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TECHNICAL NOTE

ANTHROPOLOGY

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Palatine Sutures as Age Indicator: A Controlled Study in the Elderly

ABSTRACT: Vault sutures have proven their low reliability for estimating age at death in individual forensic science cases. We broke down the palatine sutures of 134 skulls (with known sex and age at time of death) into 15 subparts and 5 stages of fusion to obtain a mean coefficient of obliteration (*C*p) which was then linked to five age classes. We completed this study with multiple regression equations of total palatine suture scores. We compared our results with those obtained using the Mann method on the one hand and classically segmented and scored ectocranial suture age determination methods on the other. Palatine sutures generally do not estimate age at death any better than cranial vault sutures. Despite the partly subjective aspect of suture study, palatine suture observation contributes additional information to age-range estimation, especially in old and very old subjects where other methods lose their effectiveness.

KEYWORDS. forensic science, forensic anthropology, cranial sutures, age at death, palatine sutures

Forensic anthropologists are frequently asked to make age at death estimations from isolated and even edentulous skulls. The ectocranial and endocranial sutures of the vault have been well studied and documented for this purpose. Vésale (1) was probably the first to establish a link between the degree of synostosis of cranial sutures and age. Further studies linking cranial sutures and age were carried out by Broca (2), Ribbe (3), Welcker (4), and Ferraz de Macedo (5). Frederic (6) established a five-stage classification of vault suture obliteration which was adopted in further studies by Todd and Lyon (7,8), Acsádi and Nemeskéri (9,10), Perizonius (11), and Masset (12). Meindl and Lovejoy studied vault sutures in four stages of fusion (13,14). These studies showed that the correlation between vault suture features and age is medium to poor. Additionally, study samples included young, middle age, and elderly individuals, whereas very old people were not significantly represented (9,10,12).

It is therefore interesting to study the progression of palatine suture fusion with age. Palatine suture fusion and more generally facial suture fusion progresses more slowly than vault suture fusion according to Wang et al. (working on *Macaca Mulatta*) (15). Palatine sutures may contribute information to age estimation, at least before the age of 60. The original Mann method (16,17) was based upon a classification of four palatine sutures (namely, *sutura incisiva*, *sutura palatina mediana, pars anterior, sutura palatina mediana, pars posterior*, and *sutura palatina transversa*) into five degrees of obliteration. The revised Mann method (18) focused on first evidence of partial obliteration of the maxillary sutures, earliest complete obliteration, and a combination of first occurrences of fusion. Two different studies attempted to verify the accuracy of the revised method for estimating age at death using the Mann method. Ginter (19) found that the revised method was more accurate in older subjects but that better results might be obtained by combining the revised Mann method with other methods of age at death estimation. A replicative study by Gruspier and Mullen (20) came to opposite conclusions. They found that the variability in predicted age, as reflected by total suture score, was too great to recommend using this age determination method in individual forensic science cases.

Therefore, we studied palatine suture fusion with age, from a sample that included old and very old individuals. We compared the results with Mann's palatine suture method as well as other classically segmented and scored vault suture age determination methods. We also studied palatine suture obliteration progression.

Materials and Methods

Four bone collections were used for the purposes of this study. A number of skulls ($n = 38$) had to be removed from the sample due to particularities (metopic sutures, *ossae wormiae*) or pathological conditions (*antemortem* fractures or various *postmortem* alterations); 134 skulls were included in the study. The Nice bone collection ($n = 95$) comes from male and female white West Europeans living in and around Nice (France), who died between 1998 and 2006 and gave their body to the Nice Medical School for

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medical research purposes. The Schoten collection (n = 29) comes from the graveyard of a small Flemish village in northern Belgium (21,22), whose individuals died in 1931. The Châtelet collection (n = 5) comes from recent exhumations of Belgian bodies dating from 19th to 20th centuries. We also added five current forensic cases (n = 5).

Sample statistics are listed in Table 1. It must be noted that most of the skulls belong to elderly individuals, most of them (80.6%) over 60 years of age. Accordingly, we split our sample into five age classes labeled I–V (Table 2) rather than the usual four (23,24). Thus, the four age groups of 20 years or younger (infant and juvenile), 21–39 years of age (young adult), 40–59 years of age (mature adult), and over 60 years of age (old adult), became five age groups by splitting the last age group into 60–79 years of age (old adult), and over 80 years of age (very old adult).

Palatine sutures (Fig. 1) were divided into 15 subparts, namely (Fig. 2): (i) incisive half-suture (right and left), medial (IN med), and lateral (IN lat); (ii) anterior median palatine suture, divided into three equal subparts, anterior (AMP a), median (AMP m), and posterior (AMP p); (iii) posterior median palatine suture, divided into anterior (PMP a) and posterior (PMP p) subparts; and finally (iv) transverse half-suture (right and left), medial (TP med), lateral (TP lat), and intraforaminal (TP foram). Suture fusion of each of the 15 subparts was rated on a scale of 0–4 (25). Theoretically, the minimal total score was 0 and the maximum was 60. Total scores were then divided by 15 (for each of the 15 subparts), leading to a mean coefficient of palatine suture fusion (C_p) ranging from 0 to 4. This C_p coefficient was then linked to the five classes of age described in Table 2. We completed this study with multiple regression equations (Minitab™ 15; Minitab, Inc., State College, PA) of the incisive suture (IN), the anterior median suture (AMP), the posterior median suture (PMP), and the transverse suture (TP) fusion scores.

We compared our method to several other methods previously published in the literature and in particular to the Mann method and other classically segmented and scored ectocranial suture fusion studies (*coronalis, sagittalis*, and *lambdoidea*) (10,11,23,26).

TABLE 1—*Statistical data of the samples.*

		n	Time of Death	Range	Mean Years	Median
Nice	F = 44 M = 51	95	1998–2006	48–101	82.19	85
Schoten	F = 10 M = 19	29	1931	19–89	59.45	68
Châtelet	F = 2 M = 3	5	19th and 20th century	48–85	65.40	66
Forensic cases	F = 0 M = 5	5	Current cases	48–89	64.40	59
Total	F = 56 M = 78	134		F: 19–101 M: 19–96	F: 80.57 M: 72.68	F: 85 M: 77.5

TABLE 2—*Five age classes.*

Age Classes	Age Range (years)	Age Group
I	≤20	Infant and juvenile
II	21–39	Young adult
III	40–59	Mature adult
IV	60–79	Old adult
V	≥80	Very old adult

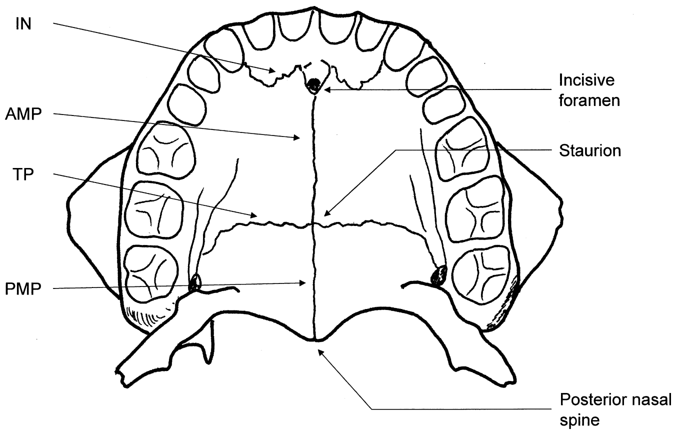

FIG. 1—*Hard palate, inferior view.*

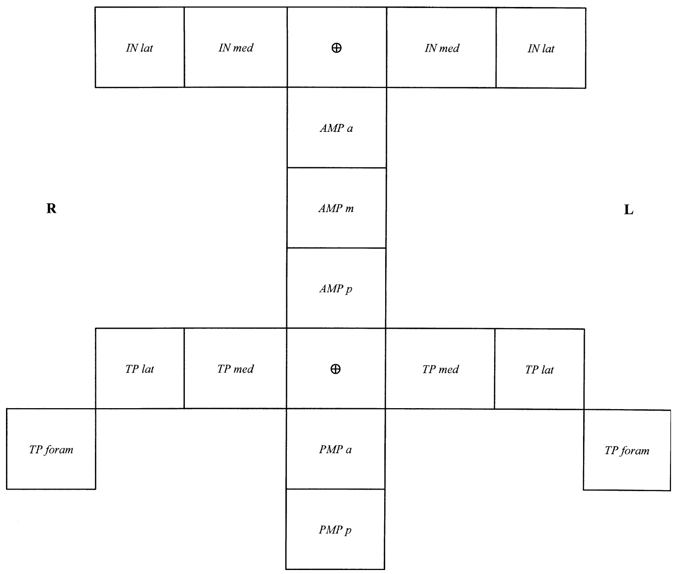

FIG. 2—*Practical scheme representing the palatine sutural divisions used in this study.*

To compare the revised Mann method with ours, we had to adjust our C_p limits as explained in Table 3, to match the Mann classes of scores (namely 0%, 1–25%, 26–51%, 51–75%, and 76–100%). Taking the *sutura incisiva* as an example, a score of 4 using the Mann method corresponds to 75–100% obliteration, and therefore corresponds to a value of 12 (75% of obliteration) to 16 (100% of obliteration) using our method.

To compare our method with other ectocranial suture fusion studies, each subpart was scored on a scale of 0–4, and the result was divided by 16, generating a mean ectocranial obliteration coefficient (C_{ec}), similar to that obtained with the Acsádi and Nemeskéri method (9,10). The coefficients C_p and C_{ec} were linked to age classes I–V (Table 2), and we compared the results using Cohen's Kappa (27). Kappa (κ) measures inter-method agreement in excess of the agreement that can be expected to occur as a result of chance. The coefficient κ calculates the ratio between, in the numerator, the observed concordance and the calculated concordance (Po − Pa) and, in the denominator, the complement of the calculated concordance (1 − Pa). Kappa is always less than or

TABLE 3—*Comparison between Mann classes, Mann sutural development, and* C_p *obtained values.*

			Values of Sutural Obliteration with Segmental Method in Mann Stages					
Stages (Mann)	Complete Obliteration	Years (Mann classes)	IN	PMP	TP	AMP	Total	C_p value
1		<20	<12	–	–	–	<12	<0.8
2	IN	20–24	≥12	–	–	–	≥12	≥0.8
3	IN + PMP	25–29	≥12	≥6	–	–	≥18	≥1.2
4	IN + PMP + TP	30–50	≥12	≥6	≥18	–	≥36	≥2.4
5	IN + PMP + TP + AMP	>50	≥12	≥6	≥18	≥9	≥45	≥3
Maximal values of obliteration score			16	8	24	12	60	4

TABLE 4—*Mean* C_p *and* C_{ec} *values obtained by observers.*

Observer	Palate Mean Coefficient of Obliteration (C_p)	Ectocranial Coefficient (C_{ec})
Obs1-t1	2.978	2.450
Obs1-t2	3.082	2.529
Obs2	2.989	2.819
Obs3	3.244	2.494

TABLE 5—*Reliability tests (ANOVA) applied on* C_p *and* C_{ec} *values.*

	C_p		C_{ec}	
	$F_{(0.95;\ 1,\ 29)}$	p	$F_{(0.95;\ 1,\ 29)}$	p
Obs1-t1/Obs1-t2	2.55	0.121	1.62	0.214
Obs1-t1/Obs2	0.04	0.846	32.33	<0.001
Obs1-t1/Obs3	16.93	<0.001	2.22	0.147
Obs1-t2/Obs2	2.22	0.147	29.32	<0.001
Obs1-t2/Obs3	7.81	0.009	0.39	0.536
Obs2/Obs3	17.9	<0.001	26.06	<0.001

TABLE 6—*Obliteration mean values obtained by observers for each palatine suture (ANOVA).*

Suture	Observers	Mean Value	$F_{(0.95;\ 2,\ 58)}$	p
IN	Obs1-t2	15.67	0.79	NS
	Obs2	15.57		
	Obs3	15.73		
AMP	Obs1-t2	7.80	10.91	<0.001
	Obs2	7.43		
	Obs3	9.00		
PMP	Obs1-t2	6.53	4.02	0.023
	Obs2	6.50		
	Obs3	7.13		
TP	Obs1-t2	16.23	3.08	NS
	Obs2	15.33		
	Obs3	16.80		

equal to 1. Kappa = 0 implies no agreement better than chance and Kappa = 1 implies perfect agreement. If Kappa is negative, which rarely happens, then the two sets of observations agree less than would be expected to occur based on chance alone. Kappa is interpreted as poor if <0.40, fair if 0.40–0.59, good if 0.60–0.74, and excellent if >0.74.

An intra-observer trial was performed by the senior author on a randomly selected sample of 30 skulls. The C_p and C_{ec} values were reevaluated (by the same observer) 30 days later. The inter-observer trials were performed by the senior author and two other independent observers (Obs2 and Obs3), working on 30 randomized skulls. The results of these intra- and inter-observer trials were tested using ANOVA.

Lastly, we documented the "progression path" of obliteration, which, according to Mann (16), is centripetal (from lateral to medial) for the incisive and transverse sutures, and is dorsoventral (from posterior to anterior) for the sagittal sutures. We described this progression path as "successful" when it was in agreement with Mann's description and "failed" in the opposite case. A few cases remained undetermined and were classified as "doubtful."

TABLE 7—*Palatine* (C_p) *and ectocranial* (C_{ec}) *suture fusion scores according to age class.*

Age Classes	n	C_p Mean	C_p SD	C_p Min	C_p Max	C_{ec} Mean	C_{ec} SD	C_{ec} Min	C_{ec} Max
I	2	2.17	0.90	1.53	2.8	0.44	0.62	0	0.88
II	3	2.44	0.14	2.33	2.6	1.13	0.31	0.81	1.44
III	21	2.90	0.50	1.87	3.87	2.41	0.72	1.15	3.75
IV	37	3.34	0.37	2.67	4	2.74	0.67	1.31	4
V	71	3.42	0.29	2.73	4	2.94	0.64	1.13	4

TABLE 8—*Cohen's Kappa test of reliability.*

P_0	P_e	P_m	κ_0	κ_m	$\left\lvert\frac{\kappa_0}{\kappa_m}\right\rvert$	SE if $\kappa = 0$	$z = \frac{\kappa_0}{SE_{(if \kappa=0)}}$	p
0.955	0.778	0.985	0.798	0.932	0.856	0.086	9.258	0

With $\kappa_m = \frac{P_m - P_e}{1 - P_e}$.

Results

Table 4 shows the results of the intra- and inter-observer trials. Table 5 shows the ANOVA results for C_p and C_{ec} values. For C_p, there was a significant difference between Obs1 and Obs3, but not between Obs1 and Obs2. For C_{ec}, there was a statistically significant difference between Obs1 and Obs2 on the one hand and Obs2 and Obs3 on the other hand, but not between Obs1 and Obs3. We think that these variations are due to the difficulty of palatine suture obliteration appreciation and to a lack of experience since reading palatine sutures is by no means routine. We noted an evolution in the first observer's results (t2) because the mean C_p value tended to increase. So, the results of this observer's second reading tended toward the results of Obs3, who had a tendency to overestimate suture scores. It is interesting to note that these two observers (Obs1 and Obs3) made very similar ectocranial suture readings.

Table 6 shows intra-segment scoring variations between the three observers. There was a significant difference in the scoring of the AMP subpart ($p < 0.001$) and the PMP subpart ($p = 0.023$).

TABLE 9—*Mean coefficient of obliteration C_p. Application of Mann method and results based on "Mann age classes" and sex repartition.*

		C_p (following Mann evolution of sutural obliteration)					
		Females			Males		
n	Mann Age Classes	*n*	Success (adequacy)	Failure	*n*	Success (adequacy)	Failure
2	<20	1	0	1	1	0	1
0	20–24	0	0	0	0	0	0
1	25–29	0	0	0	1	1	0
13	30–50	3	1	2	10	6	4
118	>50	52	41	11	66	61	5
134		56	42	14	78	68	10

Females + Males

n	Global Success	Global Failure
134	42 + 68 = 110 (82.1%)	14 + 10 = 24 (17.9%)

TABLE 10—*Sutural palatine progression.*

Evolution	Sutures	Success	Doubtful	Failure	*n*
Centripetal	Incisive suture (IN)	133 (99.3%)	1 (0.7%)	0 (0%)	134
	Transverse suture (TP)	128 (95.5%)	6 (4.5%)	0 (0%)	134
Dorsoventral	Median palatine suture—posterior part (PMP)	134 (100%)	0 (0%)	0 (0%)	134
	Median palatine suture—anterior part (AMP)	107 (80.0%)	23 (17.0%)	4 (3.0%)	134

Success: correct progression (centripetal or dorsoventral according to the concerned sutures).
Doubtful: only one section is incorrect, with correct following progression for the other sections.
Failure: incorrect sutural progression of the adjacent sections.

Table 7 links palatine suture obliteration (*C*p) to the five age classes defined in Table 2 and compares the results with the ectocranial vault suture coefficient (C_{ec}). Our results indicate that palatine suture obliteration does indeed progress with age. Additionally, suture fusion progression with age is comparable in both the palatine and the vault sutures.

Table 8 shows Cohen's Kappa between vault and palatine sutures' approaches, revealing an excellent 85.6% concordance ($\kappa_0 > 0.75$) between ectocranial and palatine age estimations.

Table 9 shows C_p scores rated as "successful" or "failed" according to concordance with Mann's score. The results show 82.1% success.

We obtained regression equations linking age and palatine suture subpart scores: (i) estimated age in female subjects = (7.4 × IN) − (0.5 × AMP) + (1.84 × TP) + (0.79 × PMP) − 77.8 and (ii) estimated age in male subjects = (5.94 × IN) − (1.53 × AMP) + (2.37 × TP) + (3.86 × PMP) − 81.9. The correlation coefficient (*R*) was 0.72 in female subjects and 0.62 in male subjects. Both are statistically significant ($p < 0.001$).

This study was also concerned with the obliteration progression path of palatine sutures (Table 10). In agreement with Mann, we confirmed a centripetal (from lateral to medial) progression of the incisive and transverse sutures, and a dorsoventral progression of the sagittal palatine sutures (Fig. 3).

Discussion

Age at death estimation remains extremely difficult, even with validated methods studying the pubic symphysis (28–32), the fourth rib (33–35), dentition (Lamendin's method) (36–39), and also multivariate methods (40,41). These methods all have their limits when applied to elderly subjects.

In the literature, palatine sutures contribute information to age-range estimation, at least before the age of 60. There is insufficient data concerning subjects above the age of 60 to justify using palatine sutures as age indicators in this particular population. The sample we worked with was composed of 134 contemporary (19th and 20th centuries) Western Europeans from the South of France (Nice area) and from Belgium. The ratio of old and very old subjects was very significant (more than 80.6% were more than 60 years of age). The median age of the Nice bone collection is 85, the year of death ranges from 1998 to 2006.

The study calculated mean palatine suture fusion scores (C_p coefficient) ranging from 0 to 4 based on the individual scores of palatine suture subparts. Persson and Thilander (42) and Persson (43) stated that palatine suture fusion starts during the third decade of life, although there is a wide range of individual variation. As expected, in our work, there was a clear evolution of C_p coefficient with age in age classes III–V. We did not take classes I and II into consideration because of our small sample size in these age groups. Furthermore, according to Kokich (44), most facial sutures remain patent until the eighth decade of life. This explains our ability to distinguish between old and very old people based on the observation and scoring of palatine sutures.

Overall, C_{ec} and C_p follow quite similar curves. C_{ec} has a weak rate of progression between age classes III–V, whereas C_p has a weak rate of progression between classes IV and V. This observation is not clearly explained, though the obliteration of palatine sutures (and more generally that of the facial sutures) is considered slower than vault suture obliteration. This fact was first noted by Wang et al. (15) in a study performed on monkeys. He recorded suture obliteration scores for 28 sutures or suture segments in a collection of *Macaca Mulatta* with known age and sex. Individual sutures and suture segments fused at very different ages in different

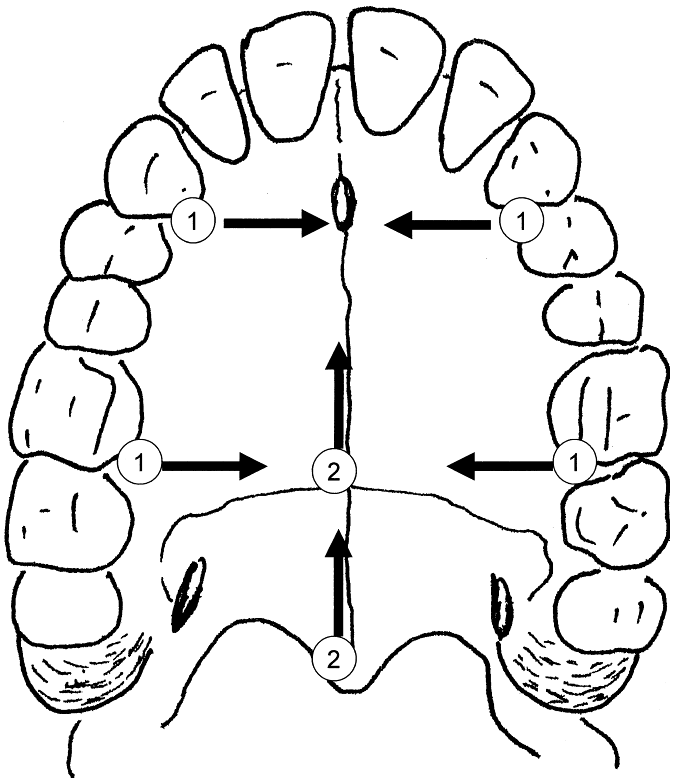

FIG. 3—*Sutural progression (centripetal for the sutures in a coronal plane and dorsoventral for the median palatine sutures).*

subjects. Facial sutures have an overall lesser rate of suture obliteration. Although the frequency of suture fusion increased with age, few cranial sutures showed any potential to single-handedly determine chronological age. Furthermore, there were significant differences in patterns of suture fusion between male and female subjects. Adult male subjects displayed higher overall rates of fusion when compared to adult female subjects.

This study confirms the fact that the progression of palatine suture obliteration is slower than the progression of vault suture obliteration. In fact, palatine suture obliteration both starts later and progresses more slowly, which underlines its interest in the study of skeletal remains of elderly subjects. There is no clear explanation for these phenomena but various transcription factors, growth factors, and their receptors are currently put forward (45–50). Nevertheless, even if we observed a later and slower progression of palatine suture fusion, when compared to vault sutures, there was more than 85% concordance between both estimations.

While comparing the (global) Mann method with our segmented method, we found an excellent concordance between both approaches (82% concordance). We also observed the same progression path (IN, PMP, TP, and AMP) than that described by Mann. Our segmented study confirms that the progression of the transverse sutures is centripetal (IN then TP), while the progression of the sagittal sutures is dorsoventral (essentially PMP since AMP yields more variation).

Conclusion

The cranium is sometimes the only skeletal remain available for analysis in forensic science cases. Vault sutures are well known for their poor correlation between suture features and age at death. A method similar to the Mann method, but using a segmented approach to the scoring of palatine suture fusion, was devised in the hopes of decreasing the observed variability in predicted age. However, it was found that palatine sutures generally do not estimate age at death any better than cranial vault sutures. Indeed, the fusion of the cranial and facial sutures currently remains a poorly understood phenomenon resulting from complex biomechanical, genetic, and other influences without the degenerative evolution observed in other articulations. Moreover, our segmented approach to palatine sutures allowed us to confirm the obliteration progression path of palatine sutures (centripetal progression for the incisive and transverse sutures and dorsoventral progression for the median palatine ones).

Our palatine suture approach suffers from the same drawbacks as other suture observation methods. In particular, there is a tendency to overestimate the age of young subjects and to underestimate the age of old and very old subjects, with the phenomenon of regression to the mean. Schmitt surmised that very old subjects in terms of chronological age are, in fact, people whose biological age progressed more slowly, which explains their significantly increased life expectancy. As Schmitt (51) described it, senescence is the progressive, irreversible, universal, and cumulative decline of the organism, inexorably leading to death. Its breadth varies from one individual to another. However, subjects exhibiting the potential for a longer life do not necessarily present an "old" skeleton. Subjects deceased at an early age can present a worn skeleton and subjects having achieved a respectable old age can have a skeleton that appears relatively young, which constitutes an osteological paradox (52).

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