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Maxillary Suture Obliteration: A Visual Method for Estimating Skeletal Age

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ABSTRACT: The purpose of this study was to develop a method of estimating the age of an individual based on obliteration of the four maxillary (palatal) sutures. A sample of 186 individuals of known age, race, and sex were examined. It was found that males of both races (black and white) exhibit more suture obliteration than females at the same age. During the early adult years, maxillary suture obliteration progresses at nearly the same rate in both sexes; however, the age of old individuals may be greatly overestimated using this method. Although this method cannot be used for exact estimates of individual age, it is valuable in establishing the age range, sorting commingled remains, and estimating skeletal age when only the maxilla is present.

KEYWORDS: forensic anthropology, human identification, musculoskeletal system, maxillary sutures, human maxilla, palate, age determination

Physical anthropologists concerned with determining the age, race, and sex of a skeleton must rely solely on those morphological traits present in bone. Sex, for example, is usually established based on the general morphology and measurements of the pelvis, skull, and long bones [1-3], but a number of methods and criteria can be combined to establish age. For example, the age of a subadult can be determined by analyses of the lengths of long bones [4], epiphyseal union [5], dental development [6,7], and ossification of the hand and wrist bones [8]. Because adults have completed their growth, other criteria than those employed for subadults must be used; for example, morphological changes in the os pubis [9-13], auricular surface changes of the ilium [14], closure of the medial epiphysis of the clavicle [15,16], vertebral osteoarthritis [17], and microscopic examination of the femur [18].

Although many early researchers focused on cranial vault suture closure and age [19-21], most studies dealing with the maxillary sutures have emphasized embryonic development as it relates to surgical intervention in cleft lip and palate [22,23]. The first attempt at estimating skeletal age based on maxillary suture obliteration was conducted

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by Mann et al. [24]. This preliminary study consisted of 36 individuals of known age, race, and sex. Although the study showed a correlation of suture obliteration and age, a larger sample was necessary before applying the method to individuals of unknown age.

This paper expands the earlier preliminary study, reports additional findings, and evaluates the reliability of an increased sample from three skeletal collections [25]. In both studies the percentage of obliteration of each of the four sutures was determined using sliding calipers. However, due to the variability in suture closure in the upper age ranges, simple measurements could result in overestimates of age. Here, we present the findings and observations of maxillary suture obliteration that are most reliable and easy to apply to individuals of unknown age, using a visual, not metric, method derived from the previous metrical analysis.

Materials and Methods

The sample consisted of 186 skeletons of known age, sex, and race from three skeletal collections: 5 from the Department of Geology and Anthropology, Louisiana State University, Baton Rouge; 10 from the Department of Anthropology, University of Tennessee, Knoxville; and 171 from the Terry Anatomical Collection of the National Museum of Natural History, Washington, DC. The total sample included 46 white males, 32 white females, 64 black males, and 44 black females. Only complete maxillae were included, and none was rejected based on unusual morphological traits such as torus palatinus, "premature" obliteration of the maxillary sutures, edentulism, or the wearing of orthodontic appliances. Sagittally sectioned maxillae were excluded from the study due to the destruction of one or more of the sutures.

The maxillae were randomly chosen and, in most cases, examined without knowledge of the individual's age or sex, thereby reducing bias in the sample, which can occur when individuals are selected for study. The method consisted of dividing the maxilla into the following four sutures, modified from Kopsch [26]: incisive (IN), anterior median palatine (AMP), posterior median palatine (PMP), and transverse palatine (TP) (Fig. 1). The greater palatine foramina are abbreviated as GPF.

Results

The suture variables in this study are bounded, ranging in value from 0 to 1.0 closure, and are not normally distributed; therefore, the higher scores, those approaching 1.0,

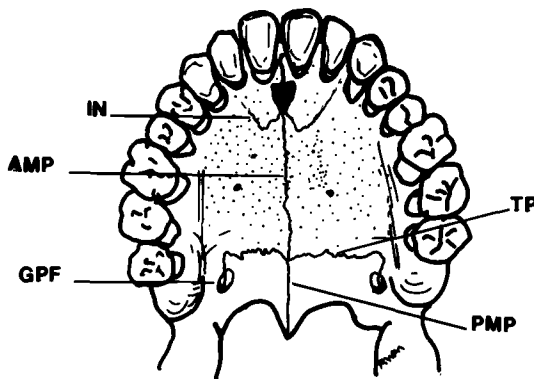


FIG. 1—Human palate showing the four maxillary sutures.

result in a truncated curve that has some effect on correlation. Because the Pearson method indicates that race has only a minor influence on suture closure but that sex is significantly correlated, the races are combined in the analysis of data. Analyses of variance (ANOVA) also indicate that significant sex differences exist. Therefore, sex, if known, should be considered when computing age based on obliteration of the maxillary sutures.

To summarize the results of the inverse predictions, we noted that great variation exists in the amount of suture obliteration with age. For any given age, males typically exhibit more obliteration of the four sutures than do females; however, the ages of the females were more accurately predicted than those of the males, with 59% of the females and 34% of the males correctly estimated to within ± 10 years. The differences in predicted-age estimates versus actual age showed that the ages of 56% of the males and 49% of the females were underestimated.

Although the intraindividual rate of obliteration of the four sutures is quite variable, the sequence of obliteration follows a general pattern beginning with the IN, followed by the PMP, TP, and AMP (Fig. 2). Tables 1 and 2, respectively, show the earliest evidence of obliteration and earliest complete obliteration of each of the four sutures. Table 3 shows the pattern of first occurrence of combined suture obliteration in the sample. These tables serve as minimum age parameters when estimating skeletal age for a single skull.

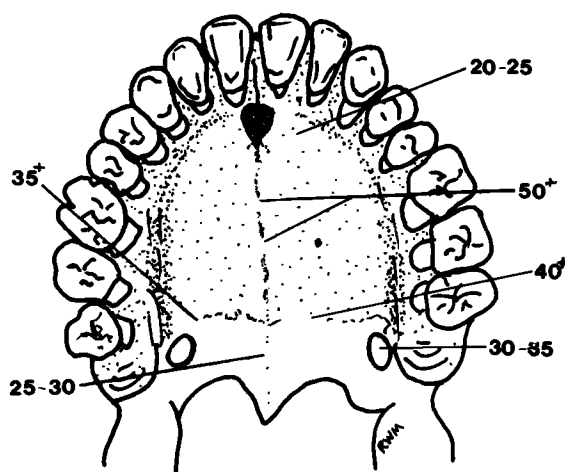


FIG. 2—General pattern of suture obliteration in an adult.

TABLE 1—First evidence of partial obliteration of the maxillary sutures.

Suture	Age, years	Race	Sex
IN	16 ^a	black	male
TP	22	black	male
PMP	25	black	male
AMP	27	black	male

^aYoungest individual in the sample.

TABLE 2—*Earliest complete obliteration of the four sutures by sex.*

Suture	Male Age, years (<i>N</i> = 110)	Female Age, years (<i>N</i> = 76)
IN	20	20
PMP	26	27
TP	33	84
AMP	40	67

TABLE 3—*Combinations of first occurrence in the sample.*

Stage of Obliteration	Sutures	First Occurrence, Years
Partial	IN, TP	22
Partial	IN, PMP, TP	26
Complete	IN, PMP	28
Complete	IN, PMP, TP	33
Complete	IN, PMP, TP, AMP	46 ^a

^aThis female showed premature obliteration of the cranial vault sutures as well. It is likely that this individual presents anomalous suture development. The next youngest individual to exhibit complete obliteration of the four sutures was 55 years of age (all others were 68 years or older).

Applying the Method

First, the hard palate is macroscopically examined and its general morphology (for example, thin bone, edentulism, signs of infection) and pattern of suture obliteration are noted. Since it is not possible to disregard extraneous age indicators, such as the palate size, edentulism, and concomitant alveolar resorption, these factors should be taken into consideration in the overall age assessment. For example, if the palate is small, the IN is nearly complete (that is, more than three fourths is still visible) and deep, it is consistent in depth and width, and the AMP and PMP are open and widely gapped, the individual is a child, probably less than 12 years of age. If approximately one half of the IN is visible, and it is consistent in depth and width but gradually fades laterally, the individual's age is probably 15 to 20 years. Obliteration of the IN begins laterally and slowly fades toward the midline.

If the palate were that of an adult, the IN would be nearly or completely obliterated. The next step would be to determine which of the remaining sutures showed any obliteration; although some variability exists in the amount and sequence of suture obliteration, most maxillae follow the sequence outlined in Tables 1 through 3. Tables 1 through 3 and Fig. 2 offer a basis for comparing the amount and combination of obliteration of each of the sutures, using the minimum age given in each table according to the appropriate suture or sutures (the minimum age estimate should be based on obliteration of the suture indicating the greatest age). For example, if the IN is completely obliterated (20+ years), one would look next for obliteration in the PMP; if there is complete obliteration of the PMP, then the minimum age estimate is increased (26+ years) to that

given in Tables 1 through 3. However, if the PMP showed no obliteration but the TP did, the minimum age estimate would be based on the TP suture. This procedure should be repeated for each of the four sutures. If all of the maxillary sutures are completely or nearly completely obliterated, the individual, regardless of sex, is probably older than 50 years of age.

Figure 3 shows the palate of an 11-year-old child. Note the wide median palatine suture as it extends from the incisive foramen to the posterior nasal spine. The incisive suture is nearly complete, showing only partial obliteration of its lateral borders. The transverse palatine is also complete as it extends from *within* the greater palatine foramina and runs perpendicular to the median palatine suture.

Figure 4 shows the palate of a 17-year-old male. Note that the IN suture shows more obliteration than that of the 11-year old. The wide gaps that once separated the palatal bones in the young child have narrowed, resulting in "thinner" suture lines. Also note the lack of obliteration of the PMP and TP sutures, further suggestive of youth.

With increasing age the sutures become shallow and narrow, and most are obliterated completely or in part. Figure 5 depicts a middle-aged adult (33 years). Note that the IN, PMP, and TP sutures show varying amounts of obliteration. A remnant of the IN is barely visible near the midline, the PMP is completely obliterated, and the TP shows some obliteration deep within the greater palatine foramina (arrow); the latter is the classic site of obliteration in a 30 to 35-year-old individual. It is important that the GPF be carefully inspected for *any* evidence of obliteration. Beyond age 35 the TP may show increased obliteration (continuously or in the form of a "dashed line") toward the midline

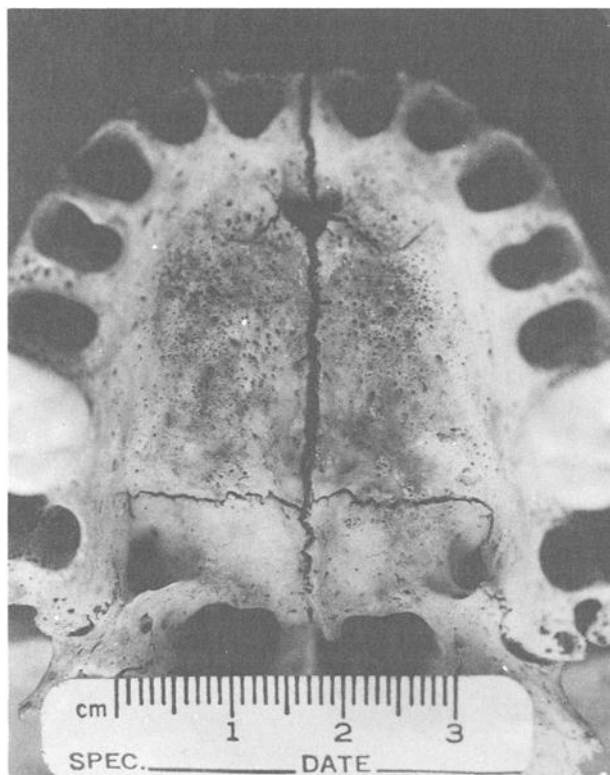


FIG. 3—Palate of an 11-year-old child. Note the widely gapped AMP and PMP sutures and interlocking "teeth" within the sutures.

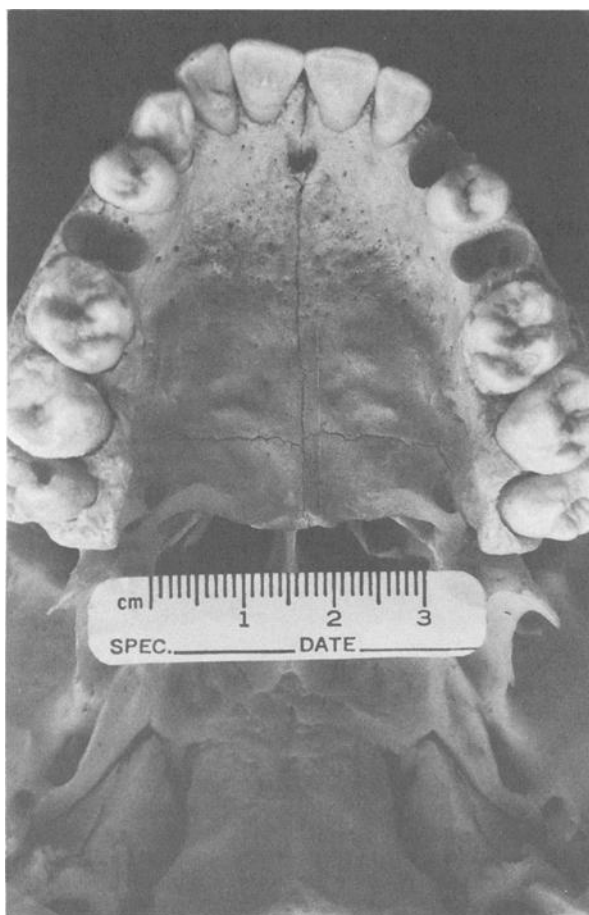


FIG. 4—Palate of a 17-year-old white male showing partial obliteration of the IN suture.

of the palate. Individuals with obliteration of more than 50% of the TP are probably over 40 years of age.

In individuals over 60 years of age, the palate typically becomes atrophic (thin) and smooth. There may be small rounded “bumps” that coalesce to form a narrow bony ridge along the anterior portion of the AMP (not to be confused with a torus palatinus). Old individuals may also exhibit obliteration of three or four of the maxillary sutures along their entire length or any segment or segments (Figs. 6 and 7). The AMP is usually the last suture to commence obliteration. Although orthodontic appliances seem to have little or no effect on the rate of suture obliteration, they can result in premature thinning (in young individuals) of the lateral portions of the palate near the alveolus.

Test Samples

A test sample of 15 modern, known-age maxillae (Table 4) was examined by the senior author (RWM) and Douglas H. Ubelaker (DHU), a physical/forensic anthropologist at the Smithsonian Institution, Washington, DC. The sample consisted of remains of individuals (mostly skeletonized) presented to Dr. Ubelaker by local, state, and federal



FIG. 5—Pattern of maxillary suture obliteration in a 33-year-old black male. Although a portion of the IN suture is visible and the PMP shows only slight obliteration, loss of the TP within the GPF (arrow) suggests an age of 30+ years.

authorities. No information concerning the age, race, or sex of any individual was known to the examiners before testing.

An additional 15 Native American maxillae (of unknown biological age) were examined by RWM and Douglas W. Owsley (DWO), (also an experienced physical/forensic anthropologist at the Smithsonian Institution) for comparison with other skeletal age indicators, including the pubic symphysis, auricular surface of the ilium, dental development and attrition, and osteoarthritis (Table 5). Age estimates were made independently by the examiners, based solely on the maxillary sutures, which were then compared with other age indicators.

Discussion

The results of this research provide evidence of marked sexual dimorphism in the rate of maxillary suture obliteration. Males typically exhibit more obliteration of the sutures at any given age than females. The principal drawback in using the percentage of obliteration of the maxillary sutures to estimate age is that overestimates of individuals of both sexes with high suture scores (that is, individuals whose combined scores approach 4.0 or complete closure of the four sutures) are likely to occur. Further, the lack of suture closure does not necessarily indicate that the individual is young; it is the *presence* of

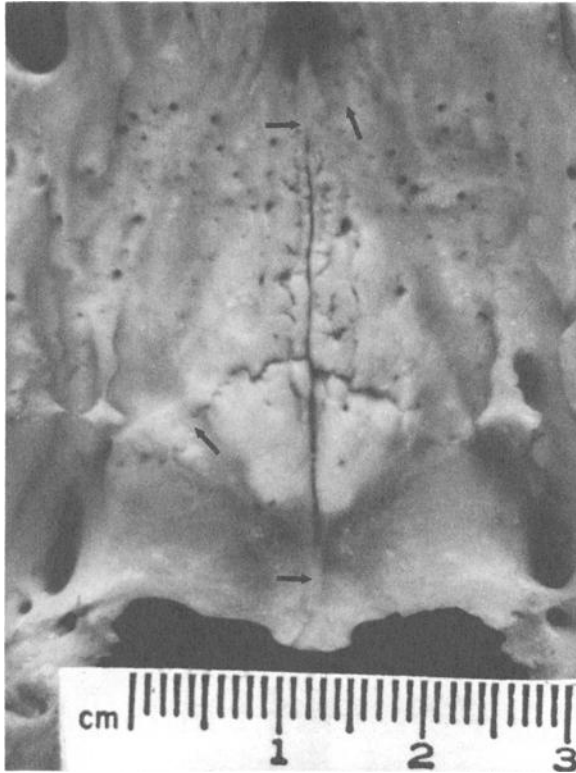


FIG. 6—Maxillary sutures in a 50-year-old black male. Although a portion of the IN suture is still visible, all four of the sutures exhibit some obliteration (arrows).

TABLE 4—Composition and results of the known-age test sample (N = 15) (estimated age based on maxillary suture closure).

Sex	Race	Known Age, years	Estimated Age, years	
			RWM	DHU
M	B	30	25–35	25–35
F	W	23	20–25	20–25
F	W	74	50+	50+
M	W	35	30–35	30–35
F	B	18	20–25	20–25
M	W	14	<20	20–25
F	W	32	30–35	30–35
M	B	54	50+	50+
F	W	41	40–45	40–50
M	W	22	20–25	20–25
M	B	28	25–30	25–30
M	W	44	40+	40+
F	W	29	20–25	20–25
M	W	38	40+	40+
M	W	27	20–25	20–25

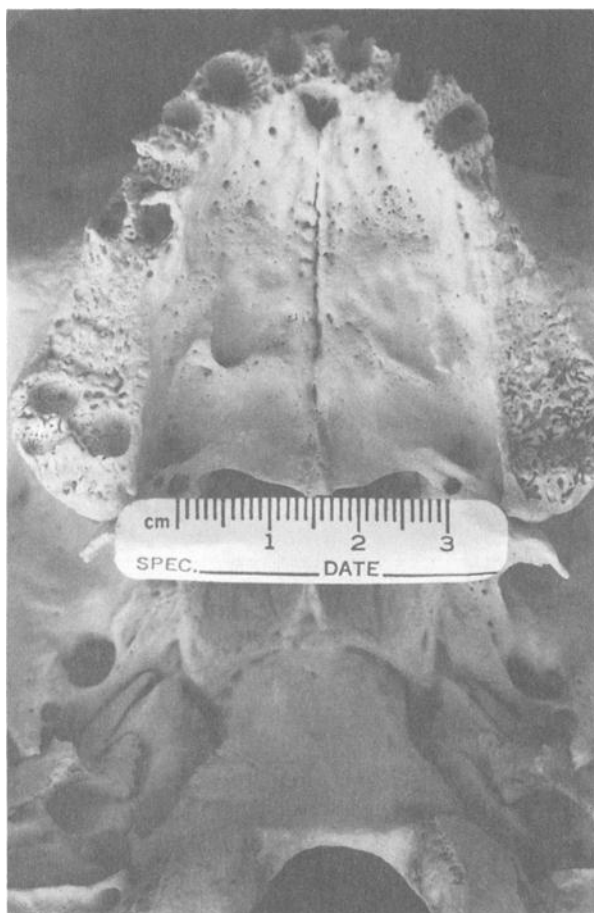


FIG. 7—Palate of a 69-year-old black male, showing advanced obliteration of the four sutures. The palate is also very thin (atrophied).

obliteration that implies increasing age. With the exception of the IN suture, moderate obliteration of two or more of the remaining sutures suggests middle age or older (however, widely gapped median palatine and nearly patent incisive sutures *are* indicative of youth).

Both test samples yielded estimated ages that were consistent for the two researchers (DHU and DWO), as well as being in general agreement with other skeletal age indicators. Table 4 shows that all but one of the age estimates using the maxillary sutures were within acceptable and practical age parameters. The one exception was a 74-year-old male estimated to be 50+ years (an error of 24 years). This underestimate reflects the inherent limitation of the maxillary sutures and other age techniques used to estimate skeletal age in individuals over 50 or 55 years. An estimate of 50+ years, however, does provide useful information for comparison and consideration with other age criteria.

After completing this study, one of us (RWM) and a number of practicing physical anthropologists applied this visual method of estimating skeletal age to skeletons from Egypt, Africa, North and South America, Alaska, Easter Island, China, Siberia, and contemporary forensic cases with success. Although some old individuals show open or

TABLE 5—Composition and results of the unknown-age (Native American) test sample (N = 15).

Sex	Predicted Age, years		
	Maxillary Sutures		Other Age Indicators
	RWM	DWO	
M	30-35	30-35	30-40
M	20-30	20-30	25-30
F	20-30	<30	25-30
M	35-45	40-45	45-49
M	20-30	20-30	20-25
F	18-25	20-25	22-28
F	20-30	20-30	20-30
F	40-50	40-50	50-55
M	>50	>50	50-65
F	15-20	18-20	18-20
M	>50	>50	50-60
M	<12	<11	6.5-7.5 ^a
F	>40	40-50	45-49
M	<20	17-20	16.5-17.5 ^a
F	>50	>50	50-60

^aEstimates based on dental development.

delayed closure of the maxillary sutures into the seventh or eighth decades of life, young to middle-aged individuals tend to show a general pattern of obliteration that correlates well with other skeletal age indicators.

In conclusion, the maxillary sutures can be of value in placing an individual in one of the general age categories of child, adolescent, or young, middle-aged or old adult; in sorting commingled remains to determine whether two or more individuals are present; and in estimating skeletal age when a complete or fragmentary maxilla is all that is present. As with any single method of estimating age in the human skeleton, care and judgment must be exercised when using the maxillary sutures. The authors hope that other researchers will investigate, compare, and refine this method of age estimation.

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