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Expert Testimony and Positive Identification of Human Remains Through Cranial Suture Patterns

ABSTRACT: North American forensic anthropological research should conform to the Daubert criteria (U.S.A.) and Mohan ruling (Canada) to ensure admissibility in a court of law. Positive identification through radiographic comparison of antemortem and postmortem cranial suture patterns was evaluated in light of these criteria. The technique is based on reliable principles, but problems with terminology and the resolution of radiographs make Sekharan's method difficult to apply. Using the location, length, and slope of a suture's component lines, rather than Sekharan's descriptions of sutural configurations, it is possible to determine the probability of a particular suture pattern occurring in more than one individual. A match of four consecutive lines is sufficient to establish positive identification. This approach meets the Daubert and Mohan criteria, although resolution of radiographs is still a major limitation. Computed tomography (CT) scans may prove a more useful modality for positive identification, due to better resolution and greater availability.

KEYWORDS: forensic science, cranial sutures, Daubert factors, Mohan ruling, positive identification

In United States of America v. Plaza, Acosta and Rodriguez, Senior U.S. District Judge Louis H. Pollak of the Eastern District of Pennsylvania ruled fingerprint identifications inadmissible. According to Pollak, the method used to match unknown fingerprints left at a scene to exemplars taken from suspects fails to satisfy the Daubert criteria for admissibility (1). The implications were enormous. Fingerprint experts could demonstrate the similarity between fingerprints found at a crime scene and those of a suspect, but could no longer say the two were the same. Similarly, the defense could not claim the prints came from another source. The ruling made it difficult to conclusively link a suspect to a crime scene. Although the ruling was made at the district level, applying only to the Eastern District of Pennsylvania, and despite the fact the judge subsequently vacated his order (2), the ruling raises the possibility that other methods of identification will be found lacking when subjected to similar scrutiny. In this case, the identification of a suspect was the point of contention, but victim identity and the techniques used to achieve a positive identification of unknown human remains are equally important to an investigation and the subsequent trial.

The prosecution's case against a defendant on trial for murder may depend heavily upon the identity of the victim. According to the FBI, 86% of victims know their killer (3). The links drawn between the deceased and the defendant speak to the opportunity and motive for the killing. Considerations such as, the nature of their relationship, when they were last seen together, and if they were on good terms, can help build a circumstantial case against a defendant. In cases where the victim and perpetrator were strangers proper identification of the body is also necessary, because the prosecution must prove the body and evidence it contains is the corpus of the alleged crime. If the defense requests a Daubert hearing on the technique used for identification and if the technique is deemed inadequate, the identification will be inadmissible and the prosecution case may be seriously threatened.

Prosecutors relying on DNA evidence to establish the victim's identity are secure in the knowledge that DNA identification has passed the Daubert test (4). Remains that are fragmentary, burned, or water damaged may not contain sufficient DNA for analysis. In these cases and in cases for which no comparative DNA sample is available, victim identification will depend on fingerprints, dental records, or skeletal characteristics. Badly decomposed bodies will not retain the necessary skin and ridge detail to make fingerprinting possible. Dental and skeletal traits are more durable, but dental radiographs can be difficult to obtain. The victim may never have visited a dentist, have changed dentists (causing valuable records to be lost), or never needed dental radiographs for diagnostic purposes (5–7). In such cases, skeletal characteristics may provide the only evidence of identity (5,8–9). The techniques used to achieve the positive ID must be defensible in a court of law. Forensic anthropological methods and theory must meet the standards set by Daubert in the U.S.A., and the Mohan ruling in Canada to ensure their admissibility in court.

Admissibility of Expert Testimony

In the U.S., expert qualifications and testimony are evaluated under Federal Evidence Rule 702, which states that a witness may qualify as an expert on the basis of knowledge, skill, experience, training, or education. Scientific, technical or other specialized knowledge may be introduced providing it will help the trier of fact to understand the evidence, or determine a fact at issue. The expert may give an opinion as long as: (1) the testimony is based on sufficient facts or data, (2) the testimony is the result of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the case (10).

In Daubert vs Merrell Dow Pharmaceuticals, Inc. (11) two minor children and their parents alleged that serious birth defects were caused by maternal ingestion of Bendectin during pregnancy. The District Court awarded summary judgment to the defendant based on their expert testimony. The plaintiffs presented their own experts,

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but the testimony was deemed inadmissible. The Court of Appeals agreed with the judgment citing Frye v. United States, 54 App. D.C. 46, 47, 293F. 1013, 1014, which states expert testimony is admissible only if the techniques are "generally accepted" in the relevant scientific community. The U.S. Supreme Court held that the Federal Rules of Evidence supercede Frye with respect to expert testimony in a federal trial. The judgment of the Court of Appeals was vacated and the case was remanded for further proceedings. The standard for admitting expert testimony under Federal Rule 702 was interpreted as follows.

Expert testimony must be based on reliable principles and methods; the methods and theories must have been tested or be testable; the theory or technique in question must have been subjected to peer review and publication; and the potential or known error rates of the technique, as well as the standards controlling the operation of the technique, must be considered by the judge before ruling on the admissibility of the testimony. An important consideration in determining admissibility is whether experts are testifying about research conducted independent of the litigation, or they developed their opinions expressly for the purposes of the trial (11). General acceptance of the technique in the field is still taken into consideration, but it is no longer the governing principle. These criteria are known as the Daubert factors (4).

The legal debate over the admissibility of expert testimony is less complicated in Canada. The Canadian Supreme Court examined the case of a pediatrician charged with sexually assaulting his patients. When ruling on the admissibility of expert testimony with respect to the psychiatric profile of the defendant, the Court held that the following criteria must be considered: relevance, necessity in assisting the trier of fact, the absence of any exclusionary rule, and the qualifications of the expert (12).

In Regina v. J.-L.J. the admissibility of expert testimony was the focus of an appeal by the Attorney General's Prosecutor to restore a conviction entered by the trial judge. The trial judge excluded the expert testimony because he was not convinced the Mohan requirements were met. A majority of the Court of Appeal allowed the accused's appeal, ordering a new trial on the basis of wrongful exclusion of expert testimony. The Supreme Court of Canada evaluated the appeal in light of the Mohan ruling, noting the Daubert factors could be helpful in evaluating the soundness of novel science (13). The appeal brought by the Attorney General Prosecutor was allowed and the conviction entered by the trial judge restored. The Daubert factors are becoming increasingly more important in resolving issues of expert testimony admissibility in both the American and Canadian legal systems. Forensic anthropologists must keep pace with these legal developments, or risk having their testimony and the evidence of their analyses ruled inadmissible.

In both the U.S. and Canada, expert qualifications relate to specialized knowledge or skill achieved through study and/or experience. Forensic anthropologists, actively engaged in case work, who maintain their teaching and research responsibilities, are active and in good standing with their professional associations, and who publish the results of their research, should have no difficulty being qualified as an expert witness. The potential problem arises from the methods we utilize. The purpose of this paper is to evaluate the cranial suture method of positive identification in light of the Daubert and Mohan criteria for admissibility in a court of law.

Reliability of Principles – Identification Theory

Forensic anthropology faces the same shortcoming identified by Inman and Rudin with respect to criminalistics, ". . . a serious deficiency in basic theory and principles, as contrasted with the large assortment of effective technical procedures" (14). We may agree about the accuracy of a given technique applied under test circumstances, but the conclusions drawn using the same technique in cases of potential forensic significance may generate considerably more debate. The meaning and the significance of findings are left open to a wide range of interpretations due to a lack of guiding theory.

Nowhere is this more evident than in the area of positive identification. Victim identification is the legal responsibility of the coroner or medical examiner. Since there are no formal or legal criteria for accepting or rejecting a putative identification, coroners and medical examiners rely on expert opinion. In the case of skeletal identifications, antemortem radiographs of a missing person are compared to postmortem radiographs of the deceased, similarities and differences are assessed. Positive identification rests on an expert's opinion of the unique nature of a particular set of characteristics. In theory, a positive identification is based on knowing how rare a series of identifying features are in relation to the identification universe—the source from which the match will be made, usually defined as the missing persons list (15). In practice, such data are not yet available (16), although Komar (17) is currently collecting frequency data of fractures and pathological conditions for victims of war crimes in the former Yugoslavia who share similar biological profiles. Rogers is working on a project to characterize the forensic "at-risk" population with a similar goal in mind.

In the absence of frequency data, Brogden (18) suggests a single unique finding is sufficient to positively identify the deceased; Morse and colleagues (19) recommend the use of at least two relatively uncommon features; and Mann (20) recommends at least four points of correspondence. Like fingerprint and bite mark analysis, there is no accepted minimum number of matching points required for a positive identification. Although the expert's conclusions are based on objective observations, the opinion is essentially subjective (4). It is left to the observer's discretion to determine the rarity of a trait based on his/her personal experience.

Since we do not share the same frame of reference, what appears to be a distinctive feature to one expert, may be a common occurrence to another. Hogge and colleagues (21) demonstrate inconsistent levels of success with radiograph-based identifications depending on the experience of the examiner and the bone being examined; ranging from 56% accuracy for the anterior lower leg to 98% accuracy for the anterior and lateral skull. Despite a lack of supporting frequency data, it is not uncommon for experts to conclude, "This combination of structural details of the cranium is unique to the individual, and offers yet another tool for identification of unknown human remains. . . " (22).

To eliminate subjectivity from this process, positive identification should be based on a probability statement indicating the likelihood that the unknown remains are those of a specific individual, or on a technique in which the features used for identification have been proven to be unique. A mathematical means of arriving at a positive identification ensures replicability, makes criteria explicit, and provides a method that can be debated and discussed (15). An intuitive approach can be neither confirmed nor denied. Konigsberg and Jantz (23) recommend reporting the results of forensic anthropological analyses in probabilistic terms, utilizing likelihood ratios to quantify the strength of expert opinions. The specificity of the likelihood ratio will depend on the antemortem information available about the individual who is putatively identified. To accomplish this task it is necessary to know: the identification universe, the degree of interdependence between traits, and trait frequencies.

Principles Behind Cranial Suture Identification

Cranial suture patterns are the result of highly variable and individual genetic factors (24–26). Unlike endochondral growth plates, cranial sutures do not have intrinsic growth potential. Their growth and development is controlled by external stimuli, specifically, neurocranial growth. Inductive signals from approaching cranial bone fronts deflect or butt up against each other, preventing obliteration. Once the cranial bones overlap, signals from the dura mater maintain suture patency and signal the mineralization of new osteoid on the periosteal surface. When the cranial suture is stabilized, the bone fronts signal the dura mater to stop producing osteogenic signals. Suture obliteration occurs when the dura mater remains osteogenic. Several transcription factors are responsible for the signaling of osteogenesis between the bone fronts and the dura mater, while others are responsible for suture patency. Variability in cranial suture patterns is the result of the genetic transcription factors that affect differential bone accredation at the centers of ossification, and responses to mechanical forces that affect growth and development (24–26).

To test the uniqueness of cranial sutures Sekharan (27) examined 521 skulls and 100 skiagrams. By superimposing video images of the skulls and skiagrams Sekharan was able to compare the sutures in minute detail. He found no duplications. Sekharan also considered bilateral symmetry within individual skulls and studied the suture patterns of twins. In 20 skulls assessed for symmetry, Sekharan found bilateral differences in all paired sutures. Although monozygotic twins do exhibit overall similarities in suture pattern types, variations can be observed in the details of the patterns. Sekharan calculated the probability of any given suture configuration repeating within any given population by measuring the slope and length of each configuration. According to his evaluation, the probability the configuration of even one sutural subdivision, e.g, pars lambddica, will be duplicated within a population is $1/10\,000^{100}$ (27).

Sekharan's results confirm the clinical research. Cranial sutures are unique to the individual. To be a useful means of identifying decedents the patterns must also remained fixed throughout an individual's life. Sekharan's research indicates cranial suture patterns are permanent, although the age at which the pattern becomes set has not yet been established (27). Based on a single case study, Jayaprakash (28) indicates ectocranial sutures may change form between early childhood and adulthood, thus limiting the usefulness of some childhood antemortem radiographs for comparison with adult postmortem radiographs.

Tested, Peer-Reviewed, Reliable Methods

Sekharan (27,29) devised a method of positively identifying individuals based on the location and order of 10 morphological suture types defined by their configuration of spikes, projections, recesses, and irregularities. According to Sekharan, the only limitation to the system appears to be the partial obliteration of sutures of older adults, representing about 3.5% of the population (29). Rogers has attempted to use the technique in two forensic cases, but had difficulty distinguishing some of the more complex of Sekharan's suture types, due to the absence of descriptions to accompany the photographs in his article. Nevertheless, Rogers was able to superimpose the antemortem and postmortem images, confirming they were identical to the smallest detail, thereby establishing a positive identification. Based on these cases, it was clear that an inter-observer error test of Sekharan's typology and methodology were needed.

Allard began an inter-observer error test, but almost immediately ran into difficulties. Two samples were selected for the study. The first was a collection of 14 hard-copy radiographs from a medical clinic in British Columbia, Canada. The second consisted of 44 digital radiographs from Credit Valley Hospital in Ontario, Canada. Following the recommendation of Sekharan (29), only antero-posterior views were selected. The analysis was limited to the Lambdoid suture because it is the easiest suture to recognize radiographically, and it exhibits the least amount of interference from superimposition of structures.

The 14 hard-copy radiographs from the British Columbia medical clinic were viewed using a standard light table. A magnifying glass was used to enhance the images. Only 2 of the 14 radiographs exhibited visible sutures. While it was possible to observe the sutures and some general characteristics, the images were too poor to distinguish Sekharan's suture pattern types. The 44 digitally stored radiographs from the Credit Valley Hospital were viewed using the program *Impax* (the imaging program used by the Diagnostic Imaging Department). These images did not depict the sutures with enough clarity to permit evaluation of the pattern types. Image enhancements were attempted using the magnification and contrast tools, but it was impossible to increase the resolution. Of the 21 adult radiographs examined, only 8 exhibited visible sutures (38%), while 17 depicted frontal sinuses (81%). Suture detail was easier to visualize in the subadult images, 15 of 23 useful radiographs (63%), due to the lack of superimposition of other structures and the wider spaces between bones. None of the adult images depicted the sutures with sufficient clarity to score according to Sekharan's typology.

Although there is sufficient evidence to establish the unique nature of cranial suture patterns, the typology and methodology suggested by Sekharan is problematic. Sekharan's (27,29) use of photographs with no accompanying descriptions created interpretive problems for the authors. The distinction between serrate, denticulate, serrated denticulate, and dentated serrate was established only after much discussion. The detail required to make these distinctions could not be observed on either the hard-copy radiographs or the digital images. Image quality was also a problem from the perspective of obtaining suitable comparative radiographs. Only 38% of the adult images exhibited visible sutures. In contrast, Smith and colleagues (22) report good visibility of sutures on computerized tomography (CT) scans. CT scans may prove to be a better modality for cranial suture identification. Sutures are easier to visualize on CT scans, and are becoming far more common than radiographs for imaging the skull (18).

Error Rates and Standards Controlling Operation

Opperman's research demonstrates cranial suture closure is largely under the control of genetic factors, but is subject to the individual vagaries of growth and development, causing each suture to follow a unique pattern of closure (24). Sekharan's study of monozygotic twins confirms the effects of both genetic and environmental factors in producing unique suture patterns. Monozygotic twins exhibit similar patterns of sutures (Sekharan's dentate, crenulate, etc.), but the details of suture projections, indentations, and other aspects of their configuration, are specific to the individual (27). Allard's analysis of Sekharan's cranial suture method of identification demonstrates a problem with the terminology used to describe suture patterns and the difficulty of obtaining radiographs of sufficient resolution to employ the technique. Still, in the two cases Rogers employed suture identification she was able to obtain clear antemortem radiographs for both of the deceased and, despite the uncertain terminology, was able to superimpose antemortem and postmortem images, matching the features detail for detail to obtain a positive identification.

The results of Oppermann's (24) and Sekharan's (27,29) analyses indicate a false identification is virtually impossible, providing the radiographic images are clear. The only issue is the amount of suture that must be compared in order to establish a positive identification. If a length of suture is divided into its component lines, defined as the section of suture between two curves, each line may be characterized by its length d_x and slope m_x. If, for simplicity, the length of a line is limited to 10 values (1–10 mm for example) and the slope is defined as 1 of 10 possible directions, the probability of a single line segment having a particular length and slope is $1/10 * 1/10 = 1/100$. If four consecutive line segments are considered, the probability of a length of suture containing four lines in a particular location on the skull, of particular lengths and slopes is $1/100 * 1/100 * 1/100 * 1/100 = 1/100\,000\,000$. This value not only exceeds the number of people in the missing persons population in North America, it also exceeds the population of Canada, making it virtually impossible that any two people in Canada could exhibit the same 4 sutural line segments.

Given the identification universe (the population of Canada, or all missing persons in Canada and the USA), any length of suture containing at least 4 consecutive lines with identical positions, lengths, and slopes observed on both antemortem and postmortem radiographs is sufficient to establish a positive identification, providing [1] both radiographs were taken after age 7, at which time neurocranial growth is largely complete (determined by weight) (30), [2] the radiographs were taken in the same orientation and at roughly the same distance from the tube to minimize distortion, [3] the section of suture being examined is in the same location in both antemortem and postmortem radiographs (measured as distance from a cranial landmark, e.g., lambda for lambdoid sutures).

Discussion and Conclusions

The use of cranial sutures to establish positive identification of unknown remains has been compared against the Daubert (11) and Mohan (12) criteria for admissibility in a court of law, which include: the reliability of the underlying principles; the use of tested, peer-reviewed, reliable methods; established error rates and standards controlling the operation of the technique; and the general acceptance of the theory or method by the scientific community. The lack of theory relating to personal identification is a problem for techniques that are not based on mathematical probabilities (15,23). Probability statements can be difficult to establish for some skeletal characteristics, e.g., a broken nose, because the frequencies of these traits in the identification universe are unknown. This is not an issue for cranial suture patterns.

Studies of cranial suture closure (24) and cranial suture patterns (27,29) confirm that cranial suture patterns are idiosyncratic. It is possible to calculate the uniqueness of a sutural configuration by dividing the suture into lines, determining the number of lines, the length, slope, and location of each line. Comparisons between the antemortem records of a missing person and the postmortem records of the deceased can be considered a positive identification based on a minimum of four consecutive matching lines within a suture. Sutural lines must be identical in their location, length and slope to be considered a match. Postmortem radiographs must be taken in the same orientation and at the same distance from the tube as the antemortem radiographs to minimize distortion. A single discrepancy is sufficient to eliminate a potential candidate. By demonstrating that the sutures occur in a specific combination, location, and orientation with a probability that exceeds the number of individuals in the identification universe (missing persons list), a positive identification can be established in an objective and consistent manner that meets the Daubert criteria of reliable principles.

Superimposition of antemortem and postmortem radiographs to compare the details of sutural line segments is a variation on Sekharan's (27,29) method of classifying suture types. The classification system proved difficult to apply in both casework and test situations, because Sekharan did not give clear descriptions for each suture type. Instead, he provided pictures of sutures, some containing more than 50 line segments, to illustrate different configurations. Using the photographs to classify suture configurations was problematic due to poor resolution of the antemortem X-rays. In some radiographs, only small sections of the suture (less than 50 segments) are visible. For these cases, it is possible to observe portions of the suture in sufficient detail to compare the location, slope and direction of the line segments, but not enough of the suture is present to establish the overall configuration with certainty. Since the uniqueness of suture patterns is observed in the details, rather than in the general configuration, as Sekharan discovered with monozygotic twin comparisons (27), assessing the sutural line segments is a more direct approach than classifying the suture type.

The usefulness of this technique will depend upon the availability of good antemortem radiographs. Antemortem X-rays are taken for diagnostic purposes, which introduces bias in their availability. Certain areas of the body are more likely to be represented than others. According to Brogdon (18), approximately 40% of all radiographs are taken on the chest; the upper and lower extremities account for roughly 10% each; the spine and breast, slightly less; and the abdomen, head/neck, pelvis/hip, and other represent approximately 5% each. Unfortunately, the frequency of radiographing a given body part for diagnostic purposes is in no way related to the frequency with which those body parts are found in a forensic context. For example, the chest is most commonly X-rayed, but Rogers' case work over a five-year period indicates skulls and fragments of femora are most commonly recovered from an outdoor forensic scene. Radiographs of the skull are becoming less common, giving way to the improved technology of CT scans and MRI (18). Cranial sutures are visible on CT scans, but suture pattern matching has not yet been tested for this modality.

The cranial suture technique meets the Daubert criteria of reliability, testability, and known error rates. Sekharan's approach is reliable and testable, producing accurate results when radiographic resolution is high (29). The simplified method proposed by the current authors can be used on radiographs with poorer resolution because it depends on matching consecutive lines within sutures, rather than entire configurations. The approach is based on probability theory and knowledge of the unique nature of sutures. The methodology involves simple superimposition of antemortem and postmortem x-rays and direct comparison of the location, direction, and length of four consecutive lines within a suture. While the theory and method are sound, the simplified suture method of positive identification has not been subjected to blind testing using large sample sizes. It has, however, proven successful in two forensic cases.

Demonstrating the admissibility of a technique is the first hurdle in the process of providing expert testimony. It is equally as important to effectively convey the results of scientific analyses to ensure the jury understands the evidence and the expert is perceived as knowledgeable, reliable and unbiased. An expert's testimony may be admitted into evidence and the information presented to the jury in an effective manner, yet the jury may choose to disregard the expert's testimony. The credibility of an expert depends heavily on the juror's perception of his/her impartiality (31). Subjective approaches to victim identification that rely on personal experience with particular skeletal characteristics will carry little weight with a jury. The opposition's expert can effectively nullify the evidence by reporting an entirely different experience of trait frequencies in his/her case work and research experience. Only methods that can be communicated clearly, demonstrated effectively, and shown to be objective in their application will be taken seriously by a jury.

Many forensic anthropologists are called upon to assist with analyses of unknown human remains, providing biological profiles and trauma analyses, but far fewer are called upon to provide evidence in court. This discrepancy has to do with the nature of the cases, some bones are not human, others are human, but of no forensic significance, e.g., medical specimens or archaeological remains (32). In cases of forensic significance, forensic anthropologists may provide information, such as the biological profile, that is used to further the investigation but is not necessary in court. Additional discoveries by the police and subsequent analyses by other experts, e.g., DNA analysts or forensic odontologists for identification, may render the biological profile redundant. Forensic anthropologists involved throughout the investigation, from the search/recovery of the remains to the analysis, and those who conduct trauma analyses are most commonly subpoenaed to testify.

Although forensic anthropologists do not testify in every case, there is no way of knowing at the outset whether a court appearance will be necessary. Forensic anthropologists must be prepared for the possibility that their expertise will be requested in court and be ready to defend their choice of techniques in every case. Forensic anthropologists should take an active role in ensuring their analyses meet, or exceed, the legal standards for admissibility in a court of law.

By incorporating the Daubert and Mohan criteria into forensic anthropological research and evaluating the work of others within this framework, forensic anthropologists can reach a consensus about the value of particular techniques; developing a body of literature to demonstrate the general acceptance, or rejection, of methods for use in court. As a discipline, forensic anthropology must see its responsibilities through from the scene to the courtroom. The results of forensic anthropological analyses are of little use if they cannot be admitted into evidence, or, once admitted, cannot be made intelligible and compelling to a jury.

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