12-1987

Maxillary Suture Obliteration: A Method for Estimating Skeletal Age

Robert Walter Mann
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Robert Walter Mann entitled "Maxillary Suture Obliteration: A Method for Estimating Skeletal Age." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

William M. Bass, Major Professor

We have read this thesis and recommend its acceptance:

P.S. Willey, Richard Jantz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

To the Graduate Council:

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MAXILLARY SUTURE OBLITERATION: A METHOD FOR ESTIMATING SKELETAL AGE

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Robert Walter Mann

December 1987

ACKNOWLEDGMENTS

Anyone undertaking a project as intimidating and time consuming as a Master's thesis must surely appreciate that such a task could not be accomplished without the help and support of many people. I would first like to thank my committee members, Dr. William M. Bass, Dr. Richard L. Jantz, and Dr. Patrick S. Willey.

Dr. William M. Bass, my committee chair, provided me with invaluable advice, support, and guidance that made the tortuous path much smoother. Of no less importance was his unwavering encouragement that I really could meet my deadlines. Dr. Richard L. Jantz provided astonishing research insights and guided my every movement throughout the statistical analysis. With his help I was able to approach a biological problem, perform the necessary statistical analyses, and actually feel as though I had a tenuous understanding of the underlying statistics. I was also fortunate to have the help and support of Dr. P. Willey who has an uncanny ability to examine a research problem and foresee the pitfalls and options that lay in the path of research.

I would also like to thank Dr. Douglas Owsley of the Louisiana State University, Baton Rouge, for granting me access to his forensic skeletal collection. My thanks are also extended to Dr. Douglas Ubelaker of the Smithsonian Institution, Washington, DC, for allowing me to obtain maxillary data from the Terry Anatomical Collection.

I would also like to take this opportunity to thank my fellow graduate students at The University of Tennessee for their continued

help and encouragement in the completion of this thesis. Special thanks go to Mr. Tony Falsetti for his invaluable assistance with the statistical and computer work. Mr. Henry Case, whom I've come to know as a brother, spent many hours agonizing with me as I crept through the research obstacles that I frequently encountered. Mr. Peer H. Moore-Jansen and Mr. Steve Symes also provided valuable advice throughout the research.

I would also like to thank Mr. Murray Marks for his friendship and assistance with the data collection on those frequent "trips" to the Smithsonian Institution. My sincerest thanks go to Miss Lee Meadows who has always prompted me to spend my time wisely away from her, in order to spent more time with her in the future. Miss Kim Johnson also deserves a hearty "thank you" for typing the many drafts presented to her.

Most importantly, I would like to thank my mother for her lifelong support, love, and many personal sacrifices, so that I might achieve my goals in life. On those many occasions when my life had no direction or meaning, you were always there. It is to you that I dedicate this thesis.

ABSTRACT

The palatal processes of the adult human maxilla consist of two horizontally directed bones of quadrilateral shape situated posterior of the nasal fossae. In the early stages of morphogenesis, these palatal folds are vertically oriented and separated by the developing tongue. Between the eighth and eleventh weeks the fetal tongue descends allowing alignment and midline fusion of the palatal processes of the maxilla. At birth the palate is composed of four bones joined by broad serrated sutures. With increasing age the suture gaps narrow, fuse, and ultimately obliterate.

The purpose of this study is to develop a method of estimating the age of an individual from obliteration of the four maxillary sutures. The sample consisted of 46 White males, 32 White females, 64 Black males, and 44 Black females of known age, race, and sex. In the initial stages of analysis, two hypotheses were tested. The first hypothesis was that there would be no differences in the rate of suture obliteration between the races (Black versus White). Statistical analysis revealed that significant race differences do not exist, so the null hypothesis was accepted and the races were pooled in subsequent analysis.

The second hypothesis was that there would be no difference in the rate of suture obliteration between the sexes. Statistical analysis revealed that significant sex differences do exist.

It was found that males of both races exhibit more suture obliteration than females at the same age. The four maxillary sutures show significant differences in the rate and/or onset of obliteration. During the early adult years, both sexes progress at nearly the same rate while older females with a combined obliteration score approaching 4.0 may be over-aged by as much as 59 years.

The biological explanations for the observed sexual dimorphism in the rate of suture obliteration remain elusive. However, it is probable that differences result primarily from hormal influences as well as nutritional, pathological, and other environmental factors producing increased obliteration in the males or decreased obliteration in the females.

Although this method does not estimate exactly the age of an individual, it is valuable in estimating the age range of an individual, sorting commingled remains and estimating the skeletal age when only the maxilla is present. In addition, this method offers valuable information concerning sex dimorphism in the human skeleton.

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CHAPTER I

INTRODUCTION

Physical anthropologists concerned with determining the age, race, and sex of a skeleton must rely solely on those morphological traits present in bone. The determination of sex, for example, is usually established based on the general morphology and measurements of the pelvis, skull, and long bones (Krogman 1962; Bass 1971; Stewart 1979). Race, on the other hand, can only be determined by examination of the facial region (Bass 1971) or by discriminant function analysis of the skull (Giles and Elliot 1962).

The estimation of age, however, can be established with a combination of methods and criteria. A subadult, for example, may be aged based on long bone lengths (Fazekas and Kosa 1978), epiphyseal union (Krogman 1962), dental development (Schour and Massler 1944; Moorrees et al. 1963) and ossification of the hand and wrist bone (Greulich and Pyle 1959).

Adults, however, have completed their growth and must therefore be aged based on criteria other than that employed for subadults. Some of the most commonly used methods of aging the adult skeleton are morphological changes in the os pubis (Todd 1920, 1921; Stewart 1957; Gilbert and McKern 1973; Katz and Suchey 1986), auricular surface changes of the ilium (Lovejoy et al. 1985), epiphyseal union of the clavicle (McKern and Stewart 1957; Webb and Suchey 1985),

vertebral osteoarthritis (Stewart 1958), and microscopic examination (osteon counting) of the femur (Kerley 1965).

Although new methods of estimating skeletal age and sex are continually being devised, acceptance of such methods is slow. McCormick (1980, 1984), for example, has developed a method of estimating the sex of an individual through X-ray examination of the chest plate. Although this method is easy to use and accurate, the traditional methods of estimating age are usually still preferred. The reasons why one "scientific" method is preferred over another remain elusive.

Estimating the skeletal age of an individual taxes the abilities of an experienced physical anthropologist when the entire skeleton is present, much less a partial skeleton. The margin of error increases as the number of elements present decreases. Although not necessarily the rule, an age estimate based on the skull alone would likely prove to be less accurate than one based on the combined features of the skull and pelvis. Further, the application of an aging technique may be inaccurate from influences such as alcoholism, poor oral hygiene, or cranial stenosis. Such aberrations might well result in an over estimation of skeletal age.

Experience has shown that it is imperative to consider all available criteria when estimating the age, race, and sex of a skeleton. Relying on a single method of estimating age can lead to inaccurate age estimates that result in false interpretations for the

paleodemographer (Willey and Mann 1986) and unsolved cases for the forensic anthropologist.

Although many early researchers focused on suture closure and age (Dwight 1890; Parsons and Box 1905; Bolk 1915), the work of Todd and Lyon (1924, 1925a, 1925b, 1925c) laid the foundation for the implementation and subsequent research in cranial suture closure. Although clouded with controversy, skeletal biologists continue to rely on cranial suture closure as a method of estimating the biological age of individuals in archaeological and forensic contexts.

Opponents of cranial suture closure as an age estimator are numerous (Singer 1953; McKern and Stewart 1957), yet the method is still widely used by skeletal biologists, if for nothing more than supportive evidence of age. One reason for the continued use of the cranial sutures as a method of aging is that in many cases the method works.

The various approaches used in studying age changes in the human skeleton, as well as the persistence of researchers to rely on cranial sutures, leads to the inevitable question why the maxillary sutures have not also been evaluated as potential indicators of age. Although extensive studies have been conducted on the human palate, no systematic method of aging has been developed. For example, many studies have been conducted on growth of the maxilla as it relates to cleft lip and cleft palate (Stark 1961; Maisels 1966), as well as normal embryonic development (Noback 1943; Shepherd and McCarthy 1955;

Hassanali and Mwaniki 1984). However, only brief mention has been made of the postnatal development of the maxillary sutures.

CHAPTER II

LITERATURE REVIEW

A. PREVIOUS MAXILLARY RESEARCH

With a few notable exceptions (Woo 1948; Kellock and Parsons 1970; Rightmire 1970, 1972; Persson and Thilander 1977; Glassman 1978; Westmoreland and Blanton 1982; Hassanali and Mwaniki 1984; Mann et al. 1987), most studies of the human maxilla have focused on embryonic development as it relates to cleft lip and cleft palate. Further, no systematic method of estimating the biological age of the human skeleton based on maxillary suture closure exists. This chapter is a brief summary of the major research conducted on the human maxilla and cranial sutures.

Most research dealing with the human palate, often referred to as the upper jaw (Wood et al. 1970), secondary palate (Burdi and Faist 1969), or maxilla and premaxilla (Woo 1949), has focused on embryonic development. By and large this research has been conducted by the medical community for corrective surgical intervention in cleft lip and cleft palate patients (Ross and Johnston 1972; Horowitz et al. 1973; Goodman and Gorlin 1977; Riski and DeLong 1984; Smahel 1984; Friede and Pruzansky 1985).

Much of the research dealing with the morphogenesis of the palate has focused on development of the maxilla and premaxilla in mammals other than man (Ashley-Montagu 1935; Siegel et al. 1985).

Although this research has yielded valuable information concerning the mechanics of palate formation, it has also resulted in considerable controversy. For example, the mammalian palate is usually described as consisting of two main components—the maxilla and premaxilla. However, some researchers deny the existence of the latter in man. For example, Wood et al. (1967, 1970) state that the upper jaw develops from only one center of ossification and therefore the premaxilla, as an independent bone in man, does not exist.

Many authors, however, propose that the human premaxilla does exist and is represented in the postnatal palate by a visible suture (Figure 1) in the antero-lingual surface of the maxilla (Ashley-Montagu 1935; Woo 1949; Shepherd and McCarthy 1955; Brash et al. 1956; Friede 1978; Slavkin 1979; Hassanali and Mwaniki 1984). The first to give a detailed account of the premaxilla in man was Callender (1869) who based his study on 20 embryos and fetuses 2-7 months of age and concluded that the premaxilla was "shut off from the face by the nasal and incisor processes of the superior maxilla." Similarly, Woo (1949) found that the human premaxilla develops from two centers; one arises during the 7th week and the other at the end of the 10th week. As Woo (1949) states:

> There is now agreement that the premaxilla is an element in the human skull and that it remains separate from the maxilla in the palatine portion. However, the details of its structure and the process of its early obliteration on the facial aspect are not yet well understood.

Woo's concluding statement concerning the obliteration of the

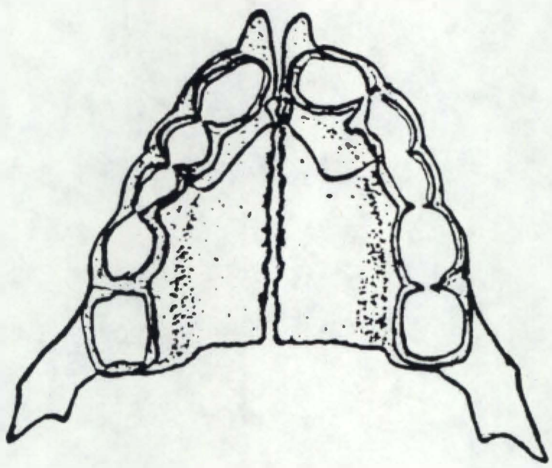

Figure 1. The human palate at birth.

premaxillary suture highlights the paucity of research dealing with the postnatal palate.

One of the fundamental disagreements concerning research of the human palate is the number of ossification centers, with estimates ranging from two to as many as nine. Noback (1943) and Woo (1949) describe the maxilla as developing from two centers of ossification; Fawcett (1911) and Sperber (1981) from three; Shepherd and McCarthy (1955) from four; and Frasetto (1914) from nine. Although the methods and materials of study are similar (staining embryos and fetuses with Alizarin Red S), much controversy still exists. Some of the conflicting findings may be due to small study samples, faulty research techniques, observations based on ambiguous stages of ossification, or developmental variation in the palate.

As mentioned earlier, few studies have focused on aspects of the maxilla other than those directed at embryological development. A review of the literature revealed that in only a few instances were the maxillary sutures discussed in relation to the age of the individual. Hassanali and Mwaniki (1984), in examining 125 Kenyan skulls, reported that the facial aspect of the incisive suture was present in 6.4% of the adult palates (Figure 2). These researchers concluded this incidence high because the incisive suture ossified at an early age (Warwick and Williams 1973).

Another study of the human maxilla was conducted by Woo (1949) on the anterior and posterior medio-palatine bones. These accessory bones are found on either side of the median palatine suture. Woo,

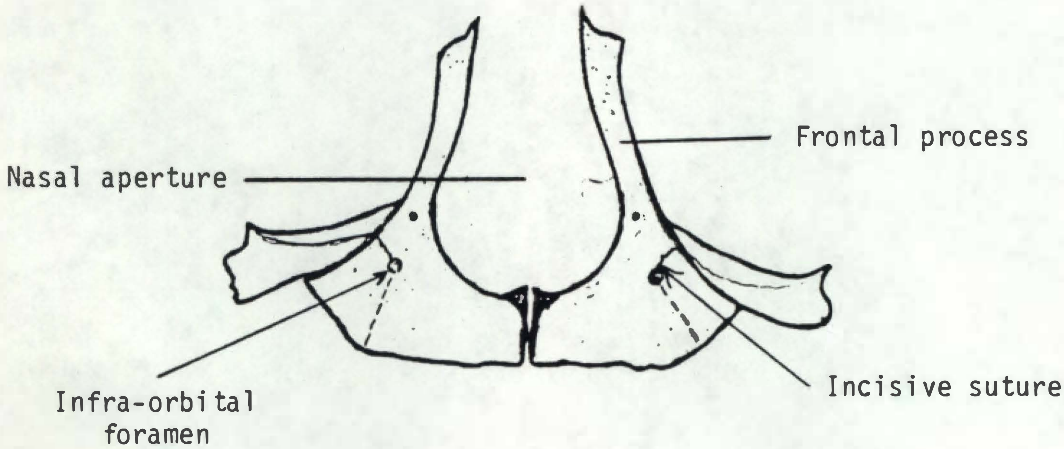

Figure 2. Facial view of human palate at birth. (Dashed line indicates path of incisive suture that has obliterated.)

in examining the hard palate in 1548 skulls of the Terry Anatomical Collection found only two cases of medio-palatine bones. Seventeen examples of incomplete medio-palatine bones were also identified in Woo's study. The presence of such accessory sutures in the palate suggests the possibility of additional centers of ossification or anomalous growth. Additional research in this area may further our knowledge of embryonic development.

Pritchard et al. (1956) conducted a thorough histological study of the cranial and facial sutures of nine human specimens ranging from 45mm crown-rump length to five postnatal months of age. The study included six pigs, five cats, four rabbits, and 93 rats ranging in age from the fifteenth day of fetal life to one year. Each specimen was sectioned coronally, sagitally or transversely and stained using a variety of staining methods. The authors state that by using a variety of staining techniques they were able to discern the five distinct layers of cells and fibers within the sutures.

Pritchard et al. (1956) found that all the sutures went through similar stages of development and could be divided into two categories: (a) those bones that unite one another through mesenchymatous tissue, as in the face and midpalatal suture, and (b) those bones which unite one another within fibrous membrane, as in the cranial vault.

Waterman and Meller (1974) used electron microscopy to study fusion of the epithelial surface of human palatal shelves. The sample included 72 therapeutically aborted human embryos and fetuses ranging

in age from 37 days to 12 weeks postfertilization. The researchers were able to identify six stages of palatal fusion based on the position and development of the palatal shelves.

Sperber (1981) briefly mentions that obliteration of the midpalatal suture may start in adolescence with complete fusion rarely occurring before age 30. No mention, however, is made as to what study sample or circumstances he is referring. Further, it is unclear whether Sperber uses the terms fusion and obliteration interchangeably or to describe different processes.

The only studies that have dealt with palatal suture closure as an indicator of age have been conducted by Persson and Thilander (1977) and Mann et al. (1987). Persson and Thilander's sample contained 24 cadavers ranging in age from 15 to 36 years (no racial information was given). The palates were dissected, fixed in alcoholic formalin, vertically sectioned and examined histologically. The researchers then devised an index based on the amount of obliteration (synostosis) of various segments of the intermaxillary and transverse palatine sutures. The following conclusions were reached:

1. Quantified calculations of the degree of closure can be made from paraffin sections, owing to the presence of basophilic cement lines at the sites of the earlier, resting-suture margins;
2. Palatal sutures may show obliteration during the juvenile period, but a marked degree of closure is rarely found until the third decade of life;

3. Great variations exist among individuals with regard to the start of closure as well as the advance of closure with age. Besides variations in the degree of closure between sutures, variations also exist between different parts of the same suture;
4. Suture closure progresses more rapidly in the oral than in the nasal part of the palatal vault. The results also seem to verify earlier observations that the intermaxillary suture starts to close more often in its posterior part than in its anterior part;
5. Though the literature is lacking in comparable quantified data, it is supposed that the closure of palatal sutures begins, in general terms, at about the same age but does not advance to the same degree as does the closure of the cranial vault sutures. Large interindividual differences are to be expected;
6. The observations indicate that more factors than age strongly influence the start and the advancement of suture closure.

In addition, no sex differences in the rate of palatal closure was noted in this sample.

To test the application of the obliteration index, Persson and Thilander tested for measuring and accidental error, s(i), by two different observors. Using the formula $s(i) = \sqrt{\underline{\Sigma}(x_1 - x_2)^2/n}$ they demonstrated that an index can be calculated with a precision of

s(i) = .075, with a confidence limit of 2.26 (t), and within a ± 0.17% of the suture length.

Mann et al. (1987) conducted a preliminary macroscopic study of the lingual surfaces of 36 human maxillae ranging in age from 13 to 79 years at death. Each maxilla was examined with the naked eye to determine the amount of suture obliteration of the four sutures based on the following categories:

0 = 0% obliteration;

1 = 1-25% obliteration;

2 = 26-50% obliteration;

3 = 51-99% obliteration;

4 = 100% obliteration.

The researchers concluded that:

1. The earliest age of complete obliteration of the incisive suture occurred at 25 years;
2. Less than 25 years there was no obliteration of the PMP suture;
3. Less than 43 years there was no obliteration of any segment of either the AMP or TP sutures;
4. At 60+ years at least two of the four maxillary sutures were completely obliterated.

Although there have been numerous studies conducted on the human palate, only a few dealing with prenatal and postnatal development have been included in this thesis. The inclusion of other palatal studies would prove to be of little pertinence because they

specifically with unrelated aspects of histological, embryological or cleft development.

B. PREVIOUS CRANIAL SUTURE RESEARCH

There have been many attempts to correlate cranial suture closure with chronological age in humans. Early work on cranial suture closure by Todd and Lyon (1924, 1925a, 1925b, 1925c) focused on adult White and Black males and has served as the basis for estimating the age of unknown crania. Although this research proved to be valuable to skeletal biologists and anatomists, Todd and Lyon were aware that the use of suture closure as the sole indicator of age was unreliable. Other researchers (Parsons and Box 1905; Singer 1953; Brooks 1955; McKern and Stewart 1957), however, concluded that cranial suture closure as direct or supportive evidence of biological age was unreliable.

Later cranial suture research conducted by Baker (1984) consisted of a modern multiracial sample (Los Angeles area) of 195 autopsied individuals 15-89 years of age. Baker's method consisted of scoring endocranial and ectocranial sutures according to three stages of union: completely open, partially closed, and completely closed. Some of Baker's findings were:

1. Interindividual variability exists in the rate of suture closure;
2. Endocranial closure may begin and be completed at earlier ages than ectocranial closure;

3. There are left and right side differences for the commencement of suture closure;
4. The endocranial sutures may remain open three years longer in the females than in the males;
5. Blacks tend to begin closure at older ages than Whites.

Most recently Meindl and Lovejoy (1985) devised a modified method of estimating age at death based on the degree of ectocranial suture closure. Their findings indicate that ectocranial suture closure is more reliable than that endocranially and:

> can provide valuable estimates of age at death in both archaeological and forensic contexts when used in conjunction with other skeletal age indicators.

The authors further point out that more research on suture closure as an age indicator is needed.

Although aging the human skeleton based on cranial suture closure has met with much skepticism, scientists continue to apply and rely upon this method in archaeological and forensic contexts. Much of the skepticism concerning the reliability of suture closure is based on observed variability in known-age crania and exacerbated by early biases in study samples. Todd and Lyon (1924), for example, rejected skulls that appeared to have anomalous suture closure. Their sample, then, would not adequately represent the variability in a random sample of crania.

The work of Dwight (1890) also resulted in methodological problems when he introduced terminological bias in his study of 100 crania. Dwight initially identified three stages of cranial suture

closure as open, closed, and obliterated. He states, however, that "I fear that in some of my earlier notes I did not always observe this distinction, and may sometimes have put 'closed' for 'obliterated.'"

Researchers, however, cannot be content to rely upon studies conducted on skeletal samples of populations that are in constant change as a result of improved nutrition, health and medical care. It is with such biological changes in mind that new standards of skeletal assessment and growth must be devised. Further, refinement of existing aging methods may serve to improve our techniques of skeletal research. The goal of the research presented here is to provide skeletal biologists with an additional method of determining the age of the human skeleton.

C. EMBRYOLOGY OF THE HUMAN HARD PALATE

As mentioned earlier, there is much controversy concerning the number of ossification centers, as well as the time of appearance. Due to such disparity I have chosen to combine the findings of a number of researchers in discussing the morphogenesis of the human palate. The authors were chosen because they offered information on particular phases of embryonic development that are often cited by other researchers and can be easily understood.

The hard palate is that part of the oral cavity comprising the palatal processes of the maxillae and the palatine bones that meet in the midline (Figure 3). Development of the palate begins during the fifth embryonic week with complete fusion of its parts occurring

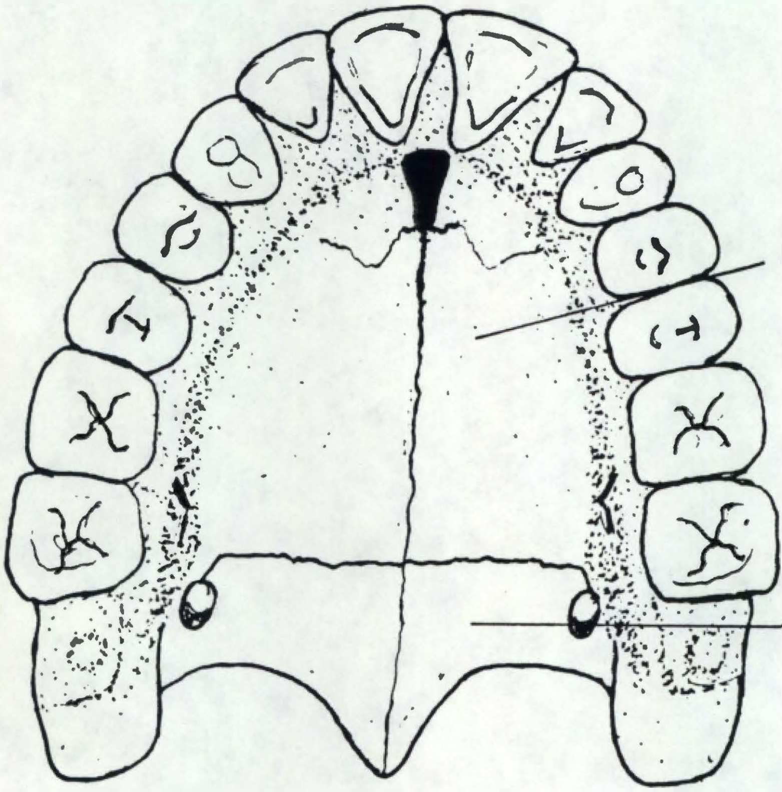

Figure 3. The human hard palate (approximately 14 years of age).

during the twelfth week (Slavkin 1979). The soft palate consists of movable musculo-aponeurotic tissue situated in the posterior one-third of the palate (Mitchell and Patterson 1954). Although the soft and hard palates form from the same continuous tissue, only the latter ossifies to become the hard palate.

The maxilla proper (excluding the premaxilla) first appears as a membranous center of ossification in the maxillary process of the mandibular arch at about 18mm crown-rump (C.R.) length (Scott and Symons 1977). This center of ossification spreads posteriorly towards the zygoma, and anteriorly towards the developing premaxilla.

As the maxillary processes continue their anterior growth, the nasal septum develops and the masses of maxillary mesoderm give rise to the palatal processes (Hamilton and Mossman 1972). These processes are, at first, free along their medial edges (median palatine or intermaxillary suture). At this stage of development, the tongue, developing from the floor of the mouth, projects upward between the palatal processes and nasal cavities (Figure 4). For a short time the palatal processes are directed downwards on either side of the tongue. About 30mm C.R. length (55-60 days), the tongue descends in a matter of a few hours and allows the palatal processes to become horizontal (Figure 5). Growth of the palatal processes continues, in a wave-like fashion, resulting in progressive fusion of their medial borders. Ossification of the hard palate commences during the eighth week in utero (Sperber 1981).

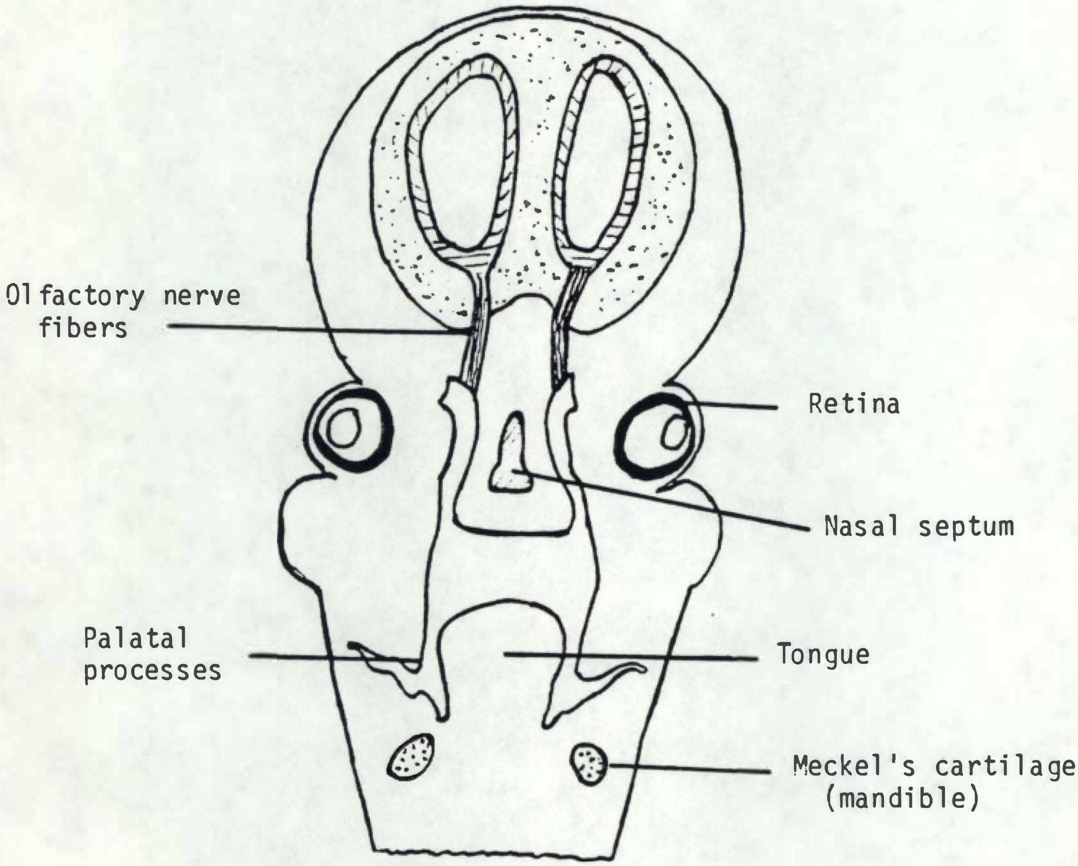

Figure 4. Coronal section of a human embryo 55 days of age. (Note that the tongue still separates the palatal processes.)

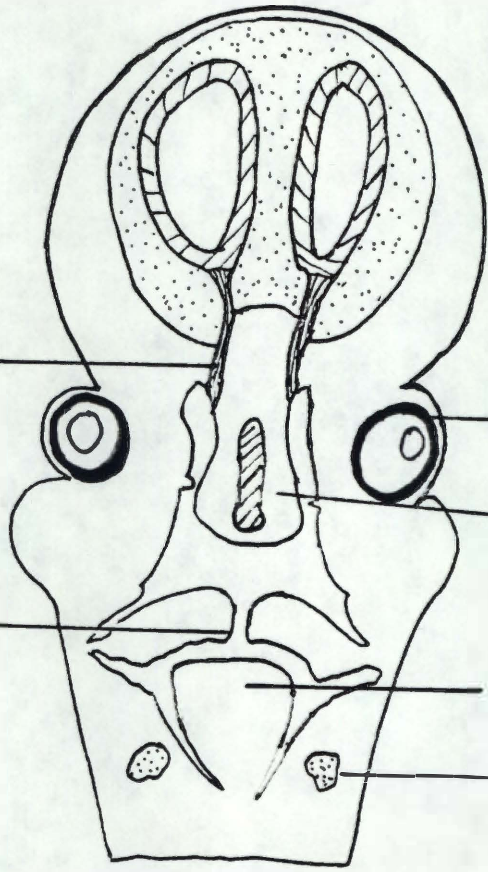

Figure 5. Coronal section of a human embryo 55-60 days of age. (Note that the tongue has descended allowing horizontal positioning of the palatal processes.)

The premaxilla, or primary palate, is a wedge-shaped bone positioned anterior to the maxilla proper, houses the incisor teeth, and abuts the descended palatal processes (incisive suture). Shepherd and McCarthy (1955) state that the premaxilla arises from three centers of ossification: the body, the palatine, and the infra-vomerine. Ossification of the body begins between 7.5 and 8.5 weeks in utero. The palatine center first showed signs of ossification at 8.5 to 9 weeks and the infravomerine center 9.5 to 10 weeks in utero.

CHAPTER III

OBJECTIVES

The first objective of this study is to examine the relationship of suture closure to age. This objective was accomplished by determining the proportion of suture obliteration of each of the four sutures of a known-age skeleton sample.

The second objective is to examine the effect of race and sex influences on maxillary suture closure and age. If significant differences exist, the magnitude of the variation must be known in order to accurately estimate the age of an individual.

The third objective is to devise a simple method of estimating age based on the amount of obliteration of the maxillary sutures.

CHAPTER IV

SAMPLE AND METHODS

A. SAMPLE

The calibration sample consists of 186 known age, sex, and race skeletons from three skeletal collections (Table A-1, Appendix): five from the Department of Geology and Anthropology, Louisiana State University, Baton Rouge; 10 from the Department of Anthropology, The University of Tennessee, Knoxville; and 171 from the Terry Anatomical Collection of the National Museum of Natural History, Washington, DC.

Maxillary data were collected from the various skeletal collections between January 1984 and March 1987. The Louisiana State University forensic collection consists of known individuals identified by Dr. Douglas Owsley and Mr. Murray Marks. The skeletons examined at The University of Tennessee represent individuals identified through forensic investigation or donated for research and curation under the direction of Dr. William M. Bass. The largest number of skeletons included in this study were obtained from the Terry Anatomical Collection that consists of 1636 macerated cadavers collected in the early twentieth century in St. Louis.

The total sample consists of 46 White males, 32 White females, 64 Black males, and 44 Black females (Table 1). Only complete maxillae were included and none was rejected based on unusual

Table 1. Composition of the calibration sample (N=186).

Race	Sex	N	Mean Age	Std Dev
White	Male	46	55.10	15.10147640
White	Female	32	50.84	22.84747374
Black	Male	64	35.81	14.11503195
Black	Female	44	31.36	11.72572388

morphological traits (e.g., torus palatinus) or suture characteristics (e.g., "premature" obliteration of the maxillary sutures). It was hoped that by including all intact maxillae the full range of sutural variability could be observed.

Maxillae were randomly chosen and, in most cases, examined without prior knowledge of the individual's age or sex. This approach was taken in order to reduce the chances of biasing the calibration sample by "selecting" individuals for the study. However, by using a blind method to gather the sample I ended up with 110 males, 76 females and a gap in the middle-age female sample (Table 2).

B. METHODS

The method used in this study consists of dividing the maxilla into four distinct sutures modified from Kopsch (1957): incisize (I), anterior median palatine (AMP), posterior median palatine (PMP), transverse palatine (TP) (Figure 6). (These abbreviations will be used when referring to a suture in the body of the thesis; however, in the tables and figures each suture is labeled by its first letter, e.g., "I" for incisive).

Table 2. Number of individuals in five-year age intervals in the calibration sample (N=186).

Age Interval	Male (110)	Female (76)
16-20	5	8
21-25	12	13
26-30	18	14
31-35	8	7
36-40	9	13
41-45	8	1
46-50	13	0
51-55	9	0
56-60	8	1
61-65	4	5
66-70	8	7
71-75	5	4
76-80	1	0
81-85	1	2
86-90	0	0
91-95	1	1

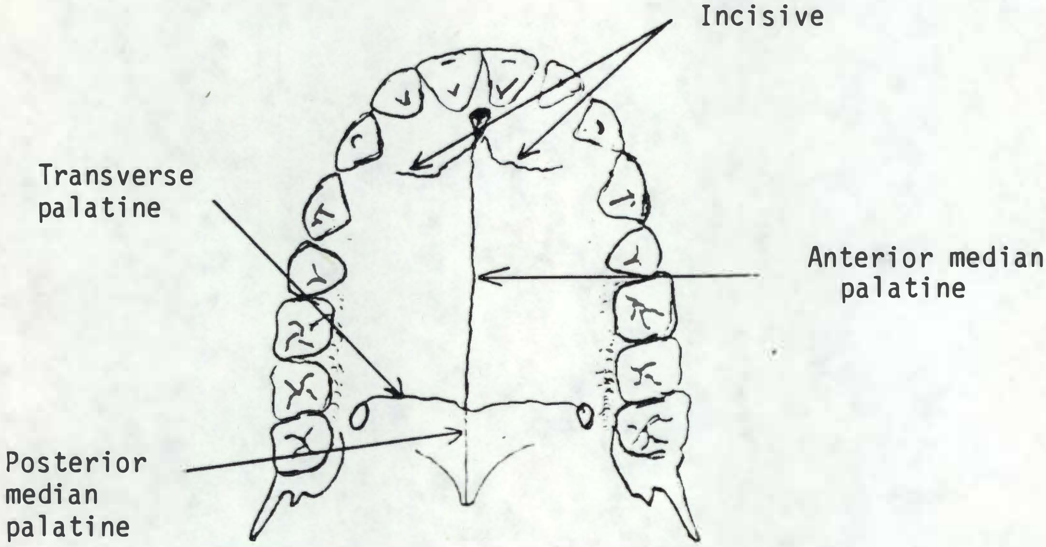

Figure 6. Sutures of the adult hard palate.

Measurements of each suture (Figure 7) were taken using a standard sliding caliper and recorded on data sheets. The length of each suture and the amount of obliteration were measured and recorded. Morphological traits (e.g., torus palatinus) and characteristics (e.g., edentulism, broad palate) of each maxilla were also recorded on the data sheets. In anticipation of possible questions or problems that could arise during the analysis stage, a sketch of the general configuration of each suture was made. Each suture was measured as described below.

The I suture extends from the posterior border of the incisive foramen and continues to the most superior point between the lateral incisors and canines. In those instances where the alveolar bone between the lateral incisors and canines was flat, the measurement was taken at the midpoint between the buccal and lingual surfaces (Figure 7, A). In rare cases (two in this study), the incisive suture divided the premaxilla-maxilla between the canines and first premolars. The alveolar midpoint between the canines and first premolars was obtained in the same manner. In edentulous individuals, the maxilla resorbs and results in a thin alveolar "rim" necessitating an estimate of where the incisive suture terminated. Because the incisive suture obliterates early, edentulism presents no problem in measurement.

In determining the amount of obliteration of the incisive suture, the maxilla was divided into halves along the midline. The half exhibiting the more obliteration was measured and divided by the total suture length of that suture half. Because the incisive suture

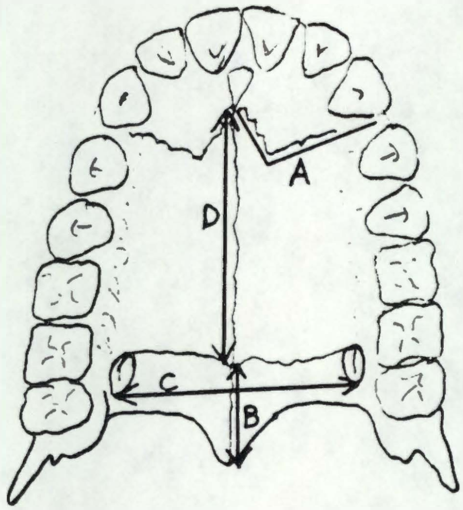

Figure 7. Measurement of the palatal sutures.

is not a straight line, but many times resembles a "W," each "stroke" of the "W" was measured and summed to obtain the length of the appropriate half. If any segment(s) of the incisive suture was obliterated or "even" with the surrounding bone, it was measured and included to obtain the amount of obliteration (all sutures were scored as open or obliterated in this manner).

The AMP suture originates at the most posterior border of the incisive foramen and extends posteriorly to the palate bones (Figure 7, D). The suture was measured from the most posterior portion of the incisive foramen to the junction of the AMP and TP sutures. In some instances, the junction of the AMP and TP was asymmetrical (Figure 8). In such cases, the measurement of the AMP was taken to the most posterior junction of the AMP and TP sutures. In some instances, a torus palatinus or build-up of bone along the AMP obscured visibility of the suture. In determining obliteration of the AMP, the line of fusion between the torus was inspected carefully for the presence of a suture line. If obliteration was obscure, the suture was scored as open.

Another condition that obscured visibility of the AMP was the presence of a "sulcus" at points along this suture. In some cases a build-up of bone was present on either or both sides of the AMP. If this condition obscured any sutural obliteration, the segment(s) was scored as open. However, in most cases, visibility into the "sulcus" was accomplished with the aid of a small penlight.

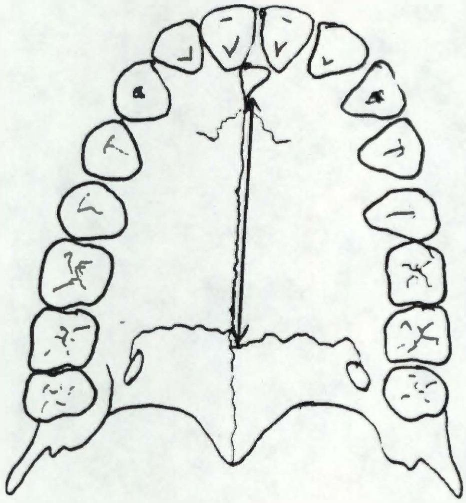

Figure 8. Measurement of an asymmetrical anterior median palatine suture.

The PMP suture is that portion of the median palatine suture that divides the palatine bones at the midline. The measurement was taken from the posterior nasal spine to the most posterior junction of the AMP and TP sutures (Figure 7, B). Again, a maxilla may exhibit a small "sulcus" at some point along its length. The same procedure for scoring was followed as outlined above.

The TP suture separates the maxillary from the palatine bones, runs perpendicular to the midline of the palate, and extends into the greater palatine foramina (Figure 6). The TP was measured in or above the most posterior margins of the greater palatine foramina (Figure 7, C). The amount of obliteration was obtained as for the other sutures.

Each suture was examined to determine the amount of obliteration. Obliteration was defined as any segment of a suture no longer visible or visible but flush with the adjoining surfaces. For example, if the incisive suture exhibited 5mm obliteration of its total length of 15mm, the proportion (percentage) of obliteration was: 5 divided by 15 = .33. The proportion of suture obliteration for each of the four sutures was then determined and summed. For example, if a palate exhibited complete obliteration of the incisive suture (1.0), no obliteration of the AMP (.0), .52 obliteration of the PMP, and .06 obliteration of the TP the total score (TS) would be 1.58. Individual and combined suture proportions were then regressed on age utilizing SAS (1986a, 1986b). All individuals in the sample (N=186) were statistically tested for sex and race differences, both within and among groups.

C. STATISTICAL METHODOLOGY

Statistical analyses of the sample consist of linear regression, Pearson's and Kendall's rank correlation as well as analysis of variance (ANOVA) utilizing SAS (1986a and 1986b). The null hypotheses stated that there would be no significant race or sex differences in the amount of suture obliteration. The alpha level for rejection of the null hypotheses was 0.05.

Examination of the relationship between age, race, and sex using regression formulae and principal components analysis was also performed. For ease in statistical computations the males were assigned the number "0" and females "1." Race categories were handled by assigning Whites a "0" and Blacks a "1."

The purpose of the linear regression was to formulate a method of estimating the age from a proportion of palatal suture closure, also called inverse prediction (Sokal and Rohlf 1981). For such an equation to be reliable, the dependent variable Y (proportion of suture obliteration) was regressed on the independent variable X (age). Using this method it is possible to predict the age of an individual by obtaining the amount of obliteration of the four maxillary sutures and plugging this value into the formula for the appropriate sex.

Kendall's rank and Pearson's correlation coefficient were chosen to test for the association between rank orders. This statistical method is designed to test for agreement between several rank orders (age and suture proportions). A principal components matrix was also devised using the summed proportion of the four sutures.

An analysis of variance (ANOVA) was also performed for each suture. This was done to determine the ability of each suture to correctly predict age based on the amount of suture closure, as well as detect differences from race and sex.

D. TEST SAMPLE

A test sample of 16 known-age maxillae were examined for accuracy of predicted age using the appropriate sex formula. The four sutures were examined and scored in the same manner as the calibration sample. No information concerning the age, race, or sex of any individual was known to the examiner before testing (Table 3).

Table 3. Composition of the test sample (N=16).

N	Sex	Race	$\bar{X}$ Age (Years)
4	F	W	35
9	M	W	46
3	M	B	44
		Total $\bar{X}$	41

CHAPTER V

RESULTS AND DISCUSSION

A. RESULTS

The summary statistics (Tables 4 and 5) reflect the properties of the variables in the sample. The standard deviation from the mean age for males (43.8 years) is 17.34 and females (39.5 years) is 19.7. The minimum and maximum ages by sex are quite similar. Again referring to the means in Tables 4 and 5 we see that the incisive suture has the highest "mean" value followed by the PMP in both sexes. The TP and AMP have the lowest means, indicating they show less obliteration in either sex.

The suture variables in this study are bounded, ranging in value from 0 to 1.0 closure (complete) and are not normally distributed. Therefore the higher values, those approaching 1.0, result in a truncated curve that has some effect on correlation. The Pearson and Kendall correlation coefficients (Tables 6 through 8) were chosen to measure the strength of the relationship (covariance) between the four suture variables, and age, sex, and race. The Pearson method indicates that while race has only a minor influence on suture closure, sex is significantly correlated. Therefore race is eliminated in computing suture obliteration and age.

The bivariate plots by sex (Figures 9 through 16) render visual impressions of the correlation of each suture with age. The scatter

Table 4. Summary statistics for males.

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Age	110	43.88182	17.34154	4827.000	16.00000	91.00000
Race	110	0.58182	0.49552	64.000	0.00000	1.00000
I	110	0.01364	0.15750	100.500	0.33000	1.00000
A	110	0.23909	0.35384	26.300	0.00000	1.00000
P	110	0.64973	0.33489	71.470	0.00000	1.00000
T	110	0.32336	0.34896	35.570	0.00000	1.00000
TS	110	2.12582	1.03678	233.840	0.33000	4.00000

Table 5. Summary statistics for females.

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Age	76	39.56579	19.70606	3007.000	17.00000	91.00000
Race	76	0.57895	0.49701	44.000	0.00000	1.00000
I	76	0.85882	0.20656	65.270	0.18000	1.00000
A	76	0.08368	0.26334	6.360	0.00000	1.00000
P	76	0.22395	0.39548	17.020	0.00000	1.00000
T	76	0.08224	0.17983	6.250	0.00000	1.00000
TS	76	1.24868	0.81989	94.900	0.18000	4.00000

Table 6. Pearson correlation coefficients for males.

	Age	Race	I	A	P	T	TS
Age	1.00000 0.0000	-0.55137 0.0001	0.42014 0.0001	0.54727 0.0001	0.65865 0.0001	0.48977 0.0001	0.69872 0.0001
Race	-0.55137 0.0001	1.00000 0.0000	-0.23896 0.0119	-0.20154 0.0347	-0.22931 0.0160	-0.24275 0.0106	-0.28541 0.0025
I	0.42014 0.0001	-0.23896 0.0119	1.00000 0.0000	0.36167 0.0001	0.47509 0.0001	0.33580 0.0003	0.59269 0.0001
A	0.54727 0.0001	-0.20154 0.0347	0.36167 0.0001	1.00000 0.0000	0.49252 0.0001	0.53288 0.0001	0.78741 0.0001
P	0.65865 0.0001	-0.22931 0.0160	0.47509 0.0001	0.49252 0.0001	1.00000 0.0000	0.55704 0.0001	0.85782 0.0001
T	0.48977 0.0001	-0.24275 0.0106	0.33580 0.0003	0.53288 0.0001	0.55704 0.0001	1.00000 0.0000	0.80903 0.0001
TS	0.69872 0.0001	-0.28541 0.0025	0.59269 0.0001	0.78741 0.0001	0.85782 0.0001	0.80903 0.0001	1.00000 0.0000

Table 7. Pearson correlation coefficients for females.

	Age	Race	I	A	P	T	TS
Age	1.00000 0.0000	-0.49131 0.0001	0.40828 0.0003	0.51645 0.0001	0.68500 0.0001	0.58108 0.0001	0.72661 0.0001
Race	-0.49131 0.0001	1.00000 0.0000	-0.94388 0.7066	-0.19479 0.0918	-0.29804 0.0089	-0.23248 0.0433	-0.26838 0.0191
I	0.40828 0.0003	-0.04388 0.7066	1.00000 0.0000	0.22010 0.0561	0.26152 0.0225	0.21989 0.0563	0.49700 0.0001
A	0.51645 0.0001	-0.19479 0.0918	0.22010 0.0561	1.00000 0.0000	0.57375 0.0001	0.75117 0.0001	0.91815 0.0001
P	0.68500 0.0001	-0.29804 0.0089	0.26152 0.0225	0.57375 0.0001	1.00000 0.0000	0.68756 0.0001	0.88333 0.0001
T	0.58108 0.0001	-0.23248 0.0433	0.21989 0.0563	0.75117 0.0001	0.68756 0.0001	1.00000 0.0000	0.84765 0.0001
TS	0.72661 0.0001	-0.26838 0.0191	0.49700 0.0001	0.81815 0.0001	0.88333 0.0001	0.84765 0.0001	1.00000 0.0000

Table 8. Kendall tau B correlation coefficients for the total sample.

	Age	Sex	Race	I	A	P	T	GRCUP
Age	1.00000 0.0000	-0.12637 0.0374	-0.40993 0.0001	0.40437 0.0001	0.47481 0.0001	0.53770 0.0001	0.48788 0.0001	-0.38310 0.0001
Sex	-0.12637 0.0374	1.00000 0.0000	-0.00286 0.9690	-0.13682 0.0420	-0.03518 0.0000	-0.43144 0.0001	-0.35900 0.0000	0.41363 0.0001
Race	-0.40993 0.0001	-0.00286 0.9690	1.00000 0.0000	-0.17083 0.0111	-0.17571 0.0095	-0.21279 0.0023	-0.26810 0.0000	0.81405 0.0001
I	0.40437 0.0001	-0.13682 0.0420	-0.17083 0.0111	1.00000 0.0000	0.38870 0.0001	0.40763 0.0001	0.31237 0.0000	-0.19161 0.0019
A	0.47481 0.0001	-0.35918 0.0000	-0.17571 0.0095	0.38870 0.0001	1.00000 0.0000	0.63469 0.0001	0.63495 0.0001	-0.29472 0.0000
P	0.53770 0.0001	-0.43144 0.0001	-0.21275 0.0023	0.40763 0.0001	0.63465 0.0001	1.00000 0.0000	0.66225 0.0001	-0.35648 0.0000
T	0.48788 0.0001	-0.35900 0.0000	-0.26810 0.0000	0.31237 0.0000	0.63495 0.0001	0.66225 0.0001	1.00000 0.0000	-0.37445 0.0001
GRCUP	-0.38310 0.0001	0 .41363 0.0001	0.81405 0.0001	-0.19161 0.0019	-0.29472 0.0000	-0.35648 0.0000	-0.37445 0.0001	1.00000 0.0000

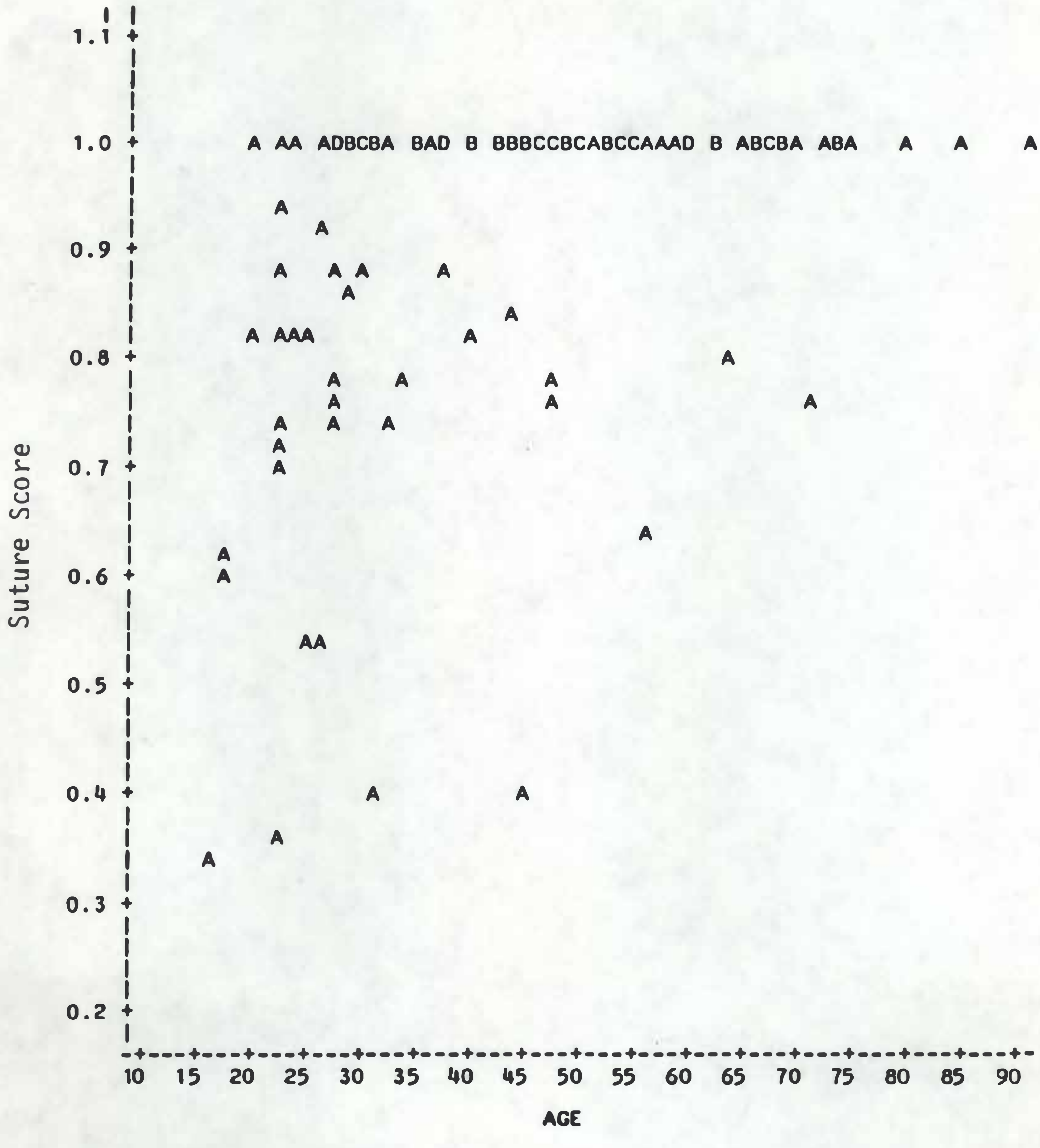

Figure 9. Plot of obliteration of the incisive suture in males. (Legend: A=1 observation, B=2 observations, etc.)

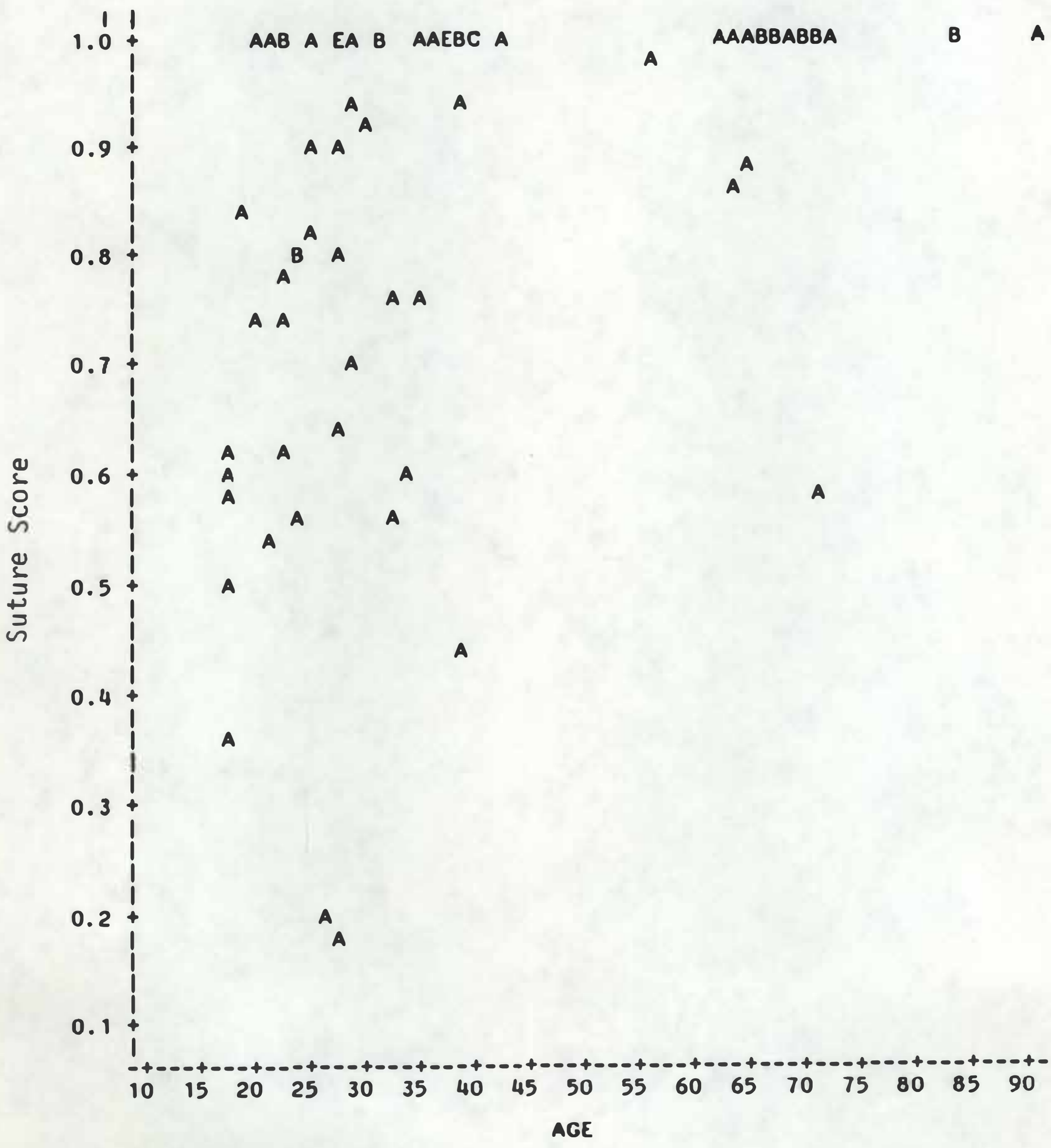

Figure 10. Plot of obliteration of the incisive suture in females.

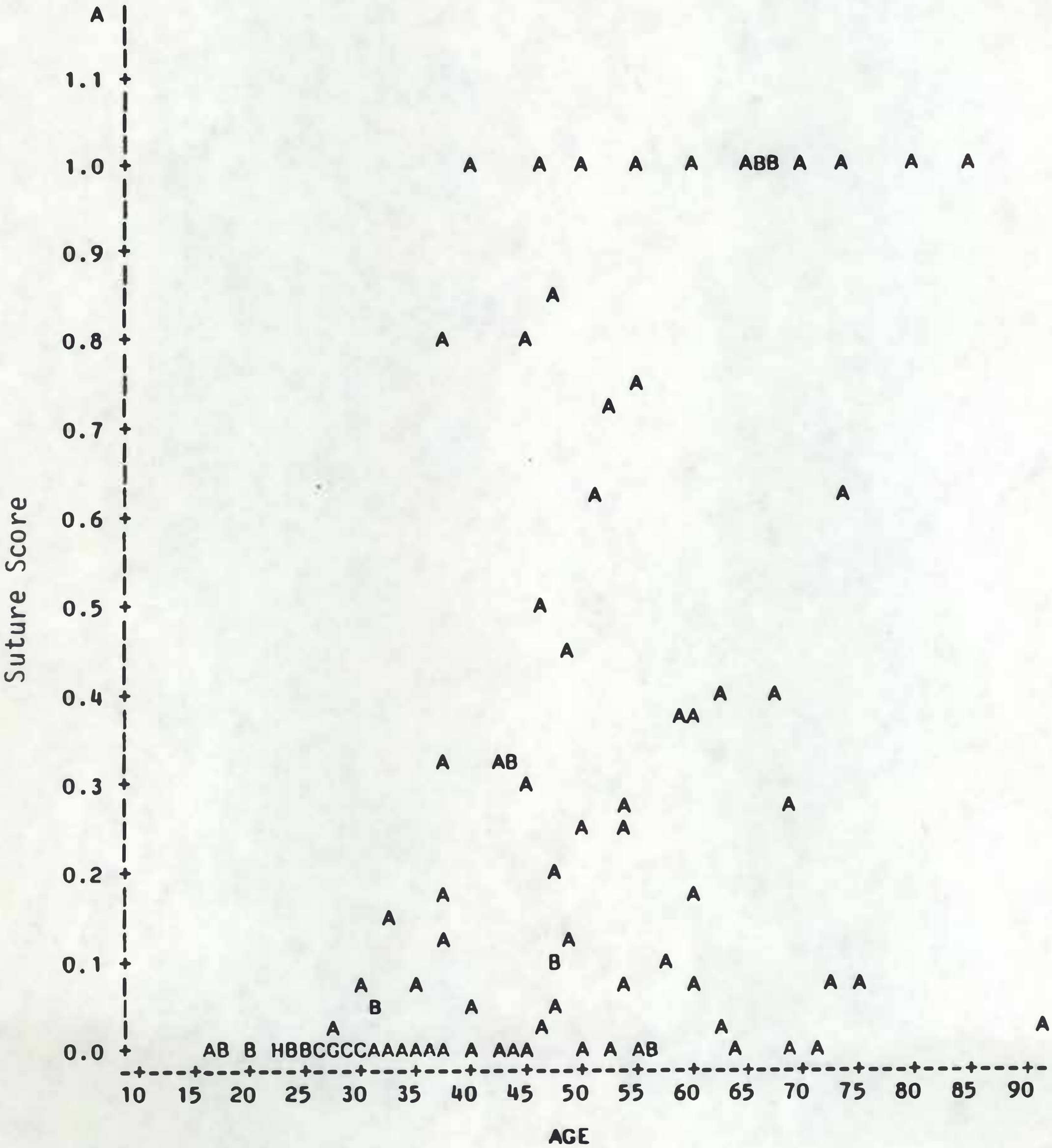

Figure 11. Plot of obliteration of the anterior median palatine suture in males.

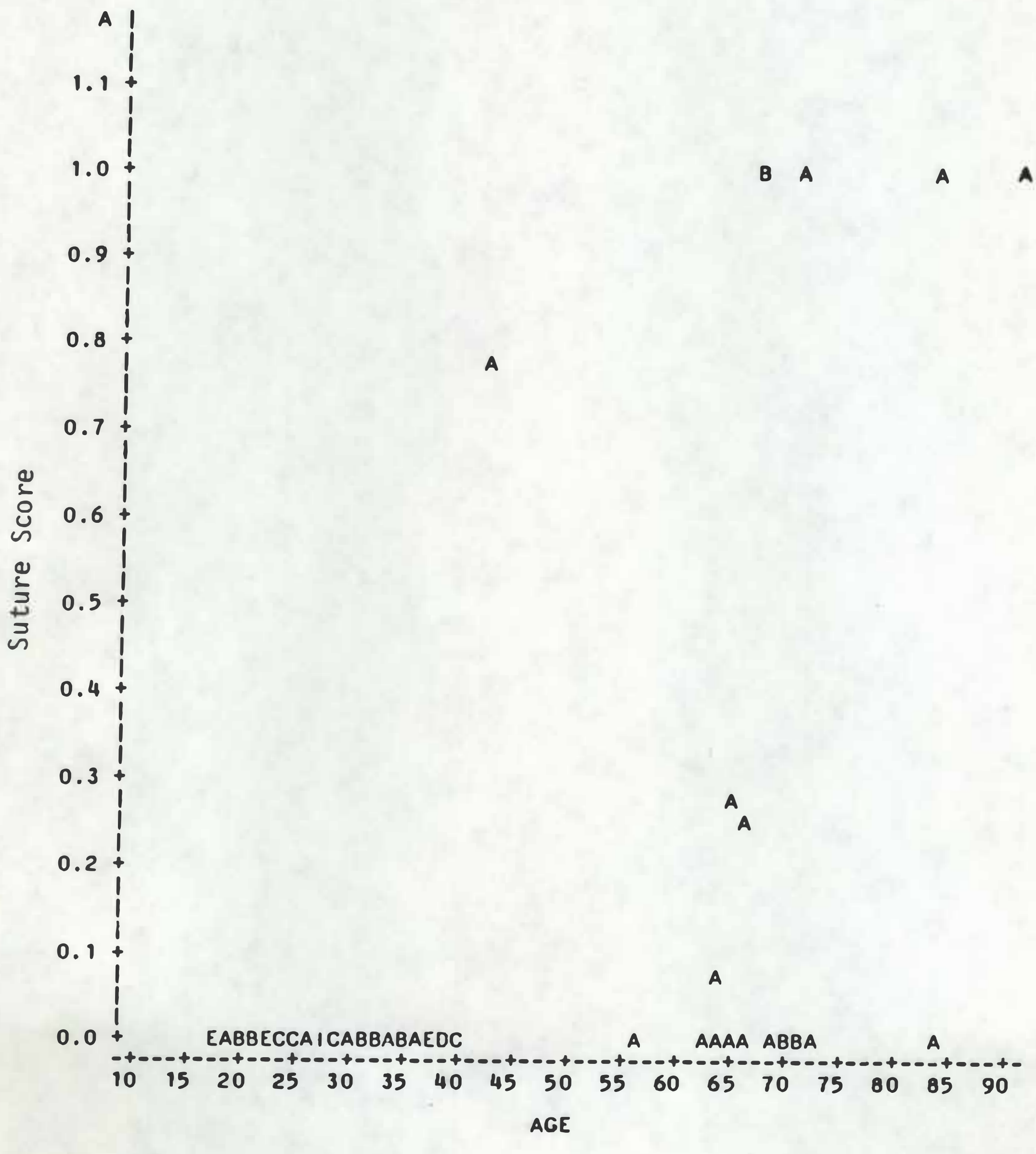

Figure 12. Plot of obliteration of the anterior median palatine suture in females.

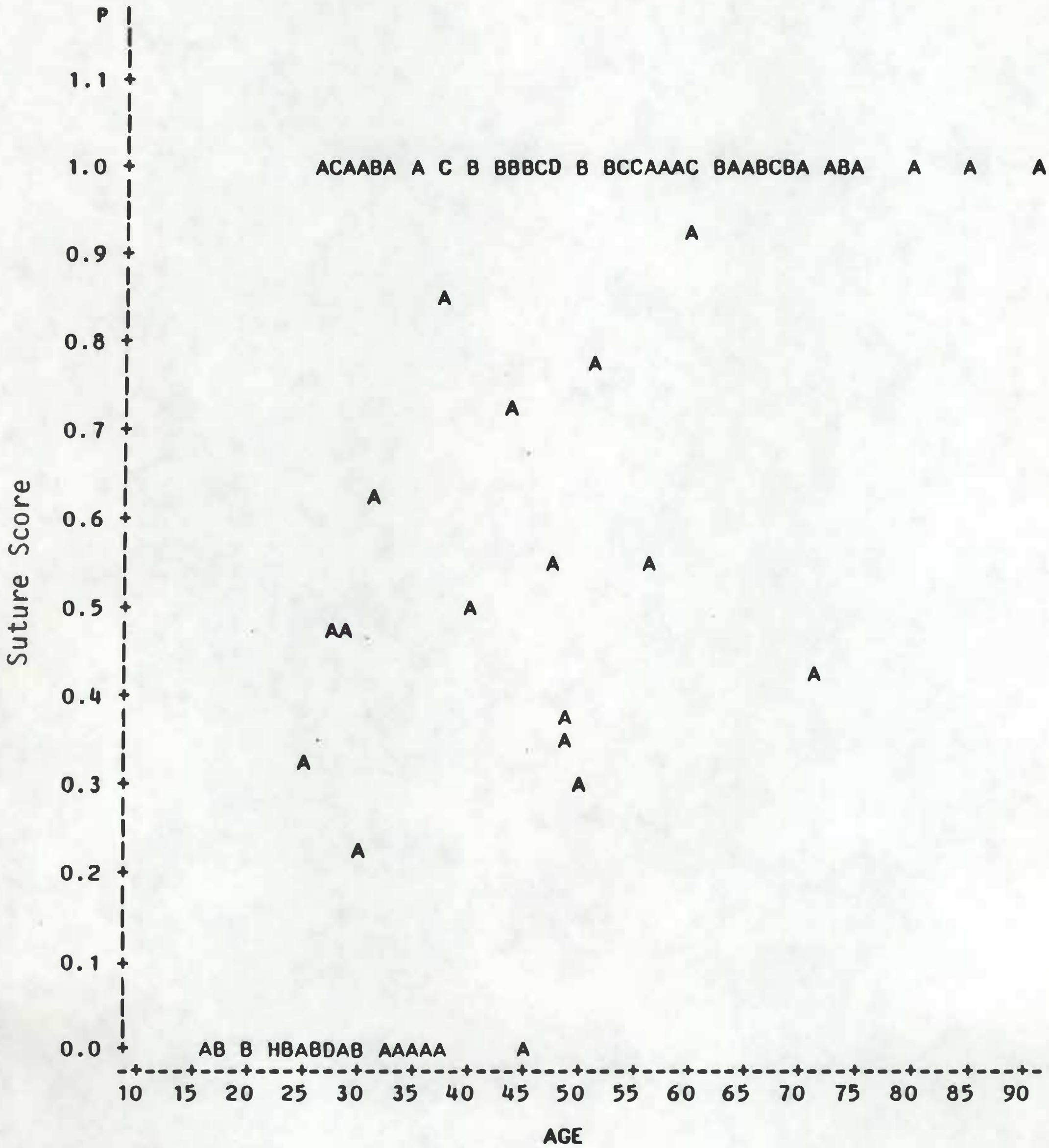

Figure 13. Plot of obliteration of the posterior median palatine suture in males.

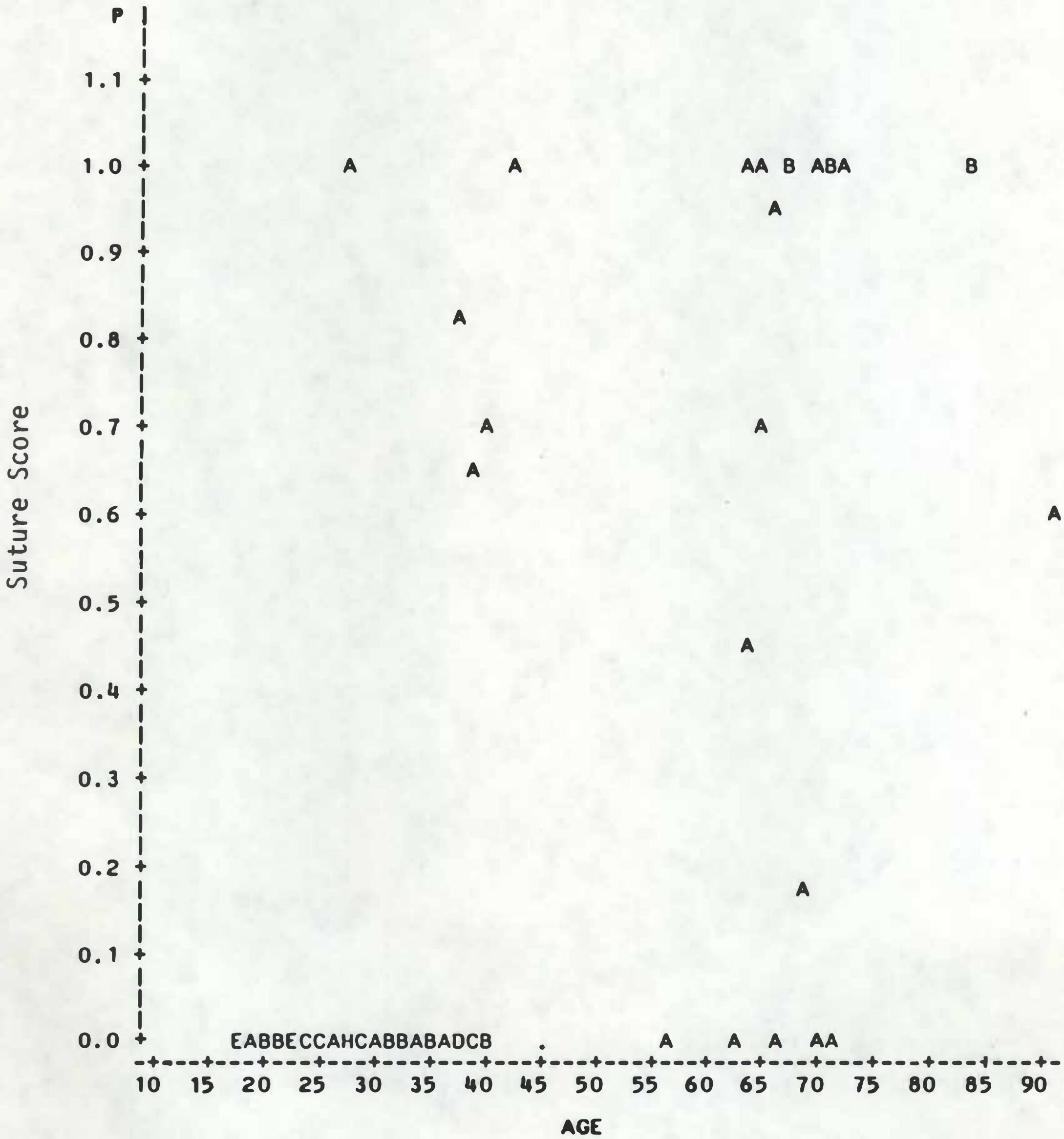

Figure 14. Plot of obliteration of the posterior median palatine suture in females.

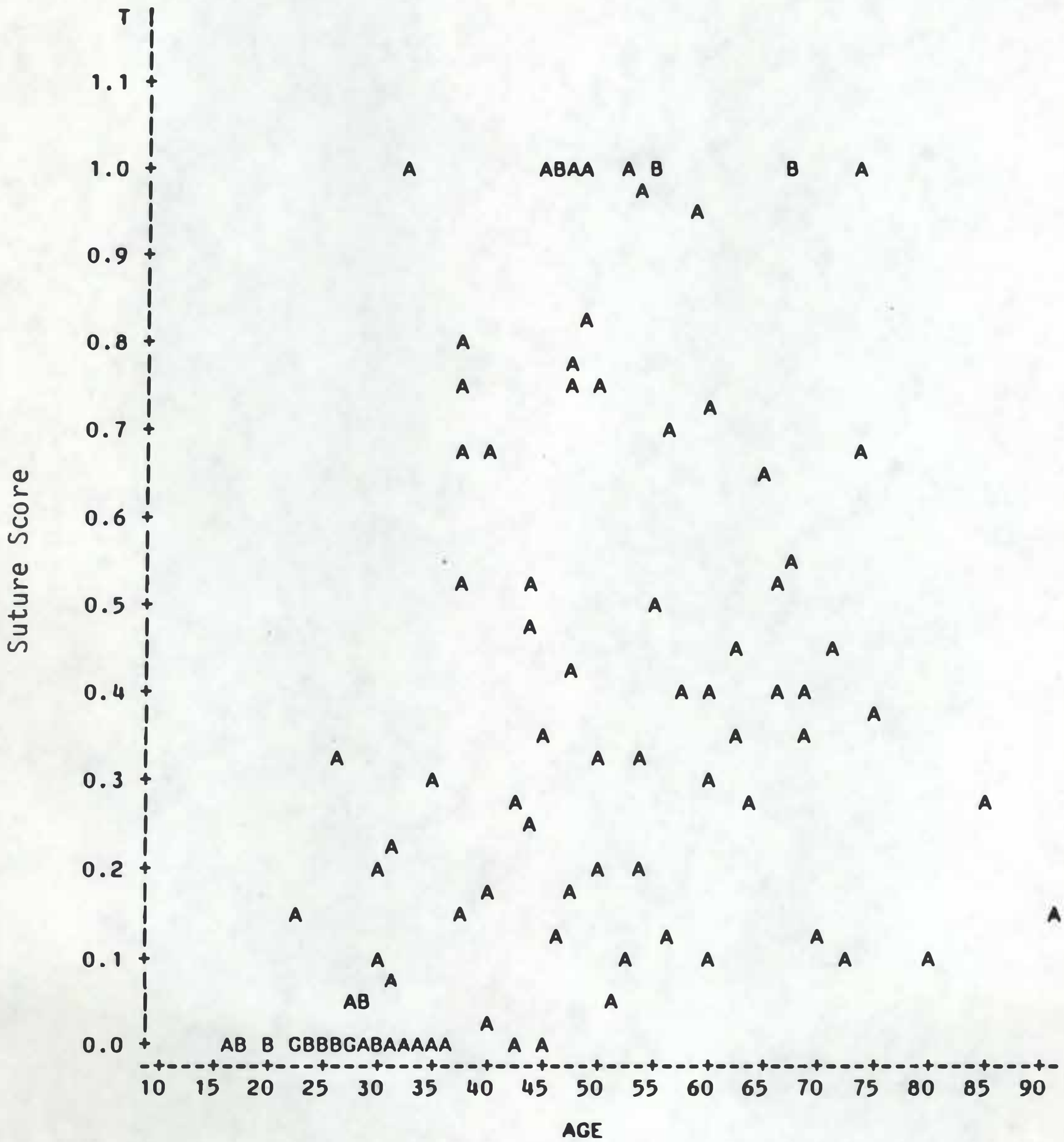

Figure 15. Plot of obliteration of the transverse palatine suture in males.

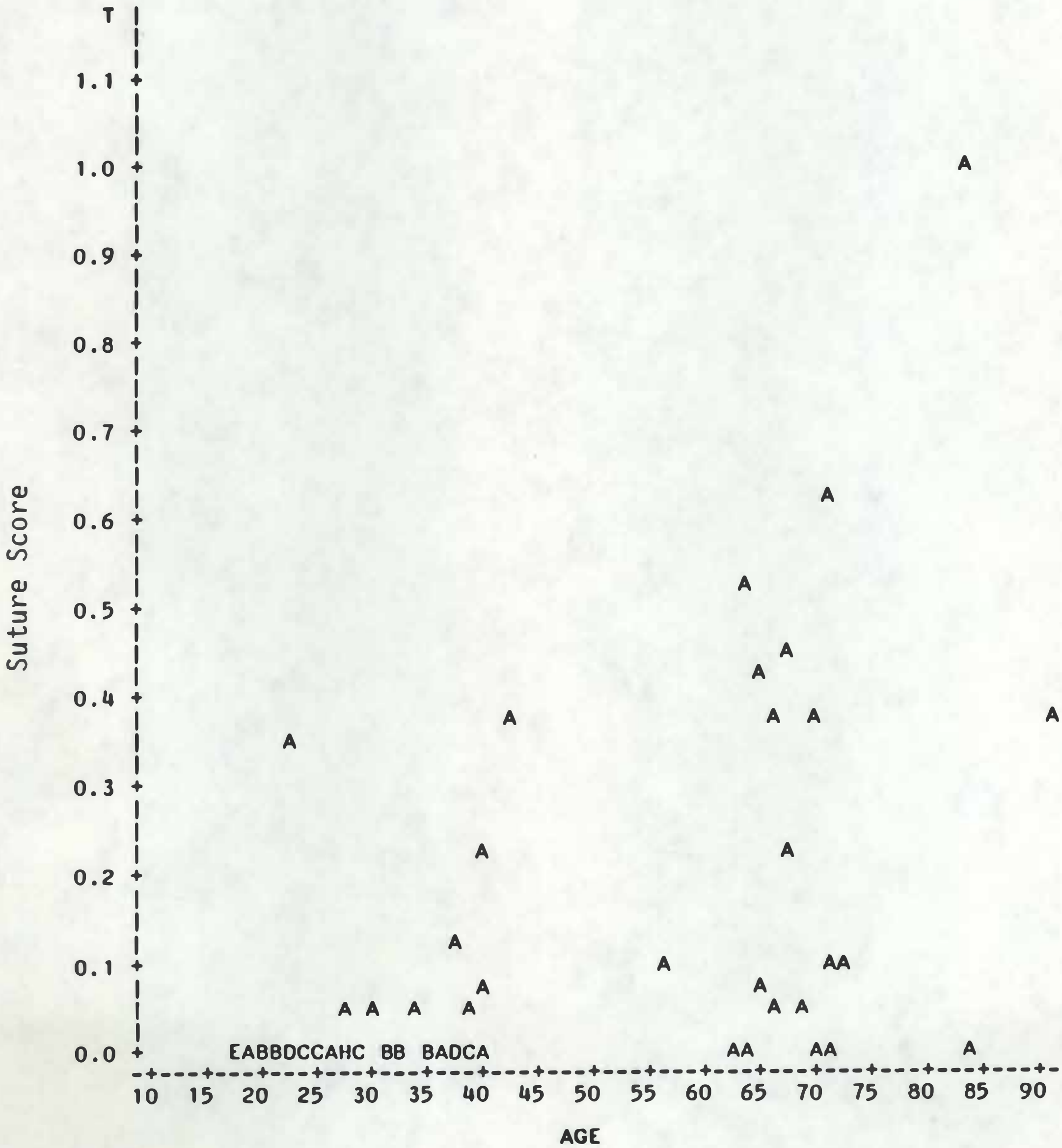

Figure 16. Plot of obliteration of the transverse palatine suture in females.

patterns reflect the degree of association and variability of each suture. A plot with a narrow scatter represents less variability in suture obliteration than one with a wide dispersion of the data.

The analyses of variance (ANOVA) indicate that significant sex differences exist (Tables 9 and 10). Sex, therefore, must be considered when computing age based on obliteration of the maxillary sutures.

The results of the inverse predictions indicate that great variation exists in the amount of suture obliteration and age. Table A-1 (Appendix) reflects the differences in predicted age (XHAT) from actual age. Males typically exhibit more obliteration of the four sutures than do females for any given age. However, the ages of the females were more accurately predicted (Table 11) than those of the males (Table 12). The differences in predicted-age versus actual-age estimates resulted in 56% of the males being under-aged and 49% of the females. We see that the ages of neither sex is greatly over or under estimated.

Although the intraindividual rate of obliteration of the four sutures is quite variable, the sequence of obliteration follows a general pattern beginning with the I followed by the PMP, TP, and AMP. The mean closures of the TP and AMP in females are nearly identical. Tables 13 through 16 reflect specific observations noted in this study.

The predicted age of an individual may be obtained by one of three methods. First, calculate the percentage of obliteration of

Table 9. Analysis of variance (ANOVA) for males.

Dependent Variable: TS

Source	DF	Sum of Squares	Mean Square	Model F = 103.02	PR > F = 0.0001	R-Square
Model	1	57.20122003	57.20122003			0.388206
Error	108	59.96485633	0.55523015			
Corrected Total	109	117.16607636				

Table 10. Analysis of variance (ANOVA) for females.

Dependent Variable: TS

Source	DF	Sum of Squares	Mean Square	Model F = 82.77 > PR	F = 0.001	R-Square
Model	1	26.61794891	26.61794891			0.521959
Error	74	23.79871951	0.32160432			
Corrected Total	75	50.41666842				

Table 11. Distribution of predicted ages for females in the calibration sample (N=76).

Age Interval (± Years)	N	%
5	25	32.89
10	45	59.21
15	53	69.73
20	58	76.31
25	65	85.52
30	65	85.52
35	68	89.47
40	72	94.73
45	72	94.73
50	75	98.68
55	75	98.68
60	76	100

Table 12. Distribution of predicted ages for males in the calibration sample (N=110).

Age Interval (± Years)	N	%
5	17	15.45
10	37	33.63
15	68	61.81
20	86	78.18
25	95	86.36
30	99	90.00
35	103	93.63
40	106	96.36
45	109	99.09
50	110	100

Table 13. Earliest complete obliteration of the four sutures by sex.

Suture	Male Age (N=110)	Female Age (N=76)
I	20	20
PMP	26	27
TP	33	84
AMP	40	67

Figure 14. First evidence of partial obliteration of the maxillary sutures.

Suture	Age (Years)	Race	Sex
I	16	Black	Male
TP	22	Black	Male
PMP	25	Black	Male
AMP	27	Black	Male

Table 15. First evidence of complete obliteration of the maxillary sutures.

Suture	Age (Years)	Race	Sex
I	20	Black/White	Female/Male
PMP	26	Black	Male
TP	33	Black	Male
AMP	40	Black	Male

Table 16. Combinations of first occurrence in the calibration sample.

Stage Obliteration	Sutures	First Occurrence (Years)
Partial	I, TP	22
Partial	I, PMP, TP	26
Complete	I, PMP	28
Complete	I, PMP, TP	33
Complete	I, PMP, TP, AMP	46

any one suture and locate the first age of occurrence on the appropriate sex plot (Figures 9-16, pages 39-46). The second method is to determine the total obliteration of the four sutures and calculate the predicted age (XHAT) using the appropriate sex formula (Figures 17-18). The third method is to determine the sum of obliteration of the four sutures (percentage), locate this value on the X axis of the appropriate sex plot and locate the corresponding point (age) on the regression line (Figures 19-20).

$$\text{Age} = \frac{\text{Total score (obliteration)}}{.04177} - .2927$$

Figure 17. Male regression formula for predicting age.

$$\text{Age} = \frac{\text{Total score (obliteration)}}{.03023} - .0525$$

Figure 18. Female regression formula for predicting age.

The results of the test sample (N=16) indicate that the ages of females were more accurately predicted than those of the males (Table 17). Although the disproportionate number of males must be taken into consideration (12 males and 4 females), we see that all of the females were aged to within ±10 years of their actual ages contrasted with 75% of the males.

When examined by sex, it becomes clear that the males exhibit the larger error in predicted versus actual age (Tables 18 and 19).

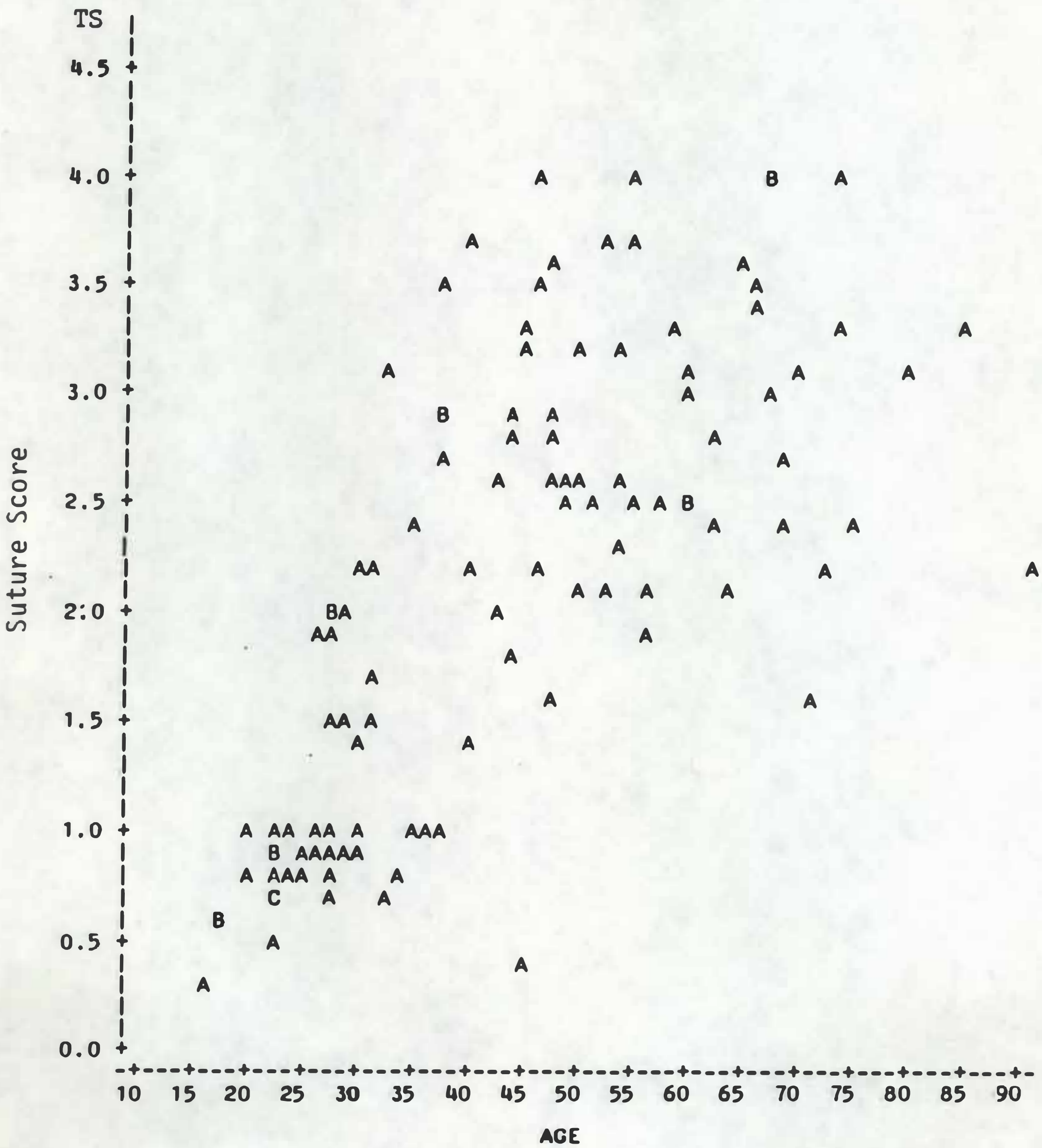

Figure 19. Plot of combined suture scores for males (N=110).

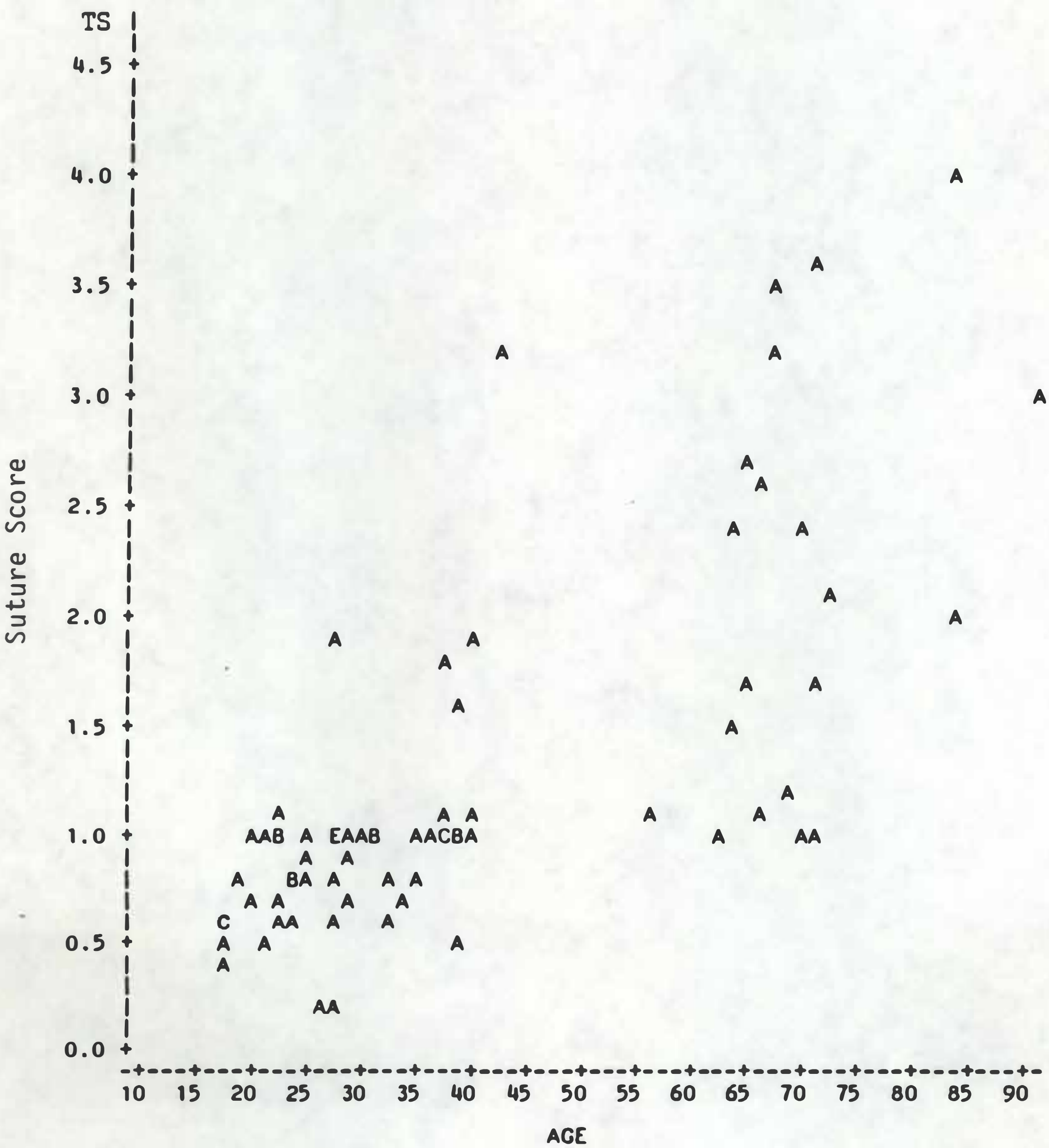

Figure 20. Plot of combined suture scores for females (N=76).

Table 17. Predicted ages in the test sample (N=16).

ID	Sex	Race	I	A	P	T	Total Score	Actual Age	XHAT	Dev
1	F	W	1.00	0.00	0.00	0.45	1.45	53	47.91	-5.09
2	M	W	1.00	0.47	1.00	1.00	3.47	75	82.78	7.78
3	M	W	1.00	0.00	1.00	0.51	2.51	55	59.79	4.79
4	M	B	1.00	0.41	1.00	0.44	2.85	63	67.93	4.93
5	F	W	0.50	0.00	0.00	0.00	0.50	18	16.48	-1.52
6	F	W	0.87	0.00	0.00	0.00	0.87	31	28.72	-2.28
7	M	W	1.00	0.00	0.00	0.00	1.00	28	23.64	-2.36
8	F	W	1.00	0.00	0.00	0.13	1.13	38	37.32	-0.68
9	M	W	1.00	0.00	0.20	0.00	1.20	36	28.72	-7.28
10	M	B	1.00	0.00	0.42	1.00	2.42	43	57.64	16.64
11	M	W	1.00	0.39	1.00	0.45	2.84	62	67.69	5.69
12	M	W	0.80	0.00	0.00	0.00	0.80	25	18.85	-6.15
13	M	W	0.76	0.84	1.00	0.77	3.37	48	80.38	32.38
14	M	W	1.00	0.39	1.00	0.45	2.84	62	67.69	5.69
15	M	W	1.00	0.00	0.00	0.33	1.33	26	31.54	5.54
16	M	B	1.00	0.36	0.40	0.41	2.17	27	51.65	24.65

Table 18. Distribution of predicted ages for males in the test sample (N=12).

Age Interval (± Years)	N	%
5	3	25.00
10	9	75.00
15	9	75.00
20	10	83.33
25	11	91.66
30	11	91.66
35	12	100

Table 19. Distribution of predicted ages for females in the test sample (N=4).

Age Interval (± Years)	N	%
5	3	75
10	4	100

The mean of the absolute values in predicted versus actual age is 8.34 years. In one case a 48 year old White male exhibits a suture score of 3.37 (advanced obliteration for his age) resulting in a predicted age of 80 which is an over-estimate of 32 years. Similarly, the predicted age of a 27 year old Black male is 24 years more than his actual age. The latter individual, however, exhibits complete obliteration of all of the cranial sutures as well as remarkably White cranial traits.

B. DISCUSSION

The results of this research provide substantial evidence for marked sexual dimorphism in the rate of maxillary suture obliteration. Males typically exhibit more obliteration of the sutures at any given age than females. As the total score for females approaches 4.0 the over-age estimate error increases markedly. This method, therefore, tends to over-estimate greatly females with high suture scores. Males, however, were not as adversely affected by high scores as females.

It is difficult to determine the biological factors responsible for the observed sex differences in suture obliteration. Previous research in other areas of skeletal biology indicate that females, for the most part, mature more rapidly than males (Glucksman 1981). Epiphyseal union of the long bones, for example, has been shown to occur earlier in females by one to three years (Greulich and Pyle 1959; Johnston 1961; Iscan et al. 1984a, 1984b, 1985). Primary

ossification centers also appear earlier in females (Pyle and Sontag 1943; Krogman and Iscan 1986).

Although most researchers agree that epiphyseal union of the long bones and ossification centers in the skeleton occur earlier in females, there are conflicting research findings regarding cranial suture closure. For example, Frederic (1905) found that cranial suture closure occurred earlier in females, while Baker (1984) found the reverse. Further, Krogman and Iscan (1986) state that when estimating the age of an individual using cranial or facial sutures, there are no age differences by sex or race. Maxillary suture obliteration appears to be one of the few, if not only, adult skeletal age indicator that shows such marked sex differences.

The most perplexing question arising from this study is what could be responsible for the sex differences in suture obliteration. Since the individuals in this study represent a sample of persons subject to similar environmental stresses (e.g., illnesses and nutritional deficiencies), the differences in obliteration must be due to influences other than postnatal in origin. It is possible, however, that since the majority of the sample is made up of individuals in the Terry Collection (indigent subgroup), there may be some unknown sample bias.)

When all the variables are considered the endocrine system appears to be responsible, in large part, for such differences. Normal bone growth is dependent on sufficient quantities of vitamins, calcium, and phosphorus, as well as the proper amounts of various

hormones. These hormones are responsible for the regulation of osteoblasts and osteoclasts. The sex hormones, in particular, are important in regulating formation of the osteoblasts (Tortora and Anagnostakos 1979). These hormones are responsible for the development of sexual characteristics, as well as the process of maturation and aging. It is likely that the growth and sex hormones play integral roles in the onset and rate of suture fusion and obliteration in the human palate. Perhaps the earlier ossified centers in the skeleton are the "targets" of the sex and growth hormones during the early maturational years. Altered hormone levels due to pregnancy might also have an effect on the female pattern of ossification.

As both sexes reach middle age, the levels of the sex and growth hormones decrease and osteoclastic activity becomes prominent. Females are most affected by the cessation of some hormones after 45 to 55 years of age (menopause). This reduction in osteoblasts and concomitant increase in osteoclasts may result in severely delayed ossification of the maxillary sutures. These sutures might well be the last targets of ossification in the human skeleton. Judging from the extreme delay in ossification in some female maxillae it is likely that these individuals would never have completed ossification, regardless of how long they might have lived. Males, on the other hand, may show slow but continuous obliteration of the maxillary sutures well into old age.

In conclusion, we find that the maxillary sutures can be of value in estimating the age of the human skeleton. However, this

method is not without fault and caution should be exercised when relying solely on the maxillary sutures. Although males exhibit advanced obliteration over the females, the ages of the latter are more likely to be accurate. Using a simple method of calculating the proportion of obliteration of the maxillary sutures, an observer is able to predict the age of an individual within ±10 years in 33% of the cases for males and 59% of the females. Although this method does not ensure that the precise age of an individual will be obtained, it is valuable in estimating age. It is certain, however, that researchers need to focus more attention to the palate in order to better understand the mechanics of suture fusion, palatal growth and sexual dimorphism in the human skeleton.

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APPENDIX

APPENDIX

Table A-1. Calibration sample (N=186).

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
1	1	1	0.57	0.00	0.00	0.00	0.57	17	17.12	0.12
2	1	1	0.83	0.00	0.00	0.00	0.83	19	25.72	4.72
4	1	1	0.73	0.00	0.00	0.00	0.73	22	22.41	0.41
14	1	1	0.64	0.00	0.00	0.00	0.44	28	19.43	-8.57
23	1	1	0.84	0.00	1.00	0.53	2.39	64	77.32	13.32
24	1	1	1.00	0.00	0.00	0.00	1.00	37	31.34	-5.66
26	1	1	1.00	1.00	1.00	0.63	3.63	71	118.34	47.34
30	1	1	0.62	0.00	0.00	0.00	0.62	22	18.77	-3.23
44	1	1	1.00	0.00	0.00	0.00	1.00	42	31.34	-30.66
47	1	0	1.00	0.27	1.00	0.42	2.69	65	87.24	22.24
50	1	1	1.00	0.00	0.00	0.00	1.00	39	31.34	-7.66
56	1	1	0.80	0.00	0.00	0.00	0.80	24	24.72	0.72
60	1	1	1.00	0.00	0.00	0.00	1.00	40	31.34	-8.66
63	1	1	1.00	0.00	0.00	0.00	1.00	21	31.34	10.34
66	1	1	1.00	0.00	0.00	0.00	1.00	35	31.34	-3.66
67	1	1	1.00	0.00	0.00	0.00	1.00	20	31.34	11.34
70	1	0	1.00	0.00	0.00	0.00	1.00	71	31.34	-39.66
71	1	1	1.00	0.00	0.00	0.00	1.00	23	31.34	8.34
75	1	1	1.00	0.00	0.00	0.00	1.00	23	31.34	8.34
76	1	1	1.00	0.00	0.00	0.00	1.00	27	31.34	4.34
83	1	0	0.18	0.00	0.00	0.00	0.18	27	4.22	-22.78
93	1	0	1.00	0.00	0.17	0.06	1.23	69	38.95	-30.05
101	1	1	0.56	0.00	0.00	0.00	0.56	32	16.79	-15.21
106	1	1	0.56	0.00	0.00	0.00	0.56	24	16.79	-7.21
107	1	1	1.00	0.00	0.00	0.00	1.00	28	31.34	3.34
108	1	1	1.00	0.00	0.82	0.00	1.82	38	58.46	20.46

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
113	1	0	1.00	1.00	1.00	0.23	3.23	68	105.10	37.10
115	1	1	0.53	0.00	0.00	0.00	0.53	21	15.79	-5.21
117	1	1	1.00	0.00	0.00	0.00	1.00	38	31.34	-6.66
120	1	1	0.80	0.00	0.00	0.00	0.80	28	24.72	-3.28
122	1	1	1.00	0.00	0.00	0.00	1.00	34	31.34	-4.66
126	1	1	1.00	0.00	0.00	0.07	1.07	40	33.66	-6.34
127	1	1	0.19	0.00	0.00	0.00	0.19	26	4.55	-21.45
128	1	0	1.00	0.00	0.00	0.00	1.00	70	31.34	-38.66
133	1	1	1.00	0.00	0.00	0.00	1.00	25	31.34	6.34
134	1	1	1.00	0.00	0.00	0.00	1.00	29	31.34	2.34
135	1	1	0.90	0.00	1.00	0.04	1.94	27	62.43	35.43
136	1	1	1.00	0.00	0.00	0.00	1.00	27	31.34	4.34
138	1	0	0.92	0.00	0.00	0.04	0.96	30	30.02	0.02
139	1	1	0.94	0.00	0.64	0.00	1.58	39	50.53	11.53
140	1	1	0.78	0.00	0.00	0.34	1.14	22	35.97	13.97
142	1	1	1.00	0.00	0.00	0.00	1.00	38	31.34	-6.66
143	1	1	1.00	0.00	0.00	0.00	1.00	27	31.34	4.34
144	1	1	0.79	0.00	0.00	0.00	0.79	24	24.39	0.39
146	1	1	1.00	0.00	0.00	0.00	1.00	31	31.34	0.34
147	1	1	0.43	0.00	0.00	0.05	0.48	39	14.14	-24.86
148	1	1	0.89	0.00	0.00	0.00	0.89	25	27.70	2.70
150	1	0	1.00	0.00	0.00	0.00	1.00	39	31.34	-7.66
154	1	1	0.59	0.00	0.00	0.00	0.59	18	17.78	-0.22
155	1	1	0.75	0.00	0.00	0.00	0.75	32	23.07	-8.93
157	1	0	0.94	0.00	0.00	0.00	0.94	29	29.36	0.36
158	1	0	0.87	0.00	0.71	0.08	1.66	65	53.17	-11.83
159	1	0	0.60	0.00	0.00	0.06	0.66	34	20.09	-13.91
160	1	0	1.00	0.07	0.44	0.00	1.51	64	48.21	-15.79
161	1	0	1.00	0.00	1.00	0.00	2.00	84	64.42	-19.58

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
162	1	0	1.00	0.00	1.00	0.37	2.37	70	76.66	6.66
163	1	0	1.00	0.00	0.70	0.23	1.93	40	62.10	22.10
164	1	0	1.00	0.00	0.00	0.05	1.05	66	32.00	-33.01
165	1	0	0.62	0.00	0.00	0.00	0.62	17	18.77	1.77
166	1	0	1.00	1.00	1.00	1.00	4.00	84	130.57	46.57
167	1	0	0.75	0.00	0.00	0.00	0.75	35	23.07	-11.93
168	1	1	0.69	0.00	0.00	0.00	0.69	29	21.09	-7.91
169	1	0	1.00	0.00	0.00	0.00	1.00	27	31.34	4.34
170	1	0	0.73	0.00	0.00	0.00	0.73	20	22.41	2.41
171	1	0	0.81	0.00	0.00	0.00	0.81	25	25.05	0.05
172	1	0	0.34	0.00	0.00	0.00	0.34	17	10.17	-6.83
174	1	0	0.50	0.00	0.00	0.00	0.50	18	14.80	-3.20
175	1	0	1.00	0.00	0.00	0.00	1.00	31	31.34	0.34
177	1	0	1.00	0.00	0.00	0.13	1.13	38	35.64	-2.34
179	1	1	1.00	0.77	1.00	0.38	3.15	43	102.46	59.46
183	1	0	1.00	1.00	0.60	0.37	2.97	91	96.50	5.50
184	1	0	1.00	0.25	0.94	0.38	2.57	66	83.27	17.27
185	1	0	0.97	0.00	0.00	0.11	1.08	56	33.99	-22.01
186	1	0	0.57	0.00	1.00	0.10	1.67	71	53.50	-17.50
187	1	0	1.00	1.00	1.00	0.46	3.46	67	112.71	45.71
188	1	0	1.00	0.00	1.00	0.10	2.10	73	67.73	-5.27
3	0	1	1.00	1.00	1.00	0.09	3.09	80	66.96	-13.04
5	0	0	1.00	0.03	1.00	0.12	2.15	46	44.46	-1.54
6	0	0	1.00	0.00	1.00	0.35	2.35	69	49.25	-19.75
7	0	0	1.00	1.00	1.00	1.00	4.00	68	88.75	20.75
8	0	0	1.00	0.00	1.00	0.12	2.12	56	43.74	-12.26
9	0	1	1.00	0.14	1.00	1.00	3.14	33	68.16	33.16
10	0	1	0.82	0.04	0.50	0.03	1.39	40	26.27	-13.73
11	0	0	1.00	0.00	1.00	0.18	2.18	40	45.18	5.18

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
12	0	0	1.00	1.00	1.00	0.40	3.40	66	74.38	8.38
13	0	0	1.00	0.27	1.00	0.33	2.60	54	55.23	1.23
14	0	0	1.00	0.32	1.00	0.53	2.85	44	61.22	17.22
15	0	1	1.00	1.00	1.00	0.68	3.68	40	81.09	41.09
17	0	0	1.00	1.00	1.00	0.53	3.53	66	77.50	11.50
18	0	1	1.00	1.00	1.00	0.19	3.19	50	69.34	19.34
19	0	1	1.00	0.20	1.00	0.42	2.62	48	55.71	7.71
20	0	1	1.00	0.38	1.00	0.94	3.32	59	72.47	13.47
21	0	0	1.00	0.45	0.35	0.83	2.63	49	55.95	4.95
22	0	0	1.00	1.00	1.00	0.12	3.12	70	67.68	-2.32
25	0	0	1.00	0.07	1.00	0.37	2.44	75	51.40	-23.60
27	0	0	1.00	0.40	1.00	0.56	2.96	47	63.85	-3.15
29	0	0	1.00	1.00	1.00	0.11	3.11	60	67.44	7.44
31	0	1	1.00	0.00	1.00	0.00	2.00	42	40.87	-1.13
32	0	1	1.00	0.81	1.00	0.35	3.16	45	68.64	23.64
33	0	1	1.00	0.00	1.00	0.00	2.00	29	40.87	11.87
34	0	1	0.53	0.00	0.33	0.00	0.84	25	13.58	-11.42
35	0	0	1.00	0.25	1.00	0.97	3.22	54	70.07	16.07
36	0	0	1.00	1.00	1.00	1.00	4.00	68	88.75	20.75
37	0	1	1.00	0.11	1.00	0.74	2.85	47	41.22	14.22
38	0	0	0.75	0.00	0.42	0.44	1.61	71	31.53	-39.47
39	0	1	0.77	0.03	1.00	0.06	1.86	27	37.52	10.52
40	0	1	1.00	1.00	1.00	1.00	4.00	46	88.75	42.75
41	0	1	0.83	0.00	0.73	0.26	1.82	44	36.56	-7.44
42	0	0	1.00	1.00	1.00	1.00	4.00	74	88.75	14.75
43	0	0	1.00	0.73	1.00	1.00	3.73	52	82.28	30.28
45	0	1	0.91	0.00	0.00	0.00	0.91	26	14.78	-11.22
46	0	1	0.88	0.00	0.00	0.00	0.88	28	14.06	-13.94
48	0	1	1.00	0.04	0.62	0.00	1.68	31	33.21	2.21

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
49	0	0	0.40	0.00	0.00	0.00	0.40	45	2.57	-42.43
51	0	0	1.00	0.00	0.00	0.00	1.00	28	16.93	-11.07
52	0	1	1.00	0.32	1.00	0.48	2.80	44	60.02	16.02
53	0	1	0.87	0.00	0.00	0.00	0.87	22	13.82	-8.18
54	0	1	0.88	0.00	0.00	0.00	0.88	30	14.06	-15.94
55	0	1	1.00	0.13	0.37	1.00	2.50	49	52.84	3.84
57	0	1	1.00	0.00	1.00	0.19	2.19	30	45.42	15.42
58	0	0	1.00	0.00	0.00	0.00	1.00	20	16.93	-3.07
59	0	0	1.00	1.00	1.00	0.64	3.64	65	80.13	15.13
61	0	0	1.00	0.00	0.00	0.00	1.00	30	16.93	-13.07
62	0	1	1.00	0.00	1.00	0.00	2.00	28	40.87	12.87
64	0	0	1.00	1.00	1.00	0.27	3.27	85	71.27	-13.73
65	0	1	0.71	0.00	0.00	0.00	0.71	23	9.99	-13.01
68	0	1	1.00	0.00	0.00	0.00	1.00	24	16.93	-7.07
69	0	1	1.00	0.50	1.00	1.00	3.50	46	76.78	30.78
72	0	1	0.73	0.00	0.00	0.00	0.73	27	10.47	-16.53
73	0	1	1.00	0.74	1.00	1.00	3.74	55	82.52	27.52
74	0	1	1.00	0.12	1.00	0.80	2.92	38	62.89	24.89
77	0	1	1.00	0.08	0.23	0.09	1.40	30	26.51	-3.49
78	0	1	1.00	0.07	1.00	0.31	2.38	35	49.97	14.97
79	0	0	1.00	0.00	1.00	0.51	2.51	55	53.08	-1.92
80	0	0	0.80	0.00	1.00	0.28	2.08	64	42.78	-21.22
81	0	1	0.53	0.00	1.00	0.32	1.85	26	37.28	11.28
82	0	0	1.00	0.00	0.31	0.75	2.06	50	42.31	-7.69
84	0	1	0.81	0.00	0.00	0.00	0.81	24	12.38	-11.62
85	0	1	0.70	0.00	0.00	0.00	0.70	22	9.75	-12.25
86	0	0	1.00	0.10	1.00	0.39	2.49	58	52.60	-5.40
87	0	0	1.00	0.07	1.00	0.09	2.16	72	44.70	-27.30
88	0	0	1.00	0.07	1.00	0.41	2.48	60	52.36	-7.64

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
89	0	0	0.64	0.00	0.54	0.70	1.90	56	38.48	-17.52
90	0	1	1.00	0.24	1.00	0.32	2.56	50	54.28	4.28
91	0	1	1.00	0.33	1.00	0.27	2.60	42	55.23	13.23
92	0	0	1.00	0.32	0.85	0.53	2.70	38	57.63	19.63
94	0	1	1.00	0.00	0.00	0.00	1.00	35	16.93	-18.07
95	0	1	1.00	0.81	1.00	0.67	3.48	37	76.30	39.30
96	0	1	1.00	0.17	1.00	0.76	2.93	38	63.13	25.13
97	0	0	1.00	0.63	1.00	0.68	3.31	74	72.23	-1.77
98	0	1	0.75	0.00	0.00	0.00	0.75	28	10.95	-17.05
99	0	1	1.00	0.00	0.47	0.00	1.47	27	28.18	1.18
100	0	1	0.33	0.00	0.00	0.00	0.33	16	0.89	-15.11
102	0	1	1.00	0.08	1.00	0.20	2.28	54	47.57	-6.43
103	0	1	1.00	1.00	1.00	1.00	4.00	55	88.75	33.75
104	0	1	1.00	0.62	0.78	0.06	2.46	51	51.88	0.88
105	0	0	1.00	0.18	1.00	0.31	2.49	60	52.60	-7.40
110	0	0	0.78	0.04	1.00	1.00	2.82	48	60.50	12.50
111	0	1	0.85	0.00	0.00	0.06	0.91	29	14.78	-14.22
112	0	1	1.00	0.03	1.00	0.16	2.19	91	45.42	-45.58
114	0	1	0.81	0.00	0.00	0.00	0.81	20	12.28	-7.62
116	0	1	0.82	0.00	0.00	0.00	0.82	23	12.62	-10.38
118	0	1	0.78	0.00	0.00	0.00	0.78	34	11.66	-22.34
119	0	1	1.00	0.00	1.00	0.22	2.22	31	46.14	15.14
121	0	0	0.88	0.00	0.00	0.15	1.03	38	17.65	-20.35
123	0	1	1.00	0.00	0.47	0.06	1.53	29	29.62	0.62
124	0	0	1.00	0.03	1.00	0.34	2.37	62	49.73	-12.27
125	0	1	0.75	0.11	0.56	0.17	1.59	47	31.06	-15.94
129	0	1	1.00	0.29	1.00	1.00	3.29	45	71.75	26.75
130	0	0	1.00	0.28	1.00	0.39	2.67	69	56.91	-12.09
131	0	1	0.93	0.00	0.00	0.00	0.93	]2	15.26	-7.74

Table A-1 (continued)

ID	Sex	Race	I	A	P	T	Total	Actual Age	XHAT	Dev
132	0	0	1.00	0.00	1.00	0.11	2.11	52	43.50	-8.50
137	0	1	0.74	0.00	0.00	0.00	0.74	32	10.71	-21.29
141	0	1	1.00	0.00	1.00	0.00	2.00	28	40.87	12.87
145	0	1	0.60	0.00	0.00	0.00	0.60	17	7.36	-9.64
149	0	1	0.74	0.00	0.00	0.00	0.74	22	10.71	-11.29
151	0	1	1.00	0.00	0.00	0.00	1.00	23	16.93	-6.07
152	0	1	0.35	0.00	0.00	0.14	0.49	23	4.72	-18.28
153	0	1	0.40	0.04	1.00	0.08	1.52	31	29.38	-1.62
156	0	1	0.62	0.00	0.00	0.00	0.62	18	7.83	-10.17
173	0	0	1.00	0.38	0.92	0.72	3.02	60	65.29	5.29
176	0	0	1.00	0.00	0.00	0.00	1.00	26	16.93	-9.07
178	0	0	1.00	0.00	0.00	0.00	1.00	36	16.93	-19.07
180	0	0	0.81	0.00	0.00	0.00	0.81	25	12.30	-12.62
181	0	0	1.00	0.39	1.00	0.45	2.84	62	60.98	-1.02
182	0	0	1.00	0.84	1.00	0.77	3.61	48	79.41	31.41

VITA

Robert Walter Mann was born in Tampa, Florida, on November 12, 1949. He attended elementary schools in that city, a naval military academy in St. Petersburg, and later a private academy in Montverde, Florida. In 1969 he graduated from H. B. Plant High School in Tampa, Florida. In that same year he entered the U.S. Navy and served in Indochina, as well as two years aboard the naval destroyer USS Eugene A. Greene and a short tour in Glynco, Georgia, before being honorably discharged.

Between the years 1972 and 1974 he was a practicing musician as well as an electronics technician in the cash register and computer fields. In 1974 Robert again enlisted in the U.S. Navy assigned to a tactical warfare squadron in Norfolk, Virginia. He was honorably discharged in 1976 and enrolled at Tidewater Community College, Portsmouth, Virginia, where he was awarded an Associate in Science degree in Education.

In 1978 he entered The College of William and Mary, Williamsburg, Virginia, and spent four years as an undergraduate in anthropology. During this time he was also employed as a security guard for Anheuser-Busch Corporation. Robert left The College of William and Mary in 1982 and entered The University of Tennessee, Knoxville, as an undergraduate in anthropology. In 1985 he was awarded the Bachelor of Arts degree in Anthropology. He began graduate studies at The University of Tennessee in September 1985 and

was awarded the Master's of Arts degree in Anthropology in December 1987. Although he was accepted as a doctoral candidate at The University of Tennessee, he accepted a position as Assistant Morgue Director at The University of Tennessee, Memphis. Robert will continue his academic pursuits while in Memphis and hopes to return to Knoxville to complete his Ph.D.

The author's main areas of interest are forensic anthropology, skeletal morphology and paleopathology. Robert is a member of Sigma Xi and the American Association of Physical Anthropologists.