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The Impact of Sex and Ancestry on Cranial Sutures in the Hamann-Todd Collection

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Cranial suture closure exhibits a large amount of variability in the commencement, progression and termination of fusion. This paper explores how the demographic factors of sex and ancestry may affect the application of current cranial aging methods. The Hamann-Todd Osteological Collection was used to examine the sagittal, coronal and lambdoid sutures in an attempt to determine the impact of sex and ancestry on synostosis. The sagittal suture does not appear to be impacted by sex, but significant sex-based differences were noted at the coronal and lambdoid sutures. Generally, females exhibited greater suture progression than males, but synostosis was more strongly related to age in males. Ancestry also affected suture progression, with stronger age-score correlations present in black individuals compared to white individuals. Future research in cranial suture methodology should develop sex-specific methods and place greater weight on the use of the coronal suture to estimate age-at-death.

Introduction

Observations on cranial sutures go back as far as Hippocrates (McKern & Stewart, 1957). Its application as an age indicator caught the attention of researchers after work done in the mid-1800s by Gratiolet, whose research showed that there was an association between age and cranial suture closure (Ashley-Montagu, 1938; Todd & Lyon, 1924). Since then, countless authors have performed original research in an attempt to test the age-suture-closure relationship and understand the mechanisms behind sutural biology, from the early work of Todd and Lyon (1924, 1925a, 1925b, 1925c) to more recent publications like Chiba et al. (2013). Contradicting results have surfaced.

The fundamental question is whether or not cranial suture closure is influenced by age-related physiological processes like the closure of the pubic symphysis or the auricular surface of the ilium. According to many authors, there exists a positive but variable correlation between synostosis (suture closure) and age (e.g., Chiba et al., 2013; Kumar, Agarwal, & Bastia, 2013; Todd & Lyon, 1924, 1925a, 1925b, 1925c). When Dorandeu et al. (2008) examined the frontosphenoidal suture for age estimation, their prediction variability and R^2 value indicated that one or more co-factors in addition to age impacted cranial synostosis. So, the answers to this question are numerous and can include sex (e.g., Brooks, 1955; Dorandeu et al. 2008; Key, Aiello, & Molleson, 1994; Meindl & Lovejoy, 1985), ancestry (e.g., Meindl & Lovejoy, 1985), genetics (i.e., idiosyncratic differences or interpopulation variation, see Wolff, Hadadi & Vas, 2013), nutrition and pathology (e.g., Reilly, Leeming & Fraser, 1964), biomechanical stress (e.g., Cohen, 1993), and environment factors (e.g., Perizonius, 1984). To complicate matters, not all of these factors will be consistent across different populations; what impacts sutural union in one group may not be evident in another group.

Singer reports that "...the age of the

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individual at death cannot be estimated from the degree of closure of the various cranial sutures, whether taken individually or collectively or whether observed exocranially or endocranially" (1953, p. 56). Although scoring cranial sutures is relatively simple, the limitations of this technique can yield unreliable results. The single most influential limitation of cranial suture aging is the large degree of variability that exists in the commencement, progression, and termination of fusion in sutures. For instance, even when Todd and Lyon (1924, 1925a, 1925b, 1925c) eliminated all subjects that exhibited abnormal closure patterns (e.g., early or delayed fusion, abnormal rate of union during fusion), concrete age ranges failed to surface. The factors that influence sutural mechanics, like sex and ancestry, continue to be a subject of debate.

There is much debate on the impact of sex on synostosis. Authors like Dorandeu et al. (2008) (modern-day French autopsy cases), Perizonius (1984) (20th century Dutch sample from Amsterdam), and Acsádi and Nemeskéri (1970) (19th century Hungarian population) found no sex-based biases in their samples. Meindl and Lovejoy (1985) used the Hamann-Todd Collection (American population, 19th-20th century) for their research and concluded that sex and race did not bias age estimation.

On the other hand, when Key, Aiello, and Molleson (1994) analysed the Spitalfields sample from London, England, they saw that sex-related differences in closure were apparent, especially in the coronal and sagittal sutures. Here, females exhibited a stronger relationship between synostosis and age. Males exhibited open or partially closed ectocranial (exterior surface of the skull) sutures in senescence more frequently than females. Earlier works, like Singer (1953) and Brooks (1955), support a sex-based influence on closure as well. Brooks (1955) found that cranial suture closure in females lagged behind the age-related changes observed in the pubis. Although this delay was present in males as well, there was a greater discrepancy between female pubic and cranial ages. Mann, Jantz, Bass, and Willey's (1991) study on the maxillary suture showed that males of both white and black ancestry exhibited more suture obliteration than similarly-aged females. However, they noted that the rate of progression toward union in early adulthood was virtually the same in both sexes. In response to these mixed results, Key, Aiello, and Molleson (1994) concluded that sex-based differences in synostosis varies across populations, and the degree of dimorphism is reflected more extensively on the ectocranial surface rather than the endocranial (or interior) surface.

More recently, in Kumar, Agarwal, and Bastia's (2013) study on an Indian sample, synostosis occurred earlier in females on both the endocranial and ectocranial surfaces of the sagittal suture. The pattern was the same for the coronal and lambdoid sutures as well. Chiba et al. (2013) documented sex-based differences in progression of the sagittal suture in a modern-day Japanese sample. Even though sutural progression was not significantly different between the sexes, progression in the sagittal suture of females advanced in a more predictable manner than males. If fusion is connected to genetics, then different populations may or may not show sex-based trends. If genetics plays a minimal role, then the contradicting results are rather puzzling.

Due to the high degree of variability in synostosis, cranial suture closure is not recommended for aging and is often not used, particularly when the pelvis (a far better indicator of age) is recovered in archaeological and forensic remains. However, since the skull is composed of some of the most robust bones in the skeleton and thus preserves well, it is vital to re-examine cranial sutures (White & Folkens, 2005). In a case where the skull (without dentition) is the only preserved part of the body, aging is solely dependent on progression in cranial sutures. This is of particular importance for archaeological specimens, which have endured greater exposure to taphonomic processes (i.e., processes that affect preservation after death) and are subject to poor preservation.

Presently, studies done by anthropologists tend to focus solely on the presence or absence of age-synostosis trends. This study approaches this problem from a combined biological-anthropological point of view and attempts to find the factors that may cause variation in fusion. It is hypothesized that a number of variables are responsible for the high degree of variability seen in age estimations based on cranial sutures. Controlling these variables may restrict this variability and produce smaller age ranges. Specifically, the impact of sex and ancestry were tested using the Hamann-Todd Osteological Collection. The aims of this study were two-fold: first, the paper distinguished how males and females of white and black ancestry differ in regards to sutural progression. Two Aboriginal individuals were considered here as well for further comparison. The implication of the results on the usage of cranial sutures as a means of aging was considered. Second, the reason(s) for sex-based differences in sutural progression was explored.

Materials and Methods

Sample

The impact of sex and ancestry on sutural progression was examined in the sagittal, coronal, and lambdoid sutures. The crania used in this study came from the Hamann-Todd Osteological Collection housed at the Cleveland Museum of Natural History (CMNH) in Cleveland, Ohio. The collection is comprised of individuals of low socioeconomic status dating to the 19th and 20th centuries with documented age, sex, and ancestry. This information was initially amassed by the collectors from medical records, autopsy reports, and in-lab examination of the cadavers.

The sample size consists of 259 to 276 individuals, depending on the suture (Table 1). The youngest individual is 15 years old while the oldest is 89 years. The average age for each suture group is approximately 50.2 ± 20.5 years, indicating that the collection is relatively aged. The age distribution of the sample is illustrated in Figure 1. Males and females made up 58.7% (n=162) and 41.3% (n=114) of the sample, respectively. Three ancestral groups were included: white (n=170), black (n=104), and aboriginal (n=2). More specific ancestral information was not available for these groups, although one of the aboriginal individuals is suspected to be of Amerindian origin from the Southwest United States (likely Pima or Papago).

Methods

In order to assess the impact of sex and ancestry on sutural closure, the subjects were divided as being male or female, and white or black. Using these categories, age was plotted against a score that described the degree of fusion that had occurred at the time of death (see below for more details). The subjects were then divided arbitrarily into decade-long age groups (with the exception of the adolescent group, 15-19 years) in order to examine the strength of the age-score correlation as a function of age, and to further explore differences in sutural progression between the sexes.

The age groups were divided as follows: group 1, 15-19 years; group 2, 20-29 years; group 3, 30-39 years; group 4, 40-49 years; group 5, 50-59 years; group 6, 60-69 years; group 7, 70-79 years and group 8, 80-89 years. Male scores were subtracted from female scores and absolute values were used to assess the greatest difference in progression.

Scoring System

A revised scoring system based on the Meindl-Lovejoy method was used to establish the degree of fusion reached in the suture (Table 2). As demonstrated in Table 2, the first three stages are synonymous with the Meindl-Lovejoy system. A score of one describes an open suture; the margins of the bones are not connected (equivalent to the Meindl-Lovejoy score of zero; see Appendix I). A score of two implies minimal closure. At this stage, bony spicules (thin, irregular projections that stem from the margins) have formed (equivalent to the Meindl-Lovejoy score of one). Significant closure is denoted by a

Table 1. Number of individuals (n) used for each suture

Suture	n	Sex		Ancestry		
		Male	Female	White	Black	Aboriginal
Sagittal	276	162	114	170	104	2
Coronal	264	150	114	159	103	2
Lambdoid	259	147	112	156	101	2

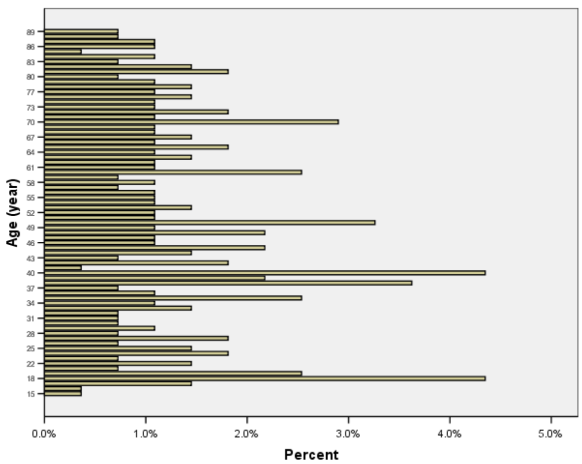

Figure 1. Age distribution of the Hamann-Todd sample used in this study for the sagittal suture. Coronal and lambdoid age distributions vary only slightly.

score of three (equivalent to the Meindl-Lovejoy score of two). The bones are connected by larger masses of bone rather than spicules. Stage 4 describes the suture as it nears obliteration. A shallow groove is present to mark the location of the suture, which is now well-fused. This stage is not present in the Meindl-Lovejoy system; it is not distinguished from complete obliteration. The last stage (Stage 5) describes a completely obliterated suture where all traces of the suture have been eradicated. A smooth bony surface is the outward appearance. This is similar to stage 3 of the Meindl-Lovejoy system. In the new methodology, however, the surface appearance of stage 5 is restricted (i.e., it can only take one form: a smooth bone layer), but in the Meindl-Lovejoy system, obliteration can refer to both near and complete obliteration.

The importance of using this particular scale is to track exactly (as allowed for by macroscopic observation) how much progression is reached by a certain age. Even though stages 4 and 5 have essentially undergone the same level of sutural closure, their surface appearance looks different (see Appendix I), and this may be important for constructing age techniques based on sutures. Essentially, this scale is a more precise tracker of progression, because it addresses stages of closure not accounted for in the generalized Meindl-Lovejoy method (e.g., stage 4 is not seen in the Meindl-Lovejoy method). Although Meindl and Lovejoy (1985) reported that lateral-anterior sutures are better predictors of age, vault sutures were examined here to test whether a revised methodology would improve the strength of age-score correlations.

Scoring began at the anterior tip of the sagittal suture (bregma), and proceeded posteriorly. For the bilateral coronal and lambdoid sutures, measurements began at the rightmost portion of the suture. Using a digital caliper, the suture was measured from the starting position to the point where there was a change in the appearance of the suture. At this point, the length of that segment (to the tenth decimal place) and its score were recorded in an Excel spreadsheet. Using the segment lengths obtained for each person's suture and their respective scores, a single weighted score was calculated and used in statistical analysis to determine the relationship between age and synostosis. The following formula was used to generate a weighted score between 1 (open) and 5 (complete obliteration):

Weighted score = ((segment 1/total suture length) x segment 1 score) + ((segment 2/total suture length) x segment 2 score) +... ((segment n/total suture length) x segment n score)

Table 2. A 5-point scale used to track sutural progression.

Stage	Description	Bone activity	Surface appearance	Meindl-Lovejoy[1] equivalent
1	Open	Suture is patent; no bony protrusions uniting the two sides	Open	0
2	Minimal closure	Bony spicules have formed and connect the two sides	There are many deep grooves	1
3	Significant closure	The bones are connected by larger masses of bone rather than spicules	The depth of grooves is just below the surface	2
4	Near obliteration	Significant fusion has occurred	Depth of the groove is very shallow, sometimes appearing as a faint line	2
5	Complete obliteration	All traces of the suture have been obliterated	Smooth bone layer	3

[1]Meindl and Lovejoy (1985)

Using this formula means that a score is no longer a discrete variable like the Meindl-Lovejoy system; it is continuous instead. So, a score of 2.7 would mean that the suture is at minimal fusion but progressing towards significant closure. It allows for a more meaningful comparison of individuals as well. For instance, if scores of 1.6 and 1.9 were rounded, both individuals would be classified as exhibiting minimal fusion. Keeping the weighted score as a continuous variable shows that second individual shows more progression, however slight it may be. Thus, the exact stage of progression of a suture is not lost under broad categories.

Statistics

Spearman's rank order correlation was calculated by SPSS 14.0 to determine the strength of the relationship between weighted score and age, sex, and ancestry. This was used rather than Pearson's correlation because most of the data are not normally distributed (the exception is the lambdoid suture). Furthermore, Pearson is sensitive to skewed data. There are many outliers, which cannot be justified for exclusion; Spearman is good at minimizing the effect of outliers. Lastly, even though weighted score is continuous, it is based on ordinal data and is interpreted categorically, making Spearman the appropriate method of determining correlation in this dataset. Due to the lack of normality, non-parametric Mann-Whitney tests were conducted to compare average weighted scores of subgroups. All p values under 0.05 were regarded as significant.

Terminology

The definitions of a few terms are clarified here. Ancestral groups are referred to as white or black. The former is used to describe individuals of European background while the latter refers to people of African descent. Population refers to a broad group of people who exhibit biological (i.e., genetic) similarities. In this study, the terms white and black populations are used in a general sense to convey the genetic differences between these groups. It is acknowledged that intra-group genetic variation may exist.

Results

Impact of Sex

Table 3 demonstrates that when the sample was divided by sex for the sagittal suture, the male sagittal scores (r_s=0.33, p=0.000, n=162) showed a stronger correlation to age than that of females (r_s=0.25, p=0.007, n=114), but the difference in mean weighted score was not significant (U=8481.0, p=0.250). Females, however, showed greater overall progression ($\bar{x}$ =3.61±1.11) compared to males ($\bar{x}$ =3.40±1.18). The age distribution of both groups was not significantly different, eliminating the idea that the presence

Table 3. The Spearman rank order correlation (r_s) of the weighted scores of the sagittal, coronal, and lambdoid sutures and exclusion variables (sex and ancestry) with their associated *p* value and sample size (n).

		Sagittal			**Coronal**			**Lambdoid**		
Variables	**Exclusion**	r_s	***p***	**N**	r_s	***p***	**n**	r_s	***p***	**n**
Sex	Males only	.334	.000	162	.492	.000	150	.253	.002	147
	Females only	.251	.007	114	.384	.000	114	.364	.000	112
Sex and ancestry	Black males only	.474	.000	56	.567	.000	55	.345	.011	54
	White males only	.237	.014	106	.370	.000	95	.164	.117	93
	Black females only	.326	.024	48	.566	.000	48	.405	.005	47
	White females only	.122	.338	64	.192	.129	64	.264	.036	63

of certain age groups accounts for the above results (U=8989.0, *p*=0.710). Even within the adolescent group, females show a faster rate of development; the difference was significant in the sagittal (U=24.0, *p*=0.019, n=23) and coronal (U=27.0, *p*=0.015, n=24) sutures.

In the coronal suture, the weighted scores of males and females were significantly different from each other (U=6443.5, *p*=0.001). As observed with the sagittal suture, males (r_s=0.49, *p*=0.000, n=150) had a stronger age-score correlation compared to females (r_s=0.38, *p*=0.000, n=114), but females showed greater overall progression with a mean weighted score of 3.52 ± 0.84 ($\bar{x}_{males}$=3.19±0.74; Table 3). Patency was not observed in females; this supports the idea of faster progression in females. Both sexes showed obliteration of the coronal suture, but there were more cases of obliteration in females (n=5) compared to males (n=3).

Both sexes showed low correlations in the lambdoid suture (Table 3), but females (r_s=0.36, *p*=0.000, n=112) showed a stronger age-score correlation than males (r_s=0.25, *p*=0.002, n=147). In fact, females had significantly greater scores than males (U=6831.5, *p*=0.019). On average, females showed greater progression, where mean weighted scores were 2.86 ± 0.62 for males and 3.16 ± 0.90 for females. Although obliterated lambdoid sutures were uncommon (n=3), females were more likely to exhibit obliteration since not a single case of obliteration was seen in males. When the sample was divided according to sex and ancestry (Table 3), black individuals exhibited stronger correlations compared to white individuals. In the sagittal suture, black males had the highest r_s value (r_s=0.47, *p*=0.000, n=56), followed by black females (r_s=0.33, *p*=0.024, n=48). White males exhibited a moderately weak trend (r_s=0.24, *p*=0.014, n=106). These correlations were all significant with the exception of white females, who had the lowest correlation as well (r_s=0.12, *p*=0.338, n=64).

In the coronal suture, the age-score correlations were weakest in white males (r_s=0.37, *p*=0.000, n=95) and females (r_s=0.19, *p*=0.129, n=64; Table 3). It was strongest in black males and females (r_s=0.57, *p*=0.000, n=55,48). Compared to the sagittal and coronal sutures, white females had a stronger age-score correlation in the lambdoid suture (r_s=0.26, *p*=0.036, n=63), while white males had the lowest correlation (r_s=0.16, *p*=0.117, n=93; Table 3). Again, age-score correlations of black males (r_s=0.34, *p*=0.011, n=54) and females (r_s=0.40, *p*=0.005, n=47) were considerably stronger than their white counterparts. There were no concrete consistencies between the three sutures, although the same population-based differences were present in all three.

Combining Sex and Ancestry

When the weighted scores of two Aboriginal individuals (females aged 34 and 35 years) were compared with white and black individuals (belonging to age group 3, 30-39 years), the Aboriginal scores were much lower. For instance, in the sagittal suture, average weighted scores were comparable in white (3.78±1.08, n=20; significant fusion progressing toward near obliteration) and black individuals (3.47±1.18, n=14), but the Aboriginal individuals exhibited minimal fusion (progressing toward significant fusion). A similar trend was seen in the coronal

Table 4. Average weighted scores for males and females and their respective standard deviations (SD) and sample size (n) according to age group.

Suture	**Age group**	**Males**	**SD**	**n**	**Females**	**SD**	**n**	$\lvert \Delta\ \bar{x}_{fm} - \bar{x}_m \rvert$ *
Sagittal	15-19 yrs	2.01	0.99	16	2.97	1.06	9	0.96
	20-29 yrs	3.09	1.36	19	2.32	0.77	10	0.77
	30-39 yrs	3.34	1.15	18	3.86	1.13	23	0.52
	40-49 yrs	3.60	1.04	27	3.70	1.17	18	0.10
	50-59 yrs	3.69	1.17	21	3.70	0.92	14	0.01
	60-69 yrs	3.92	0.85	19	3.86	1.11	19	0.06
	70-79 yrs	3.69	0.89	23	3.92	0.85	13	0.23
	80-89 yrs	3.81	0.83	19	3.89	0.99	8	0.08
Coronal	15-19 yrs	2.54	0.68	16	2.67	0.27	9	0.13
	20-29 yrs	2.51	0.52	16	3.02	0.63	10	0.51
	30-39 yrs	3.00	0.58	17	3.44	0.73	23	0.44
	40-49 yrs	3.27	0.64	26	3.53	0.99	18	0.26
	50-59 yrs	3.33	0.94	17	3.72	0.78	14	0.39
	60-69 yrs	3.43	0.74	16	3.69	0.72	19	0.26
	70-79 yrs	3.53	0.60	23	3.99	0.81	13	0.46
	80-89 yrs	3.38	0.52	19	3.78	1.00	8	0.40
Lambdoid	15-19 yrs	2.41	0.97	16	2.55	0.45	9	0.14
	20-29 yrs	2.68	0.52	18	2.30	0.51	10	0.38
	30-39 yrs	2.80	0.43	15	3.17	0.71	22	0.37
	40-49 yrs	2.80	0.48	21	3.31	1.14	18	0.51
	50-59 yrs	2.98	0.62	18	3.16	0.93	14	0.18
	60-69 yrs	3.09	0.65	18	3.26	0.88	18	0.17
	70-79 yrs	3.08	0.51	23	3.57	0.90	13	0.49
	80-89 yrs	2.90	0.49	18	3.72	0.68	8	0.82

* $\bar{x}_m$ and $\bar{x}_{fm}$ are the average weighted scores for males and females, respectively.

and lambdoid sutures as well. Although only two Aboriginal individuals were used here, this may suggest that significant population-based differences may exist in sutural progression.

Age Groups

In the sagittal suture, the female average weighted score surpassed that of males in virtually every age group (Table 4). The exceptions were age groups 20-29 years and 60-69 years. Females showed faster progression in every age group in the coronal suture (Table 4). In the lambdoid suture, only males aged 20 to 29 years progressed more rapidly than similarly aged females; every other age group showed greater sutural progression in females (Table 4). The greatest difference between male-female scores was seen in adolescent individuals in the sagittal suture. This stands in contradiction to the coronal and lambdoid sutures, where adolescents of both sexes exhibited minimal differences in score. Differences did not increase or decrease in a predictable (i.e., linear) manner with increasing age. However, in the sagittal suture, differences between male-female scores decreased after 40 years of age. Definite patterns could not be discerned from the other sutures.

Discussion

It is interesting to note that there were no statistically significant sex-based differences in the progression of the sagittal suture, although the opposite was true for the coronal and lambdoid sutures. Quizzically, Meindl and Lovejoy's (1985) study was based on the same collection, but yielded no sex- or population-based differences in fusion. Use of the entire length of the suture and the altered scoring system may have more readily detected these otherwise subtle trends. This points to the significance of methodology and its impact on results. Simply approaching the problem from another point of view is enough to produce contradicting patterns. Future studies should compare fusion in segments with the entire suture in order to test whether the results shown here are present in other populations.

There is no single sex-based trend that is consistent across these sutures. This explains why contradicting data are present in the literature. Some trends, however, are apparent in the Hamann-Todd Collection. Despite the lack of significance, even in the sagittal suture, females had greater overall scores than males. This contradicts the general consensus reached by many studies, like Hershkovitz et al.'s (1997) work, where females exhibited an open sagittal suture more often than males. Nevertheless, it does support the results of more recent works like Kumar, Agarwal, and Bastia (2013).

A potential complication may be that only parts of a suture are impacted by sex. Zambrano (2005) found that age-score correlations were stronger for females in sutures of the vault and on the endocranial surface while males showed better correlations in the lateral-anterior sutures. Ultimately, the question is why it is necessary for the sutures of females to fuse faster.

The Hamann-Todd data may suggest that different sutures may be influenced by different genetic and perhaps environmental factors. Each sex may react differently to these impacts due to physiological dissimilarity. For example, females have more estrogen in their bodies than males, which is a hormone that has been linked to limb bone growth and maintenance. James et al. (2009) tested the role of estrogen in synostosis in mice. They found that estrogen signaling through one particular estrogen receptor (ERα) was essential for synostosis to occur in the interfrontal suture (analogous to the human metopic suture). It is hypothesized that estrogen is closely associated with osteoblastic (bone-producing) activity in the cranium as well as in the appendicular skeleton. Since females carry a larger quantity of estrogen in their body, this is a potential explanation for elevated weighted scores. Current age estimation techniques do not account for these sex-based differences in sutural development.

Population-based differences

The presence of population-based differences is not surprising. Like sex, contradicting patterns have been seen in different ancestral groups. For instance Cray, Mooney, and Siegel (2011) investigated sutural development patterns in the Islands by comparing Paleo-Aleutians and present-day Aleutians, both of whom exhibit distinct cranial shapes (e.g., dolichocranic vs. brachycranic; long and short crania, respectively) and varying degrees of facial prognathism. They found that both groups exhibited similar ectocranial sutural development, and they suggest that sutural progression is independent of skull shape. Despite the temporal distance and difference in cranial morphology between both groups, genetic mechanisms remained unchanged. Even within a population, there is variation in synostosis. Goyal, Singh, Verma, Asawa, and Kochar (2011) examined the lambdoid suture via radiograph in males and females from the Indian states of Rajasthan and Punjab to find that the suture closed at 80-81 years in the former and 55-65 years in the latter. The authors attribute this difference to climate, genetics, diet, and lifestyle differences.

The results show that different populations will exhibit greater progression in specific sutures. In the Hamann-Todd sample, black individuals showed greater progression in the coronal suture, but less development in the sagittal suture compared to white subjects. In the lambdoid suture, white individuals showed greater degrees of synostosis. When the age distribution of the samples is taken into account, it was evident that faster progression is seen in black subjects in all three sutures. Despite having a younger sample, black individuals showed average weighted scores that were similar to the older white individuals. Like sex, population-based based differences in fusion are not accounted for in current aging methods using cranial sutures.

Why white subjects would be less likely to have a predictable age-score relationship is puzzling. It may be due to the differing age distributions of the sample. A population-based, genetic difference might influence development or it may be entirely environmental; after all, the subjects of the Hamann-Todd Collection date to a period in American history where life would have been very different for white and black individuals. The Hamann-Todd subjects lived during a time of racial discrimination and social inequality, where living conditions tended to be poorer for black individuals compared to their white counterparts in the 19th and 20th centuries in America. Employment opportunities were minimal and they were restricted to the slums and subjected to unsanitary housing conditions (Case Western Reserve University and the Western Reserve Historical Society, n.d.). The differences in standards of living were apparent even amongst the poor class, which would have reduced the survivability of black individuals and increased their chances of contracting disease.

Further, ancestral designations may have affected outcomes. The label 'white' is comprised of a number of European populations and consequently can encompass a large amount of genetic diversity. If different ancestral groups have unique sutural pathways, strong age-score correlations will not emerge. Future studies should be directed at a single, genetically-similar group in order to neutralize this error. For example, the Coimbra Skeletons Collection, which is made up of individuals of predominantly Portuguese ancestry from a cemetery site, would serve as an ideal sample.

The results of this study hold serious implications to current aging methods based on cranial sutures. The need for a dependable method developed using cranial sutures is urgent as the skull is one of the most readily preserved elements of the skeleton. The Meindl-Lovejoy aging system is popular amongst osteoarchaeologists and forensic anthropologists; it is both easy to use and practical. However, sutures are affected by a number of variables that are not accounted for in present-day techniques, and sex and ancestry are only two of them. The discrepancy between results based on the same sample is worrisome and may be a result of differences in methodology. Thus, researchers' methodologies need to be heavily scrutinized.

Conclusion

Cranial sutures and their applicability to skeletal aging is a complex problem with a multifactorial solution. This study explored sex- and population-based differences in sutural progression in the Hamann-Todd Collection. A number of authors report that sex-based differences in the progression of sutures is non-existent (see, for example, Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985; Perizonius, 1984; Todd & Lyon, 1924; Wolff, Hadadi, & Vas, 2013). Brooks (1955) contradicts this, showing that females exhibited patency longer than males in her sample. In fact, she recommended that cranial sutures not be used for aging in females due to its variability.

This study generated results that are both in accordance and disagreement with current literature, and has contributed to the existing knowledge on cranial sutures in two major ways. Firstly, it was shown that differences in methodology can produce contradicting results that researchers need to be aware of. Using a revised scoring technique on three vault sutures has demonstrated that sex-linked differences in sutural progression exist, even though Meindl and Lovejoy's (1985) study concluded otherwise.

Secondly, the effects of sex and ancestry as revealed by Clevelanders from the 19th and 20th centuries were described. Correlations were generally weak, particularly in females, which aligns well with Brooks' (1955) observations. In the coronal and lambdoid sutures, females showed greater progression than similarly-aged males. The sagittal suture was the only suture to exhibit similar rates of sutural progression between the sexes.

These results offer three important propositions to the construction of future techniques. First, the same cranial aging methods should not be used for males and females. Secondly, cranial sutures should be used with caution on females. The results show that age estimations generated from cranial sutures are more likely to be accurate for males as they have a stronger age-score correlation. Lastly, the coronal suture (or segments of the coronal) may be more helpful in predicting age than the sagittal or lambdoid sutures.

Fusion in cranial sutures is clearly impacted by multiple factors, like sex and ancestry. In order to increase the accuracy of cranial aging methods, further research needs to be done on the biological and environmental factors that can alter sutural pathways. Some factors that future studies can focus on are impacts of malnourishment, illness (acute and chronic), biomechanical stress to the suture, genetics, and secular change. Although ancestry was discussed in this paper, further research needs to be done on the sutural pathways of other ancestral groups in order to determine the extent of population-based variability. Sutural pathways need to be documented on a single, genetically similar group. Once the effects of these factors have been established, existing and future techniques can be (re)designed to minimize variability.

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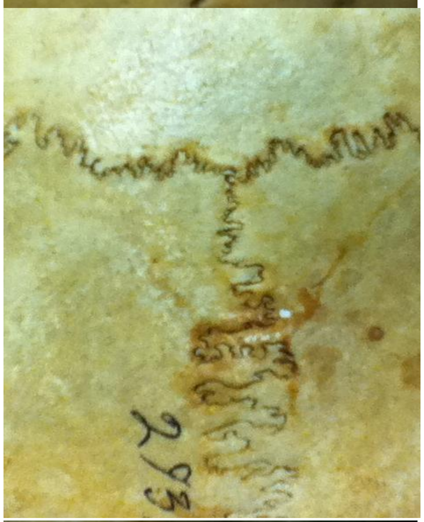
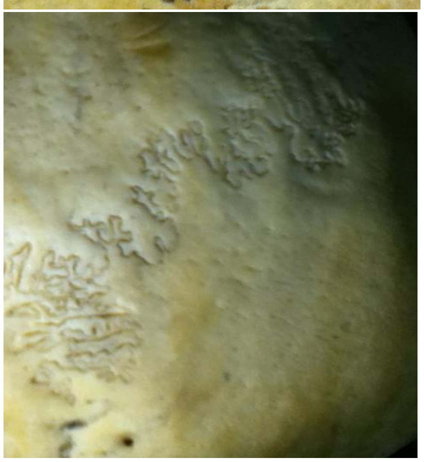
Appendix I Illustrations of stages of fusion

1

2



3



4

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Source: Hamann-Todd Collection, Cleveland Museum of Natural History.