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T. Kahana,[1] *Ph.D.; W. H. Birkby,*[2] *Ph.D.; L. Goldin,*[3] *M.D.; and J. Hiss, M.D.*[3]

Estimation of Age in Adolescents —The Basilar Synchondrosis

ABSTRACT: The state of fusion of the basilar synchondrosis as a biological age indicator was assessed in a sample of 91 cadavers of both sexes whose ages ranged between 8 and 26 years. The correlation between the degree of closure and chronological age was investigated. Although the female population sample was very small ($n = 21$), the data indicate a tendency of differences in age between the "open" and "closed" groups. In the male population ($n = 70$), no significant differences were detected between the "open" and "closed" categories; in fact, the mean age of the two groups was the same ($p = 0.9$). These findings indicate that the stage of fusion of the basilar synchondrosis is not a good indicator of age in male cadavers, while in females the feature could be useful when estimating age of unknown human remains, although further investigation on a larger sample is advocated.

KEYWORDS: forensic science, age estimation, basilar synchondrosis, adolescence, autopsy

The identification of unknown human remains begins with the creation of an anthropological profile, which includes sex, biological age, stature, and individualizing features. The estimation of age at death is based on the bodily biological changes that occur throughout life (1). The degree of accuracy of the biological age assessment is inversely proportional to the length of time lived. The estimation of biological age is usually most accurate in the early phases of development and greatly depends on the state of preservation of diagnostic features in the remains. Macroscopically, two types of parameters are useful indicators of biological age: dental development and epiphyseal closure throughout the skeleton.

One of the features that has been advocated as a good age indicator is the state of fusion of the basilar synchondrosis (spheno-occipital fissure) (Fig. 1). In most anatomy textbooks, the fissure is described as "open" throughout childhood and puberty (Fig. 2), whereas its fusion (Fig. 3) indicates the beginning of adulthood (2–7). This last assertion has been disputed by some researchers who contend that the synchondrosis fuses during the adolescent period (8–12), around 10 to 14 years of age. The precise onset of adolescence is difficult to establish; sometimes the completed eruption of the premolars and second permanent molar are used as an indicator of the beginning of this period (13). Sex differences in the rate of human growth and development are well documented; as with other age indicators, the basilar synchondrosis is assumed to close earlier in females than in males (11).

Apparently the discrepancies in the reported age of closure of the spheno-occipital fissure are related, in some degree, to the method of assessment, i.e., direct inspection, imaging or histological examination, and to the discipline of the investigators, i.e., odontology or anatomy.

[1] Division of Identification and Forensic Science (DIFS), Israel Police, Headquarters, Jerusalem, Israel.
[2] Forensic Science Center, Pima County, Tucson, AZ.
[3] National Centre of Forensic Medicine, Tel Aviv, Israel.

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Since the closure of the basilar synchondrosis is considered an important landmark in growth and is regarded as a significant age marker when investigating incomplete human remains, the discrepancies observed in the literature make it imperative to establish the age of fusion of this trait. The purpose of the present investigation was to corroborate the validity of implementing the stage of closure of the spheno-occipital fissure as an indicator of biological age.

Materials and Methods

The stage of closure of the basilar synchondrosis of 92 cadavers was assessed during autopsy. The sample included 38 individuals from necroscopies performed at the Forensic Science Center of Pima County, Tucson, Arizona, and 54 autopsied at the National Centre of Forensic Medicine in Tel Aviv, Israel. One individual, a five-year-old female, was eliminated from the sample since the medicolegal examination indicated that she might have suffered from craniodiaphyseal dysplasia, a condition that affects the normal development of bones; thus, we report on a total of 91 cases (Table 1).

The stage of closure of the fissure was established after stripping the dura mater completely from the surface of the endocranium, between the rostral margin of the foramen magnum through the body of the sphenoid bone and the clinoid anterior processes. The fissure was classified either "open" or "closed" according to the presence or absence of cartilage as viewed on the endocranium. The determination of stage of closure of the synchondrosis was performed in the Israeli series by at least two of the three investigators (TK, LG, and JH), and the Arizona sample was examined by a very experienced investigator (WB).

The customary classification utilized for evaluation of the state of closure of the vault sutures, in which the line can be either 0 = "open," 1 = "one quarter closed," 2 = "one half closed," 3 = "three quarters closed," or 4 = "completely closed" (14,15), was not implemented in this study since as suggested by McKern and Stewart, "Of course, all such appraisals are subjective and individ-

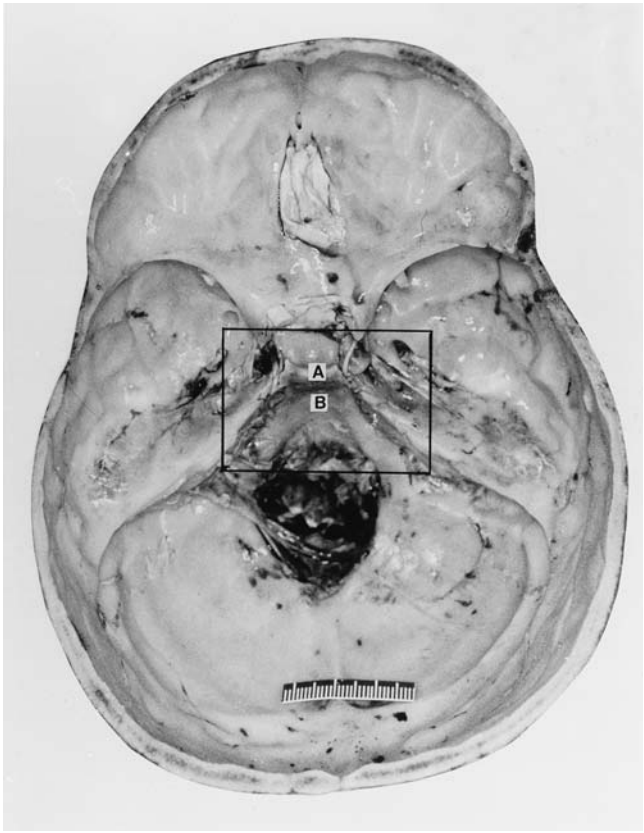

FIG. 1—*Interior of the base of skull: A. Dorsum sellae (sphenoid), B. clivus (occipital). In the immature skull the basilar synchondrosis (sphenoccipital fissure) is located at B.*

FIG. 2—*"Open" (unfused) basilar synchondrosis (see arrow).*

TABLE 1—*Distribution of age and sex.*

	Males		Females		Total	
Age	No.	%	No.	%	No.	%
8	1	1.4	. . .	. . .	1	1.1
10	. . .	. . .	1	4.8	1	1.1
11	4	5.7	1	4.8	5	5.4
12	3	4.3	1	4.8	4	4.3
13	5	7.1	3	14.3	8	8.7
14	12	17.1	2	9.5	14	15.3
15	6	8.6	3	14.3	9	9.8
16	1	1.4	4	19.0	5	5.4
17	6	8.6	3	14.3	9	9.8
18	6	8.6	. . .	. . .	6	6.5
19	5	7.1	1	4.8	6	6.5
20	7	10.0	2	9.5	9	9.8
21	3	4.3	. . .	. . .	3	3.3
22	5	7.1	. . .	. . .	5	5.4
23	4	5.7	. . .	. . .	4	4.3
26	2	2.9	. . .	. . .	2	2.2
Total	70	100	21	100	91	100

FIG. 3—*"Closed" (fused) basilar synchondrosis.*

ual interpretations may vary slightly among different observers." In our experience, the differences between the intermediate stages (1–3) in the basilar synchondrosis are difficult to assess correctly; thus, in the present investigation, stages 0 to 2 were classified as "open" and three and four as "closed."

The age of the individuals ranged from 8 to 26 years old, and both sexes were represented in the sample (Table 1).

The statistical analysis was conducted on SPSS for Windows 8.0. The female sub-sample, which consisted of 21 individuals, included only three with "open" basilar synchondrosys; thus, the statistical analysis was limited to descriptive statistics. On the male sub-sample ($N = 70$), a t-test was conducted to compare the mean age of the individuals with "open" and with "closed" synchondroses. Furthermore, a t-test to compare the proportion of "open" and "closed" synchondroses within individuals younger and older than 19 years of age was performed.

The effect of ethnic affinity on the time of closure of the sphenoccipital fissure could not be assessed since there is a greater representation of Caucasian individuals in the sample; of a total of 91 individuals, 76 were Caucasians, 14 were Mexican-American, and one was African-American.

Results

The sample included 91 cadavers of both sexes whose age ranged from 8 to 26 years old (Table 1).

The mean age of the female sub-sample whose synchondrosis was closed was 15.7 years, while in the female sub-sample with "open" synchondrosis the mean age was 12.3 years. These results, which are based on a rather small sample ($N = 21$) (Table 2), are of no real statistical value, although a tendency can be inferred (Fig. 4), especially since these results are similar to those reported elsewhere in the literature (8–12). Further investigation on larger samples should substantiate these figures.

The findings for the male sub-sample are unambiguous; the synchondrosis was found fused in individuals as young as eleven years old and "open" in subjects as old as 26 years (Table 2). The t-test conducted to examine the differences between mean age of closure of the synchondrosis indicates that there are no significant differences between the "open" and "closed" groups; the mean age of the male sub-sample whose synchondrosis was "closed" was 17 years, while in the male sub-sample with "open" synchondrosis the mean age was 16.9 years ($p = 0.9$).

Furthermore, when the hypothesis that the basilar synchondrosis fuses by the age of 19 was tested (14), the results showed that there is no statistical difference ($p = 0.48$) between the proportion of in-

TABLE 2—*Basilar synchondrosis stage by sex and age.*

	Males		Females	
Age	"Open"	"Closed"	"Open"	"Closed"
8	1	. . .	. . .	. . .
10	. . .	. . .	1	. . .
11	1	3	1	. . .
12	2	1	. . .	1
13	3	2	. . .	3
14	5	7	. . .	2
15	. . .	6	. . .	3
16	1	. . .	1	3
17	2	4	. . .	3
18	4	2	. . .	. . .
19	1	4	. . .	1
20	1	6	. . .	2
21	1	2	. . .	. . .
22	3	2	. . .	. . .
23	1	3	. . .	. . .
26	2	. . .	. . .	. . .
Total	28 (40%)	42 (60%)	3 (14.3%)	18 (85.7%)

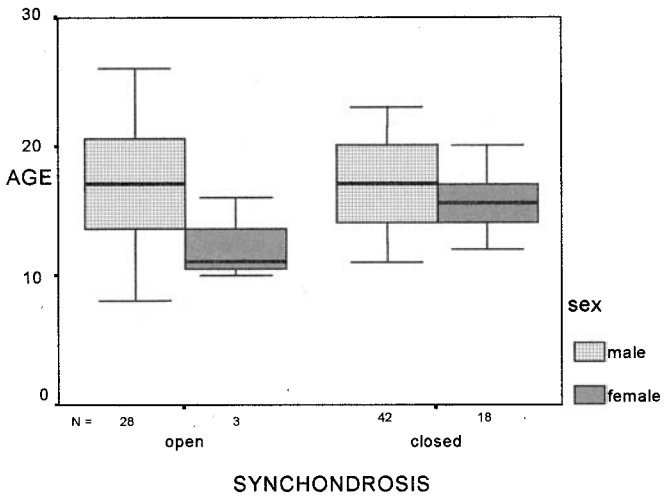

FIG. 4—*Box-plot of status of synchondrosis by age and sex.*

TABLE 3—*Reported age of closure of basilar synchondrosis according to various authors. The column age denotes either the range of age at closure (when sited by the author) or the minimal age of complete fusion. Primary and secondary data are presented.*

Method	Discipline	Age	Author and Year
Direct Inspection	Anatomy	11–20	Frick et al. 1991 (27)
	Anatomy	15–19	Sahni et al. (1998) (30)
	Odontology	17–20	Scott 1958 (20)
	Odontology	17–25	Ford 1958 (21)
	Anatomy	18–20	Cunningham 1978 (6)
	Anatomy	18–23	Schmidt 1888 (22)
	Anatomy	18–25	Gray 1995 (4)
	Anatomy	19–20	McKern & Stewart 1957 (14)
	Anatomy	20–23	Morris 1953 (23)
	Anatomy	20–25	Montagu 1951 (24)
	Anatomy	25	Grant 1972 (3)
	Anatomy	25	Mc Minn et al. 1990 (5)
	Anatomy	25	Hamilton 1976 (7)
Imaging	Odontology	10–12	Ohtsuki et al. 1982 (11)
	Odontology	11–13	Irwing 1960 (9)
	Odontology	12–13	Powell & Brodie 1963 (10)
	Odontology	12>	Madeline & Elster 1995 (25)
	Odontology	12–14	Melsen 1969 (8)
	Radiology	13	Okamoto 1996 (12)
Histology	Odontology	13–16	Thilander & Ingervall 1973 (26)

dividuals with "closed" synchondrosis in both sub-groups (younger than 19 and older than 19 years of age).

Discussion

The age of an individual can be subdivided into four broad phases based on the developmental and degenerative changes that characterize them: prenatal, childhood, adolescent, and adulthood. This subdivision is somewhat artificial, since the patterns of ontogenic and post-ontogenic metamorphosis of the various "age indicators," i.e., dental, cranial, and postcranial features, do not form a sequence of events but rather overlap (16). The present research focuses on the adolescent period—from the time of eruption of the premolars and the second permanent molar to the end of the skeletal growth. The onset of puberty in different populations is not constant; thus, extreme caution should be exercised when establishing age during the adolescent period (13).

During this phase, the most accurate source of information for age estimation is the sequence of fusion of epiphyses and the unification of the three bones of the os coxa. The sequence of epiphyseal coalescence proceeds from elbow to hip, ankle, knee, wrist, and shoulder (17). The standard deviation of age estimated from epiphyseal closure is greater than that of age estimation based on the appearance of the centers of ossification and oscillates between two and four years depending on the sex of the individual. The pace of growth and development differs between the sexes and between various biological and cultural groups. The differences are the result of genetic and environmental factors, which affect the timing of the onset of the diverse age indicators (18).

The stage of fusion of the basilar synchondrosis (spheno-occipital fissure) has been regarded as a trustworthy indicator of biological age (19). A number of authors proffer that the synchondrosis remains open throughout childhood and adolescence and coalesces as the individual reaches adulthood (2–7,20–24); a second group proposes that fusion commences during the adolescent stage concomitant with the eruption of the second permanent molars (8–12,25,26); finally, Frick et al. (27) report on a wide variation in the fusion of this feature (Table 3).

In the present study, the sample was subdivided into males and females. In the male sample ($n = 70$) no correlation was detected between chronological age and the time of closure of the synchondrosis. The mean age of the group of individuals with "closed" synchondrosis ($\bar{X} = 16.9$ years old) was almost the same as that of the group with "open" synchondrosis ($\bar{X} = 15.7$ years old). These findings seem to suggest that the high variability in the age of fusion of the basilar synchondrosis would preclude a reliable age estimation based solely on the stage of fusion of the basilar suture, especially when the questioned remains pertain to the forensic realm.

In the female sample ($n = 21$) there were significant differences in age between the sub-groups with "open" and "closed" spheno-occipital fissure. The mean age of the group with "open" synchondrosis was 12.3 years old, while in the group of individuals with "closed" synchondrosis the mean age was 15.7 years old. Although these findings are statistically significant, the sample size is rather small. Should the results presented in this study be corroborated by further investigation, it could be advocated that the stage of the fusion of the basilar synchondrosis is a reliable indicator of age in female individuals.

Albeit the assertions regarding the basilar synchondrosis as a good age indicator for the adolescence period (28,29), forensic investigators should be aware of the variability in the time of closure of this trait in male individuals. Various ages of fusion of the spheno-occipital fissure have been reported by different researchers, from as early as ten years old (11) to as late as 25 years old (5). These inconsistencies might be the result of different methods of assessment of the stage of closure of the synchondroses (31) or rather the expression of the variability of the phenomenon as reflected by the results of the present study.

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Additional information and reprint requests:
Tzipi Kahana, Ph.D.
Division of Identification and Forensic Science
Israel Police
67 Ben Zvi st.
P.O. Box 8495
Tel Aviv 61085
Israel