JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, May 2011, Vol. 56, No. 3
doi: 10.1111/j.1556-4029.2011.01705.x
Available online at: onlinelibrary.wiley.com

PAPER

ANTHROPOLOGY

Natalie R. Shirley,[1] *Ph.D. and Richard L. Jantz,*[1] *Ph.D.*

Spheno-Occipital Synchondrosis Fusion in Modern Americans*,†

ABSTRACT: This study examines spheno-occipital synchondrosis fusion in the modern American population and presents age ranges for forensic use. The sample includes 162 modern individuals aged 5–25 years. The basilar synchondrosis was scored as open, closing, or closed via direct inspection of the ectocranial site of the suture. Transition analysis was used to determine the average ages at which an individual transitions from unfused to fusing and from fusing to fused. The maximum likelihood estimates from the transition analysis indicate that females are most likely to transition from open to closing at 11.4 years and males at 16.5 years. Females transition from closing to closed at 13.7 years and males at 17.4 years. The probability distributions associated with these maximum likelihood estimates were used to derive age ranges for age estimation purposes. These results reflect sexual dimorphism in basilar synchondrosis fusion and agree approximately with average age at pubertal onset.

KEYWORDS: forensic science, forensic anthropology, spheno-occipital synchondrosis, basilar suture, skeletal maturation, age estimation, transition analysis

A great deal of disparity exists in the forensic and biological literature in terms of fusion ages for the spheno-occipital synchondrosis, as well as in research methodologies used to study its fusion (i.e., dry bone gross morphology, wet bone morphology at autopsy, bone histology, radiographs, and computed tomography [CT] scans). The spheno-occipital synchondrosis (i.e., basilar suture) is a vital contributor to subadult age estimates in that it can provide an upper or lower age bound depending on its state of fusion. This information is particularly useful when combined with information obtained from other epiphyses and the dentition, but in the absence of supplementary skeletal evidence, the basilar suture is used frequently as a stand-alone age indicator. This study aims to provide the forensic community with updated standards for basilar synchondrosis fusion in the American population that can be applied easily in a lab or field setting.

Review of the anatomical and anthropological literature on spheno-occipital synchondrosis fusion provides little consensus about the age at which this skeletal maturation indicator fuses. Early studies suggest complete fusion between 17 and 25 years in both sexes (1–3). Radiographic (4,5) and histological (6,7) studies were the first to report sexual dimorphism in fusion age, with females beginning to fuse between 11 and 14 years and males between 13 and 16 years. During the past decade, researchers have begun to use CT scanning technology to examine basilar suture closure (8–10). Okamoto et al. (8) report fusion in Japanese females by age 12 and in males by age 13. Sahni et al. (9) observed fusion in Indian females between 13 and 17 years and in males between 15 and 19 years. A recent CT study of Arabian Gulf populations reported that females fuse between 11 and 16 years, and males fuse between 12 and 18 years (10). However, an analysis of modern populations using direct inspection of the basilar suture endocranially at autopsy suggested that the basilar synchondrosis is not a good indicator of age in male cadavers, but that it could be useful in females (11). The authors argued that age-at-fusion was highly variable and not a reliable age indicator in skeletal remains. These results stand out as unusual in the published literature, possibly because of difficulty in accurately assessing closure status on autopsy, but this remains unclear.

Standards proposed by Scheuer and Black (12) state that females fuse between 11 and 13 years and males between 13 and 18 years, while *Gray's Anatomy* (13) gives an estimate of 18–25 for males and females alike. Scheuer and Black (12) ascertain that spheno-occipital synchondrosis fusion is related to maturation events that occur at adolescence and that estimates of 18–25 years are most certainly overestimates. A suitable illustration of this dilemma exists in the form of a case summary submitted by Rhine and Sperry (14), in which a fused spheno-occipital synchondrosis was used to support an age of 25 years for a missing person. A second visit to the crime scene yielded additional skeletal remains, and the initial age estimate came into question. In an effort to account for the disparity, the authors derived an age range using 24 female skulls from modern forensic collections. Based on these data, they noted that fusion can occur as early as 13 in females, with 90% of females fusing by age 16. The corrected age estimate agreed with the condition of the rest of the postcranial remains and with the missing person's description. Rhine and Sperry (14) point out that one major problem with the initial estimate was the use of McKern and Stewart's (2) standards for males, which overestimate age-at-death in females because males fuse later than females. Furthermore, an age range assigned to a fused synchondrosis sets the lower age limit but cannot offer further information about an upper age limit (14). Bassett et al. (15) reported a similar experience with

[1]Department of Anthropology, University of Tennessee, 250 South Stadium Hall, Knoxville, TN.

*Funded by a grant from the William M. Bass Endowment.
†Presented at the 60th Annual Meeting of the American Academy of Forensic Sciences, February 18–23, 2008, in Washington, DC.

Received 20 Jan. 2010; and in revised form 22 Mar. 2010; accepted 4 April 2010.

2011 American Academy of Forensic Sciences
Published 2011. This article is a U.S. Government work and is in the public domain in the U.S.A.

a forensic case whose identity was suspected to be that of a 13-year-old missing black female. Initial inspection of the closed synchondrosis led them to believe that the individual was over 18 years based on standards in the literature, but the postcranial skeletal epiphyses were consistent with a younger age. Bassett et al. point out that this incongruence could have affected the age estimate had there not been a putative identification. Accordingly, the present study aims to dispel some of the ambiguity that exists regarding fusion age, scoring methodologies, and sex dimorphism in the spheno-occipital synchondrosis.

Methods

Sample

The sample for this study consists of 162 individuals between 5 and 25 years of age (100 females, 62 males). Most individuals ($n = 112$) are positively identified cases from the Forensic Data Bank, which is a central database of forensic anthropology cases from around the United States. A smaller portion of the sample ($n = 50$) consists of casework submitted by forensic anthropologists in response to a call for basilar suture data initiated by the authors in May 2008. The birth years for individuals in this study range from the 1950s to the 1990s, and the sample is *c.* 65% American White, 22% American Black, 6% Hispanic, 4% mixed (White-Hispanic, White-Black, White-Native American, White-Vietnamese), and 4% unknown ancestry (the 101% total is because of rounding to the nearest percent). Individuals with known developmental diseases (e.g., Turner's syndrome) were not included this study.

Scoring

Most of the cases submitted in response to the call for data were accompanied by photographs which allowed the researchers to make an independent assessment of the score. Presumably, the Forensic Data Bank cases were scored as described by Moore-Jansen et al. (16). The following descriptions of scoring encompass this system and provide additional details in an effort to increase standardization and minimize observer error. The synchondrosis should be scored via direct inspection of the ectocranial surface of skeletonized remains. Direct inspection is the method used most frequently in forensic anthropology—it is the fastest, most cost-effective, and does not necessitate an autopsy cut.

The synchondrosis was scored as open/unfused, closing/fusing, or closed/fused. The unfused suture has a visible gap between the basilar portion of the occipital and the body of the sphenoid (Fig. 1). In an unfused synchondrosis, the gap contains no bone, and there is complete separation between the basilar portion of the occipital and the adjacent sphenoid. A fusing synchondrosis shows fusion activity when the gap begins to fill with bone as fusion proceeds from the endocranial to the ectocranial surface (12), but some form of hiatus exists in the suture (Figs. 2 and 3). The synchondrosis was scored as fused when the gap was completely filled with bone, and the ectocranial surface between the occipital and sphenoid is continuous. Occasionally, a fusion scar may remain at the site of the fused synchondrosis (Fig. 4), but this scar may remain in individuals for decades after fusion has occurred. Consequently, fusion scars at the spheno-occipital synchondrosis should not be considered a sign of recent fusion and should not be incorporated into age estimates. Table 1 summarizes the features used to score the basilar suture and provides a quick reference chart for scoring a synchondrosis in the laboratory or field.

Statistical Analysis

Transition analysis is used to obtain statistically robust age ranges that are less sensitive to problems presented by developmental outliers and sample size constraints than age ranges obtained using the percentile method (17). Transition analysis addresses some of the pitfalls associated with developing aging standards, including age mimicry and sample size limitations (17–19). Konigsberg's Nphases2 program was used for the transition analysis (available at http://konig.la.utk.edu/nphases2.htm). The program performs probit regression wherein the intercept and slope are converted to the mean and standard deviation, respectively (19). Nphases provides a maximum likelihood estimate that represents the average age at which an individual is most likely to transition

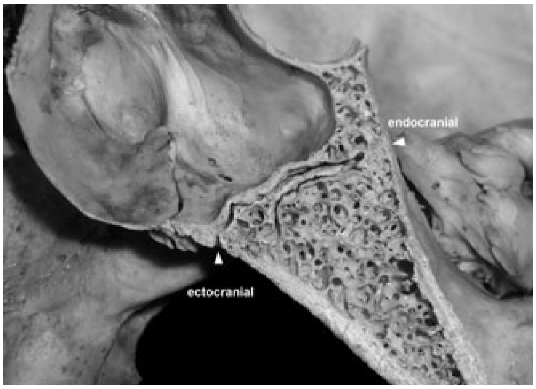

FIG. 2—*Fusing synchondrosis. Sagittal cross-section showing fusion proceeding from the endocranial to ectocranial surface. Note: This individual would be scored as fused if scored endocranially.*

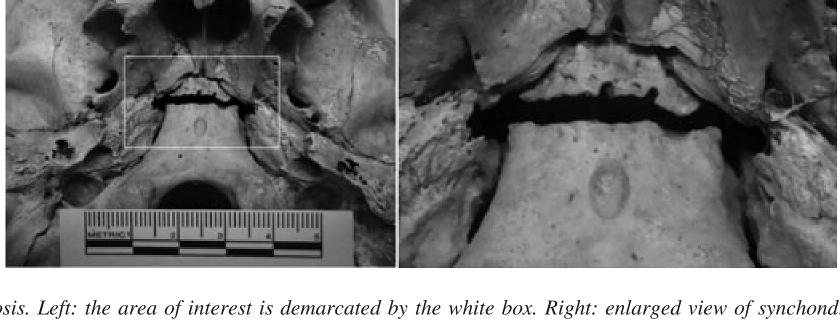

FIG. 1—*Unfused synchondrosis. Left: the area of interest is demarcated by the white box. Right: enlarged view of synchondrosis. Note the gap between the sphenoid and basilar portion of the occipital bone.*

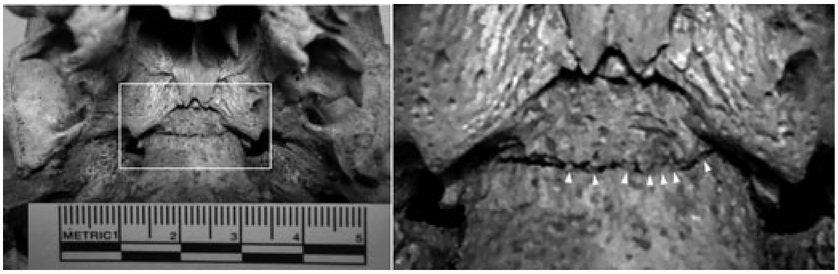

FIG. 3—*Fusing synchondrosis. Left: the area of interest is demarcated by the white box. Right: enlarged view of synchondrosis. The gap is narrowing and becoming filled with bone, especially in the areas indicated by the arrows.*

FIG. 4—*Fused synchondrosis with scar. The sphenoid and the basilar portion of the occipital are a continuous bony segment at the site of the synchondrosis. The fusion scar is most apparent in the area between the arrows.*

from one phase to the next. A cumulative probit model on log age, or proportional odds model with a probit link, was used for the transition analysis; this option assigns the same standard deviation to each transition using a natural log scale. Analyses were run separately on males and females to investigate sexual dimorphism, and ancestries were combined to increase statistical power.

Although it was not possible to measure observer error among contributors to the Forensic Data Bank, a Spearman's rank correlation coefficient (r_s) was calculated to test the relationship between age and phase. While this is not a direct test of observer error, a strong correlation presumably indicates relative consistency in scoring. The r_s values were tested for significance using a test statistic based on the t distribution:

$$t^* = \frac{r_s\sqrt{n-2}}{\sqrt{1-r_s^2}}$$

A Student's t-statistic was used to evaluate sex differences in fusion age. The t-statistic was calculated using the maximum likelihood estimates of the transitions and the corresponding standard errors from the transition ages:

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{\mathrm{se}_2^2 + \mathrm{se}_1^2}}$$

Finally, the prediction interval age ranges were checked for accuracy against the study sample and against McKern and Stewart's Korean War sample (2).

TABLE 1—*Features used to score the basilar suture. These features should be scored on the ectocranial surface of clean, dry bone.*

Score	Description
Unfused/open	Visible gap between the basilar portion of occipital and the sphenoid No bone present in gap
Fusing/closing	Synchondrosis beginning to ossify (proceeding endo- to ectocranially) The gap is narrowing and becoming filled with bone
Fused/closed	No gap remains between occipital and sphenoid Occipital and sphenoid are continuous at the basilar portion Fusion scar may be present

Results

The Spearman's rank coefficients indicate a strong positive relationship between age and phase across all groups: $r_s = 0.624$ for females, 0.744 for males, and 0.629 for the combined sample. The associated t values are 7.91, 8.63, and 10.23, respectively, all of which are significant at $\alpha = 0.01$. Table 2 provides the full range of variation in the raw data. The earliest age at which fusion is complete is 13 years in females and 16 years in males. The latest age at which the suture remains open is 13 years in females and 17 years in males.

Table 3 shows the anti-logged transition ages and the p-value from the two-tailed t-test for sexual dimorphism. These age ranges are based on the probability density functions from the transition analysis. Figure 5 shows the transition distributions summarized in Table 3; this graph also illustrates the difference between males and females in transition age. Table 4 gives age ranges based on the probability distributions depicted in Fig. 5 and Table 3. The "unfused" age limit was derived from the upper bound of the unfused-fusing transition distribution using +1 and +2 standard deviations for the 68% and 95% prediction intervals, respectively. This number gives the oldest age at which an individual is likely to be unfused. Similarly, the "fused" age limit was derived from the lower bound of the fusing-fused transition curve, and this gives the youngest age at which an individual is likely to be fused. The "fusing" age range was derived by combining the two curves and using the youngest probable age at which fusion commences for the lower limit and the oldest probable age at which complete fusion occurs for the upper age limit.

The prediction interval age ranges were checked against the study sample and against McKern and Stewart's Korean War sample (2). For the study sample, the 68% prediction interval correctly predicts age in 100% of the unfused and fused individuals in the study sample, but only predicts age correctly in 70% of the fusing females and 50% of fusing males. On the other hand, the 95% prediction interval predicts age correctly for all of the fusing

TABLE 2—*Percentage and actual number of individuals in each stage of fusion for males and females.*

	Males (n = 62)			Females (n = 100)		
Age	Open	Closing	Closed	Open	Closing	Closed
5	100* (2)[†]			100 (3)		
6	100 (1)			100 (2)		
7	–	–	–	100 (2)		
8	–	–	–	100 (1)		
9	–	–	–	–	–	–
10	100 (1)	–	–	100 (2)		
11	100 (1)			67 (2)	33 (1)	
12	100 (2)			–	–	–
13	–	–	–	50 (3)	17 (1)	33 (2)
14	100 (5)				25 (2)	75 (6)
15	100 (3)				10 (1)	90 (9)
16	20 (1)	20 (1)	60 (3)			100 (8)
17	100 (3)				22 (2)	78 (7)
18			100 (5)			100 (7)
19		17 (1)	83 (5)		33 (3)	67 (6)
20		11 (1)	89 (8)			100 (6)
21		50 (1)	50 (1)			100 (4)
22		25 (1)	75 (3)			100 (5)
23			100 (4)			100 (6)
24			100 (5)			100 (4)
25			100 (3)			100 (6)

*Percentage.
[†]Actual number (n).

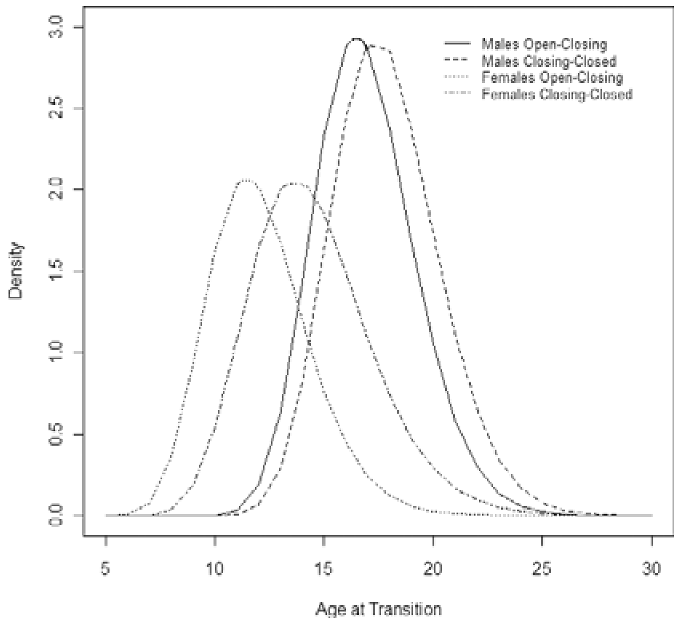

FIG. 5—*Transition distributions. Probability density plot of male and female transition distributions.*

individuals in this sample. For McKern and Stewart's sample, both the 68% and 95% prediction intervals correctly predict age in 100% of the individuals in the sample. A larger and more evenly distributed number of fusing individuals would likely improve the prediction rates in the study sample, but in lieu of this, the 95% prediction intervals can be used to assign age to fusing individuals. However, the 68% prediction intervals are adequate for assigning age to unfused and fused individuals, especially if additional age indicators are available for age estimation.

Discussion

This investigation demonstrates that complete fusion at the basilar synchondrosis occurs well before age 25, and the onset of fusion corresponds closely with the onset of puberty, with females beginning fusion *c.* 4 years before males. Endocrinology and osteological data suggest that females begin puberty 2–3 years before males (12,20). The slightly greater sex difference in synchondrosis closure compared to the onset of puberty could be an artifact of the sample size and distribution. The male sample contained only five individuals in the "fusing" stage. However, combining the fusing individuals with the fused sample and computing a 2-phase transition analysis gives similar results. Nonetheless, a larger sample of fusing males would provide for a better evaluation of this possibility. A second possibility is that this difference is a reflection of the true amount of sexual dimorphism in basilar suture fusion. If this scenario is accurate, we may be seeing the effects of a greater secular trend in early maturation in females than in males. While a secular trend toward earlier onset of puberty is well documented in females, inadequate or inconsistent data have made this more difficult to substantiate in males (21). A study of Greek maturation during the 20th century reported a significant decline in maturational (i.e., menarcheal) age of females but no detectable trend in males (22). However, earlier onset of epiphyseal union in the medial clavicle has been reported for males and females in the U.S. population (23). In addition, cranial base growth data indicate that the male cranial base reaches 95% of adult length 2–3 years later than females (i.e., 15.3 years for males and 12.6 years for females) (24). Presumably, attainment of adult cranial base length marks the cessation of growth; as such, these ages are concordant with the transition ages in the present study, although more so for females than males.

The basilar suture commences fusion at the endocranial surface, and fusion proceeds to the ectocranial surface, so it may appear "closed" endocranially but "closing" ectocranially (12). Standards based on endocranial versus ectocranial evaluation will likely differ. Furthermore, radiographs and CT scans enable earlier detection of fusion than gross examination of skeletal material, so standards based on these data collection procedures should not be applied to dry bone observations (25–28). Consequently, forensic experts using the age ranges proposed in this study should score the suture via direct inspection of the ectocranial surface of cleaned dry bone.

Owing to sample size constraints, ethnic differences could not be evaluated statistically. Nonetheless, socioeconomic status and level of modernization are cited more frequently than ethnicity as factors

TABLE 3—*Transition analysis maximum likelihood estimates and transition age ranges based on the probability density functions.*

	Unfused–Fusing			Fusing–Fused		
	Males	Females	p-value	Males	Females	p-value
Maximum likelihood estimate	16.5	11.4	<0.0001	17.4	13.7	<0.0001
Standard deviation age range	14.6–18.2	9.5–13.9	–	15.5–19.3	11.3–16.6	–
Standard deviation age range	13.1–20.4	7.8–16.8	–	13.9–21.5	9.3–20.1	–

TABLE 4—*Age ranges for modern individuals based on transition analysis probability distribution (PI, prediction interval).*

	Males (n = 62)		Females (n = 100)	
	68% PI	95% PI	68% PI	95% PI
Unfused	<18.9	<21.6	<13.9	<16.8
Fusing	14.4–19.9	12.6–22.8	9.5–16.6	7.8–20.1
Fused	>15.2	>13.3	>11.3	>9.3

influencing growth and maturation rates (26,27,29–39). Schmeling et al. (40) argue that skeletal maturation occurs in stages that are the same for all ethnic groups; the critical factor causing differences in ossification rates is the socioeconomic status of a population. Indeed, regression analysis has shown a positive relationship between ossification rates and medical modernization, as well as economic progress (41,42). The combined race sample used in this study likely does not pose a critical problem because similar environmental factors affect the American population as a whole. Nonetheless, these results should not be generalized to populations outside of the United States where different growth environments may influence development and maturation until this potential problem is tested.

Unfortunately, a sufficiently large modern sample was not available to test the accuracy of the transition age ranges; such a test would be the next logical step in the endeavor to provide sound age estimates with associated error rates for the forensic community. Consequently, we encourage validation studies of these results on other modern samples, as well as observer error tests on the scoring system proposed here. In addition, although it is beyond the scope of this article, further investigation into additional skeletal epiphyses may provide insight into the effects of secular change on skeletal maturation. Finally, an accurate understanding of spheno-occipital synchondrosis fusion has implications beyond skeletal aging as the basilar suture plays a critical role in craniofacial growth (24,43). In that the timing of suture closure is linked to cranial growth trajectories, basilar suture fusion likely accounts for certain morphological variation in cranial form, as well as for documented secular changes in the cranium (44,45).

Acknowledgments

We extend our gratitude to the forensic anthropologists who contribute to the University of Tennessee's Forensic Data Bank. We are especially grateful to Dave Hunt of the Smithsonian Institution, Dana Austin of the Tarrant County Medical Examiner's District, Dana Ritchie Parker of the Department of Sociology and Anthropology at the University of Texas at Arlington, Frank and Judy Saul, and Judy Suchey for providing additional cases from their files in response to the call for data. In addition, we would like to thank Dr. Suchey for her input on basilar suture closure, for providing us with her personal slides for examination, and for her detailed correspondence during the writing of this manuscript. Thanks also to the board members of the William M. Bass Endowment for recognizing the importance of this research. The conclusions in this paper do not represent the opinions of any of the aforementioned individuals and institutions.

References

1. Scott JH. The cranial base. Am J Phys Anthropol 1958;16:319–48.
2. McKern T, Stewart T. Skeletal age changes in young American males analysed from the standpoint of age identification. Natick, MA: Quartermaster Research and Development Center, Environmental Protection Research Division, 1957.
3. Ford EHR. Growth of the human cranial base. Am J Orthod 1958;44:498–506.
4. Powell T, Brodie A. Closure of the spheno-occipital synchondrosis. Anat Rec 1963;147:15–23.
5. Konie JC. Comparative value of X-rays of the spheno-occipital synchondrosis and of the wrist for skeletal age assessment. Angle Orthod 1964;34:303–13.
6. Melsen B. Time of closure of the spheno-occipital synchondrosis determined on dry skulls: a radiographic craniometric study. Acta Odont Scand 1969;27(1):73–90.
7. Ingervall B, Thilander B. The human spheno-occipital synchondrosis. I. The time of closure appraised macroscopically. Octa Odont Scand 1972;30(3):349–56.
8. Okamoto K, Ito J, Tokiguchi S, Furusawa T. High-resolution CT findings in the development of the spheno-occipital synchondrosis. Am J Neuroradiol 1996;17:117–20.
9. Sahni D, Jit I, Neelam Suri S. Time of fusion of the basisphenoid with the basilar part of the occipital bone in northwest Indian subjects. Forensic Sci Int 1998;98:41–5.
10. El-Sheikh M, Ramadan S. Closure of the spheno-occipital synchondrosis in the Arabian Gulf region. Proceedings of the 58th Annual Meeting of the American Academy of Forensic Sciences; 2006 Feb 16–21; Seattle, WA. Colorado Springs, CO: American Academy of Forensic Sciences, 2006;12:276.
11. Kahana T, Birkby WH, Goldin L, Hiss J. Estimation of age in adolescents—the basilar synchondrosis. J Forensic Sci 2003;48(3):504–8.
12. Scheuer L, Black S. Developmental juvenile osteology, 1st edn. New York, NY: Academic Press, 2000.
13. Williams PL, Bannister LH, Berry MM, Collins P, Dyson M, Dussek JE, et al. Gray's anatomy. New York, NY: Churchill Livingstone, 1995.
14. Rhine S, Sperry K. Radiographic identification by mastoid sinus and arterial pattern. J Forensic Sci 1991;36(1):272–9.
15. Bassett HE, Manhein MH, Listi GA, editors. Variation in adolescent epiphyseal union and basilar suture closure. Proceedings of the 52nd Annual Meeting of the American Academy of Forensic Sciences; 2000 Feb 21–26, 2000; Reno, NV. Colorado Springs, CO: American Academy of Forensic Sciences, 2000;6:218.
16. Moore-Jansen PM, Ousley SD, Jantz RL. Data collection procedures for forensic skeletal material, 3rd edn. Knoxville, TN: The University of Tennessee Department of Anthropology and Forensic Anthropology Center, 1993.
17. Konigsberg LW, Herrmann NP, Wescott DJ, Kimmerle EH. Estimation and evidence in forensic anthropology: age-at-death. J Forensic Sci 2008;53(3):541–57.
18. Kimmerle E, Ross A, Slice D. Sexual dimorphism in America: geometric morphometric analysis of the craniofacial region. J Forensic Sci 2008;53(1):54–7.
19. Boldsen JL, Milner GR, Konigsberg LW, Wood JW. Transition analysis: a new method for estimating age from skeletons. In: Hoppa RD, Vaupel JW, editors. Paleodemography: age distributions from skeletal samples. Cambridge, U.K.: Cambridge University Press, 2002;73–106.
20. Wheeler MD. Physical changes of puberty. Endocrinol Metab Clin North Am 1991;20(1):1–14.
21. Lee PA, Guo SS, Kulin HE. Age of puberty: data from the United States of America. APMIS 2001;109:81–8.
22. Papadimitriou A, Chiotis D, Tsiftis G, Hatzisimeon M, Maniati M, Krikos X, et al. Secular growth changes in the Hellenic population in the twentieth century. Hormones 2002;1(4):245–50.
23. Langley-Shirley NR, Jantz RL. A Bayesian approach to age estimation in modern Americans from the clavicle. J Forensic Sci 2010;55(3):571–83.
24. Roche AF, Lewis AB, Wainer H, McCartin R. Late elongation of the cranial base. J Dent Res 1977;56:802–8.
25. Schulz R, Mühler M, Reisinger W, Schmidt S, Schmeling A. Radiographic staging of ossification of the medial clavicular epiphysis. Int J Legal Med 2008;122:55–8.
26. Todd T. Atlas of skeletal maturation. St Louis, MO: Mosby, 1937.
27. Cardoso H. Epiphyseal union at the innominate and lower limb in a modern Portuguese skeletal sample, and age estimation in adolescent and young adult male and female skeletons. Am J Phys Anthropol 2008;135(2):161–70.
28. Cardoso HFV. Age estimation of adolescent and young adult male and female skeletons II, epiphyseal union at the upper limb and scapular girdle in a modern Portuguese skeletal sample. Am J Phys Anthropol 2008;137(1):97–105.
29. Abioye-Kuteyi EA, Ojofeitimi EO, Aina OI, Kio F, Aluko Y, Mosuro O. The influence of socioeconomic and nutritional status on menarche in Nigerian school girls. Nutr Health 1997;11(3):185–95.

30. Alberman E, Filakti H, William S, Evans S, Emanuel I. Early influences on the secular change in the adult height between the parents and children of the 1958 birth cohort. Ann Hum Biol 1991;18:127–36.
31. Bagga A, Kulkarni S. Age at menarche and secular trend in Maharashtrian (Indian) girls. Acta Biol Szeged 2000;4:53–7.
32. Bodzsar E. A review of Hungarian studies on growth and physique of children. Acta Biol Szeged 2000;44:139–53.
33. Laska-Mierzejewska T, Milicer H, Piechaczek H. Age at menarche and its secular trend in urban and rural girls in Poland. Ann Hum Biol 1982;9(3):227–34.
34. Low W, Kung L, Leong J. Secular trend in the sexual maturation of Chinese girls. Hum Biol 1982;54(3):539–52.
35. Malina R. Secular changes in size and maturity: causes and effects. Monogr Soc Res Child Dev 1979;4:59–102.
36. Prado C. Secular change in menarche in women in Madrid. Ann Hum Biol 1984;11:165–6.
37. Rimpela AH, Rimpela MK. Towards an equal distribution of health? Socioeconomic and regional differences of the secular trend of the age of menarche in Finland from 1979 to 1989. Acta Paediatr 1993;82(1): 87–90.
38. Kim JY, Oh IH, Lee EY, Choi KS, Choe BK, Yoon TY, et al. Anthropometric changes in children and adolescents from 1965 to 2005 in Korea. Am J Phys Anthropol 2008;136(2):230–6.
39. Meijerman L, Maat GJR, Schulz R, Schmeling A. Variables affecting the probability of complete fusion of the medial clavicular epiphysis. Int J Legal Med 2007;121(6):463–8.
40. Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. Int J Legal Med 2000;113:253–8.
41. Schmeling A, Olze A, Reisinger W, Geserick G. Forensic age estimation and ethnicity. Legal Med 2005;7(2):134–7.
42. Schmeling A, Schulz R, Danner B, Rösing F. The impact of economic progress and modernization in medicine on the ossification of hand and wrist. Int J Legal Med 2006;120:121–6.
43. Rosenberg P, Arlis H, Haworth R, Heier L, Hoffman L, LaTrenta G. The role of the cranial base in facial growth: experimental craniofacial synostosis in the rabbit. Plast Reconstr Surg 1997;99(5):1396–407.
44. Jantz R, Meadows Jantz L. Secular change in craniofacial morphology. Am J Hum Biol 2000;12:327–38.
45. Jantz R. Cranial change in Americans. J Forensic Sci 2001;46(4): 784–7.

Additional information and reprint requests:
Natalie R. Shirley, Ph.D.
Adjunct Faculty, Department of Anthropology
University of Tennessee, Knoxville
250 South Stadium Hall
Knoxville, TN 37996
E-mail: nrshirley@gmail.com