	34	99.7352441	4.65350193	90.0000000	107.0000000	0.79806900
GNK	32	116.9375000	5.52961236	107.0000000	128.0000000	0.97750660
NAK	36	93.4166667	4.33177628	85.0000000	106.0000000	0.72196271
SSK	35	92.4428571	4.87456096	83.0000000	105.0000000	0.82395119
ZMK	35	72.5428571	3.76784271	64.0000000	84.0000000	0.63698166
FMK	35	76.6571429	3.78031167	70.0000000	89.0000000	0.63898930
IDA	32	104.3125000	5.27525798	94.0000000	114.0000000	0.93264874
FRC	34	111.4401538	4.19227649	104.5000000	120.1000000	0.67130149
BZb	29	136.1379310	5.68666166	125.0000000	150.0000000	1.05597542
CSH	41	13.8170732	2.15096246	9.0000000	18.0000000	0.33589891
CHP	39	50.0128205	4.05476354	40.7000000	60.4000000	0.64927219
CPA	42	46.4285714	6.31352732	26.0000000	50.0000000	0.97419842

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=2 SEX=1 -----						
SMH	6	34.1P33333	1.96714683	31.3CC0000	37.000G000	0.80308433
SHb	6	13.6166667	0.62423286	13.0CC000C	14.5000000	0.25484200
SWA	5	5.14C0000	0.75696763	4.1CC0C00	6.2000000	0.33852622
BCN	5	14.2800000	0.63796552	18.8CC0000	20.3CC0000	0.28530685
CPH	6	32.2833333	2.35577305	28.70C0000	34.7000000	0.96174032
CPT	6	11.2333333	0.73393914	10.2000C00	12.4000000	0.29962940
CDH	6	16.25C0000	2.31408729	13.0000000	19.1000000	0.94472218
CDh	6	17.5666667	1.29563369	16.2C00C00	19.3000000	0.52894024
BCB	5	115.6600C00	6.76631362	107.50C0000	122.4C00C00	3.02598744
BGB	5	96.04C0000	5.84362901	91.60C0000	105.800C000	2.61335034
CPC	5	57.9400G00	4.19857119	54.C0C0000	64.8000000	1.87765812
ART	6	12.6333333	3.23892986	1C.8CC0C00	19.2C00000	1.32228758
ARB	6	34.9606667	1.30175363	33.7000000	36.7C00000	0.53145503
ARM	6	54.5C00000	4.41588043	48.0000000	59.0000000	1.80277564
TML	6	1C1.8333333	5.38206899	95.C0C0C0C	1C9.0000000	2.19722C47
PTL	6	91.0C00000	4.14728827	85.C000C00	95.0000000	1.69312335
IBK	6	9C.0C00000	3.03315518	85.0000000	93.0000000	1.23627837
PBA	6	96.1666667	4.3089C551	93.00C0000	1C3.000C000	1.75910331
CPA	6	33.500C000	2.81069386	31.0CC0000	37.000C000	1.14746097
PTK	6	83.1666667	3.06050105	78.0000000	87.0000000	1.24944432
MBK	6	62.6666667	2.33809039	60.CCC00CC	66.0000000	0.95452140
CTK	6	42.3333333	2.50333111	38.0C00000	45.0C00000	1.02198065
IBP	6	91.7333333	3.41389318	86.5000000	95.1000000	1.39371606
PBP	6	1C2.3166667	3.19463091	98.C0C0C00	1C6.1000000	1.3C4202e1
CPP	6	34.7166667	3.08247736	30.3C00000	38.3C0C000	1.25841611
PTP	6	85.4166667	3.60411802	79.5000000	90.0000000	1.47137502
MBP	6	67.4166667	2.78665458	63.5000000	71.000C000	1.13766330
CTP	6	44.2333333	2.48408266	41.6C0CC00	47.6000000	1.01412250
GDP	6	57.7166667	2.30427140	55.3000000	62.0000000	0.94071486
PCN	6	12.6333333	0.64394617	11.9000000	13.3000000	0.26288992
CDT	6	10.8333333	0.71740272	1C.00C0C00	12.0000000	0.29287844
SFA	6	77.1666667	7.46770826	70.0000000	88.0000000	3.04867913
GNA	6	126.8333333	8.06019024	113.C000000	135.0C00000	3.29055889
AVH	5	2C.1C00000	1.91833261	17.4000000	22.6000000	0.85790442
UFH	4	67.75C0000	2.4946e097	65.6000000	70.2000000	1.24733048
MMH	5	22.2000000	2.19544984	19.2CC0000	24.9C00000	0.98183502
PLL	2	48.4500000	0.77781746	47.9000000	49.0000000	0.55000000
PLB	4	41.575CC00	1.64595464	40.0000000	43.6000000	0.82297732
ZAT	3	4.6C00000	0.45825757	4.2000000	5.1000000	0.26457513
ZRS	3	32.1666667	4.25245027	29.0000000	37.0C00000	2.45515331
IFL	3	34.4666667	4.89931968	29.1000000	38.7000000	2.82862354
IFW	2	23.5500000	1.06066017	22.8000000	24.3000000	0.75000000
EZP	3	48.1666667	2.89194283	45.6C00000	51.3000000	1.66966397
EUP	3	57.4666667	2.40069434	55.7000000	60.2000000	1.38604153
EIS	3	97.2CC0000	5.52177508	93.2C00000	1C3.5C00000	3.18799833
XCL	4	163.CCC0C00	11.16542282	154.C00000C	178.0C00000	5.58271141
XCb	4	143.CCC0C00	10.09950494	133.00C0000	157.0000000	5.04975247
BBH	2	132.0C00000	2.82842712	130.0000000	134.0000000	2.00C00000
TMB	2	164.6666667	5.50757055	161.C000000	171.0000000	3.17979734
PRK	3	96.3333333	5.7735C269	95.0000000	105.0C00000	3.33333333
GNA	3	113.6666667	4.50924975	109.0000000	118.0C00000	2.60341656
NAK	3	9C.6666667	1.52752523	89.00C000C	92.0000000	0.88191710
SSK	3	89.0C00000	4.00000000	85.0000000	93.0000000	2.30940108
ZMR	3	65.6666667	3.51188458	62.CC00000	69.0000000	2.02758751
FMK	3	77.0C00000	3.0C000000	74.0000C00	80.0000000	1.73205081
IDK	3	1C5.6666667	3.055C5C46	1C1.C0C0C00	1C7.0000000	1.76383421
FRG	3	1C7.8333333	1.15C36226	106.7C0C0C0	1C9.0000000	0.66416196
BZB	2	131.0C0C000	1.41421356	13C.C000000	132.0C00000	1.00C0C000
CSH	6	14.65C00C0	3.61483056	11.7000000	21.9000000	1.47574840
CMP	6	45.5333333	2.361C7320	42.90C0000	48.8000000	0.96390410
CPA	6	45.3333333	6.63130951	35.0000000	55.0C00000	2.78886676

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=2 SEX=2 -----						
SPH	15	34.7533333	3.10181207	29.7000000	41.0000000	0.8008444
SHB	16	14.5312500	1.26154621	13.0000000	17.2000000	0.3153951
SNA	10	5.7300000	0.51214486	5.0000000	6.5000000	0.1619671
BCN	15	14.1000000	2.29154957	15.2000000	25.4000000	0.5916885
CPH	16	33.8125000	2.65552882	30.3000000	38.5000000	0.6638822
CPI	16	12.8937500	1.17953027	10.5000000	14.5000000	0.2948826
CDH	16	15.6502500	2.22140158	12.1000000	19.1000000	0.5553504
CDW	16	14.8375000	1.96022958	17.0000000	23.5000000	0.4900574
BCB	16	123.6687500	7.75918542	114.9000000	141.9000000	1.9397964
BGB	16	96.6312500	7.69317609	85.2000000	116.5000000	1.9232940
CPG	16	62.7750000	4.97384503	53.9000000	72.5000000	1.2434663
ART	16	12.5937500	1.22934603	10.2000000	14.7000000	0.3073365
ARB	16	24.6125000	2.43095548	28.6000000	39.4000000	0.7327389
ARM	16	56.6875000	4.74297726	50.0000000	65.0000000	1.1857443
TML	16	104.1875000	4.90195539	94.0000000	111.0000000	1.2254888
PTL	16	92.1250000	4.17731971	85.0000000	99.0000000	1.0443299
IBK	16	91.6250000	3.22231801	86.0000000	98.0000000	0.8055795
PBA	16	101.2500000	3.66066104	96.0000000	108.0000000	0.9151503
CPR	16	30.6750000	4.06407021	25.0000000	39.0000000	1.0160176
PTK	16	85.3125000	3.94493346	78.0000000	92.0000000	0.9862334
PBK	16	64.3750000	3.84491006	56.0000000	71.0000000	0.9612275
CTK	16	41.1250000	3.28379861	34.0000000	47.0000000	0.8209497
IBP	16	93.3875000	3.41406405	88.8000000	100.1000000	0.8535160
PBP	16	105.5502500	3.63735477	100.1000000	112.8000000	0.9593387
CPP	16	32.1875000	3.85034630	25.0000000	40.4000000	0.9625866
PTP	16	86.1502500	4.40423565	80.7000000	94.0000000	1.1010589
MBP	16	69.4002500	3.68337804	62.0000000	74.9000000	0.9708445
CTP	16	42.6750000	3.41647519	35.0000000	49.9000000	0.8546198
GBP	16	66.4937500	4.35495735	54.2000000	68.2000000	1.0887481
PGN	16	12.6312500	1.34596620	10.5000000	14.4000000	0.3364915
COT	16	10.4875000	0.79390050	8.9000000	12.0000000	0.1959751
SMA	16	73.9375000	8.27420641	60.0000000	88.0000000	2.0685517
GMA	16	117.4375000	5.96063475	110.0000000	130.0000000	1.4901587
AVH	12	21.1916667	3.59379727	13.7000000	26.2000000	1.0374359
UFH	7	64.1571429	5.32724355	63.3000000	78.9000000	2.0135088
WMH	7	24.6714286	2.53884113	20.4000000	28.7000000	0.9595917
PLL	8	48.2500000	3.22401702	42.1000000	52.5000000	1.1398621
PLB	7	42.2142857	1.92823630	40.0000000	45.5000000	0.7288048
ZAT	7	5.2785714	0.54072262	4.5000000	6.2000000	0.2043739
ZRS	6	35.0333333	3.69135795	29.6000000	38.5000000	1.5886402
IFL	7	34.4428571	2.71161523	31.3000000	39.5000000	1.0248442
IFW	5	23.8000000	2.19632111	21.5000000	26.1000000	0.9777525
EZP	7	50.9428571	2.45279238	47.7000000	54.9000000	0.9270684
EUP	5	54.6400000	2.46231598	56.8000000	62.3000000	1.1011812
EIS	6	94.1166667	2.09226742	96.6000000	101.6000000	0.8541728
XCL	6	173.8333333	7.67897563	164.0000000	187.0000000	3.1349287
XCB	6	143.3333333	7.11805217	134.0000000	155.0000000	2.9059326
BBH	3	145.0000000	17.34935157	134.0000000	165.0000000	10.0166528
TMB	6	164.5000000	1.76066169	162.0000000	167.0000000	0.7187953
PRR	6	100.1666667	5.19294393	93.0000000	108.0000000	2.1200105
GNR	6	117.3333333	4.80277697	110.0000000	124.0000000	1.9607255
NAK	6	94.3333333	4.13118224	91.0000000	102.0000000	1.6865481
SSR	6	93.1666667	5.11533642	85.0000000	101.0000000	2.0883273
ZMK	6	64.3333333	3.61476446	65.0000000	74.0000000	1.4757296
FMK	6	78.1666667	3.81663028	75.0000000	85.0000000	1.5581328
IDK	6	103.6333333	3.97072621	99.0000000	111.0000000	1.6210422
ERC	6	110.8666667	3.76811182	105.0000000	114.6000000	1.5383252
BZB	6	130.1666667	2.63444439	133.0000000	139.0000000	1.0775487
CSH	16	14.7437500	2.03894376	11.3000000	17.6000000	0.5097359
CRP	16	50.6437500	5.54316020	41.5000000	62.5000000	1.3857900
CPA	16	47.0000000	7.51886516	35.0000000	60.0000000	1.8797163

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=3 SFX=1 -----						
SMH	94	34.0425532	2.61108017	26.5000000	39.4000000	0.26931236
Shb	94	13.3908685	1.31242631	10.1000000	16.2000000	0.13536644
ShA	83	5.4000000	0.70034935	3.8000000	6.8000000	0.07687322
BCN	94	15.4329787	1.33717631	16.3000000	23.4000000	0.13791921
CPH	94	31.6505106	2.10944673	26.4000000	36.3000000	0.21757282
CPT	94	11.8606383	1.15108346	9.6000000	14.8000000	0.11872519
CDH	94	14.1563830	1.62228667	10.0000000	18.8000000	0.18801640
CDh	40	16.2711111	1.86351694	14.3000000	22.2000000	0.19443163
BCB	82	121.0817073	5.43087034	105.5000000	133.3000000	0.59573930
BGB	93	92.6634409	6.71108403	76.2000000	116.9000000	0.69590700
CPG	94	56.5343617	3.76003814	47.5000000	65.7000000	0.38864346
APT	94	11.5343617	1.21196704	8.8000000	14.5000000	0.12500486
ARE	94	32.5343617	2.15682054	27.3000000	39.5000000	0.22245905
ARM	94	52.3141489	5.26953665	41.0000000	65.0000000	0.54351121
TAL	93	100.9677414	4.79232088	88.0000000	114.0000000	0.49494053
PTL	93	86.7046774	4.56732403	78.0000000	104.0000000	0.47360944
IBk	93	89.3548387	4.46397454	80.0000000	103.0000000	0.46289260
PBK	93	97.4301075	4.61188882	87.0000000	110.0000000	0.47823059
CPK	93	29.9892473	3.22185007	19.0000000	39.0800000	0.33409029
PTk	93	82.1240323	4.35946199	74.0000000	93.0000000	0.45205515
MBR	92	62.2826087	4.30007944	54.0000000	73.0000000	0.44631427
CTK	93	36.8307097	3.15639559	30.0000000	49.0000000	0.32730268
IBP	93	90.0247312	4.35549707	79.7000000	103.1000000	0.45164407
PBP	93	101.1143540	4.35374047	92.5000000	113.2000000	0.45146186
CPP	93	31.5700015	2.84962207	22.0000000	39.0000000	0.29549204
PTP	93	84.6000000	4.09765288	76.2000000	94.6000000	0.42491096
MBP	91	66.1175824	3.77440484	56.8000000	76.0000000	0.39566514
CTP	93	40.4817204	3.20227318	31.7000000	49.9000000	0.33206026
GBP	93	55.5745699	3.26431826	48.3000000	66.1000000	0.33649404
PGN	94	12.0276596	1.79763311	8.4000000	17.3000000	0.18541170
CDT	94	10.0351064	0.96237916	8.3000000	13.6000000	0.09526183
SPA	93	77.3118280	7.26961887	47.0000000	90.0000000	0.75382436
GMA	94	122.49361702	6.62320539	109.0000000	138.0000000	0.68313148
AVH	75	21.2546667	2.46342397	16.5000000	27.2000000	0.28445170
UFH	53	70.8150943	3.44307534	60.6000000	77.5000000	0.47294277
BMH	71	23.1690141	1.67976658	18.6000000	27.5000000	0.22308962
PLL	35	48.9257143	3.57691478	39.6000000	55.7000000	0.60460895
PLB	57	42.2614035	2.70625957	35.9000000	48.5000000	0.35845284
ZAT	47	4.6446809	0.63547603	3.3000000	6.2000000	0.09269371
ZRS	48	31.6270833	2.76557405	25.8000000	38.6000000	0.39917623
IFL	49	32.4367347	3.57693385	24.7000000	41.3000000	0.51099055
IFh	46	23.7152174	2.61108470	17.0000000	30.7000000	0.38498344
EZP	48	48.5583333	3.24980087	41.6000000	57.4000000	0.46906835
EUP	46	59.7978261	4.09506419	52.3000000	67.1000000	0.60378427
EIS	48	94.3520833	3.95458202	90.0000000	106.4000000	0.57075475
XCL	48	154.3541667	8.23198118	146.0000000	176.0000000	1.18818414
XCB	49	144.4183073	9.89072953	125.0000000	170.0000000	1.41296136
BBH	29	137.6551724	5.77726988	123.0000000	148.0000000	1.07281208
TMB	47	166.4787234	6.48573472	152.0000000	182.0000000	0.94604164
PRK	46	98.4782009	5.01437547	86.0000000	111.0000000	0.73932933
GNR	45	112.2666667	4.36096404	100.0000000	124.0000000	0.65009712
NAR	47	84.8085106	4.16840235	82.0000000	100.0000000	0.60802397
SSK	46	86.4505217	4.38029183	80.0000000	103.0000000	0.64583880
ZPK	46	86.9782604	3.69473808	80.0000000	75.0000000	0.54328499
FPK	46	76.1956522	4.00696749	70.0000000	85.0000000	0.59105296
IDA	45	101.8000000	4.47510410	95.0000000	113.0000000	0.66712106
FRC	51	107.6568627	4.89065455	95.0000000	118.8000000	0.68482862
BZB	34	130.4117047	4.37013034	122.0000000	140.0000000	0.74947117
CSH	94	12.7545745	1.83919800	6.5000000	16.5000000	0.18969879
CMP	92	47.4076087	3.71114252	40.1000000	56.0000000	0.38691335
CPA	94	47.6063830	7.35025138	30.0000000	70.0000000	0.75812054

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=3 SEX=2 -----						
SMH	101	30.5772277	3.05453825	29.8000000	44.8000000	0.30692303
SWB	101	14.1207921	1.50586907	10.5000000	18.1000000	0.14983368
SWA	42	5.6407391	0.77039323	4.3000000	8.0000000	0.08031905
BCH	101	14.5900490	1.55290063	16.4000000	22.6000000	0.15451941
CPH	100	33.4700000	2.58335777	28.4000000	41.0000000	0.25633578
CPT	100	12.0000000	1.22490981	9.4000000	16.3000000	0.12249098
CDH	101	14.0821782	2.04467093	10.4000000	20.3000000	0.20345236
CDL	97	14.8742268	2.13413331	11.9000000	24.0000000	0.21719608
BCB	94	120.8865417	6.90319331	110.1000000	145.3000000	0.70455422
BGB	100	100.0000000	6.88312084	81.8000000	116.7000000	0.68831208
CPG	101	63.0643564	4.63647773	51.5000000	72.6000000	0.46124752
ART	101	12.0722772	1.22752750	8.7000000	14.7000000	0.12214355
ARB	101	34.0930693	2.64458510	27.5000000	41.0000000	0.26314645
ARM	101	52.6930693	6.23176151	38.0000000	71.0000000	0.62008345
TML	101	105.1287129	4.94502450	94.0000000	118.0000000	0.49204833
PTL	101	92.1306139	4.00007426	84.0000000	105.0000000	0.39802226
IRH	100	92.2600000	4.19865298	81.0000000	105.0000000	0.41986530
PBK	101	102.5841584	4.47044735	91.0000000	114.0000000	0.44483111
CPK	101	30.0831683	3.00642876	24.0000000	38.0000000	0.29915084
PTK	101	84.6435644	4.08309725	74.0000000	96.0000000	0.40628336
MRK	101	65.4653465	4.02135389	56.0000000	77.0000000	0.40013967
CTK	101	46.7128713	2.61544538	34.0000000	47.0000000	0.26014729
IRP	100	94.2140000	3.78483276	84.7000000	104.3000000	0.37898328
PBP	101	100.4930693	4.42495452	96.6000000	117.9000000	0.44080093
CPP	101	32.3900990	2.89060163	25.3000000	39.5000000	0.28822263
PTP	101	87.4108411	3.40642806	78.8000000	98.7000000	0.38870412
MRP	101	70.2574206	3.71794711	61.3000000	82.2000000	0.36994956
CTP	101	42.2643564	3.09569327	34.7000000	49.8000000	0.30803299
GBP	101	60.0049505	4.95452369	46.4000000	73.2000000	0.49349105
PGH	101	12.2663366	2.09085041	7.2000000	17.9000000	0.20804739
CDT	101	10.6732673	1.20448255	8.7000000	14.2000000	0.11985049
SMA	100	76.0100000	8.17052475	45.0000000	90.0000000	0.81705248
GMA	101	119.5841584	6.9595763	106.0000000	145.0000000	0.69214365
AVH	75	21.6973333	2.69486840	16.4000000	29.7000000	0.33427061
UFH	55	73.5709091	3.71267462	64.7000000	85.2000000	0.50061694
BMH	67	24.8716418	2.11486843	19.6000000	30.2000000	0.25837230
PLL	44	44.3977273	3.20635188	42.0000000	55.2000000	0.48337573
PLB	66	44.0742424	3.03147898	37.6000000	52.3000000	0.37314927
ZAT	50	5.1220000	0.89175132	3.5000000	7.9000000	0.12611268
ZRS	51	34.2352941	3.50381641	27.0000000	42.8000000	0.49063243
IFL	51	32.8941176	3.46013941	25.8000000	41.1000000	0.48451643
IFW	47	24.2872340	2.24786053	19.3000000	29.7000000	0.32788416
EZP	53	44.6641509	3.30233567	43.9000000	61.2000000	0.45361069
EUP	51	61.5000000	3.43470523	54.8000000	70.3000000	0.48095493
ETS	52	101.0538462	4.53044003	92.2000000	113.1000000	0.62825899
XCL	51	165.7754902	9.50595273	148.0000000	188.0000000	1.33109963
XCB	52	147.0269231	7.37170306	127.0000000	161.0000000	1.02227128
BBH	33	143.0606061	5.68928791	128.0000000	153.0000000	1.02519344
TMB	53	171.9056604	6.34963400	159.0000000	188.0000000	0.87218931
PRR	52	94.5576923	4.53485071	90.0000000	110.0000000	0.62687619
GMR	52	117.4038462	4.90001847	106.0000000	129.0000000	0.67951030
NAR	53	92.0377358	4.77155943	78.0000000	102.0000000	0.65542409
SSR	50	90.0600000	4.22050389	79.0000000	101.0000000	0.59686938
ZMR	52	67.7307692	3.79475595	59.0000000	76.0000000	0.57617418
FMR	53	70.7547170	4.77938546	58.0000000	86.0000000	0.65649908
IOK	51	104.5098034	4.53154521	95.0000000	116.0000000	0.63454325
FRC	53	110.4113208	5.01675496	100.3000000	122.4000000	0.68931646
BZB	35	139.7142657	6.68430027	126.0000000	153.0000000	1.12586311
CSH	101	14.4544054	2.12307222	9.6000000	21.4000000	0.21125358
CMF	101	53.0460000	4.51482228	42.7000000	63.5000000	0.45148223
CPA	101	47.6435644	6.39622413	35.0000000	65.0000000	0.63644809

Group 1=Archaic, 2=Woodland, 3=Mississippian;
Sex 1=Female, 2=Male.

APPENDIX C

Descriptive Statistics--Dental Dimensions

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=1 SEX=1 -----						
LRDL	18	14.61111111	1.59701519	11.60000000	17.60000000	0.37642009
LRMD	18	3.81666667	0.39295262	3.20000000	4.50000000	0.09261982
LRBL	18	5.97222222	0.54211520	5.00000000	7.00000000	0.12777778
LCMD	18	5.92777778	0.54965824	4.70000000	7.00000000	0.12955569
LCBL	18	6.12222222	0.50938897	5.10000000	6.90000000	0.12006413
MRDL	13	12.80769231	1.32127561	11.00000000	15.30000000	0.36645592
MRMD	13	3.48461538	0.32364114	3.00000000	4.10000000	0.08976190
MRBL	13	5.50000000	0.39791121	5.00000000	6.10000000	0.11036071
MCMD	13	5.06000000	0.48819395	4.30000000	5.80000000	0.13540064
MCBL	13	5.67692308	0.33703078	5.10000000	6.20000000	0.09347552
CRDL	13	16.94615385	1.65661069	14.70000000	19.80000000	0.45946114
CRMD	13	5.10000000	0.71995370	3.20000000	6.00000000	0.19967923
CRBL	13	7.24230769	0.54994172	6.30000000	8.00000000	0.15252639
CCMD	13	6.71538462	0.40382784	6.20000000	7.50000000	0.11200169
CCBL	13	7.36923077	0.51701808	6.50000000	8.40000000	0.14334501
----- GROUP=1 SEX=2 -----						
LRDL	21	14.76190476	1.39981291	12.20000000	17.80000000	0.30546422
LRMD	21	3.92380952	0.50882685	2.80000000	4.80000000	0.11103512
LRBL	21	6.05238095	0.36962014	5.30000000	7.00000000	0.08065773
LCMD	21	5.76666667	0.54802676	4.80000000	6.70000000	0.11958924
LCBL	21	6.12857143	0.41969377	5.30000000	7.20000000	0.09158469
MRDL	16	13.36875000	1.27107238	10.70000000	16.00000000	0.31776810
MRMD	16	3.44375000	0.43584210	2.70000000	4.00000000	0.10896052
MRBL	16	5.54375000	0.49455579	4.80000000	6.50000000	0.12364845
MCMD	16	4.64375000	0.51116697	3.60000000	5.40000000	0.12779174
MCBL	16	5.66875000	0.54125625	4.80000000	6.80000000	0.13531406
CRDL	18	19.07222222	1.63700068	16.60000000	22.10000000	0.38554476
CRMD	18	5.66111111	0.54787170	4.80000000	7.30000000	0.12913460
CRBL	18	7.83333333	0.66598004	6.90000000	9.80000000	0.15697300
CCMD	18	6.93888889	0.69038684	5.30000000	8.40000000	0.16272574
CCBL	18	7.93333333	0.68169339	6.90000000	9.60000000	0.16067667
----- GROUP=2 SEX=1 -----						
LRDL	1	16.30000000	.	16.30000000	16.30000000	.
LRMD	1	3.70000000	.	3.70000000	3.70000000	.
LRBL	1	5.90000000	.	5.90000000	5.90000000	.
LCMD	1	6.10000000	.	6.10000000	6.10000000	.
LCBL	1	6.00000000	.	6.00000000	6.00000000	.
MRDL	1	12.50000000	.	12.50000000	12.50000000	.
MRMD	1	3.00000000	.	3.00000000	3.00000000	.
MRBL	1	5.10000000	.	5.10000000	5.10000000	.
MCMD	1	5.10000000	.	5.10000000	5.10000000	.
MCBL	1	5.30000000	.	5.30000000	5.30000000	.
CRDL	1	20.10000000	.	20.10000000	20.10000000	.
CRMD	1	5.30000000	.	5.30000000	5.30000000	.
CRBL	1	7.50000000	.	7.50000000	7.50000000	.
CCMD	1	7.20000000	.	7.20000000	7.20000000	.
CCBL	1	7.30000000	.	7.30000000	7.30000000	.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
----- GROUP=2 SEX=2 -----						
LRDL	2	15.60000000	0.14142136	15.50000000	15.70000000	0.10000000
LRMD	3	3.70000000	0.00000000	3.70000000	3.70000000	0.00000000
LRBL	3	6.03333333	0.15275252	5.90000000	6.20000000	0.08819171
LCMD	3	6.06666667	0.20816660	5.90000000	6.30000000	0.12018504
LCBL	3	6.20000000	0.10000000	6.10000000	6.30000000	0.05773503
MRDL	3	14.06666667	0.98149546	13.50000000	15.20000000	0.56666667
MRMD	4	3.40000000	0.28284271	3.20000000	3.80000000	0.14142136
MRBL	4	5.40000000	0.61644140	4.50000000	5.80000000	0.30822070
MCMD	3	5.43333333	0.47258156	4.90000000	5.80000000	0.27284509
MCBL	3	6.03333333	0.15275252	5.90000000	6.20000000	0.08819171
CRDL	1	16.50000000	.	16.50000000	16.50000000	.
CRMD	1	4.90000000	.	4.90000000	4.90000000	.
CRBL	1	6.10000000	.	6.10000000	6.10000000	.
CCMD	1	6.80000000	.	6.80000000	6.80000000	.
CCBL	1	6.50000000	.	6.50000000	6.50000000	.
----- GROUP=3 SEX=1 -----						
LRDL	62	14.55645161	1.08848232	12.50000000	17.30000000	0.13823739
LRMD	62	3.80322581	0.33873813	3.10000000	4.90000000	0.04301979
LRBL	62	5.76451613	0.36218679	4.80000000	6.40000000	0.04599777
LCMD	62	5.99516129	0.50842973	4.50000000	6.90000000	0.06457064
LCBL	62	5.95483871	0.36828242	5.00000000	6.70000000	0.04677191
MRDL	49	13.20816327	0.82457988	11.40000000	14.90000000	0.11779713
MRMD	49	3.36122449	0.24564229	2.70000000	3.80000000	0.03509176
MRBL	49	5.27142657	0.33229003	4.50000000	5.90000000	0.04747000
MCMD	49	5.00204082	0.58469714	3.60000000	6.20000000	0.08352816
MCBL	49	5.50000000	0.32467933	4.80000000	6.20000000	0.04638276
CRDL	55	17.88545455	1.23684458	15.10000000	21.00000000	0.16677609
CRMD	55	5.05454545	0.35891719	4.20000000	5.90000000	0.04639638
CRBL	55	7.17272727	0.39367354	6.10000000	8.20000000	0.05173453
CCMD	55	6.92000000	0.46523590	5.30000000	7.80000000	0.06273240
CCBL	55	7.36909091	0.36710717	6.50000000	8.50000000	0.04950072
----- GROUP=3 SEX=2 -----						
LRDL	57	15.21403509	1.23598408	12.40000000	17.40000000	0.16371009
LRMD	57	3.84035088	0.34218815	3.10000000	4.70000000	0.04532393
LRBL	57	5.89824561	0.35076001	5.10000000	6.80000000	0.04645930
LCMD	56	5.97142857	0.61310366	4.60000000	7.00000000	0.08192942
LCBL	56	5.94464286	0.33052005	5.40000000	6.90000000	0.04416760
MRDL	54	13.85370370	1.13996242	11.40000000	16.60000000	0.15512924
MRMD	54	3.45185185	0.23611697	3.00000000	4.00000000	0.03213145
MRBL	54	5.34259259	0.35480627	4.20000000	6.00000000	0.04828302
MCMD	54	5.06888889	0.52760286	3.80000000	6.00000000	0.07179766
MCBL	54	5.54814815	0.36587488	4.80000000	6.30000000	0.04978927
CRDL	52	19.44038462	1.62411480	16.40000000	21.70000000	0.22522420
CRMD	52	5.63461538	0.42972158	4.40000000	6.40000000	0.05959166
CRBL	52	7.68076923	0.48549084	6.80000000	8.70000000	0.06732547
CCMD	52	7.18653846	0.53834490	5.50000000	8.40000000	0.07465501
CCBL	52	7.85384615	0.46461518	7.00000000	8.80000000	0.06443053

Group 1=Archaic, 2=Woodland, 3=Mississippian;
Sex 1=Female, 2=Male.

VITA

Donna Catherine Markland Boyd was born June 15, 1960, in Johnson City, Tennessee. She graduated from University High School in 1977, and, after visiting Europe entered the University of Tennessee in September, 1977. She graduated magna cum laude with a Bachelor of Arts degree in Anthropology in December, 1981, and in December, 1984, received a Master of Arts in Anthropology at UT. She served as a Teaching Assistant in the anthropology department for two years and a Graduate Teaching Assistant for one year. She received the Doctor of Philosophy degree in Anthropology in December, 1988.

Her research interests include skeletal biology of southeastern skeletal populations, human osteology, human paleontology, primate paleontology, and archaeology of the southeastern U. S. She is a member of the American Association of Physical Anthropologists, the Southeastern Archaeological Conference, the Tennessee Anthropological Association, Phi Kappa Phi, and the Sigma Xi Research Society.

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