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TECHNICAL NOTE

ANTHROPOLOGY

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Utility of the Frontonasal Suture for Estimating Age at Death in Human Skeletal Remains*

ABSTRACT: This project evaluated the utility of the frontonasal suture for estimating age at death. Utilizing human remains of known age at death with varying degrees of fusion, curated at the American Museum of Natural History in New York City and the Smithsonian Institution's National Museum of Natural History in Washington, DC, data were collected from the ectocranial surface of 522 crania; 68 of these were sagittally sectioned, allowing collection of internal data and observation of suture closure through the bone. Degree of ectocranial suture closure does not significantly predict age, even when sex and ancestry are accounted for. Suture closure progression data were converted into a Hershkovitz ratio (sum of the measurement of open portion divided by the total suture length), and regression models demonstrate that the effect of age accounts for only 13% of variation in suture closure.

KEYWORDS: forensic science, forensic anthropology, frontonasal suture, age at death estimation, Hershkovitz ratio

Estimating age at death of human remains is a vital component of archaeological and forensic research. It is a complex and often varied process in which multiple techniques are employed. Based on the available bones and state of the remains, different techniques are utilized in an attempt to attain the most accurate age. Considerable research has previously focused on closure of the sutures of the cranial vault as a tool for age estimation (1–5). In contrast, little is known about age changes in facial sutures and any utility they may offer for age estimation.

In their 1924 investigation of all of the cranial vault sutures, Todd and Lyon (1) observed that some sutures had an apparent lack of union and were accompanied by a "heaping up of bone tissue along the edges of the unclosed part" (p. 337). However, the study did not reveal a strong relationship between age and suture closure, and the authors concluded with a caution that the variability in the progress of the suture union makes it "unwise to depend too much upon the stage as an age marker" (1, p. 334).

Meindl and Lovejoy (2) further refined the study of cranial vault sutures using 236 crania from the Hamann-Todd Collection in Cleveland, Ohio. Meindl and Lovejoy (2) found that age-related changes in the cranial vault sutures were the same regardless of sex and ancestry. The refinements of the Meindl–Lovejoy model allowed for data originating from observations of multiple sutures. Using this method, evaluations of multiple cranial sutures are combined to generate a composite score. Each score can then be related to a corresponding age.

Galera et al. (3) suggest that data deriving from endocranial suture closure are more accurate in determining age than that from ectocranial observations. This may be so in part because a cranial suture closes endocranially first and then proceeds ectocranially (1,4,6,7). However, observations on endocranial closure can be difficult to make on intact crania (8). Further, relatively little research has been conducted on the age progression of craniofacial suture closure (5,8,9). Facial sutures have different qualities and reflect different growth patterns than those on the cranial vault (9). Information is needed on the age progression of closure of craniofacial sutures to assist with age estimations when those areas of the skeleton are the only ones available. Therefore, this study investigated the usefulness of closure of the frontonasal suture for age estimation, including both ectocranial and endocranial observations.

Materials

The sample consists of 522 human crania of known age and ancestry. Four hundred crania (100 black females, 100 black males, 100 white females, and 100 white males) originated from the Terry Collection curated at the Smithsonian Institution in Washington, DC (Table 1). Most of these 400 crania were either intact or had the skull cap separated at autopsy. The Terry Collection consists of the remains of over 1700 individuals who lived in the late 1800s and early 1900s. The majority of the collection consists of white males, and the most common cause of death is pulmonary tuberculosis (10).

The sample also included 122 crania (two black females, 16 black males, eight white females, and 96 white males) from the Osteological Collection at the American Museum of Natural History in New York City. This collection was created in the last 50 years and consists of a larger majority of white males over the age of 35 from the late 1800s and early 1900s. Additionally, the majority of the crania in this collection have been sagittally sectioned allowing examination of the progression of the suture closure from the endocranial to the ectocranial surface.

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TABLE 1—*Sample size and descriptive statistics for ectocranially observed crania.*

	Number of Specimens	Age Range (years)	Median (years)	Mean (years)	SD (years)
Stage 0	66	20–92	57.5	56.4	16.8
Stage 1	132	17–95	61	59.3	16.6
Stage 2	254	17–102	60.5	58.7	16.3
Stage 3	70	32–91	64	62.8	13.1
Total	522	17–102	60.75	59.3	15.7

The crania included in this study were selected based on their accessibility, completeness (to allow observation of the frontonasal suture), and their balanced representation of sex and ancestry. The total sample consisted of 102 black females, 116 black males, 108 white females, and 196 white males. The relatively low number of black females and high number of white males reflect their representation in the collections examined. The age at death distribution of the entire sample consists of 15 crania under 25 years (2.8%), 132 crania between 26 and 50 years (25.3%), 303 crania between 51 and 75 years (58.2%), and 72 crania over 76 years (13.8%). The sample of 68 used for evaluation of the progression of the suture consists of one cranium under 25 years (1.5%), 15 crania between 26 and 50 years (22.1%), 43 crania between 51 and 75 years (68.2%), and nine crania over 76 years (13.2%).

Methods

The extent of ectocranial closure of the frontonasal suture was evaluated using a qualitative four-stage classification modified predominantly from the system employed by Todd and Lyon (1) as well as others (2, 11). The modified classification employed here is as follows: stage 0: completely open sutures with large gaps and pronounced pitting; stage 1: sutures are mostly open, with very few points of closure; stage 2: mostly closed, where the suture is still visible, but no physical gap exists and only minor pits or lines are visible; and stage 3: completely closed, the suture is obliterated and there is no discernable gap or line (Fig. 1).

As there was a great deal of variation exhibited by each individual suture, it was important to create a standard evaluation technique. Cases of variable suture closure (Fig. 2) that did not fall clearly into one stage were given the higher score (more closed). For these cases, statistics were run giving them the next lowest score, and no significant change in the results was found. Only 33 cases warranted such judgment. For example, in Fig. 2, the suture is not closed on either side and does not have a uniform or clear boundary; this suture appears fused in some areas but open in others and thus is difficult to classify (this suture was considered a stage 2). Furthermore, sutures that did not clearly have more than 50% fused were given a lower score (a 1), and those with more than 50% were given a higher score (a 2). The score of 2 that signifies "mostly closed" indicates more than half on visual inspection was fused, and likewise, the score of 1 that signifies "mostly open" indicates more than half on visual inspection was unfused. Several crania presented only a barely discernable hairline space between the frontal and nasal bones; these were treated as near closures and given a score of 2. Only crania with clear fusion and near obliteration of the suture were given a score of 3.

In addition, a method developed by Hershkovitz (6) was utilized to quantitatively express suture condition as the "sum of the length of the open sutural segment divided by the total sutural length" (p. 395). Using sagittally sectioned crania, the progression of the frontonasal suture closure was assessed (Fig. 3). The bottom arrow in Fig. 3 denotes the open portion of the suture (on the anterior/ectocranial surface). The top arrow shows the portion of the suture that has already fused (on the endocranial surface). The

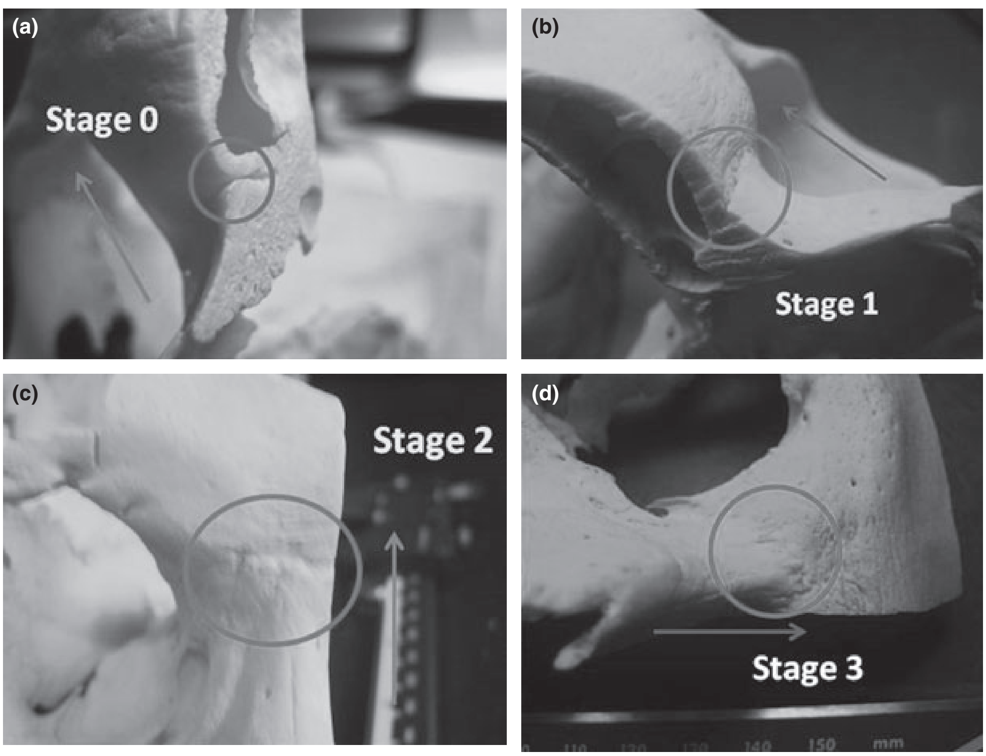

FIG. 1—*(A–D) The stage system utilized in this project was modified from previous studies (1,2), using only four stages because of the compact nature of the suture. Circles indicate the location of the suture. Arrows point superiorly.*

FIG. 2—*The variable closure of the frontonasal suture. On the ectocranial suture surface, the suture does not close in any one direction (right or left).*

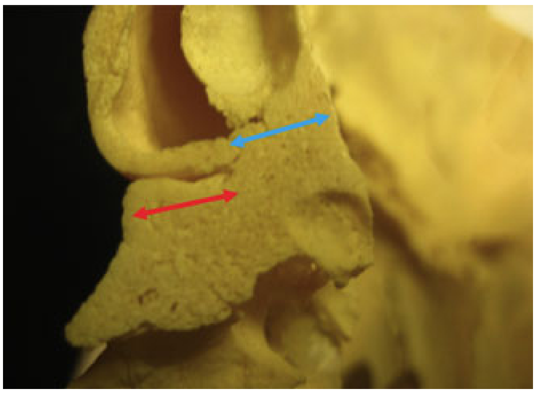

FIG. 3—*A sagittal section of the frontonasal suture. The bottom arrow ranges the span of the open portion of the suture. The top arrow ranges the closed portion. View is of the right portion of the crania, and anterior surface is on the left. This progression observation on available crania provided more significant results than looking at the ectocranial surface alone.*

Hershkovitz ratio utilizes the length of the bottom arrow and the sum of the lengths of the two arrows (or total suture length). All measurements were recorded in millimeters using digital calipers.

If the suture was completely fused endocranially and ectocranially, the ratio was given a score of 0 (as there is no open portion). This is not to be confused with the qualitative stage evaluation of the ectocranial surface of 0 that indicates an entirely open suture. In almost all sagittally sectioned crania, the suture was closed endocranially. Any suture that had not closed endocranially was given a score of 1, as the open portion is equal to the length of the suture; only three samples exhibited such a configuration. All evaluations and measurements of suture closure were made blind to actual age at death.

The results of these two assessments (qualitative on only the ectocranial surface and quantitative on sagittally sectioned crania) were then used to evaluate their association with actual age at death. First, a chi-square test was used to examine the association between suture closure and age along with the contributing influence of sex and ancestry in the ectocranially observed sutures. Second, for the quantitative data, ordinary least squares (OLS) regression was used to examine the predictive power of the progressive ratio data for estimating age, taking sex and ancestry into account. All data were evaluated using Statistical Analysis Software (SAS) Version 9.1 (12).

TABLE 2—*Results of chi-square test for independence on (A) stage and sex variables and (B) stage and ancestry variables (Fisher's exact test) for ectocranial data.*

Age Group	χ^2	*p*-Value
(A)		
Under 20	3.73	0.5714
21–30	0.31	1.0000
31–40	3.41	0.3557
41–50	3.46	0.3528
51–60	10.25	**0.0160**
61–70	5.39	0.1537
Over 70	6.92	0.0751
(B)		
Under 20	N/A	N/A
21–30	3.56	0.2335
31–40	7.35	0.0591
41–50	2.11	0.5738
51–60	1.39	0.7230
61–70	11.85	**0.0102**
Over 70	5.05	0.1859

Bold indicates significance at $p < 0.05$. Group "under 20" was not included because of lack of specimens with white ancestry.

Results

Ectocranial/Qualitative Results

The degree of closure of the ectocranial surface of the frontonasal suture shows weak association with age across most age categories. Each stage of classification shows overlapping age ranges, with markedly high standard deviations (Table 1). Further, sex and ancestry overall do not appear to exert a strong influence on the relationship between ectocranial stage of closure and age (Table 2*A*,*B*). An effect of sex on the relationship between ectocranial suture closure and age is only found for age group 51–60, where fusion in females occurs at a slightly earlier age (Table 2*A*). Similarly, ancestry shows a significant effect for the relationship between age and ectocranial suture closure stage only for ages 61–70 (Table 2*B*). Finally, there is no regularity in the direction of suture closure on the ectocranial surface of the frontonasal suture; instead, sporadic fusion was observed throughout the sample (Fig. 2).

Endocranial/Quantitative Results

The results of this study suggest that frontonasal suture closure occurs along an endocranial–ectocranial gradient. In all cases where the degree of endocranial suture closure is observed, it had progressed to a further stage of closure than seen in the ectocranial aspect of the same cranium. Using data derived from these crania, the Hershkovitz progressive ratio model was included in OLS linear regression models to determine whether the ratio predicts age at death. There is, overall, a general trend for a slight negative relationship between age and ratio; in other words, as age increases, the ratio decreases.

Two regression models estimating age utilizing the progressive ratio method indicate that sex and ancestry do not add any significant explanatory power for the predictive relationship of progressive ratio for age (Table 3). The first model estimated included all independent variables (ratio, sex, and ancestry) as predictors of age. As the analysis including all variables returned nonsignificant results for sex and ancestry as explanatory factors, these were removed and the model was run again including only the ratio value as an independent variable. This did not appreciably change

TABLE 3—*Results of three ordinary least squares regression models, examining the relationship between progressive ratio and age, sex, and ancestry (Model 1) and progressive ratio and age only (Model 2).*

Variable	Model 1	Model 2
Intercept	68.81*** (3.61)	68.53***(3.51)
Ratio	15.32***(5.55)	15.54***(5.45)
Ratio^2		
Sex	−1.73 (5.16)	
Ancestry	−1.4 (4.25)	
N	68	68
F Stat.	2.71*	8.13***
R^2	0.11	0.11
Adj. R^2	0.07	0.09

*Significant at $p = 0.10$, **significant at $p = 0.05$, ***significant at $p = 0.01$.

the R^2 values from the first model (explaining 13% of the variance with Model 2, as opposed to 9% of the variance with Model 1).

Discussion

This study suggests that the ectocranial aspect of the frontonasal suture is not particularly useful for estimating age at death. The results presented here, based on analyses of suture closure state of over 500 crania, do not reveal a statistically significant relationship between age and degree of closure observed from the ectocranial aspect. Still, there are a number of influences that must be accounted for. Most of the individuals of the Terry Collection are of a lower socioeconomic status and often held jobs of hard labor, a factor that has been suggested to influence the rate of fusion of the cranial vault sutures (5,7) and thus may also affect the rate of fusion of facial sutures. Other factors that could exert an effect on the fusion of the sutures include disease, nutrition, and trauma; these were not accounted for in this study. Frequently, the ectocranial surface was not fused in its entirety (and thus would not be scored as a 3), but was completely fused on the endocranial surface. The 68 sagittally sectioned crania showed that this closure often extended almost completely to the ectocranial surface. This would give a ratio value of almost 0, but the ectocranial stage would still be viewed as incomplete.

While the state of fusion of the frontonasal suture is fairly easily observed with macroscopic techniques, the methods used here have some shortcomings. For example, it is nearly impossible to view the progress of the suture without access to a sagittally sectioned cranium. The sectioning is, of course, destructive and may limit other subsequent forensic methods (estimation of sex, trauma, ancestry, etc). The use of computed tomography scans or other imaging methods remains unexplored for such an application and could perhaps be used to evaluate endocranial surfaces without damaging the bone. However, such imaging methods would add significant financial cost and time to an analysis. The remaining advantage of the Hershkovitz ratio technique is its relative simplicity (after access to the suture is attained).

As noted in previous studies of cranial suture closure, this study did not find any statistically significant differences among groups of different ancestry in the age-related progression of frontonasal suture closure. The Terry Collection, from which the largest proportion of the sample was derived, represents a regional population almost entirely of lower socioeconomic status, classified into white and black ancestry groups, and clearly does not represent all potential population variation in this feature. Future studies should examine other regional and ancestral groups to establish whether such variation exists in this and other age-related suture closure patterns. Cause of death (which for these individuals was largely pulmonary tuberculosis) was not considered as a factor contributing to age-related variation in suture closure patterns in this study, although other health-related variables may contribute. The data presented here suggest that the ratio of the frontonasal suture does not permit estimation of age and may therefore not be particularly useful for estimating age at death in many forensic applications. Additional data collection focused on younger samples may improve the resolution of the regression models.

While certain cranial vault sutures exhibit a "failure of union" (1, p. 337), the frontonasal suture appears to remain open much longer than those of the cranial vault and not follow the same general timing of closure. In most cases observed in this study, the suture would close completely endocranially, but even in very old individuals, fusion did not always fully extend to the ectocranial surface. This explains why the ratio of open to closed portion was far more statistically relevant than simple ectocranial observation. This suture demonstrates a tremendous amount of variation in the pattern of fusion. While the bones seem to appear to have a lose trend of fusing with age, the borders of each bone at the suture varied in their degree of obliteration.

The results of the analyses suggest that the pattern of closure in the frontonasal suture is not a strong predictor of age at death, but clearly show that the path of fusion is endocranial to ectocranial. The ratio method was most useful in cases where the suture was neither completely open nor completely closed. As with most techniques for estimating skeletal age, sex, and ancestry, it is desirable to employ multiple techniques whenever possible. While the frontonasal suture does not provide highly accurate information for estimating age at death, with further study and analyses situations may arise where utilizing this feature can be helpful. In such scenarios, the method and results provided by this study may provide a starting point for the investigative forensic anthropologist.

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