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Positive identification using frontal sinus comparisons: Developing empirically based guidelines

Final Research Report

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Summary of Project

Major Goals and Objectives

When faced with an unknown decedent, medical examiners, investigators, and forensic personnel are tasked with obtaining a positive identification as quickly as possible. Owing to their unique morphology, frontal sinus morphology, assessed via radiographic comparisons, has been recognized as a method of identification since the 1920s (e.g., Schuller, 1943; Culbert and Law, 1927; Asherson, 1965). However, many of these early forensic studies establishing frontal sinus "uniqueness" are based on subjective, anecdotal evidence of frontal sinuses with conclusions drawn from simple visual comparisons. While this visual-based method has a reportedly high rate of success (Kullman et al., 1990; Kirk et al., 2002; Besana and Rogers, 2010; Smith et al., 2010), others suggest it lacks the objectivity and statistical rigor now expected for admissibility in court, as detailed by the *Daubert* guidelines *(Daubert v Merrell Dow Pharmaceuticals, 1993)* and the 2009 National Academy of Sciences report (see Christensen, 2004b; Cox et al., 2009; Presidents Committee of Advisors, 2016). Several frontal sinus identification methods have been proposed as more objective pursuits, such as those using outline-based analyses, linear metrics, and/or coded frontal sinus traits (Christensen, 2004a; Cameriere et al., 2005; Tatlisumak et al., 2007; Cox et al., 2009). However, most identification methods utilizing frontal sinuses either have relatively small sample sizes and/or have not been externally validated, thus the most accurate and repeatable frontal sinus method has not been established. Further, other external factors— such as sex- and population-based differences in sinus appearance and whether slight differences in orientation, age, and/or varying image modality between ante- and post-mortem images affect sinus identification methods— have not been fully explored.

Research Questions

This grant funded projects operates under seven research objectives to ultimately determine which frontal sinus method is the most accurate and repeatable, in addition to considering the external factors listed above. These methods include two outline methods, the elliptical Fourier analysis (EFA) Method (Christensen, 2004a) and Total Difference Method (Cox et al., 2009); two coding methods, referred here as the Cameriere Method (Cameriere et al., 2005) and the Tatlisumak Method (Tatlisumak et al., 2007); and visual assessment methods.

Obj. 1) ***What are the standard accuracy & error rates as related to frontal sinus positive identification methods?*** While several frontal sinus identification methods have been proposed, most have relatively small sample sizes and/or have not been externally validated. This portion of the grant assesses which frontal sinus method listed above is the most accurate.

Obj. 2) ***What are the intra- & inter-observer reliability rates across these methods?*** Similar to Obj. 1, as most studies have not been externally validated, they have not been tested for intra- and inter-error. This portion assesses which frontal sinus method is the most repeatable/reliable.

Obj. 3) What is the effect of comparing traditional radiographs to CT scans on these methods? While the use of CT scans for assessing head/neck structures is increasing in the clinical setting, medical examiner offices in the U.S. are more likely to have access to traditional radiographs (Smith-Binden et al., 2019). As such, forensic practitioners will likely be faced with comparing ante-mortem CT scans to post-mortem radiographs. This portion assesses how varying image modalities may affect sinus appearance.

Obj. 4) What is the effect of varying cranial orientation on these methods? Ideally antemortem and postmortem radiographs are oriented in the same exact position, but this can be challenging. This portion investigates how slight variations in radiographic orientation affects sinus appearance.

Obj. 5) What is the effect of sinus size on these methods? Compared to larger sinuses, smaller sinuses tend to be less complex by lacking (or presenting less) arcade counts, septa, etc. This portion assesses whether the lack of sinus traits among smaller sinuses negatively impacts identification methods.

Obj. 6) What is the effect of age-related changes on these methods? Most studies on frontal sinus growth typically are based on cross sectional data or lateral radiographs. Thus, individual growth patterns of frontal sinus traits (e.g., arcade count) useful in identifications are largely unknown. This portion assesses when these relevant traits reach maturity in a longitudinal sample of frontal radiographs.

Obj. 7) What are the population frequencies of specific frontal sinus traits, which may affect these methods? The need for population frequency data associated with radiologic identifications has recently been promoted by the Forensic Science Standards Board (FSSB) through OSAC. This portion collects that data of coded and metric traits of the frontal sinus in U.S. based populations.

Research Design, Methods, Analytical and Data Analysis Techniques

Samples: For each grant project objective, samples originated from three major sources and involved several types of image modalities: the New Mexico Decedent Imaging Database (NMDID), consisting of CT scans and scout radiographs (Edgar et al., 2020); the Terry Collection from the Smithsonian Institution (TCSI), consisting of CT scans (Copes, 2012) and frontal radiographs (Hanson & Owsley, 1980; Hunt & Everest, 2001); and/or the AAOF Legacy Collection (AAOF), consisting of frontal radiographs across a longitudinal sample (https://www.aaoflegacycollection.org/aaof). This project incorporates several types of image modalities (e.g., radiographs, CT-derived 3D models), depending on sample availability and the specific objective being assessed (see Figure 1). Radiographs from the NMDID and AAOF collections were available for download from their respective online sites. Radiographs from the TCSI sample were digitized for the purpose of this study using a digital camera and lightbox. CT scans for the NMDID were directly available from their site, while those from the TCSI are publicly available from www.lynncopes.com. While CT slices were used to directly test the Tatlisumak Method (following the original method), 3D translucent cranial models were used to compare image modalities. Using 3D models versus the actual CT slices were beneficial for several reasons. Compared to 2D CT slices, 3D models allow one to see complex 3D structures in their entirety and allow repositioning of the cranium to best match an antemortem image. Details on processing CT scans and the radiographs can be found in associated Zenodo files (FS_ImageMode_Coded_Data_ReadMe.pdf).

Data Collection: This project incorporates several types of data, with specific data collection techniques depending on the identification method and specific objective being assessed. A brief overview is presented here by each identification method utilized in the study. Details regarding these methods are available in the associated dataset files published on Zenodo (Butaric et al., 2023) and/or in associated manuscripts (see Artifacts Section).

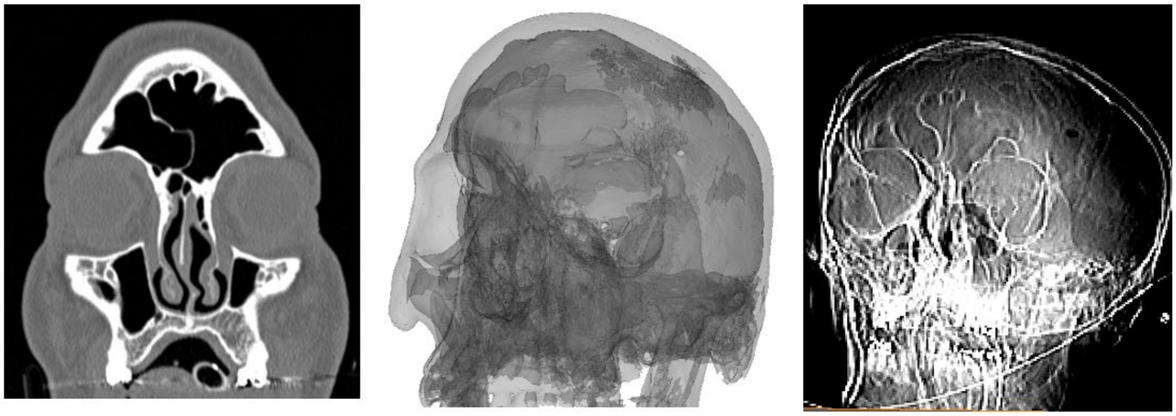

Figure 1. *Example of CT scan slice showing maximum frontal sinus pneumatization (left), translucent 3D-rendered cranium (middle), and Scout Image (right) of same individual. Note that for this example, the translucent model has been oriented to match the Scout view.*

For the visual assessment portion of the grant, an IRB was approved through DMU (IRB-2023-2; January 2023), and an online Qualtrics survey was disseminated (open January 31 to April 17, 2023). For the survey, a sample of 25 image pairs (18 pairs matching, 7 non-matching) from the AAOF Collection was utilized. All pairs chosen had been determined to be a match by preliminary outline analyses, and thus should represent more challenging comparisons. Pairs were presented as simulated ante- and post-mortem images of radiographs cropped to showcase just the frontal sinuses, and respondents were requested to indicate whether the pairs were a “match” or “not a match” and to provide their confidence levels (1-10) for each pair. Demographic questions regarding experience levels were also collected. Additional details are provided on Zenodo (FS_VisualAssess files).

The two primary outline methods assessed here are the elliptical Fourier analysis (EFA)-Method (Christensen, 2004a) and Total Difference Method (Cox et al., 2009). For both, all outlines were first traced on digital radiographs following Christensen (2004a) in *ImageJ* freeware (Schneider et al., 2012). This entailed setting the supraorbital line to demarcate the inferior boundary of the sinus, tracing the superior borders, and removing the background to isolate the sinus (see Figure 2). To assess the EFA Method, outlines were subjected to EFA using 20 harmonics, resulting in two (xy) coordinates and four coefficients per harmonic for each individual outline. These resulting coordinates and coefficients were then either directly compared across individuals or subjected to a principal components analysis (PCA) depending on the project objective (see Outcomes: Results Section). For the Total Difference Method, after the frontal sinus outline was traced, 59 linear measurements were collected from the origin (cranial midline) to the sinus outline at 3° intervals (Figure 2, bottom right). For each individual, these 59 linear measurements were standardized by their sinus baseline length. The "Total Difference" refers to the sum of each line's absolute difference between an ante- and post-mortem images. In an array of possible matches, images from the same individual (same-individual pairs) would have a lower Total Difference than images from different individuals (different-individual pairs). To streamline this process, a semi-automatic macro and measurement aid was created and validated in *Image J* (see Campbell & Butaric, 2022 for more details on this process). In all outline analyses, while combined samples were used to test different-individual pairs (e.g., a different-individual pairing could include individuals from the TCSI and AAOF collection), same-individual pairs were confined to the AAOF collection. This is because only the AAOF collection had actual radiographs of the same individual taken at different times in their life, more accurately simulating ante- and post-mortem images.

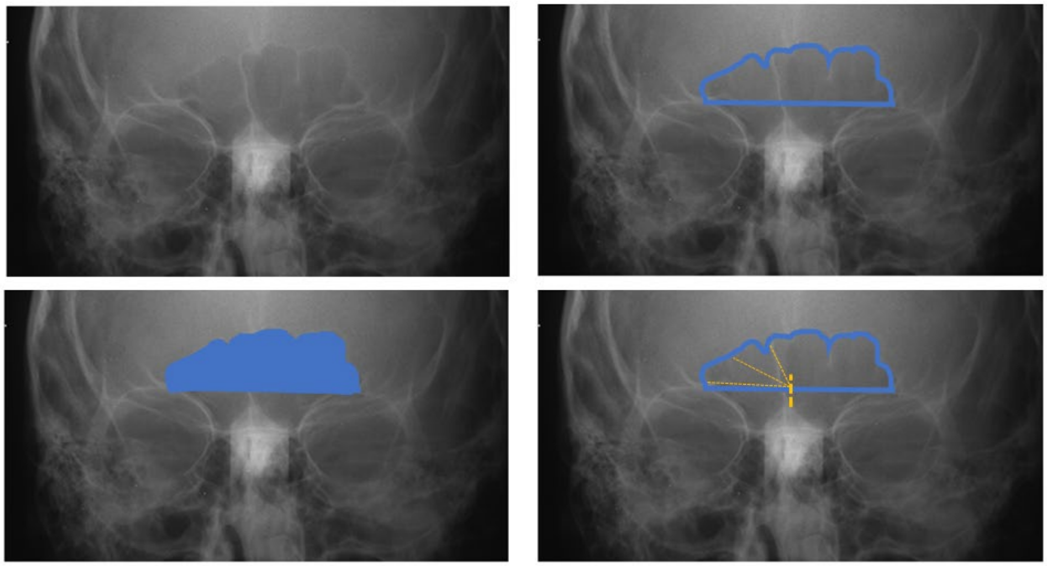

Figure 2. Process of tracing the frontal sinus outline. Top row: original radiograph (left) with inferior border and outline (right); Bottom row: Filled-in outline on radiograph (EFA Method; left) and outline with point of origin (thick dashed yellow line) and example measurement lines at 3° , 30°, and 60° (thin dashed yellow lines) (Total Difference Method; right).

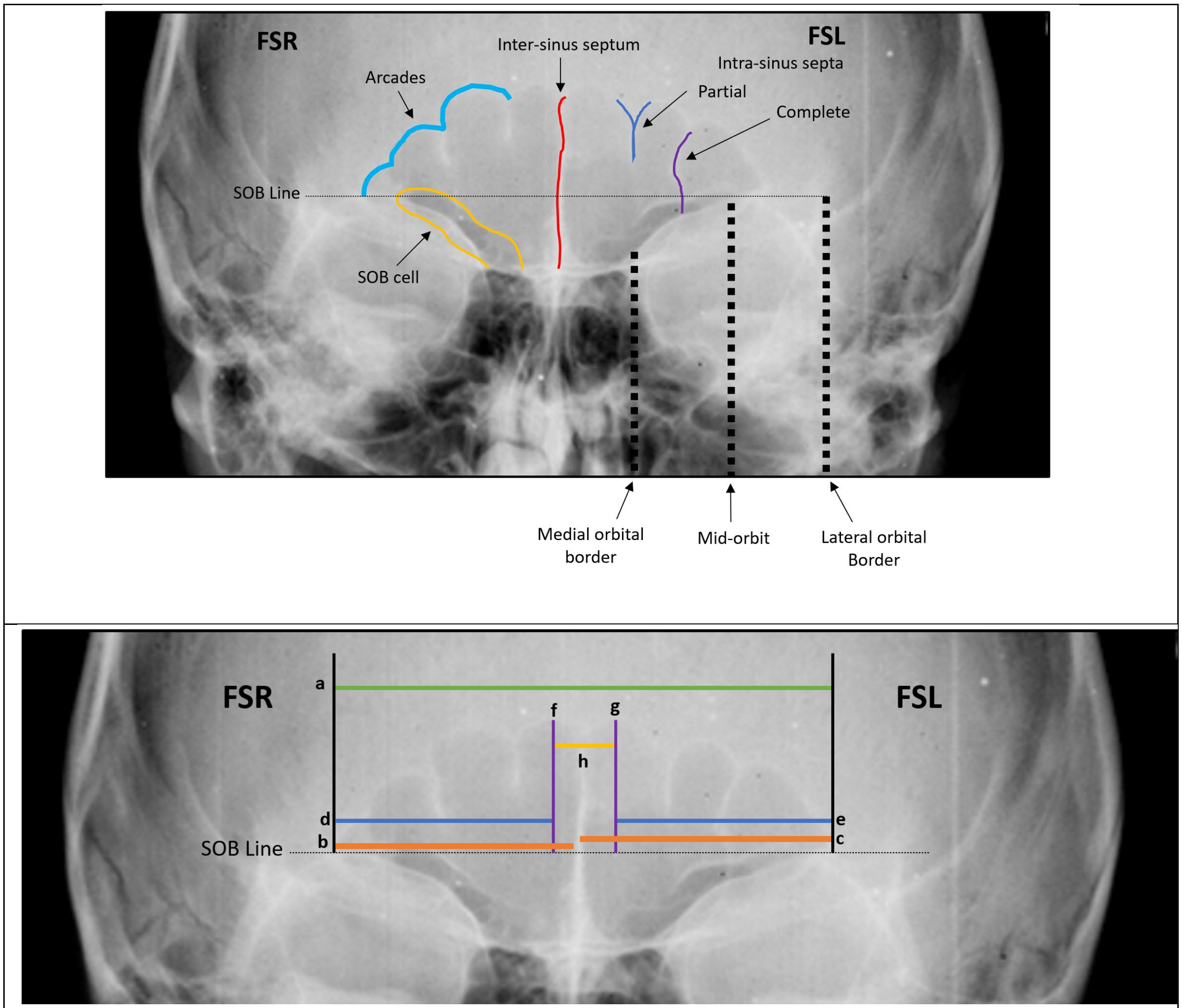

Figure 3. Illustration of several right (FSR) and left (FSL) frontal sinus traits (top) and measures (bottom). Measures: a, max breadth; b, c, right and left sinus breadth; d,e, right and left lateral peak breadth; f,g, right and left sinus height (peaks); h, inter-peak breadth. SOB, supraorbital line. See Table 1.

The two primary coding methods were assessed in the current study. The Cameriere Method is a modification of Yoshino et al. (1987), which utilized traditional radiographs based on frontal sinus area and various morphological traits, such as superiority of side and number of arcades, to obtain an identifier "code" unique to an individual using six variables. The Tatlisumak Method, also known as the FSS system, was created as a "simplified" coding system compatible with CT scans. Focusing on three basic traits, presence/absence of the frontal sinus, its septum morphology, and its scalloping (lobe/arcade) morphology, this system creates a unique code using three variables, with the option to include metric variables. Presence/absence, count, and coded variables associated with these methods were collected directly from the radiographic, CT slices, and/or 3D model images (see Figure 3, Table 1). Linear (cm) and area (cm^2) measurements were also collected from the radiographs using the *draw, freehand,* and *measure* tools in *ImageJ.* Note, since varying image modalities and radiographs are subject to different errors of magnification and scaling parameters, all metric measures were scaled by bi-orbital breadth prior to statistical analyses: linear measures were directly divided by bi-orbital breadth, while the squared-root of area measures were divided by bi-orbital breadth.

Table 1. *Overview of frontal sinus traits collected in the grant. See Zenodo dataset ReadMe files and associated manuscripts corresponding to specific objectives for more details.*

Demographic Data	
ID	Identification number as assigned by archival institution
Sex	Identification of sex, as given in archival records: M, male or F, female,
Pop	Ancestral population, as given in collection records; AFR, African; EUR, European; NVA, Native American
Age	Age-of-death in calendar years, as given in collection records
Coded Frontal Sinus Traits (see Figure 3 top)	
Sinus Presence/ Absence	Presence of the right and left frontal sinus lobe separately, done two ways: any indication and above the supraorbital line
Supraorbital Cells	Counts (#) of supraorbital cells for right and left lobes, above the supraorbital line
Arcades	Counts (#) of arcades on right and left lobes (separately), above supraorbital line
Complete Intra-Septa	Counts (#) of complete intrasinus septa in right and left lobes (separately), intersecting supraorbital line
Partial Intra-Septa	Counts (#) of partial intra-septa in right and left lobes (separately), remaining above supraorbital line
Lateral Extensions Relative to Orbit	Lateral extension of the left and right lobes, relative to the orbit (0: does not reach orbital medial border; 0.5: at orbit medial border; 1: past medial border, but does not reach orbit midline; 1.5: at orbit midline; 2: past orbit midline; 2.5 at lateral border; 3 past lateral border)
Lobes Touching	Whether right and left frontal sinus lobes are touching or discontinuous (coded as touching or separated).
Taller Lobe	Whether the right or left lobe is taller (coded as left, right, or equal); determined based on metric measures of right and left lobal heights (see below)
Metric Traits (units: linear distances cm, with areas cm^2) (See Figure 3 Bottom)	
Discontinuous Breadth	Distance between the right and left lobes (separately) at the level of the supraorbital border; only taken if lobes were marked as “separated” above (if touching, breadth recorded as 0; if unilateral or bilateral absence, breadth was not recorded and cell was left blank)
Areas	Area taken of left and right sinus lobes (separately); with supraorbital line demarcating inferior boundary. Also taken with left and right lobes combined
Breadths	Distance from most lateral point of left and right lobe to inter-sinus septum or medial edge of respective lobe, parallel to supraorbital line; taken for right/left separately

Heights	Perpendicular distance from tallest peak of left and right lobes to supraorbital line; if multiple peaks are same height, take at most medial point
Lateral Peak Breadths	Distance from most lateral point of left and right lobes (separately) to vertical line intersecting tallest peak of left lobe, taken parallel to the supraorbital line
Max Breadth	Distance between two vertical lines placed on the most lateral edges of the sinus lobes (or lobe, if unilateral); vertical lines are placed perpendicular to the supraorbital line, while the actual distance is taken parallel to the supraorbital line
Inter-Peak Breadth	Distance between vertical lines intersecting the tallest right and left lobe peaks (reflective sinus heights); taken parallel to supraorbital line
Bi-orbital Breadth	Maximum distance taken across the right and left orbits, wherever that occurs. Primary variable used to scale frontal sinus traits (see text).
Orbit Areas	Area taken of left and right orbits (separately)
Orbit Breadths	Distance between medial and lateral borders of the left orbit, as if splitting orbit in two superior/inferior halves

Expected applicability of research

The goal of this project is to provide medicolegal practitioners with a set of guidelines and important considerations for frontal sinus identification that will be developed based on a comprehensive analysis of previously published identification methods, including factors that may affect the accuracy of those methods (e.g., intra/inter observer reliability, image modality, sinus size/complexity, individual's age). A false positive identification, or erroneously excluding an actual true identification, can have significant consequences. That is why it is vital to better understand frontal sinus morphology and how best to use this trait in forensic identifications.

Participants & Other Collaborating Organizations

The primary individuals who were involved in the development of the project, supervision of data collection and analyses, and reporting/dissemination of the project were the Principal Investigator, **Lauren N Butaric, PhD** Associate Professor of Anatomy at Des Moines University, and the co-Principal Investigator, **Heather M Garvin, PhD, D-ABFA** Professor of Anatomy at Des Moines University. **Jessica Campbell, PhD, D-ABFA** was a post-doctoral researcher who led the Cox analyses and provided support for the remaining analyses. **Jodi Caple**, **PhD,** served as a contractor on the grant, providing assistance in running the EFA outline analyses. **Naeema Abdulrazak**, **MA** was a partially grant-funded Masters of Anatomy student, who conducted research in the subadult portion of the grant. **Patricia Avent**, **MA** served as the other partially grant-funded Masters of Anatomy student, who led the research in the image modality portion of the grant. Additionally, nine medical student researchers at Des Moines University (not grant funded) took part in various portions of the grant: Cole Amundson, Joshua Broussard, Kristin Fischer, Anna Geiger, Lilly Horst, Madelyn Johnson, Allison Richman, Garunkit Singh, Matthew Wright.

Outcomes

Activities/Accomplishments

Grant activities included the assessment of 1,850 of total images (1,625 radiographs; 225 3D models) across 933 individuals, collection of 14 different coded frontal sinus traits and 16 measurements, and 1,785 total traced outlines (note sample size and variables collected vary per objective). The main accomplishment of this project was the development of several recommendations for forensic practitioners using the frontal sinus for identification purposes in varying scenarios (see Result Recommendations Section below). As part of this project, eight distinct databases (with associated ReadMe files) of frontal sinus traits across varying image modalities have been created and are freely available on Zenodo for future researchers to utilize. Additionally, 281 physical frontal sinus radiographs from the Terry Collection were digitized and provided to the Smithsonian Institution, from which future researchers can request access to. Through data collection exercises, this project has contributed research experiences, radiographic/CT scan training, and/or training in forensic identification procedures to 11 total graduate/medical students, as well as mentoring to one post-doctoral researcher. Those student and post-doctoral researchers have been included as co-authors on published abstracts and manuscripts listed in the Artifacts and Dissemination Sections.

Results and Findings

Below we provide statistical results of each objective, with summarized recommendations provided in the Expected Applicability Section.

Obj. 1) Testing standard accuracy & error rates. For the visual assessment portion, 145 individuals completed the survey. Eighty-three respondents (57%) scored 92% or better (of those 29 scored 100%). Even with 65% reporting zero previous experience conducting radiographic comparisons, 89.9% (94.5% median) of the total comparisons (n=3,625) were scored correctly. Forensic odontologists, forensic pathologists, and board-certified forensic anthropologists all had accuracy rates >95%. While experience level, training, and specialties were shown to affect the results, it is interesting to note that the overall average accuracy rate (89.9%) is still relatively high considering that 24% of observers had zero training and 65% of observers had never conducted any kind of radiographic identification before. There was a bias with individuals more likely to report matches as mismatches (12.6%), than reporting mismatches as matches (3.6%). Errors appeared associated with slight differences in radiographic orientations, which were difficult for the practitioners to assess given that they were only given the cropped area of the sinus and could not use the context of the overall skull orientation. Note that the non-matching sinus pairs chosen for this study were amongst the most similar non-matches (i.e., presenting somewhat of a worst-case scenario), thus, if sinus pairs were randomly chosen, accuracy rates would be expected to be even higher. Overall, results support the utilization of visual comparisons in frontal sinus identification, but also highlight the importance of training and experience in these methods. More details and associated data can be found on Zenodo (FS_VisualAssess files).

Following the methods outlined in Christensen (2005), EFA shape coefficients were used to calculate Likelihood Ratios (LR) to examine reliability of using the frontal sinus outline in identification. When examining simulated ante- and post-mortem images of the AAOF sample, same-individual pairs have the lowest LR (Mean=1.63, SD=0.09) and different-individual pairs have the highest (Mean=3.37, SD=1.63), as would be expected. Accuracy was calculated by summing the true positive and negative frequencies over the frequencies of all the true and false negative and positives. While Christensen (2005) utilized a thresholding of 1 (LR>1 indicating two outlines match, or "fail to exclude"; LR<1 indicating a non-match, or "exclude"), the use of this threshold in our sample gave poor results. Instead, thresholds were "corrected" based on the low/high 95% confidence intervals and means of the samples. When examining the AAOF sample alone, the threshold defined by the upper 95% (LR = 1.81) performed the best, with 95.95% of same-individual pairs correctly matched, and 86.11% of different-individual pairs correctly excluded as a match. The threshold set to the mean (LR=1.63) was more conservative with same-individual pairs (59.46% correctly classified), but the exclusion rate for different-individual pairs increased to 99.93%. Overall, these results support Christensen's original study and suggest that the EFA Method of outline analysis is a relatively accurate method for forensic identification. The method is limited, however, by the need for a reference database to calculate appropriate LR thresholds, the method complexity, and time required. More details and associated datasets can be found on Zenodo (FS_EFA_Outline_Data files).

To test the accuracy of the Total Difference Method, data from 697 total individuals originating from three collections (AAOF, NMDID, TCSI) were collected by one observer in *ImageJ* following Campbell & Butaric (2022). The Total Differences for all possible pairs in the sample were calculated, with Total Differences for Same-Skull pairs collected from the AAOF sample (n=239 Same-Skull pairs). An Odds Ratio was used to quantify the probability of a match. Results indicate lower accuracy rates than the original publication: 74.3% of same skulls were correctly indicated as matches, and 79.2% of different skulls were correctly indicated as non-matching pairs— meaning 20.8% of the Different-Skull pairs were incorrectly identified as a match. Overall, these results suggest that the Total Difference Method is not a reliable method for forensic identification. More details and associated datasets can be found in Campbell & Butaric (2022) and Zenodo (FS_TD_Outline_Data files).

To test the accuracy of the Cameriere Method, 225 radiographs from the NMDID and TCSI collections were scored following the original method. When the string codes were compared, there were 159 total duplicates (71%) (Avent, 2023). To test the accuracy of the Tatlisumak Method, 50 CT scans from the NMDID collection was scored following the authors' original methods. When the 50 string codes were compared, there were there were eight duplicates (16% of sample). This duplication rate is lower compared to Tatlisumak's original study, which found 45 duplicates (45%) in 100 individuals. No codes from the current study matched those from Tatlisumak' original study, equaling a 98% exclusion rate for the combined datasets (n=150) (Avent & Butaric, 2023a). Based on the ability to obtain duplicate codes and the fact that a misinterpretation of a single coded variables (perhaps due to radiographic quality) can result in a different code, this method is not recommended to be used in isolation.

Obj. 2) Intra- and inter-observer reliability. Overall, the outline-based methods had lower intra- and inter-reliability error rates compared to the coding methods (in other words, outline analyses were more reliable). Intra-reliability on EFA-outline analyses was conducted by one observer re-tracing 84 outlines from the AAOF collection; using the coefficients and LR ratio thresholds discussed in Obj 1, results indicated the highest accuracy rate of 100% when utilizing the upper 95% confidence interval threshold. Inter-reliability on EFA analyses was conducted using 80 outlines traced by a second observer from the AAOF collection; results indicated the highest accuracy rate of 90% when utilizing the upper 95% confidence interval threshold. Details and associated data can be found on Zenodo (FS_EFA_Outline_Data files). Intra-reliability for the Total Difference Method was conducted by one observer re-collecting data on 70 outlines from the AAOF collection. Results indicate 100% of Same-Skull pairs were correctly indicated as matches; 97.4% of different skulls were also correctly indicated as non-matching pairs, meaning that 2.6% of the Different-Skull pairs were incorrectly classified as a match. For inter-reliability, a second observer traced 70 outlines from the AAOF collection; 100% of Same-Skull pairs were also correctly matched. 96.2% of Different-Skull pairs were correctly classified as non-matching pairs, meaning 3.83% were incorrectly classified. The fact that a single deviation in a single coding variable can affect identification intra- and inter-rater should be considered when applying these methods.

To test reliability of the Tatlisumak Method, 99 CT scans from the NMDID collection were assessed following Tatlisumak et al. (2005), with a subset of 18 individuals coded by a second observer. 12 of the 17 codes matched, and a weighted kappa showed substantial to near perfect inter-observer agreement (k = 0.638–1.000, p = 0.005–<0.001) (Avent et al., 2023). To gain a more accurate insights into intra- and inter-reliability of coding methods, we tested reliability of each sinus trait (e.g., arcade count, present/absence) versus the string codes themselves in a sample of 80 individuals from the TCSI and NMDID collections. Weighted kappa analyses indicate that intraobserver reliability was "strong to almost perfect" for most traits (k=0.727–0.971; p<0.001). Interobserver reliability was much lower, with intrasinus septa and arcade counts scoring primarily as "weak to moderate" (k=0.45–0.746; p<0.001); however, sinus presence/absence traits scored as "perfect" (k=1; p<0.001) in both inter- and intra-reliability analyses.

Obj. 3) Effect of image modality. For this objective of the grant, we compared frontal sinus morphology between adult radiographs and their paired 3D digital models (total n=225 from the TCSI and NMDID collections). Frontal sinus traits were recorded and applied into string codes, following both Cameriere and Tatlisumak Methods. When the string codes from a paired radiograph and CT model were the same, it was considered a "match", otherwise it was considered a "non-match". A Cohen's kappa showed moderate agreement (κ=0.517, p<0.001, 95% CI:0.364–0.663) for match rates between the two methods, with the Cameriere Method performing slightly better. Still, overall match-rates were quite low: the Tatlisumak Method had 30 matches (13.3%) and 195 non-matches (86.7%); the Cameriere Method had 41 matches (18.2%) and 184 non-matches (81.8%). Most of the incorrectly unmatched pairs were the result of arcade or intrasinus septa being one to two counts different. Other sinus traits (particularly presence vs absence) show good fit between radiographs and their respective 3D models. Although not statistically significant in a larger binary logistic analysis, correct match rates were higher among individuals from the TCSI sample. This likely relates to better quality in frontal sinus trait appearance among these radiographs, which were taken without soft tissue present. More details and associated data can be found on Zenodo (FS_ImageMode_Code_Data files) and Avent (2023).

Obj. 4) Effect of Orientation. Frontal sinus models were segmented directly from CT scans (n=21 individuals from TSCI) and digitally oriented across three clinically and/or research relevant orientations. From each standard orientation (looking straight ahead), eight 5-degree deviations were obtained in horizontal (left/right), vertical (up/down), and diagonal (e.g., left-up vs. right-down) directions, resulting in a total of 567 sinus orientations for comparisons. Within and between individual differences in sinus size (area, breadth, height) and outline shape [based on elliptical Fourier analyses (EFA) and principal component analyses (PCA)] were assessed. Wilcoxon sign rank tests indicated that sinus breadth remained relatively stable ($p>0.05$) across orientations, while sinus height was significantly affected with vertical deviations ($p<0.006$). Mann-Whitney U tests on Euclidean distances from the PC scores indicated consistently lower intra- versus inter-individual distances ($p<0.05$). All three views had high identification match rates ranging from 98–100%. When apparent, mismatches were largely the result of deviations in vertical orientation resulting in the disappearance of a smaller arcade, near the supraorbital border. Details and associated data can be found on Zenodo (FS_Orient_Outline_Data files) and in the related manuscript (Butaric et al., 2022b).

Obj. 5) Effect of size. Smaller frontal sinuses tend to be less complicated in nature, having fewer distinguishing features (such as septa and arcades) and making them less useful in personal identification. Our results tend to support this assertion. When analyzing coding and outline methods specifically, smaller arcades tend to get “lost” in varying orientations (see Obj. 4). For the visual assessment study (see Obj.1), the two lowest scoring matches (51.7% and 53.1% answered correctly) were of sinuses that were relatively small. In these cases, orientation also varied slightly and may have affected the presentation of structures leading to poorer scores. On the other hand, larger more complex sinuses may also present an issue, particularly with coding methods. These sinuses tend to have more complicated arcade structures and septa: a single count may through off the match/no match based on a coding system. This tended to result in the mismatch and lower reliability among coding systems, as discussed in the coding method sections (see Obj. 1 & 2).

Obj. 6) Effect of age. This objective focused on the longitudinal AAOF Legacy Collection series; analyses on outline shape (via EFA) and coded variables were conducted separately. When examining specific morphological traits (e.g., lobe presence; arcade and septa counts), we analyzed 1,500 radiographs of 141 (66F/75M) distinct individuals ranging from 3yoa to 56yoa. For each individual, trait age-of-stabilization was recorded by identifying the year at which each coded trait became consistent across images. Analyses indicate that frontal sinus traits stabilize on average 10–15yoa, with sinus presence being the first to stabilize and arcade counts the last. Females generally stabilized earlier (9–14yoa) versus males (10–15yoa). However, sex differences were generally not statistically significant. More details and associated data can be found in the preprint manuscript (Abdulrazak et al., 2023) and on Zenodo (FS_Ontogeny_Coded_Data files).

To analyze overall shape, 935 outlines were traced on radiographs ranging from 8–29yoa among 111 (55F/56M) distinct individuals. Outlines were subjected to elliptical Fourier analysis (EFA) and principal components analysis (PCA). Analyses on the resulting principal component scores indicate that frontal sinus shape is mostly attained by 20yoa regardless of sex. However, similar to previous results, females tend to reach their adult shape earlier than males: female shape shows decreased development at 14–16yoa, with males approaching stabilization at 18–20yoa. While these data are slightly later than the averages mentioned for specific traits, something to keep in mind is that they align with arcade counts (on average 14.38 for females and 15.59yoa for males), which is what outline analyses largely capture. More details and associated data can be found in Butaric et al. (2022a), and on Zenodo (FS_Ontogeny_Outline_Data files).

Obj. 7) Population Frequencies. Population frequency data is focused on 409 of individuals from the TCSI and NMDID collections. Tables 2 and 3 provide data for the sinus measurements and traits, respectively; definitions of traits can be found in Table 1 and Figures 3 and 4. Analyses of variance (ANOVA) (Table 2) was used to assess frontal sinus dimensions (scaled by bio-orbital breadth) across the six sex-ancestral groupings (e.g., European-American female vs African-American female). Most scaled dimensions were shown to be significantly different ($p<0.05$), with the exceptions of individual right and left sinus breadths. In looking at the Tukey pairwise *post-hoc* results, most significant differences occurred between African-American males and African-American females—indicating these differences are primarily sex, not ancestral, based. Compared to the other samples, African-American females tended to have the smallest frontal sinus dimensions.

Table 2. *Population frequency data with mean, standard deviations (SD), and analysis of variance (ANOVA) results for select dimensions obtained by ancestral-sex groups (AFR, African American; EUR, European American; NAV, Native American: F, Female; M, Male). Note, metric dimensions have been scaled by bi-orbital breadth. Total sample sizes provided; data does not include aplasia values. See Table 1 and Figures 3-4 for variable definitions.*

	AFR_F (n=85)	**EUR_F (n=80)**	**NAV_F (n=40)**	**AFR_M (n=84)**	**EUR_M (n=80)**	**NAV_M (n=40)**	**ANOVA results**	
Variable	**mean (SD)**	**mean (SD)**	**mean (SD)**	**mean (SD)**	**mean (SD)**	**mean (SD)**	**F (sig.)**	**Post-hoc results**
Max Breadth	0.498 (0.177)	0.566 (0.141)	0.515 (0.192)	0.586 (0.186)	0.538 (0.182)	0.508 (0.148)	**2.928** **(0.013)**	AFR_F < AFR_M
Left Breadth	0.256 (0.091)	0.280 (0.093)	0.283 (0.108)	0.299 (0.092)	0.288 (0.097)	0.286 (0.085)	1.784 (0.115)	*not sig.*
Right Breadth	0.246 (0.098)	0.280 (0.086)	0.252 (0.137)	0.287 (0.099)	0.275 (0.118)	0.254 (0.088)	1.778 (0.116)	*not sig.*
Left Height	0.133 (0.072)	0.169 (0.080)	0.143 (0.068)	0.172 (0.076)	0.163 (0.077)	0.162 (0.075)	**2.844** **(0.016)**	AFR_F < AFR_M FR_F < EUR_F
Right height	0.133 (0.080)	0.154 (0.073)	0.129 (0.087)	0.176 (0.081)	0.49 (0.072)	0.142 (0.079)	**3.114** **(0.009)**	AFR_F < AFR_M NAV_F < AFR_M
Total Area	0.215 (0.091)	0.258 (0.087)	0.229 (0.104)	0.276 (0.092)	0.252 (0.093)	0.243 (0.093)	**3.408** **(0.005)**	AFR_F < AFR_M NAV_F < AFR_M
Left Area	0.155 (0.065)	0.185 (0.075)	0.175 (0.071)	0.196 (0.067)	0.187 (0.073)	0.185 (0.071)	**3.073** **(0.010)**	AFR_F < AFR_M
Right Area	0.156 (0.073)	0.177 (0.064)	0.156 (0.090)	0.199 (0.070)	0.172 (0.074)	0.169 (0.072)	**4.132** **(0.001)**	AFR_F < AFR_M AFR_F < EUR_F

Bold *ANOVA results indicate significant at 0.05alpha level.*

Chi-Square results on frontal sinus traits largely did not indicate significant associations with ancestral-sex groupings (Table 3). However, African-American males were more likely to present supraorbital cells, followed by European-American males. Sinuses that exhibited lobes touching (versus separated), with 3–4 arcades per lobe were most common in all groups. In terms of lateral extension, most sinuses extended past the medial border of the orbit but did not reach the mid-orbital line (coded as “1”), followed by sinuses that extended past the mid-orbital line but did not reach the lateral orbital border (coded as “2”). Incidences of bilateral and unilateral aplasia was rare across all groups, as were the presence of intrasinus septa (whether partial or complete). In terms of unilateral aplasia, left sinuses are most likely to be absent (total 14 individuals without using the supraorbital line, 25 individuals with supraorbital line) compared to right sinuses (5 individuals without using the supraorbital line, 10 individuals with supraorbital line). As to be expected, frequencies for aplasia when using the supraorbital line are higher than without (also see Butaric et al., 2020). More details and associated data can be found on Zenodo (FS_PopFreq_Data files).

Table 3. *Population frequency data of frontal sinus traits by ancestry (AFR, African American; EUR, European American; NAV, Native American) and sex (F, female; M, male). Chi-Square results provided for individual count and frequency (freq.) data, median and variance (var.) provided for variable count data. See Table 1 for variable definitions.*

Variable	**Type of data**	**AFR_F (n=85)**	**EUR_F (n=80)**	**NAV_F (n=40)**	**AFR_M (n=84)**	**EUR_M (n=80)**	**NAV_M (n=40)**	**X^2 (sig.)**
Absence Left Sinus (any)	***Count (freq.)***	3/85 (3.5%)	1/80 (1.3%)	1/40 (2.5%)	1/84 (1.2%)	1/90 (1.3%)	0/40 (0%)	1.121 (0.952)
Absence Left Sinus (SOB line)	***Count (freq.)***	5/85 (5.9%)	1/80 (1.3%)	4/40 (10%)	2/84 (2.4%)	2/80 (2.5%)	1/40 (2.5%)	5.904 (0.316)
Absence Right Sinus (any)	***Count (freq.)***	1/85 (1.2%)	1/80 (1.3%)	0/40 (0%)	1/84 (1.2%)	1/80 (2.5%)	1/40 (2.5%)	1.073 (0.956)
Absence Right Sinus (SOB line)	***Count (freq.)***	4/85 (4.7%)	2/80 (2.5%)	1/40 (2.5%)	3/84 (3.6%)	6/80 (7.5%)	5/40 (12.5%)	5.729 (0.333)
Bilateral absence (any)	***Count (freq.)***	2/85 (2.4%)	1 /80 (1.3%)	1/40 (2.5%)	2 /84 (2.4%)	2/80 (2.5%)	1/40 (2.5%)	0.424 (0.995)
Bilateral absence (sob line)	***Count (freq.)***	4/85 (4.7%)	2/80 (2.5%)	1/40 (2.5%)	2/84 (2.4%)	3/80 (2.8%)	1/40 (2.5%)	1.142 (0.950)
Lobes Touching (vs separated)	***Count (freq.)***	54/72 (75%)	65/75 (86.67%)	26/34 (76.47%)	69/77 (89.61%)	62/70 (88.57%)	30/33 (90.91%)	10.487 (0.063)
SOB Cell Present Right	***Count (freq.)***	14/80 (17.5%)	16/79 (20.2%)	6/40 (15%)	30/81 (37%)	19/76 (25%)	2/36 (5.6%)	**18.844** **(0.002)**
SOB Cell Present Left	***Count (freq.)***	12/78 (15.4%)	17/80 (21.3%)	10/40 (25%)	28/82 (34.1%)	19/78 (24.4%)	8/40 (20%)	8.574 (0.127)
Intrasinus Septa Partial Right	***Median (var.)***	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (0)	-
Intrasinus Septa Partial Left	***Median (var.)***	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	-
Intrasinus Septa Complete Right	***Median (var.)***	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	-
Intrasinus Septa Complete Left	***Median (var.)***	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0(1)	-
Arcades Left	***Median (var.)***	3 (3)	3 (3)	4 (2)	4 (4)	3 (4)	4 (4)	-
Arcades Right	***Median (var.)***	3 (4)	3 (3)	3 (5)	4 (4)	3 (5)	3 (3)	-

Lateral Extension Right								-
0	***Count (freq.)***	0/77 (0%)	0/77 (0%)	1/38 (2.6%)	1/79 (1.3%)	0/73 (0%)	0/34 (0%)	
0.5	***Count (freq.)***	2/77 (2.6%)	2/77 (2.6%)	2/38 (5.3%)	0/79 (0%)	2/73 (2.7%)	0/34 (0%)	
1	***Count (freq.)***	56/77 (72.7%)	48/77 (62.3%)	24/38 (63.2%)	38/79 (48.1%)	48/73 (65.8%)	26/34 (76.5%)	
1.5	***Count (freq.)***	4/77 (5.2%)	4/77 (5.2%)	1/38 (2.6%)	11/79 (13.9%)	4/73 (5.5%)	0/34 (0%)	42.332 (0.067)
2	***Count (freq.)***	15/77 (19.5%)	23/77 (29.95)	9/38 (23.74%)	28/79 (35.4%)	19/73 (26%)	8/34 (23.55)	
2.5	***Count (freq.)***	0/77 (0%)	0/77 (0%)	1/38 (2.6%)	0/79 (0%)	0/73 (0%)	0/34 (0%)	
3	***Count (freq.)***	0/77 (0%)	0/77 (0%)	0/38 (0%)	1/79 (1.3%)	0/73 (0%)	0/34 (0%)	
Lateral Extension Left								-
0	***Count (freq.)***	2/78 (2.6%)	0/77 (0%)	0/35 (0%)	2/81 (2.5%)	1/77 (1.3%)	0/38 (0%)	
0.5	***Count (freq.)***	2/78 (2.6%)	1/77 (1.3%)	0/35 (0%)	2/81 (2.5%)	1/77 (1.3%)	1/38 (2.6%)	
1	***Count (freq.)***	52/78 (66.7%)	43/77 (55.8%)	19/35 (54.3%)	38/81 (46.9%)	46/77 (59.7%)	23/38 (60.5%)	
1.5	***Count (freq.)***	6/78 (7.75%)	5/77 (6.5%)	1/35 (2.9%)	7/81 (8.6%)	7/77 (9.1%)	1/38 (2.6%)	20.907 (0.698)
2	***Count (freq.)***	16/78 (20.5%)	28/77 (36.4%)	15/35 (42.9%)	31/81 (38.3%)	22/77 (28.6%)	13/38 (34.5%)	
2.5	***Count (freq.)***	0/78 (0%)	0/77 (0%)	0/35 (0%)	1/81 (1.2%)	0/77 (0%)	0/38 (0%)	
3	***Count (freq.)***	0/78 (0%)	0/77 (0%)	0/35 (0%)	0/81 (0%)	0/77 (0%)	0/38 (0%)	

***Bold** Chi-square results indicate significance at 0.05 alpha level.*

Recommendations. Based on the results above, we have the following recommendations for forensic investigators:

- When considering the varied amount of frontal sinus identification methods available to the forensic practitioner, visual comparison is the simplest method to apply while also providing highly accurate and reliable results, even when considering experience levels. Visual comparison allows for interpretation of explainable differences, such as effects of orientation discrepancies, age-related changes, and image quality. While coding and outline methods have helped highlight the individuality and uniqueness of the frontal sinus morphology — supporting this structure's usefulness in personal identification — these techniques are often time-consuming and need large, sex/ancestral/age specific comparative samples that are freely available. Coding methods appeared most sensitive to error given that a difference in a single coding variable (perhaps due to image quality or orientation) could result in identification errors. Outline analyses, while accurate and repeatable, require comparative databases and complex steps to make a comparison, with results suggesting that identification thresholds are dependent on the reference sample. If resources are available and these objective techniques are utilized for an identification itself, they should still always be confirmed by a visual identification for secondary validation to avoid an incorrect identification (false positive) or incorrect exclusion (false negative).

- When obtaining a postmortem image, practitioners should aim to match the antemortem radiographic parameters as close as possible, including specific cranial orientation, beam direction (e.g., AP vs PA), and angle of beam trajectory through the cranium to the film. However, precise positioning may not always be feasible. Understanding patterns of sinus shape variation that are expected with slight orientation differences can help practitioners interpret explainable differences between images. While sinus breadth and outline were minimally affected, differences in vertical orientations of the crania— particularly when more inferiorly rotated— will most likely affect sinus height and the visibility of smaller lobes or arcades near the supraorbital borders. Practitioners should avoid relying on those morphological traits for identification purposes in such cases.
- When analyzing two images to support/negate a potential identification, investigators need to be aware of two primary issues concerning frontal sinus size. 1) Smaller sinuses may be more difficult to distinguish between different individuals due to their simplified nature and/or aspects that may be lost in slight discrepancies in orientations, leading to potential false positive matches. In such cases, investigators should use more caution, assessing their confidence based on any

unique features the simplified sinus presents, and may want to expand their radiographic comparison to other cranial features, assessing the number of points of concordance. If based solely on a small, simple frontal sinus, it may be best to note the consistency between radiographs and fail to exclude the identification. Note that such information can still contribute to an identification if the medical examiner/coroner has other case context or evidence to support the identification. 2) Coding and outline methods using larger and more complex sinuses that are difficult to discern due to image quality or deviations in radiographic parameters are more prone to inter- and intra-reliability errors and may be more likely to result in slightly different counts in arcade and septa numbers; in such cases, visual assessment of morphology of the structures, versus counts alone, would be the preferred method (see first bullet point).

- Forensic practitioners should be cautious using frontal sinus identification methods in subadults, especially when several years may have elapsed between images and when analyzing traits that may stabilize later in time (e.g., arcades). Overall, analyses indicate that sinus presence is the earliest trait to stabilize (as to be expected), with sinus arcades (and thus the overall outline) being the last trait to stabilize. Similar to other skeletal maturation patterns, females tend to stabilize a few years earlier than males across most traits. A conservative approach would be to warrant caution for any individual under 20 years of age, especially if male. Radiographs of individuals less than eight years of age may not yet exhibit a frontal sinus that is in the process of developing. While there is a trend for sinuses to increase in arcades and septa with development (until stabilization is reached), there were a few cases in which arcades or septa decreased. Coding methods would be most sensitive to such age-related changes and should not be applied under the age of 20 years. Outline methods may also be affected. If conducting a visual radiographic comparison that involves a subadult antemortem image, practitioners should refer to more specific published results associated with this grant (Butaric et al., 2022a; Abdulrazak et al., accepted) to assess whether the differences they observe in the ante- and post-mortem images could possibly be the result of age-related changes, as ages of stabilization vary across sinus traits. In many cases, though, it is easy to visually recognize the expansion of the sinus with age and still discern a general consistency or points of concordance between images. Practitioners need to consider possible age-related changes and their confidence in their comparison when determining whether to report a subadult sinus comparison as a positive identification or exclusion versus a failure to exclude the identification or an inconclusive determination. Other methods of identification (e.g., radiographic dental comparison) should be considered with subadult remains, especially if there is significant time lapse between antemortem and postmortem radiographs.

- When confronted with two images of varying modality (e.g., antemortem CT slice and postmortem radiograph), the forensic practitioner should keep several things in mind. If resources are available, creating a translucent 3D skull from the CT scan creates the closest approximation to a radiograph, allowing full visualization of the sinus in its entirety with superimposed structures (vs single image slices) and easy 3D re-positioning to ensure similar orientation. However, septa and arcades may appear different between these image modalities, as bony septa at times are not as evident in 3D-generated models and arcades will appear to be more spaced apart. Due to these discrepancies, caution is also warranted for forensic investigators utilizing population frequency data (see below) collected from varying image modalities.
- Finally, although not a specific recommendation, this report provides relevant insights into population frequencies of frontal sinus traits across U.S. based populations, which can be helpful in interpreting radiographic comparisons and court testimony. Bilateral aplasia was found at low frequencies across the data set (pooled data: 9/409, 2.2%); note, this frequency is slightly higher when utilizing the supraorbital line (pooled data: 13/409, 3.2%). Overall, significant differences in frontal sinus traits were not indicated across the three U.S.-based ancestral populations sampled here (African-American, European-American, and Native American). However, sex-based differences were indicated: females tend to exhibit smaller sinus dimensions (particularly when assessing African-American females vs African-American males) and also had earlier

maturation times compared to males. While contraindicated in the current sample (see Table 3), previous studies on global populations have also indicated a higher rate of aplasia among females (see Butaric et al., 2020 and references therein). As such, practitioners should take care to not generalize these frequencies based on the samples here.

Limitations

First, this study included just a small sub-sample of the diversity within U.S. based populations. While the population frequency data obtained in the current study did not suggest strong evidence of ancestral differences in frontal sinus shape/size, previous studies in more globally diverse samples have suggested this— indicating that population frequency data should only be compared across sex and ancestral cohorts, as well as from similar image modalities (see last bullet point recommendation above). This caution should be considered both in basic science research as well as in practice. While this study may not have captured the full global variation in sinus morphologies, with 1,625 radiographs across 933 individuals in total, it has still captured a high degree of variation and supports previous research indicating the individuality of the frontal sinus. Additional research, particularly in terms of frontal sinus growth/development in various populations would be beneficial; however, obtaining longitudinal radiographic and/or CT scans, particularly of subadults, may not be feasible to due ethical and health concerns related to radiation exposure.

Second, when considering varying image modalities, this study assessed the use of CT-derived 3D cranial models and not the CT slices themselves. While this allowed a more encompassing view of the sinus, resources to create the 3D models may not always be available. Medical examiners offices may only have access to individual CT slices. In such cases, practitioners must gauge their confidence in comparing those individual slices to the 2D radiographic postmortem image. Multiple side-by-side comparisons can be made and the cumulative points/features of concordance can be considered in the determination. Individual slices may also be overlaid with changes in translucency to try to recreate the 2D image; however, these methods were not specifically tested as part of this project. Additional studies investigating the best ways to approach these cases are needed. Despite these limitations, this grant-funded study is one of the most comprehensive assessments for using the frontal sinus in forensic identification.

Artifacts

Publications, conference papers, and presentations

Peer reviewed publications (* indicates student researcher)

Avent P*, Garvin HM, Campbell JL, Butaric LN. *In Prep.* Forensic identification using frontal sinus coding methods: the effect of mixed image modality comparisons. To be submitted to *Journal of Forensic Sciences.*

Abdulrazak N*, Butaric LN, Garvin HM. Accepted (2023). Age-related changes to frontal sinus traits and implications for forensic identification. Accepted to *Forensic Anthropology* Sept. 11, 2023.

Butaric LN, Fischer KM*, Campbell JL, Garvin HM. 2022a. Ontogenetic patterns in frontal sinus shape: a longitudinal study using elliptical Fourier analysis. *Journal of Anatomy* 241:195-210. https://doi.org/10.1111/joa.13687

Butaric LN, Richman A*, Garvin HM. 2022b. The effects of cranial orientation on forensic frontal sinus identification. *Biology* 11(1): 62. *Special Issue*: *Recent advances in forensic anthropological methods and research.* https://doi.org/10.3390/biology11010062

Campbell JL, Butaric LN. 2022. Technical modifications for the application of the Total Difference Method for frontal sinus comparison. *Biology* 11 (7): 1075. *Special Issue Forensic Anthropology: New methodological and theoretical perspectives in forensic human skeletal identification and methods.* https://doi.org/10.3390/biology11071075.

National Conference presentations (* indicates student researcher)

Garvin HM, Campbell JL, Butaric LN. (2024). Visual comparisons of frontal sinus radiographs: Documenting accuracy and exploring effects of experience. Oral Presentation accepted to American Association of Forensic Sciences, February 2024.

Avent P*, Campbell JL, Butaric LN. 2023. A validation and assessment of interobserver error for the FSS method of frontal sinus identification. Virtual poster presentation. American Association of Biological Anthropologists, March 2023. Abstract published in the *American Journal of Biological Anthropology* 180 (S75): 11.

Campbell JL, Avent PR*, Van Baarle AL*, Butaric LN. 2023. Visual comparisons for personal identification in forensic anthropology: a scoping review. Virtual poster presentation. American Association of Biological Anthropologists, March 2023. Abstract published in the *American Journal of Biological Anthropology* 180 (S75):26.

Avent P*, Butaric LN. 2023. A validation of the FSS method for forensic frontal sinus identification using a U.S. sample. Poster presentation. American Association of Forensic Science, Orlando, FL. February 2023. Abstract published in 75th AAFS Conference Proceedings vol XXIX: 53.

Avent P*, Butaric LN. 2022. Frontal Sinus morphology: variation among US-based populations. Poster Presentation. American Association of Anatomy Regional Meeting, October 8, 2022. University of Iowa, Iowa City.

Avent PR*, Campbell JL, Garvin HM, Butaric LN. 2022. Frontal sinus morphology as a forensic identification method: a comparison of intra-observer scores between scout radiographs and 3D skull images. Poster presentation. American Association of Biological Anthropologists, March 2022. Denver, CO. Abstract published in *American Journal of Biological Anthropology*177(S73): 8.

Butaric LN, Amundson CT*. 2022. Sex-based differences in absolute and scaled frontal sinus volumes among humans. Poster presentation. American Association of Biological Anthropologists, March 2022. Denver, CO. Abstract published in American Journal of Biological Anthropology 177 (S73):25-26.

Avent PR*, Campbell J, Garvin H, Butaric LN. 2022. A comparison of frontal sinus morphology using digital radiographs and 3D skull images: implications for forensic identification methods. Poster presentation. American Association of Forensic Sciences Meeting, February 2022. Seattle, WA. Abstract published in 74th AAFS Conference Proceedings vol XXVIII: 172.

Campbell JL, Butaric LN. 2022.Validation Test of the total difference technique for assessing the frontal sinus. Poster presentation. American Association of Forensic Sciences Meeting, February 2022. Seattle, WA. Abstract published in *74th AAFS Conference Proceedings vol XXVIII*: 177.

Internal University Symposia Presentations (* indicates student researcher)

Geiger A*, Butaric LN. 2022. Frontal sinus morphology and effect of thresholding protocols. Poster presentation. DMU Research Symposium, December 2022. Des Moines, IA.

Wright M*, Butaric LN. 2022. Secular changes in frontal sinus volume. Poster presentation. DMU Research Symposium, December 2022. Des Moines IA.

Abdulrazak N*, Garvin HM, Butaric LN. 2021. Stabilization of frontal sinus traits with age: forensic implications. Poster presentation. DMU Research Symposium, December 2021. Des Moines, IA.

Avent PR*, Campbell JL, Garvin HM, Butaric LN. 2021. Frontal sinus morphology as a forensic identification method: a comparison of intra-observer scores between scout radiographs and 3D skull images. Poster presentation. DMU Research Symposium, December 2021. Des Moines, IA.

Horst L*, Singh G*, Butaric LN. 2021. Inter- and Intra-reliability of orienting skull models. Poster presentation. DMU Research Symposium, December 2021. Des Moines, IA.

Theses

Avent PR*. 2023. Forensic identification using the frontal sinus: the effect of mixed image modality comparisons. *Master's Thesis.* Department of Anatomy, Des Moines University.

Abdulrazak N*. 2022. An investigation into the stabilization of frontal sinus development and its forensic implications. *Master's Thesis.* Department of Anatomy, Des Moines University.

Webinars, workshops, invited talks

September 21, 2023. Campbell JL. "Renovating Forensic Anthropology: It can be done, but can it be implemented?". Virtual presentation given to the 39th Annual Forensic Science Seminar, hosted by the Minnesota Coroners and Medical Examiners Association. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

June 29, 2023. Garvin HM. "Human Skeletal Research and Forensic Implications." Delivered to the Mentored Student Research Program at Des Moines University. Des Moines IA. *As part of this talk,* *she discussed what positive identification entails, including the role of the frontal sinus.*

May 1, 2023. Garvin HM. "Decedent Identification and Introduction to Forensic Anthropology" 1.25hr talk given at the 2023 Midwest Death Investigation Course. Ankeny, IA. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

April 27, 2023. Avent P*. “Forensic Identification Using the Frontal Sinus: The Effect of Mixed Image Modality Comparisons.” Hybrid Virtual/On Campus Presentation. Department of Anatomy, Des Moines University, Des Moines IA. *MSA student Patricia Avent defended her thesis proposal in a presentation, open to the DMU College of Osteopathic Medicine faculty, staff, and students.*

March 8, 2023. Garvin HM. “A Career in Forensic Anthropology,” Hour-long talk presented to four high school classes at Saydel High School, Des Moines, IA. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

November 15, 2022. Garvin HM “Forensic Anthropology for Beginners.” Two 1.5 hour workshops given at the Iowa Division of the International Association of Identification, Ankeny, IA. Assisted by Dr. JL Campbell. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

November 3, 2022. Garvin HM. “A Day in the Life of a Forensic Anthropologist,” Invited lecture to an introductory Forensic Anthropology undergraduate class at the University of Iowa. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

July 20, 2022. Garvin HM. “Forensic Anthropology Introduction.” Invited talk given at the Midwest Death Investigation Course. Ankeny, IA. *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

November 17, 2022. Avent P*. “Introduction to Forensic Anthropology.” Delivered to Anatomy Ambassadors club at Des Moines University. *As part of this talk, she discussed what forensic anthropology entails (including positive identification and frontal sinus morphology) to a group largely composed of Medical and Allied Health students.*

June 15, 2022. Campbell JC. “Personal Identification in Forensic Anthropology.” On Campus Presentation. Hosted by Department of Anthropology, Eastern New Mexico University, Portales NM. *In this talk, she discussed the roles and responsibilities of a forensic anthropologist, including the ways an unknown skeleton could be identified, before discussing the current research assessing the frontal sinus for its use in personal identification.*

May 13, 2022. Avent P*. “Forensic identification using the frontal sinus: the effect of mixed image modality comparisons”. Hybrid Virtual/On Campus Presentation, Hosted by Department of Anatomy, Des Moines University, Des Moines IA. *MSA student Patricia Avent defended her thesis proposal in a presentation, open to the DMU College of Osteopathic Medicine faculty, staff, and students.*

May 13, 2022. Abdulrazak N*. “An Investigation into the Stabilization of Frontal Sinus Development and its Forensic Implications.” Hybrid Virtual/On Campus Presentation. Department of Anatomy, Des Moines University, Des Moines IA. *MSA student Naeema Abdulrazak defended her thesis in a presentation, open to the DMU College of Osteopathic Medicine faculty, staff, and students.*

February 28, 2022. Campbell JL. “Personal Identification of Skeletal Remains in Forensic Anthropology.” Virtual Presentation Delivered to Department of Anthropology, University of Illinois-Chicago. *In this hybrid teaching lecture, she discussed the role of forensic anthropology and how skeletal remains can be identified, focusing in on a case example demonstrating various methods of assessing the frontal sinus.*

January 24, 2022. Butaric LN. “Applicable anatomy: How paranasal sinus variation informs medico-legal fields.” Delivered to the Craniofacial Research Group, Department of Orthodontics, University of Chicago, Illinois. 24 *As part of this talk, she discussed what positive identification entails, including the role of the frontal sinus.*

December 10, 2021. Campbell JL. “Forensic Anthropology: Age Estimation, Commingling and Identification of Skeletal Remains.” Delivered to Des Moines University, Friday Research Seminars. *In this event, she discussed the role of the Forensic Anthropologist in identifying human decedents, as well as specific aspects of her involvement in this grant.*

December 1, 2021. Garvin HM “Forensic Anthropology in the Medicolegal Setting.” 2-hour talk delivered to the Division of Criminal Investigations (DCI) Major Crime Unit workshop in Adel, IA. With assistance from JL Campbell. *As part of this talk, they discussed what positive identification entails, including the role of the frontal sinus.*

June 24, 2021. Butaric LN. “Dissecting the Path from Anthropology to Anatomy.” Delivered to Des Moines University Mentored Student Research Program Breakfast Sessions (audience: medical students). *During this talk, she was again able to discuss how the fields of medicine, anthropology, forensics, and anatomy intersect across careers and research projects. She also included discussion of portions of this grant, with emphasis on medical-student involvement in research.*

June 17, 2021. Butaric LN. “Research and Research Opportunities at DMU: How Diversity Strengthens Scientific Discovery.” Delivered to Des Moines University’s Health Professions Advanced Summer Scholar (Health P.A.S.S.) program offered through the Des Moines University’s Department of Diversity & Multicultural Affairs *During her talk PI-Butaric highlighted how one’s diverse cultural and educational experiences shape scientific research, with specific discussions on the intersection between the anatomical, anthropological, medical, and forensic fields, as related to this grant.*

April 9, 2021. Butaric LN. “Frontal Sinus Radiography: Applications for Forensic Science.” Delivered to Radiology Technicians of Iowa. *During this invited talk to medical professionals, she provided a general overview of what forensic anthropology entails and how radiology is used in forensic identification, including discussion of portions of this grant.*

General press, podcasts, and other media

January 13, 2021. CO-PI Garvin gave a radio/podcast interview to Podcast on Frontal Sinus Identification in Forensics - WHO Radio/ IHeartRadio - Need to Know with Jeff Angelo. (audience: general public) *There, she briefly discussed this project and its potential impact in forensic anthropology.* https://whoradio.iheart.com/content/2021-01-13-how-are-iowa-schools-spending-covid-money/

January 12, 2021. PI-Butaric gave an interview to Radio Iowa (audience: general public) discussing the role of forensic anthropology and positive identification, as related to the grant. https://www.radioiowa.com/2021/01/12/dmu-researcher-trying-to-make-sinuses-legal-for-identification/

Data Sets & Scripts Generated

Butaric L. 2023. FS_PopFreq_Data [Data set]. Zenodo. *Contains data and readme files associated with population frequency portion of grant.* https://doi.org/10.5281/zenodo.10035703

Butaric L, Avent P. 2023. FS_ImageMode_Coded_Data [Data set]. Zenodo. *Contains data and readme files associated with effect of varying image modalities portion of grant.* https://doi.org/10.5281/zenodo.10037538

Butaric L, Campbell J, Caple J. 2023. FS_EFA_Outline_Data [Data set]. Zenodo. *Contains data and readme files associated with EFA analyses portion of grant.* https://doi.org/10.5281/zenodo.10035680

Butaric L, Garvin H. 2023. FS_Ontogeny_Outline_Data [Data set]. Zenodo. *Contains data and readme files associated with ontogeny portion of grant.* https://doi.org/10.5281/zenodo.10037448

Butaric L, Garvin H. 2023. FS_Orientation_Outline_Data [Data set]. Zenodo. *Contains data and readme files associated with effect of orientation portion of grant.* https://doi.org/10.5281/zenodo.10037503

Butaric L, Garvin H. 2023. FS_Ontogeny_Coded_Data [Data set]. Zenodo. *Contains data and readme files associated with ontogeny portion of grant.* https://doi.org/10.5281/zenodo.10035697

Campbell J, Butaric L. 2023. FS_TD_Outline Data [Data set]. Zenodo. *Contains data and readme files associated with Total Difference Method portion of grant.* https://doi.org/10.5281/zenodo.10037304

Garvin H, Butaric L, Campbell J. 2023. FS_VisualAssess_Data [Data set]. Zenodo. *Contains data and readme files associated with visual assessment portion of grant.* https://doi.org/10.5281/zenodo.10037382

Campbell JL. 2022. ImageJ Macro Script, measurement aids, and instruction manual created for conducting the Total Difference Method (Outline method by Cox et al.). Freely available resources available on Github: https://github.com/jcampbelljess/FrontalSinus_TD_macros

Digitized Terry Collection Radiographs. Frontal sinus radiographs of 281 individuals were digitized from the Terry Collection and shared with the Smithsonian Institution. Questions regarding the use of these digitized radiographs can be directed to PI Lauren Butraic (ORC ID: 0000-0003-3743-2408) and/or Sabrina Sholts at the Smithsonian Institution (ORC ID: 0000-0003-4168-0578).

Dissemination Activities

As listed above, this project has generated three published manuscripts (additionally with one accepted, and one near submission), nine presentations at national and regional meetings, five student presentations at internal research symposia, and two successfully defended Masters of Science in Anatomy thesis projects. Portions of this project have also been presented in 19 invited talks and workshops, as well as discussed in two radio/podcast shows. Eight datasets and one macro-script related to the project are publicly available, being shared on Zenodo and GitHub, respectively. Digitized radiographs from the Terry Collection are available upon request (see above details). Study-level information has also been uploaded to the National Archive of Criminal Justice Data (NACJD) website.

References

Abdulrazak N, Butaric LN, Garvin HM. Accepted (2023). Age-related changes to frontal sinus traits and implications for forensic identification. Accepted to *Forensic Anthropology* Sept. 11, 2023.

Asherson N. 1965. *Identification by Frontal Sinus Prints: A Forensic Medical Pilot Survey*. London, UK: H.K. Lewis.

Avent P, Butaric LN. 2023. A validation of the FSS method for forensic frontal sinus identification using a U.S. sample. Abstract. *75th AAFS Conference Proceedings vol XXIX*: 53.

Avent P, Campbell JL, Butaric LN**.** 2023. A validation and assessment of interobserver error for the FSS method of frontal sinus identification. Abstract. *American Journal of Biological Anthropology* 180 (S75): 11.

Avent PR. 2023. Forensic identification using the frontal sinus: the effect of mixed image modality comparisons. *Master's Thesis.* Department of Anatomy, Des Moines University.

Besana JL, Rogers TL. 2010. Personal identification using the frontal sinus. *Journal of Forensic Sciences* 55(3):584-9. doi:10.1111/j.1556-4029.2009.01281.x.

Butaric LN, Jones GC, Garvin HM. 2020. Revisiting global patterns of frontal sinus aplasia utilizing computed tomography. *Forensic Science International* 315:110458. doi:10.1016/j.forsciint.2020.110458.

Butaric LN, Fischer KM, Campbell JL, Garvin HM. 2022a. Ontogenetic patterns in frontal sinus shape: a longitudinal study using elliptical Fourier analysis. *Journal of Anatomy* 241:195-210. https://doi.org/10.1111/joa.13687

Butaric LN, Richman A, Garvin HM. 2022b. The effects of cranial orientation on forensic frontal sinus identification. *Biology* 11(1): 62. *Special Issue*: *Recent advances in forensic anthropological methods and research.* https://doi.org/10.3390/biology11010062

Campbell JL, Butaric LN. 2022. Technical modifications for the application of the Total Difference Method for frontal sinus comparison. *Biology* 11 (7): 1075. *Special Issue Forensic Anthropology: New methodological and theoretical perspectives in forensic human skeletal identification and methods.* https://doi.org/10.3390/biology11071075

Cameriere R, Ferrante L, Mirtella D, Rollo FU, Cingolani M. 2005. Frontal sinuses for identification: Quality of classifications, possible error and potential corrections. *Journal of Forensic Sciences* 50(4):770–3. doi:10.1520/JFS2004343.

Christensen AM. 2004a. Assessing the variation in individual frontal sinus outlines. *American Journal of Physical Anthropology* 127(3):291-5. doi:10.1002/ajpa.20116.

Christensen AM. 2004b. The impact of Daubert: Implications for testimony and research in forensic anthropology (and the use of frontal sinuses in personal identification). *Journal of Forensic Sciences* 49(3):427-30. doi:10.1520/JFS2003185.

Christensen AM. 2005. Testing the reliability of frontal sinuses in positive identification. *Journal of Forensic Sciences* 50(1):1-5. doi:10.1520/JFS2004145.

Copes LE. 2012. Comparative and experimental investigations of cranial robusticity in Mid-Pleistocene hominins. PhD Dissertation. Tempe, AZ: Arizona State University.

Cox M, Malcolm M, Faigrieve SI. 2009. A new digital method for the objective comparison of frontal sinuses for identification. *Journal of Forensic Sciences* 54(4),761-72. doi:10.1111/j.1556-4029.2009.01075.x.

Culbert WL, Law FL. 1927. Identification by comparison of roentgenograms of nasal accessory sinuses and mastoid processes. *JAMA.* 88(21):1634-6. doi:10.1001/jama.1927.02680470020009.

Daubert W. Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 (1993).

Edgar HJH, Daneshvari Berry S, Moes E, Adolphi NL, Bridges P, Nolte KB. 2020. New Mexico Decedent Image Database. Office of the Medical Investigator, University of New Mexico: Albuquerque, NM, USA. doi:10.25827/5s8c-n515.

Hanson CL, Owsley DW. 1980. Frontal sinus size in Eskimo populations. *American Journal of Physical Anthropology* 53(2):251-5. doi:10.1002/ajpa.1330530209.

Hunt DR, Everest K. 2001. Frontal sinus size: Sex, population and metopism affinities. Abstract. *American Journal of Physical Anthropology* 114(S32):82–83. doi:10.1002/ajpa.21502.

Kirk JN, Wood RE, Goldstein M. 2002. Skeletal identification using the frontal sinus region: a retrospective study of 39 cases. *Journal of Forensic Sciences* 47:318-323.

Kullman L, Eklund B, Grundin R. 1990. The value of the frontal sinus in identification of unknown persons. *Journal of Forensic Odontostomatology* 8:3–10.

President's Committee of Advisors on Science and Technology. 2016. *Report to the President on forensic science in criminal courts: ensuring scientific validity of feature-comparison methods.* Washington, DC: Executive Office of the President.

Schneider CA, Rasband WS, Eliceiri KW. 2012. NIH Image to ImageJ: 25 years of image analysis. *Nature Methods* 9(7): 671–675. https://doi.org/10.1038/nmeth.2089

Schuller A. 1943. A note on the identification of skulls by X-ray pictures of the frontal sinuses. *Medical Journal of Aust.* 1(25):554-6. doi:10.5694/j.1326-5377.1943.tb44655.x

Smith-Bindman R, Kwan ML, Marlow EC, Theis MK, Bolch W, Cheng SY, et. al. 2019. Trends in use of medical imaging in US health care systems and in Ontario, Canada, 2000-2016. *JAMA* 322(9):843-56. doi:10.1001/jama.2019.11456.

Smith VA, Christensen AM, Myers SW. 2010. The reliability of visually comparing small frontal sinuses. *Journal of Forensic Sciences* 55(6):1413–5. doi:10.1111/j.1556-4029.2010.01493.x.

Tatlisumak E, Ovali GY, Aslan A, Asirdizer M, Zeyfeoglu Y, Tarhan S. 2007. Identification of unknown bodies by using CT images of frontal sinus. *Forensic Science International* 166(1):42-48. doi:10.1016/j.forsciint.2006.03.023.

Yoshino M, Miyasaka S, Sato H, Seta S. 1987. Classification system of frontal sinus patterns by radiography. Its application to identification of unknown skeletal remains. *Forensic Science International* 34(4):289-99. doi:10.1016/0379-0738(87)90041-7.