CASE REPORT

Kathleen J. Reichs,[1] *Ph.D., A.B.F.A.*

Cranial Suture Eccentricities: A Case in Which Precocious Closure Complicated Determination of Sex and Commingling

REFERENCE: Reichs, K. J., "**Cranial Suture Eccentricities: A Case in Which Precocious Closure Complicated Determination of Sex and Commingling,**" *Journal of Forensic Sciences,* JFSCA, Vol. 34, No. 1, Jan. 1989, pp. 263-273.

ABSTRACT: The union of the cranial sutures can follow a somewhat erratic course. While it is recognized that this can cause inaccuracies in estimating age at death, deviant closure patterns can influence assessments other than age. Premature or eccentrically fusing sutures can alter cranial growth and, therefore, shape. Such modified growth vectors can significantly influence metric analysis.

A case is described in which precocious synostosis of the sagittal suture complicated determination of sex in a set of skeletalized remains. Features of the cranium and post-cranial skeleton indicated the individual was male, while the mandible, both metrically and morphologically, appeared to have come from a female. This led to the question of commingling. Techniques are described which were used to resolve these issues.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, commingling, discriminant function, sex determination

Currently, metric analyses, particularly those based on discriminant function techniques, are a standard part of any forensic science examination. There are, however, cases in which individuals may be misclassified because of idiosyncratic growth patterns. Precocious fusion of cranial sutures can result in shape abnormalities of both the cranium and mandible. The following describes a case in which subtle shape changes complicated the determination of individual sex and caused initial confusion as to whether or not a set of remains represented one or two individuals.

Case Report

On 7 May 1986 an adult, human cranium was discovered in the front yard of a house in Wilkes County, North Carolina. Dogs had dragged the remains up from a trash dump lo-

Received for publication 4 March 1988; revised manuscript received 23 April 1988; accepted for publication 28 April 1988.
[1]Assistant professor, Department of Sociology and Anthropology, University of North Carolina at Charlotte, Charlotte, NC.

cated at a lower elevation on the mountainside. On 13 May, a search of the dump by the local sheriff's office yielded a human mandible, three vertebrae, several long bones, and a right innominate (Figs. 1 to 3).

Initial examination of the mandible raised doubts as to its association with the cranium and pelvis and suggested the possibility of commingled remains. Because a body had been recovered from the same trash dump on a previous occasion, the possibility of a scenario involving three deaths seemed real. The Chief Medical Examiner made an on-site visit on 15 May and discovered a partially chewed human femur at the same elevation at which the cranium had been found. In early June a special rapelling crew of the State Bureau of Investigation undertook a thorough survey of the area. On 3 June, bones recovered in this search were analyzed in the Mecklenburg County Medical Examiner's Office. Four cervical vertebrae and the left innominate of an adult human skeleton were found, along with most of a deer and parts of several other animals.

First the human remains, designated #86-336, were cleaned, sorted, and examined to determine how many individuals were represented. The innominates looked decidedly male. The ischio-pubic rami were convex and appeared robust when viewed from the medial aspect. The sciatic notches were deep and narrow. There were no preauricular sulci, pubic pits, or ventral arcs. The auricular surfaces were not raised. Measurements yielded an ischio-pubic index of 88.5. The acetabular diameters (vertical 55 mm; transverse 52.8 mm) were well within the male range [*1*]. The long bones were robust. The femoral A-P diameter was 29.4 mm, close to the mean of 29.8 mm given by McLaughlin and Bruce [*2*] for males. Postcranially, the individual appeared to be male.

The skull was exceptionally narrow, with a maximum cranial breadth of 116 mm (length, 182 mm), and exhibited complete ectocranial and endocranial closure of the sagittal suture (Fig. 4). The cranial index was 63.7, considerably below the threshold of 70 suggested by Brothwell [*3*] as demarcating scaphocrania. Although of unusual shape, the skull looked

FIG. 1—*Cranium and mandible of Case 86-336, right lateral view. Cranium and mandible recovered separately.*

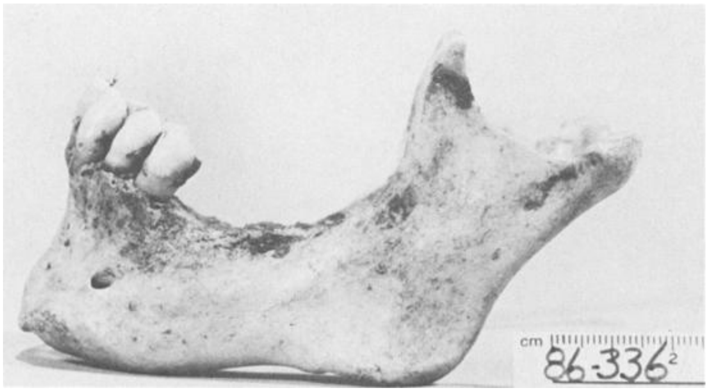

FIG. 2—*Case 86-336, mandible, left lateral view.*

FIG. 3—*Case 86-336, right innominate, lateral view.*

male. The occipital protuberance was very prominent, the supraorbital tori and mastoids moderate.

The low nasal bridge suggested negroid ancestry. A small portion of preserved pubic symphysis showed a smooth, inactive face with some definition of its lower extremity, but lacking distinct rim formation or lipping. This suggested an age of 22 to 43 years [*4*].

While consistent in terms of age and racial morphology, the mandible appeared incongru-

FIG. 4—*Case 86-336, superior view. Note fused sagittal suture and consequent cranial narrowing.*

ous with regard to sex. The gonial area was well developed, but the angle was obtuse and the condyles were extremely gracile, with a breadth of 16.5 mm. Additionally, articulation with the cranium did not appear good. (This was difficult to determine since the face was missing below nasion.) While some increase in mandibular angle could be expected given the loss of posterior dentition, the extremely narrow condyle breadth seemed quite female. Discriminant function analysis [5] yielded scores well within the female range when calculated for blacks and whites, using three separate sets of mandibular measurements (see Tables 1 and 2).

TABLE 1—*Mandibular measurements.*

Measure[a]	Value, mm
1. Symphysis height	37.5
2. Mandibular body length	88.0
3. Ramus height	55.0
4. Bigonial diameter	94.5
5. Mandibular body height	36.0
6. Mandibular body thickness	11.8
7. Ramus breadth	26.0
8. Ramus thickness	38.0

[a]For a full description see Giles [5].

TABLE 2—*Discriminant function sexing of the mandible.*[a]

	Caucasian						American Negro					
Measurements[b]	Score[c]	Male 0.05 Level	Male Mean	Sectioning Point	Female Mean	Female 0.05 Level	Score	Male 0.05 Level	Male Mean	Sectioning Point	Female Mean	Female 0.05 Level
1,3,4	273.345	306.93	302.25	287.43	272.60	256.99	250.2125	279.03	278.36	265.74	253.13	240.19
1,2,3,4,5	1610.645	2081.52	2065.71	1960.05	1854.39	1810.12	486.246	571.09	572.64	549.82	526.99	515.44
1,2,3,6,7,8	505.055	558.74	553.10	524.79	496.48	470.39	1499.1254	1689.14	1701.19	1628.79	1556.39	1488.28

[a]Calculated using William R. Maples Microcomputer Program for Forensic Anthropology, 1981.
[b]See Table 1 for a listing of measurements and individual values.
[c]Calculated using formulae provided by Giles [5].

A test sample of crania and mandibles was drawn from within the UNCC Physical Anthropology Laboratory to clarify the question of congruence between the mandible and cranium. Sixteen individuals were measured for the following: condyle breadth, bicondylar breadth, bigonial breadth, fossa breadth, bifossae breadth, and maximum cranial breadth. The measurements are described in Table 3. All measurements, except maximum cranial breadth (spreading), were taken with dial reading sliding calipers to the nearest 0.1 mm, recorded, and later retaken to check for accuracy. Repetitions were consistent to within 0.1 to 0.2 mm. That measurement exhibiting the most variance between repeated recordings was fossa breadth. This could be attributed to the absence of clearly defined landmarks along the border of the fossa. When repetitions for each measurement agreed to within 0.1 to 0.2 mm, an average of the readings was taken. In no case was the difference greater than 0.2 mm.

Correlations between sets of measures thought to indicate cranio-mandibular congruence were calculated, and scattergrams generated, using the SPSS program Scattergram [*6*] for the following pairs: condyle breadth to fossa breadth; bicondylar breadth to bifossae breadth; and bigonial breadth to maximum cranial breadth. It was hoped that this would provide a visual plot of where #86-336 lay relative to the sample subjects.

As expected, bigonial breadth and maximum cranial breadth were not strongly correlated at $r = 0.254$ ($p = 0.17$). Condylar breadth and fossa breadth were correlated at $r = 0.865$ ($p < 0.01$). The scattergram in Fig. 5 shows that the case in question fell somewhat outside the main scatter. Bicondylar breadth and bifossae breadth were also correlated, $r = 0.604$, ($p < 0.01$), and the case again fell off the primary slope of the scatter (Fig. 6). In the fossa-condylar comparison, the case in question was not so extreme an outlier as to suggest that the mandible and cranium came from different individuals. The bifossae-bicondylar findings were somewhat more problematical. The individual fell well outside the plot, suggesting one of two possibilities. Either the mandible and cranium did not belong together, or the individual to whom they belonged was in some way abnormal.

While the scattergrams provided useful visual representations of the degree of congruence between the mandibular and cranial measures in this case relative to the test sample, a more precise picture of the degree of fit between the joint surfaces seemed desirable. Following

TABLE 3—*Definition of measurements.*

1. Fossa breadth	maximum medial-lateral distance within the mandibular fossa, taken from the most medial point on the superior border of the fossa to the point where the fossa itself gives way to the suprameatal crest at its most lateral point
2. Condyle breadth	greatest distance measured from medial to lateral outermost points on the condyle
3. Bifossae breadth	maximum distance between the outer borders of the mandibular fossae, taken at the point where the fossa itself gives way to the suprameatal crest at its most lateral point
4. Bicondylar breadth	maximum breadth measured externally from the most lateral point on the left condyle to the most lateral point on the right (condylion to condylion)
5. Maximum cranial breadth	greatest breadth of the cranium, taken perpendicular to the median sagittal plane, avoiding the supramastoid crest (euryon-euryon)
6. Bigonial breadth	maximum diameter, taken externally between the angles of the jaw (gonion-gonion)
7. Fossa-condyle derived	calculated as the difference between fossa breadth and condyle breadth
8. Bifossae-bicondylar derived	calculated as the difference between bifossae breadth and bicondylar breadth

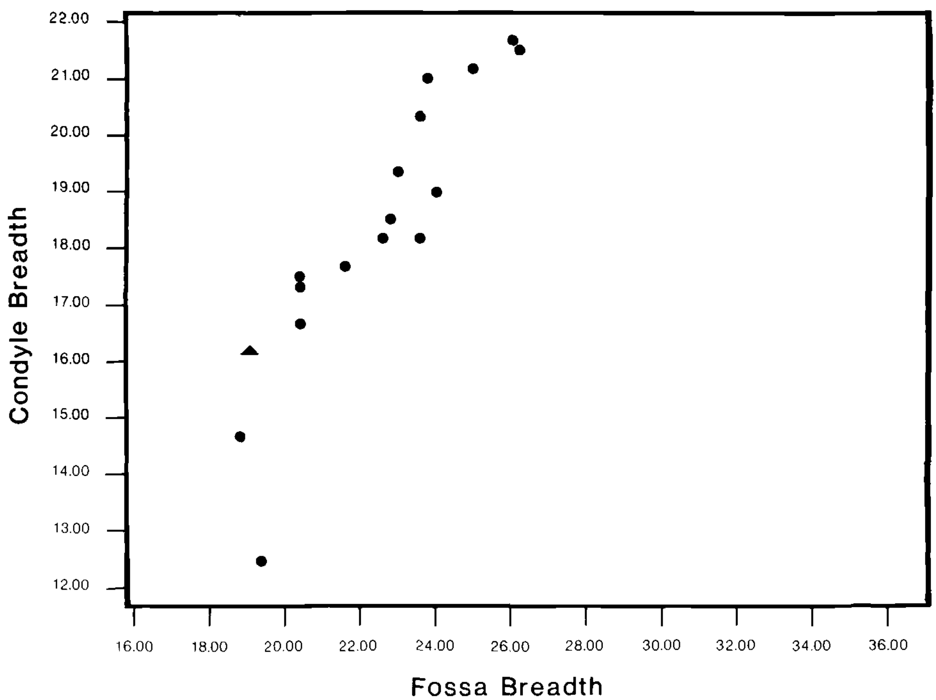

FIG. 5—*Scattergram showing correlation of condyle breadth to fossa breadth. Triangle indicates Case 86-336.*

Buikstra et al. [7], a new variable was calculated for each of the two sets of strongly correlated measurements. These derived variables represent the differences between: fossa breadth-condyle breadth, and bifossae breadth-bicondylar breadth. Sample means and standard deviations were calculated for each. These statistics are presented in Table 4 along with similar calculations for the subject in question.

The derived value for fossa-condyle breadth difference (2.50 mm) fell well below the mean of the sample (4.42 mm) for the same derived variable, but within two standard deviations of the mean. This suggests reasonably close congruence between the joint elements of the subject case. The difference between measurements for #86-336 was within two standard deviations of the average difference between joint elements in individuals in the test sample. The derived value for bifossae-bicondylar breadth (4.40 mm) fell close to the test sample mean (4.69 mm), suggesting that the degree of fit between the adjacent joint surfaces (mandible and temporal bone) was within the range to be expected in one individual. This was seen as sufficient to conclude that the bones came from one individual. A Type II error (accepting the remains as those of one person when, in fact, they represented two) seemed unlikely.

A conclusion was reached, therefore, that the skeletal elements belonged to one individual with moderate cranial abnormality. Premature fusion of the sagittal suture had resulted in elongation of the cranium. As would be expected, the mandible had followed a path of compensatory growth, resulting in a somewhat feminine morphology. A report was submitted profiling the individual as a black male, aged 22 to 43 years, with a most likely age at death between 27 and 35 years. He was described as having an unusually long and narrow cranium, and a long face, with some narrowing in the area of the lower jaw.

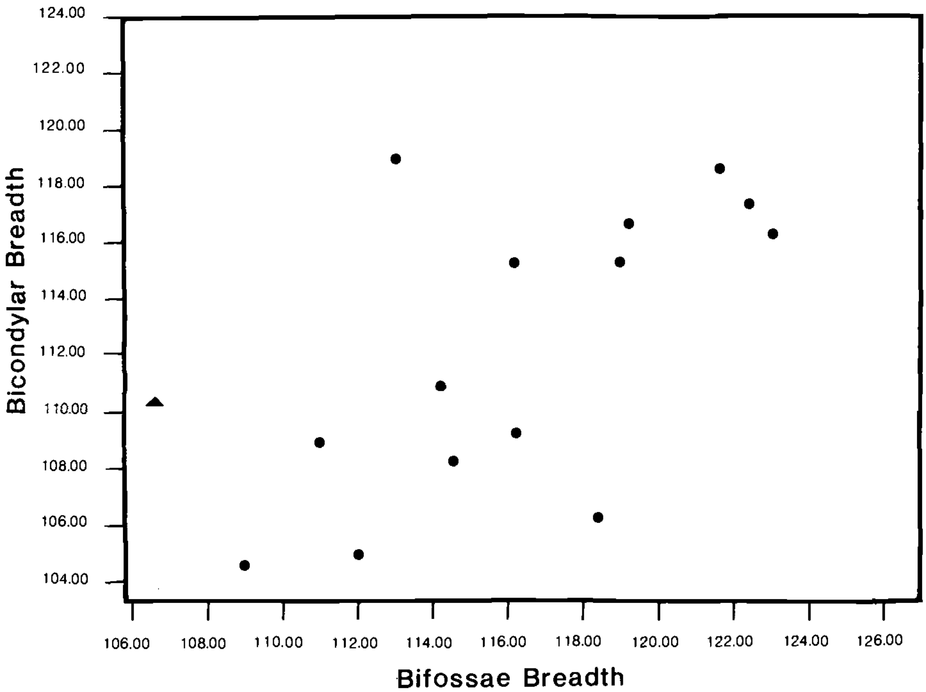

FIG. 6—*Scattergram showing correlation of bicondylar breadth to bifossae breadth. Triangle indicates Case 86-336.*

TABLE 4—*Statistics for derived variables, mm.*

Variable	Case 86-336	Sample Mean	Minimum/Maximum	Standard Deviation
Fossa-condyle (n = 16)	2.50	4.42	2.10- 6.50	1.36
Bifossae-bicondylar (n = 14)	4.40	4.69	1.00-12.70	3.56

Resolution of the Case

Analysis of items recovered from the vicinity of the bones in the trash dump turned up a pair of men's trousers containing a wallet. Snapshots retrieved from the wallet led sheriff's department personnel to a local household. A family member was reported as missing. He had last been seen in flight, his brother in hot pursuit with a loaded shotgun. The incident had occurred the previous November, and the pursuee had not been seen since. The remains were subsequently identified using dental records and "panorex" radiographs. They were those of a black male, aged 33 years at the time of his disappearance. The distinct craniofacial features can be seen in the life photograph (Fig. 7). His brother was convicted of second-degree homicide in December of 1986 and is currently serving a life sentence.

Discussion

In the years since Todd and Lyon published their standards for commencement and termination of ectocranial and endocranial suturual union based on the Western Reserve Univer-

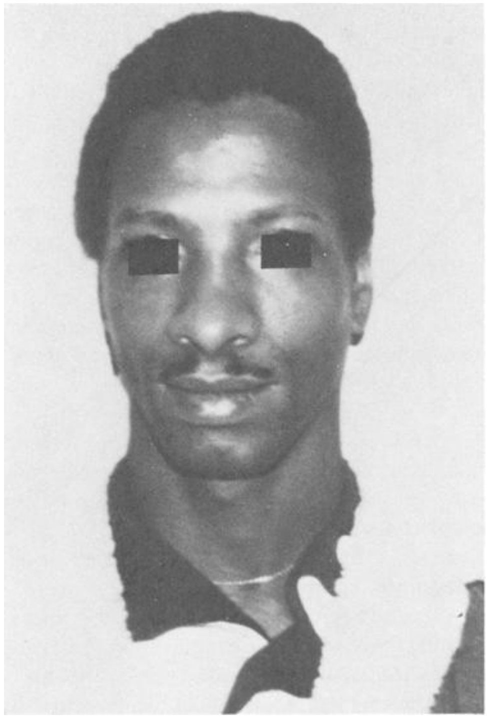

FIG. 7—*Case 86-336, life portrait. Note long, narrow cranio-facial morphology.*

sity skeletal collection [*8–11*], forensic scientists have become increasingly aware of problems in their use of the system for determination of age at death. Most discussions have focused on whether sutural closure is an accurate age indicator [*12–14*]. Two recent reanalyses have again taken up the question [*15*].[2] Erratic closure patterns have implications beyond age estimation, however. Alterations in growth vectors, brought about by the early fusion of one or more sutures, may result in changes in cranial shape. As this case indicates, such alterations in shape may significantly affect metric analyses, particularly those aimed at establishing an individual's sex or ancestry.

Although modal commencement and termination sequences, however broad, may characterize suture closure, there will always be individuals who do not conform to the general pattern. As early as 1915, Bolk recognized that premature synostosis may occur in the development of the human skull [*16*]. Although he attributed it to genetics, suggestions as to the cause of premature closure are abundant and include meningeal inflammation, microcephaly, mutation, rickets, birth trauma, atavism, lues, hyper/hypovascularization, disturbances of growth correlation between the brain and vault [*17*], and trauma [*3*]. Ultimately, explanations of abnormal closure must derive from an understanding of the processes governing normal calvarial growth.

Nonpathological suture closure results from mechanical forces. The work of Moss [*18–22*] using animal models has shown that sutures are not active growth sites, but that they function in several ways. Under stress from external forces, sutures prevent the separation of the cranial bones, while permitting relative motion to take place during growth of the brain.

[2]R. K. Baker, "The Relationship of Cranial Suture Closure and Age Analyzed in a Modern Multi-Racial Sample of Males and Females," unpublished M.A. thesis, California State University, Fullerton, CA, 1984.

Additionally, they provide areas where bone may be added as the brain expands. According to this mechanistic view, when cerebral expansion is complete, external forces, such as muscle activity, provide the stimuli for fusion. Factors which stimulate sutural fusion are functionally related and include the vault itself, the dura mater, the skull base, and the brain [*23*].

It follows, therefore, that abnormal sutural fusion may be due to extrinsic forces as well. As pointed out by Bennett [*23*], premature fusion must best be viewed as a symptom, not a cause, and due to factors that form the functional whole of the cranium. Moss [*19*] showed a correlation between premature metopic closure and the cranial base in crania with cleft palate. According to his model, basal kyphosis shifts the basal points of attachment of the dura mater relative to each other and alters the dural fibrous organization. Various patterns of premature suture closure may be similar, deriving from different basal abnormalities. While carried out using rat models, these studies have significant implications for human processes.

It must be recognized, therefore, that, even should modal trends for suture closure be confirmed, not all individuals will conform. As in the case described above, some will exhibit eccentricities. The forensic anthropologist must be aware of the possibility of aberrant individuals, particularly those with unusually early union.

Krogman [*24*] classifies early sutural closure into two categories. "Precocious" is used to designate closure before seven years, the age at which skull growth is 95% complete. "Premature" refers to closure after the age of seven, but before the "normal" time period. While premature and retarded sutural closure can have implications for estimating the age at death of an individual, precocious closure can complicate forensic analysis even further. Union of the cranial sutures prior to the completion of growth can lead to subtle changes in cranial shape or to severe deformation of the skull. Although eccentric skull shapes or noticeable asymmetries can actually be useful in establishing individual identity, the more subtle changes in cranial morphology can confound metric analyses. Use of discriminant function analysis may be inappropriate in cases in which the parameters of cranial and mandibular shape have been altered by abnormal sutural development.

Conclusion

This case illustrates the complications which precocious suture closure can cause in several aspects of forensic analysis. The most obvious is in the calculation of age at death (in which case both lapsed and early union must be considered). Recent research is suggesting, and this case supports, the conclusion that individual patterns of suture closure can be quite variable. Additionally, early union, particularly during the growth phase, can result in unusual cranial shapes. Although such eccentricities can be useful in individual identification, one must be cautious in applying techniques of metric analysis to these individuals.

In the case presented, the growth of the skull was impaired in its normal direction as a result of a precocious union of the sagittal suture. Growth proceeded perpendicular to the fused suture, resulting in scaphocrania. This abnormality was reflected in unusual mandibular growth. In cases such as this, the morphological features upon which one normally relies for determination of sex and ancestry, characteristics critical in the separation of commingled remains, may be altered. Application of discriminant function analysis for determination of race or sex or both may generate erroneous results in such cases and should be applied with extreme caution.

Acknowledgments

I am most grateful to Mr. William Brinkhous, Office of the Chief Medical Examiner, State of North Carolina, for photographs, and to Dr. Page Hudson, former Chief Medical Examiner, State of North Carolina, for his help on this case.

References

[*1*] London, M. R. and Curran, B. K., "The Use of the Hip Joint in the Separation of Commingled Remains," paper presented at the 55th Annual Meeting of the American Association of Physical Anthropologists, Albuquerque, NM, 9-12 April 1986.

[*2*] McLaughlin, S. M. and Bruce, M. F., "A Simple Multivariate Technique for Determining Sex from Fragmentary Femora: Its Application to a Scottish Cist Population," *American Journal of Physical Anthropology*, Vol. 67, 1985, pp. 413-417.

[*3*] Brothwell, D. R., *Digging Up Bones*, Cornell University Press, Ithaca, 1981.

[*4*] Katz, D. and Suchey, J. M., "Age Determination of the Male Os Pubis," *American Journal of Physical Anthropology*, Vol. 69, 1986, pp. 427-435.

[*5*] Giles, E., "Sex Determination by Discriminant Function Analysis of the Mandible," *American Journal of Physical Anthropology*, Vol. 22, 1964, pp. 129-135.

[*6*] Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., and Brent, D. H., *SPSS: Statistical Package for the Social Sciences*, second ed., McGraw-Hall, New York, 1975.

[*7*] Buikstra, J. E., Gordon, C. C., and St. Hoyme, L., "The Case of the Severed Skull: Individuation in Forensic Anthropology," in *Human Identification: Case Studies in Forensic Anthropology*, T. A. Rathbun and J. E. Buikstra, Eds., Charles C Thomas, Springfield, IL, 1984, pp. 121-135.

[*8*] Todd, T. W. and Lyon, D. W., Jr., "Endocranial Suture Closure. Part I. Adult Males of White Stock," *American Journal of Physical Anthropology*, Vol. 7, 1924, pp. 325-384.

[*9*] Todd, T. W. and Lyon, D. W., Jr., "Cranial Suture Closure. Part II. Ectocranial Suture Closure in Adult Males of White Stock," *American Journal of Physical Anthropology*, Vol. 8, 1925, pp. 23-45.

[*10*] Todd, T. W. and Lyon, D. W., Jr., "Cranial Suture Closure. Part III. Endocranial Closure in Adult Males of Negro Stock," *American Journal of Physical Anthropology*, Vol. 8, 1925, pp. 47-71.

[*11*] Todd, T. W. and Lyon, D. W., Jr., "Suture Closure. Part IV. Ectocranial Closure in Adult Males of Negro Stock," *American Journal of Physical Anthropology*, Vol. 8, 1925, pp. 149-168.

[*12*] Singer, R., "Estimation of Age from Cranial Suture Closure: A Report on its Unreliability," *Journal of Forensic Medicine*, Vol. 1, 1953, pp. 52-59.

[*13*] Brooks, S. T., "Skeletal Age at Death: The Reliability of Cranial and Pubic Age Indicators," *American Journal of Physical Anthropology*, Vol. 13, 1955, pp. 567-597.

[*14*] McKern, T. W. and Stewart, T. D., "Skeletal Age Changes in Young American Males," Technical Report EP-45, Quartermaster Research and Development Command, 1957.

[*15*] Meindl, R. S. and Lovejoy, C. O., "Ectocranial Suture Closure: A Revised Method for the Determination of Skeletal Age at Death Based on the Lateral Anterior Sutures," *American Journal of Physical Anthropology*, Vol. 68, 1985, pp. 57-66.

[*16*] Bolk, L., "On the Premature Obliteration of Sutures in the Human Skull," *American Journal of Anatomy*, Vol. 17, 1915, pp. 495-523.

[*17*] Moss, M. L., "The Pathogenesis of Premature Cranial Synostosis in Man," *Acta Anatomica*, Vol. 37, 1959, pp. 351-370.

[*18*] Moss, M. L., "Growth of the Calvaria in the Rat. The Determination of Osseous Morphology," *American Journal of Anatomy*, Vol. 94, 1954, pp. 333-362.

[*19*] Moss, M. L., "Premature Synostosis of the Frontal Suture in the Cleft Palate Skull," *Plastic and Reconstructive Surgery*, Vol. 20, 1957, pp. 199-205.

[*20*] Moss, M. L., "Fusion of the Frontal Suture in the Rat," *American Journal of Anatomy*, Vol. 102, 1958, pp. 141-165.

[*21*] Moss, M. L., "Inhibition and Stimulation of Sutural Fusion in the Rat Calvaria," *Anatomical Record*, Vol. 136, 1960, pp. 457-467.

[*22*] Moss, M. L., "Extrinsic Determination of Sutural Area Morphology in the Rat Calvaria," *Acta Anatomica*, Vol. 44, 1961, pp. 263-272.

[*23*] Bennett, K. A., "Craniostenosis: A Review of the Etiology and a Report of New Cases," *American Journal of Physical Anthropology*, Vol. 27, 1967, pp. 1-10.

[*24*] Krogman, W. M., *The Human Skeleton in Forensic Medicine*, Charles C Thomas, Springfield, IL, 1962.

Address requests for reprints or additional information to
Kathleen J. Reichs, Ph.D.
Department of Sociology and Anthropology
University of North Carolina at Charlotte
Charlotte, NC 28223