CASE REPORT

Stanley Rhine,[1] *Ph.D. and Kris Sperry,* [2] *M.D.*

Radiographic Identification by Mastoid Sinus and Arterial Pattern

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ABSTRACT: A skull and some incomplete postcranial remains were discovered in two searches over a two-month period near Santa Fe, New Mexico. The discoveries could be demonstrated to be from the same person, and the remains were shown to be consistent with a specific missing person on the basis of anthropological analysis. Further work led to a positive identification on multiple grounds, including agreement of the details of the mastoid sinus and endocranial arterial patterns observed radiographically. These features may be useful for establishing positive identification from skeletal remains when antemortem radiographic studies for comparison are limited to lateral cranial vault studies.

KEYWORDS: physical anthropology, musculoskeletal system, human identification, X-rays, skull, sinus patterns, meningeal artery

On 22 Jan. 1989, a dog carried a human skull into the yard of a mobile home near the intersection of the Old Las Vegas Highway and Bobcat Crossing just outside Santa Fe, New Mexico. A search of the immediate vicinity resulted in the discovery of an incomplete femur. A subsequent search, involving the use of dogs, resulted in the surface recovery of a number of postcranial bones, including several ribs, long bones, an innominate, and vertebrae. All were clean, bleached, and showing evidence of carnivore activity.

Preliminary Analysis and Scene Search

A preliminary analysis of the skull and incomplete femur suggested that it was Hispanic, about 25 years old, and most likely male. These conclusions produced no identification leads. When the weather became propitious, the Office of the Medical Investigator (OMI) conducted a search of the area with the Santa Fe County sheriff and cadaver dogs from the New Mexico State Penitentiary. That search recovered a number of postcranial bones from the surface: vertebrae, ribs, and a clavicle, radius, ulna, scapula, sacrum, ilium,

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[1]Forensic anthropologist, Office of the Medical Investigator, State of New Mexico, University of New Mexico Medical School, Albuquerque, NM.
[2]Associate medical examiner, Fulton County Medical Examiner's Office, Atlanta, GA.

and tibial shaft. All were virtually free of soft tissue, sun bleached, and damaged by carnivores. Both extremities of many of the ribs were missing, and all but one long bone end had been destroyed. There was no indication that the body had ever been buried. In addition to the bones, a quantity of long blond hair and numerous articles of clothing were found.

Identification Leads

A 19½-year-old Hispanic female had been reported missing in July 1988. Her vehicle was found several miles from the Bobcat Crossing location later searched. In it were a purse and other personal articles. The skull found some 6 months later was believed by the police to be that of the missing 19½-year-old owner of the vehicle. However, since the skull was assumed to be male, that lead evaporated.

The discovery of clothing during the later search again alerted the authorities to the possibility of a tie-in between the vehicle, its missing 19½-year-old owner, and the evidence recovered. The clothing was identified by her parents as belonging to the missing female. The color, condition, state of skeletonization, and sizes of the bones discovered during the later search were consistent with the skull and femur discovered earlier, and were also consistent with the assumption that they all belonged to the same person. All of these circumstances might have been sufficient for identification in some jurisdictions, but the OMI wished to achieve a higher level of certainty.

Further Skeletal Analysis

The initial conclusion that the skull was probably male was based on anthroposcopic grounds. While Brothwell [*1*] cites a 90% accuracy on determination of sex from the skull alone, Stewart found only a 77% accuracy in one test [*2*], while Krogman achieved 92% [*3*]. Such estimates are based on dissecting room populations and, though widely accepted, have not been thoroughly tested.

Various metric skull sexing techniques also proved not to be definitive. For example, the technique of Giles and Elliot [*4*] produced a value of 892.53, barely above the 891.12 cutoff point. The skull weighed 638 g, which is in the middle of the overlap range [*5*]. Other measurements also left the matter of sex unresolved.

Found with the skull was a femur from which both ends had been gnawed. Its incomplete state allowed no length or extremity measurements. Though dense and heavy, it lacked high relief of the linea aspera, and other attempts to determine sex by metric means [*6*] gave ambiguous results.

Since the skull had been damaged, not all of the 45 racial skull traits compiled by the Mountain, Desert and Coastal Forensic Anthropologists (unpublished data) could be assessed. The 15 usable traits indicated a Caucasoid/Mongoloid mixture, common in skulls identified as Hispanic.

Despite the weakly masculine features of the skull, the postcranial evidence strongly suggested the female sex. The right innominate was incomplete. However, such features as the subpubic angle and auricular surface were clearly female [*3*], dictating a change in the attributed sex. None of the long bones was sufficiently complete to allow a direct estimate of stature. The ulna lacked only the olecranon process, so that its complete length could be estimated at 24 cm. Using the stature estimation formulas for white females [*7*], the stature was estimated at 160.24 cm (63 in.). The missing person flyer for the 19½-year-old Hispanic female was located, and it reported the stature was 63 in.

The bones were clean and somewhat weathered but ivorine, indicating relative youth [*8*]. The basioccipital synchondrosis was fused. McKern and Stewart [*9*] indicate that fusion of the basioccipital synchondrosis is both more rapid and more consistent than suture closure. However, their sample is restricted to males and includes no individuals under the age of 17. By age 17, 78% of males have achieved closure of the basioccipital synchondrosis, and by the age of 21, 100% of these structures are fused. The fusion process is thus likely to be spread over 6 years or more. There is no large data set which addresses the age of basioccipital fusion in females. However, one would expect the age of fusion to be earlier in females because of the generally more rapid rate of skeletal maturation typically found in females.

A total of 24 female skulls were sampled to determine the status of basioccipital fusion. Of those, 11 were from the University of New Mexico's Maxwell Museum Forensic and Documented Skeletal Collections. Data on 5 from the University of Arizona's Arizona State Museum Human Identification Laboratory (Walter Birkby, personal communication, 1989) and data on 8 from the University of Tennessee's forensic database (Richard L. Jantz, personal communication, 1990) were added. All the skulls were between the ages of 13 and 24 at death and nearly all showed fusion of the basioccipital synchondrosis (see Table 1).

Fusion of the basioccipital synchondrosis in females, as indicated by this small sample, can be complete by as early as age 13. Projection of these findings would produce an estimate of fusion in nearly 90% of females by the age of 16, well in advance of the male rates shown by McKern and Stewart. If true, this would indicate that the process of fusion is more rapid in females than in males, with a spread of typically only 3 to 4 years from beginning to end. The use of the McKern and Stewart male data for females would thus be expected to overestimate the age of a female. With fusion of the synchondrosis complete in the skull being studied, the age is thus older than 13 years. Of course, full fusion of the synchondrosis only helps to set the lower limit, not the upper limit, a factor contributing to error in the original estimation of the age. Clearly, additional research on teenagers, both males and females, is necessary.

The distal end of the recovered ulna showed a trace of an epiphyseal line. A commonly accepted time for this fusion is about 19 to 21 years of age in males. McKern and Stewart [*9*] show complete fusion in 35% of males by age 18 and 100% by age 23. Once again, the rates for females should be expected to be more rapid, so that a reasonable estimate of age based on the ulna might be no older than 19 to 20.

The lumbar and thoracic vertebrae recovered showed fusion of both superior and inferior epiphyses, which nominally does not take place in males until the midtwenties. The only cervical vertebral surface which could be evaluated for epiphyseal fusion was the inferior surface of C3. It was at Stage 3, which is consistent with an age of 17 and older [*10*]. McKern and Stewart [*9*] show 13% of their 17 to 18-year-old male sample having achieved fusion, with 100% having done so by 24 to 25. This maturation should also be expected to occur earlier in females. Thus, these vertebrae would indicate a lower age limit of around 18 to 20 years.

The meningeal arterial channel was moderately deep, and pacchionian depressions were visible endocranially. While these latter two details suggest an age older by a decade [*8*], the rest of the age estimators are consistent with an age in the late teens or very early twenties.

All teeth were in occlusion, with the exception of the third molars. They had been

TABLE 1—*Age of fusion of the basioccipital synchondrosis in females.*

	Open	Partly Fused	Fully Fused
Ages	13, 20	14, 14, 19, 22	13, 13, 13.5, 14, 15, 15, 16, 16, 17, 17, 18, 19 20, 21, 22, 23, 23, 24
Total number of skulls	2	4	18

extracted antemortem, rendering assessment of their root development impossible for use as an aging criterion. Trabecular patterns were difficult to visualize. Antemortem dental records were not immediately available, and superimposition of the dental amalgams in the lateral skull X-ray, the only available antemortem film, precluded dental identification. The dental X-rays were located weeks later, and the forensic odontologist was then able to confirm the identification that had been made through anthropological means.

Any estimate of age necessarily includes a judicious balancing of the various details elicited from the skeleton and a decision as to which factors should weigh more heavily than others. Such decisions are based on experience derived from the careful anthropological analysis of many contemporary cases in which the age at death is known or may be discovered. Experience with archaeological cases is of less value since there is no way to determine the actual age at death of an individual. The date of birth of the missing female was 4 Dec. 1968, making her 19½ years old at the time of her disappearance. The age estimated from the more complete remains is in close agreement with the reported age.

Determination of the Time Since Death

Confidence in the identification of skeletal remains can be enhanced if the condition of the remains recovered is consistent with the time of disappearance. It is essential for the anthropologist to become familiar with the details of the scene, including the ground cover, climate, elevation, precipitation, and other factors affecting the rate of decomposition and skeletonization. These conditions can vary widely within a single state.

The scene in this case was at the edge of the Santa Fe National Forest, which lies at an elevation of about 2150 m (7000 ft). This is an area of low, sparse, and scattered vegetation with well-spaced evergreens and some deciduous trees of low to medium height. The annual precipitation is less than 25 cm (10 in.). A body deposited in this area would probably be exposed to the full impact of sun, precipitation, and the attentions of numerous domestic dogs and coyotes, as well as avian and insect flesh eaters.

The remains were completely skeletonized with only small dried soft tissue tags adhering to the bones. The bones were mostly bleached and somewhat degreased, but not at all checked or cracked. This is consistent with rates of skeletonization noted for Southern Arizona [*11*]. The warm weather of July, August, and September hastened skeletonization, so that by the onset of cool weather the soft tissue was essentially gone. The remains were scattered by carnivores, as were those reported in a study from the Pacific Northwest [*12*]. Given this location, this time of the year, and the known rates of skeletonization, the condition of the remains is consistent with a six-month exposure period. As a consequence, all of the data elicited so far provide a satisfactory match with the missing person.

When remains are recovered from the same general location over a period of time, or when remains are widely scattered, it is important to demonstrate that all the bones are from the same person and have not become commingled with parts of a second individual. In this instance, all the recovered bones were of a consistent size, all were cleaned and weathered to the same extent, and there was no duplication of elements. Among the remains discovered were congenitally fused second and third cervical vertebrae, which can be seen in the antemortem radiograph (Fig. 1).

Positive Identification

The missing person had had a lateral skull radiograph made to visualize the cervical spine subsequent to an automobile accident just two months prior to her disappearance (Fig. 1). That X-ray compared favorably in terms of general morphology with postmortem

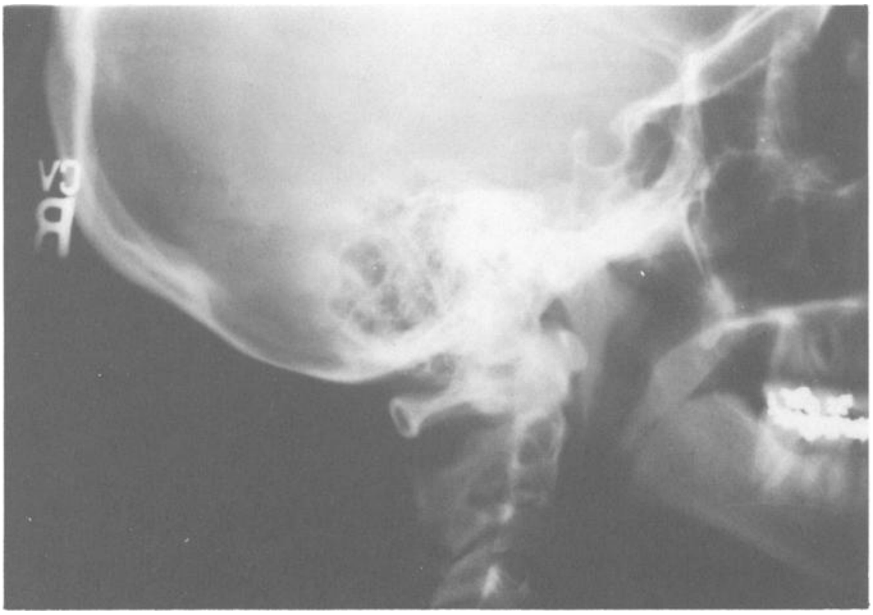

FIG. 1—*Antemortem lateral radiograph of the skull of a missing 19½-year-old Hispanic female. Note the congenitally fused C2 and C3 vertebrae.*

lateral X-rays of the skull taken at the OMI (Fig. 2). The antemortem film also showed congenital fusion of the bodies and both arches of the second and third cervical vertebrae, a condition duplicated in the recovered remains.

In addition, both X-rays revealed considerable detail of the mastoid sinus. While identification by frontal sinus patterns has long been practiced, the literature apparently holds only a single reference to use of the mastoid sinus for identification [*13*], which was done by Culbert and Law, in conjunction with the frontal sinus.

Identification by means of the frontal sinuses is possible because of their individualistic and age-stable patterns [*3,14*]. Ubelaker [*15*] has also commented in detail on this method of identification and confirmed its reliability during courtroom testimony. In this case, there were no antemortem anteroposterior skull views available to show the frontal sinus. Remodeling of the mastoid sinus pattern as a result of pathology (as with the frontal sinus) might alter the area so completely as to rule out identification on this basis. However, there was no indication of unexpected pathology. We decided that the principle demonstrated by Culbert and Law [*13*] would be applicable to the mastoid sinus pattern, which was clear on both the antemortem and postmortem X-rays.

The morphology was comparable, both in the overall outline and in the details of the individual air cell shape. Quite conservatively, five points of isomorphism can be recognized (see Figs. 3 and 4), although the features are much clearer in the original X-rays. There are, moreover, no points of disagreement, which is important in any type of radiographic identification. Culbert and Law have shown that radiographic identification can be made not only on the frontal sinuses but also on the mastoid sinuses. The method should prove acceptable in court as a means of positive identification. More extensive documentation and court tests would, however, be useful.

The lateral endocranial wall of the skull forms itself around the posterior branch of the middle meningeal artery. A perusal of suitable lateral cranial X-rays will reveal the

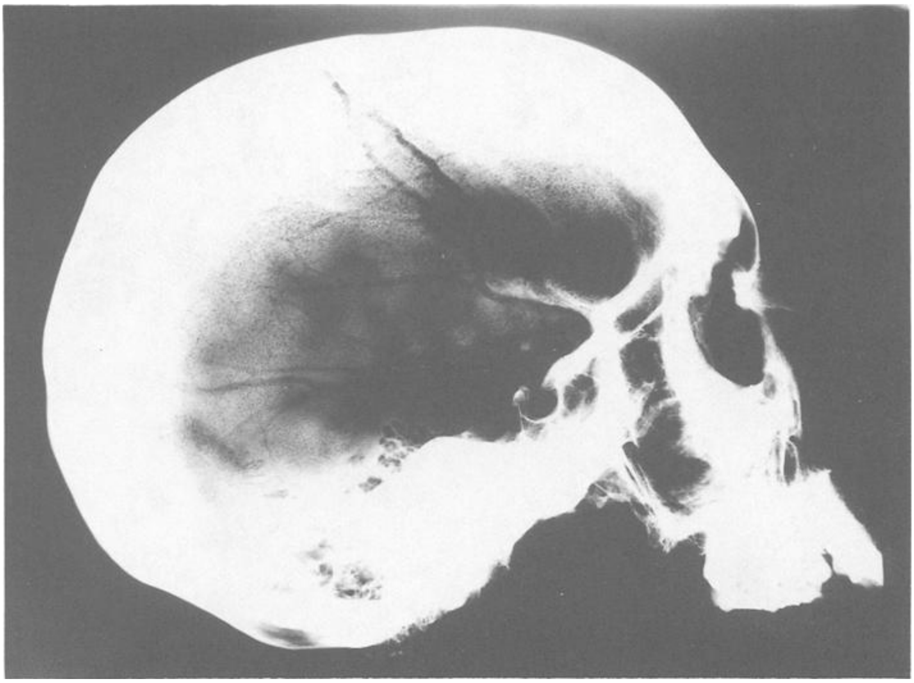

FIG. 2—*Postmortem radiograph of OMI Case No. 1279-189-1SF. The thicknesses of bone and the general morphology of the skull compare favorably with those in the antemortem view presented in Fig. 1. Note also the details of the course of the meningeal artery compared with those in Fig. 1.*

FIG. 3—*Enlargement of part of the area of the mastoid sinus in the antemortem radiograph, with the air cells outlined for clarity.*

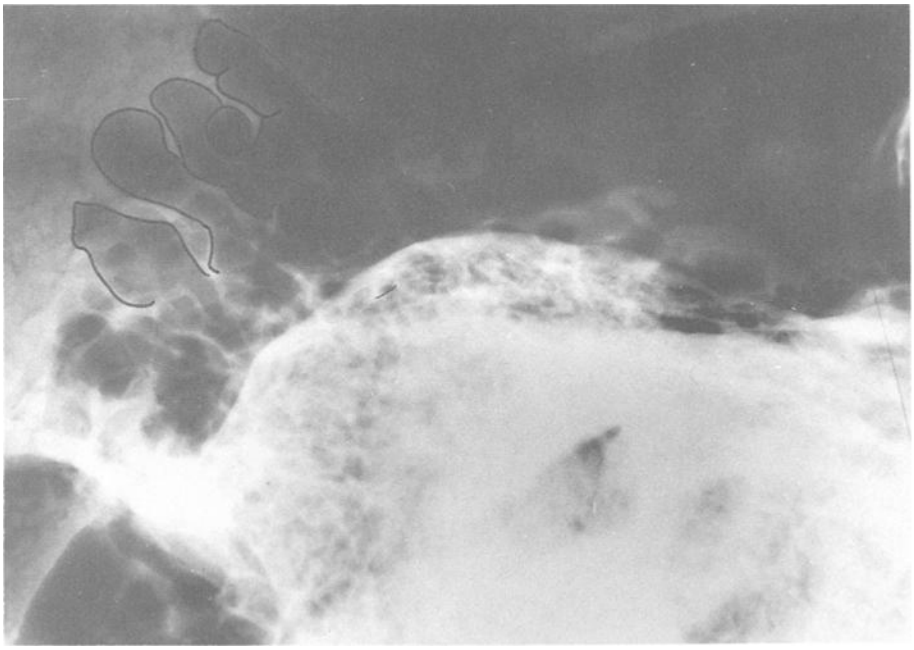

FIG. 4—*Enlargement of part of the area of the mastoid sinus in the postmortem radiograph. The air cells have been outlined for clarity. Compare the shapes of these cells with those shown in Fig. 3.*

unique branchings and coursings of this artery, seen radiographically as a dendritic radiolucent pattern. This should also be applicable to problems of identification.

Specifically, in this case, we see a long, nearly horizontal posterior arterial branch with identical meanders. The anterior branch rises at the same angle, and displays the same abrupt kink (see Figs. 1 and 2). Here again, isomorphism in the arterial morphology argues convincingly that these two radiographs are of the same person.

There also may be cases where the suture patterns can also be used for identification. A hint of this potential may be observed in the lambdoid suture, where the pattern may be seen to be identical on the antemortem and postmortem films (Figs. 1 and 2). A clearer antemortem film would enhance this possibility for matching.

Conclusions

Although the initial anthropological opinion was in error as to the sex and age of these remains, the investigative agencies persisted, and the remains discovered in January 1989 and in the subsequent search were conclusively demonstrated to be those of the missing 19½-year-old female. All of the circumstances—parental identification of the clothing, the condition of the skeleton, the stature, the fused cervical vertebrae, the various aging criteria, the radiographic morphology of the skull, the pattern of the mastoid sinus, and the meningeal artery and suture morphology—were either consistent or identical when compared with antemortem data. Indeed, a satisfactory and legally acceptable identification could have been made on almost any one of these grounds.

From the foregoing data, it is clear that much additional work remains to be done on aging criteria for modern teenaged skeletons, particularly skeletons of females.

Acknowledgments

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Address requests for reprints or additional information to
Stanley Rhine, Ph.D.
Office of the Medical Investigator
University of New Mexico Medical School
Albuquerque, NM 87131