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Stages of Epiphyseal Union for Thoracic and Lumbar Vertebral Centra as a Method of Age Determination for Teenage and Young Adult Skeletons

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ABSTRACT: Many current methods of age determination available to forensic anthropologists are limiting in that the age ranges provided are often broad, particularly for individuals in their late teens to early 20's. This study introduces an improved method for aging teenagers and young adults. The pattern and stages of union of the superior and inferior epiphyses of the vertebral centra (or ring epiphyses) were examined in 55 individuals, females and males, black and white, between ages 11 and 32 years.

Vertebral ring epiphyseal union was found to be a good predictor of age. The correlation between stages of union and known age was 0.78 ($P < .0001$). The standard deviation was 2.566 years at the 99.9% confidence level. Sex differences were observed, but were not statistically significant. A larger sample size may perhaps demonstrate statistically significant differences in sex, and may or may not yield differences in race. A preliminary interobserver bias test showed high replicability. Results of this study compare favorably with results of other aging studies.

Current age information for the progress of vertebral ring epiphyseal union is supplied for young males—and for the first time—females. This improved aging method provides necessary corroborative information for use with observations from other skeletal age indicators. Data collected from epiphyseal union of the vertebral centra aid in lessening the gap for early adult age determination.

KEYWORDS: physical anthropology, human identification, vertebral maturation

Current methods of age determination for individuals in their late teens to early 20's are often limited. Cranially, age information from third molar development was found to estimate at best whether an individual was younger or older than 18 years [*1*]. Mincer et al. [*1*] note that there remains a lack of *precise* age estimation techniques for individuals from the teenage years to the early 20's, after the permanent teeth have erupted. Postcranially, long bone epiphyseal union is sufficient for aging teenagers up until about 18 or 19 years [*2*]. Studies of epiphyseal union of the medial clavicle [*3*] and morphological changes in the pubic symphyses [*4,5*] and sternal rib end [*6–9*] show a high degree of utility, yet the age ranges provided are often broad at the 95% confidence level.

The superior and inferior vertebral rings are among the later-fusing epiphyses, thus producing useful information for estimating the age of young adult skeletons [*10*]. This study provides current data on the pattern and stages of vertebral ring epiphyseal union for thoracic and the first two lumbar centra. When this method is used in conjunction with other aging methods, it decreases the gap in early adult age determination.

In 1957, McKern and Stewart [*11*] pioneered an in-depth study on the progress of epiphyseal ring union of thoracic vertebrae from a racially mixed sample of 259 young American males of known age—17 to 25 years. They found that the first thoracic vertebra (T1) and the last five (T8 through T12) were the first to complete union, followed by T2 through T7, with T4 and T5 being last. Union was complete by age 24 to 25 years. There was no information on sex differences as the McKern and Stewart sample was limited to males; and they do not mention any racial differences in epiphyseal union for the vertebrae.

Other studies concerning the vertebrae are either based on skeletal collections older than McKern and Stewart's sample collected in 1954, or do not specifically address the *stages* of epiphyseal ring union [*12–14*]. Information from anatomy textbooks is also limited. Rothman and Simeone's [*15*] two volume collection of articles on the spine do not mention epiphyseal union of the vertebral centra. Steele and Bramblett [*16*], and Krogman and Işcan [*17*] refer to McKern and Stewart's [*11*] original study of vertebral ring epiphyseal union, yet they do not provide detailed explanations concerning the ages of the *stages* and *progress* of the superior and inferior ring epiphyses. Most anatomy and osteology books, however, simply state that vertebral ring epiphyses appear at puberty and completely unite by age 25 years [*18–24*].

Method

Sample

Thoracic and the first two lumbar vertebrae were collected from 55 individuals of known age, sex, and race. There were 6 black females, 16 white females, 3 black males, and 30 white males. Vertebral specimens were obtained mainly during autopsy. Some specimens came from skeletal remains received for analysis at the C.A. Pound Human Identification Laboratory at the University of Florida in Gainesville, Florida. All of the individuals whose vertebrae were included in the study appeared well nourished and had no disease that would have affected skeletal growth.

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The first two lumbar vertebrae were included in this study because it was not known how the timing and sequence of union would compare with that of thoracic vertebrae, since lumbar vertebrae were not examined by McKern and Stewart [*11*]. Cervical vertebrae were not included in this study because they were not easily obtained at autopsy without considerable internal and external damage to the neck region. Extraction of thoracic and lumbar vertebrae was simpler in that during autopsy, body cavities were already opened, and internal organs were removed.

Specimen Preparation

Examination of stages and progress of vertebral ring epiphyseal union via radiographic analyses proved inadequate. Ossified epiphyses were evident in most cases; however, the extent of union could not be determined. The procedure discussed below was therefore necessary to accurately document the stages of vertebral ring epiphyseal union.

A "wedge" measuring approximately 2 to 3 cm in width was cut from the anterior portion of the centrum of each vertebra at autopsy using an electric bone saw. Each vertebral wedge was disarticulated prior to maceration. The cartilaginous disk above and below each vertebra was sliced through using a surgical scalpel, number 22 blade. Each vertebra was placed in its own separate, labelled 250 mL pyrex beaker filled with tap water and boiled to loosen soft tissue. Upon completion of maceration, cleaning, and drying, the vertebrae were examined and the progress and stages of union were recorded. Scoring for the progress of union is described below.

Scoring

Stage 0—This stage indicates a vertebral specimen for which no union has taken place. The superior and inferior surfaces of the centrum are billowed and striated. Edges are rounded, but become sharp before union. The bone surface is rough and "bare." Some higher thoracic vertebrae (T1 to T7) occasionally lack the billowed appearance; yet all surfaces are rough and bare, clearly showing no evidence of ring adhesion (Fig. 1a–d).

Stage 1—The epiphysis has begun to unite or is in the process of uniting to the vertebral centrum. In the early phase, the epiphyseal ring is attached in some places to the centrum. The epiphysis appears thin and fragile (Fig. 2).

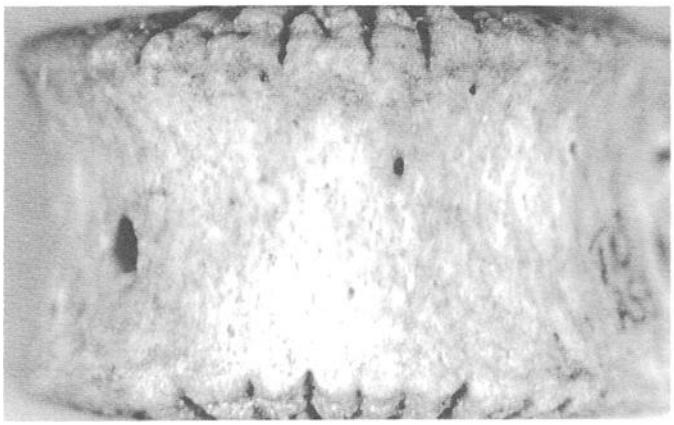

FIG. 1a—*No union (Stage 0). Anterior view T10. Note the billowed appearance of the superior and inferior surfaces.*

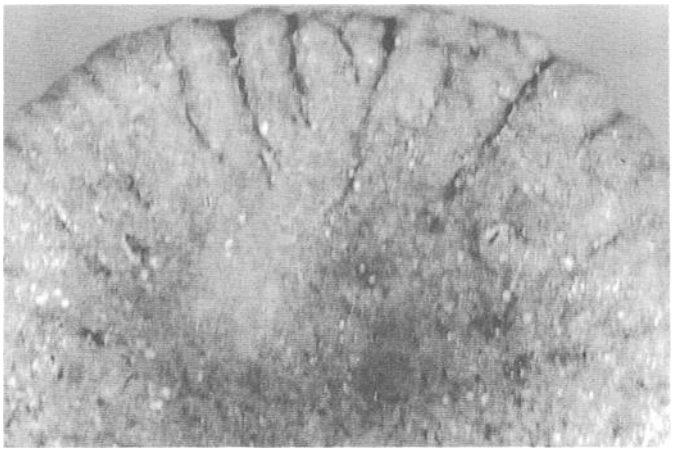

FIG. 1b—*No union (Stage 0). Superior view T10. Surface is rough, bare, and billowed.*

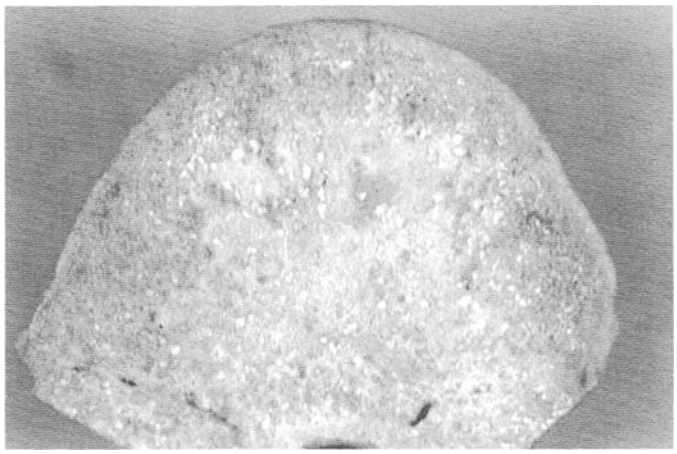

FIG. 1c—*No union (Stage 0). Superior view T3. Surface is rough and bare. No billowing is seen.*

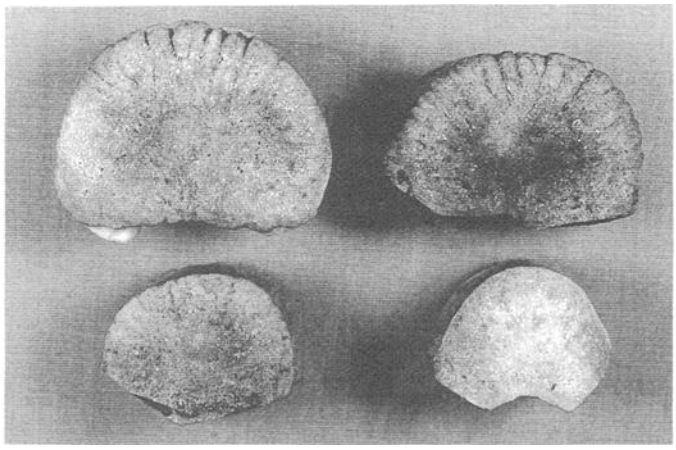

FIG. 1d—*No union (Stage 0). Superior view from left to right:* (top) *L1, T10,* (bottom) *T7, T3.*

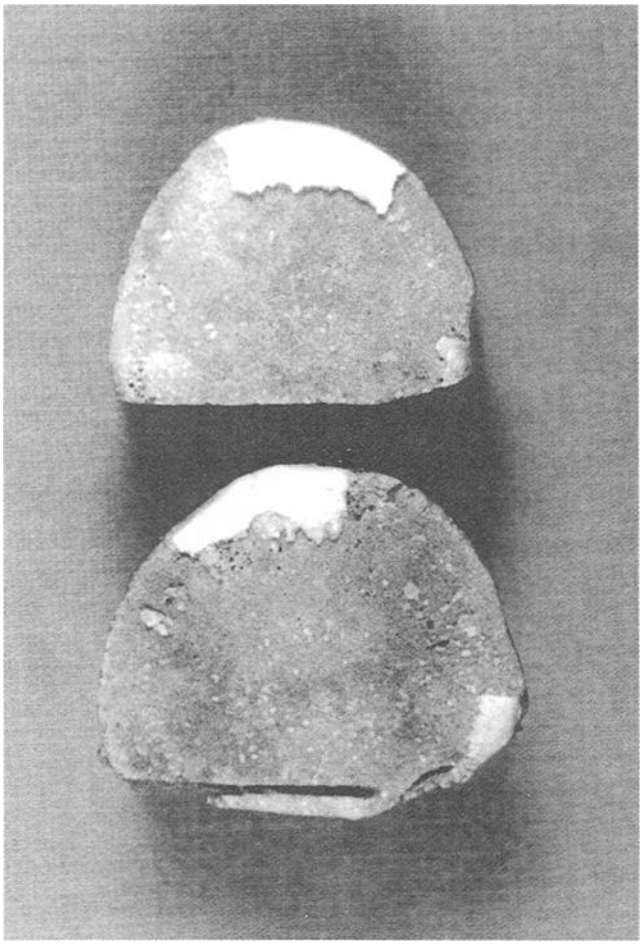

FIG. 2—*Beginning union (Stage 1). Superior view* (top) *T4 and* (bottom) *T7. Ring epiphyses have begun to unite to centra.*

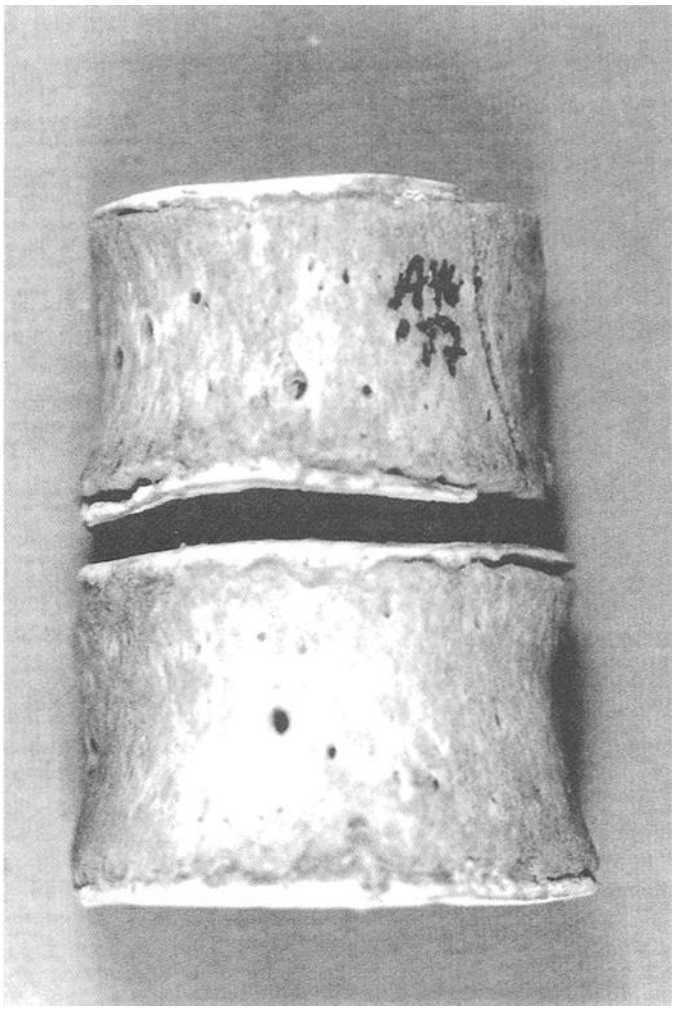

FIG. 3a—*Progressing union (Stage 1). Anterior view* (top) *T7 and* (bottom) *T9.*

In the late phase, progressing union, the epiphysis appears more solidly attached to the centrum. There are less widely open spaces. More than 50% of the area between the epiphysis and centrum is "open" (Figs. 3a and 3b).

Stage 2—The epiphysis is almost completely united, or shows recently completed union. In the early phase of this stage, almost complete union, the spaces between the epiphysis and vertebral centrum are considerably diminished. More than 50% of this area is "filled in." A distinct, slightly indented line or shallow groove is seen in some areas between the epiphysis and the centrum (Figs. 4a and 4b).

In the late phase of this stage, recent union, there are no spaces left between the epiphysis and the centrum. There is a definite uniform line or groove (with no spaces) between the epiphysis and the centrum (Fig. 5, bottom).

Stage 3—The epiphysis is completely united to the centrum. The vertebra appears as one whole piece. The line demarcating the superior and inferior epiphyses from the centrum is totally obliterated, although occasionally a faint scar persists (Fig. 5, top; and Fig. 6).

A scar is sometimes seen in the completed union phase and is a smooth, shallow depression between the epiphyseal ring and vertebral centrum, whereas in the recent union phase (Stage 2),

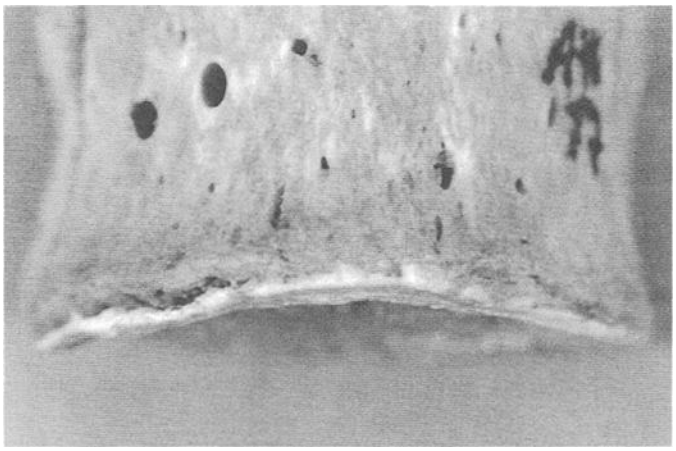

FIG. 3b—*Progressing union (Stage 1). Anterior view, inferior epiphysis T7.*

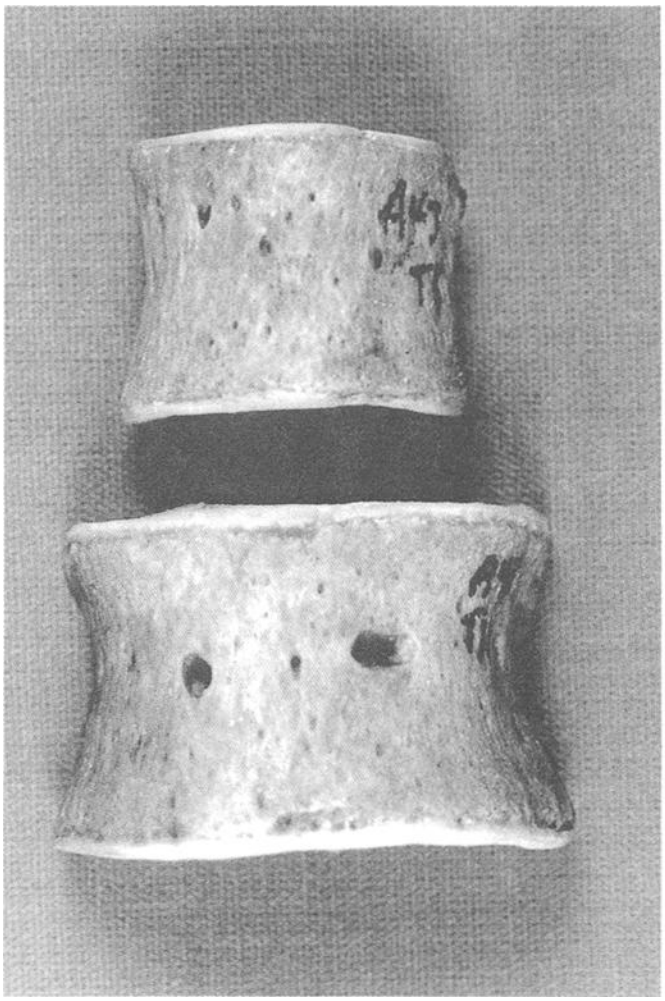

FIG. 4a—*Almost complete union (Stage 2). Anterior view* (top) *T5 and* (bottom) *T11. Minute spaces are evident between the epiphyses and the centra.*

FIG. 5—(Top) *Complete union (Stage 3). Left lateral view T9.* (Bottom) *Recent Union (Stage 2). Left lateral view T9. Recent union is marked by a line that is deeper and more pronounced than a scar from complete union, which is faint and shallow.*

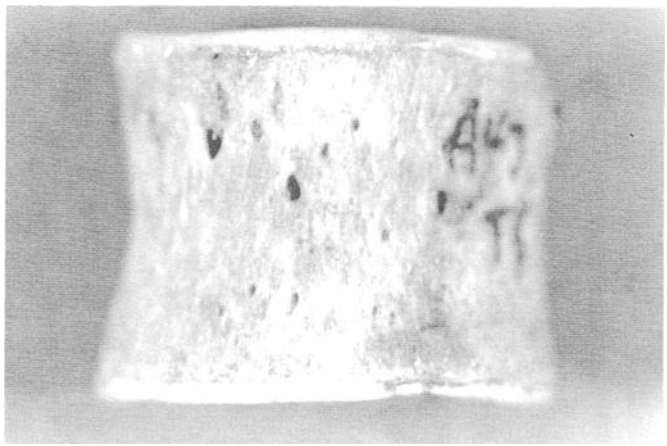

FIG. 4b—*Almost complete union (Stage 2). Anterior view, inferior epiphysis T5* (top epiphysis shows recently completed union).

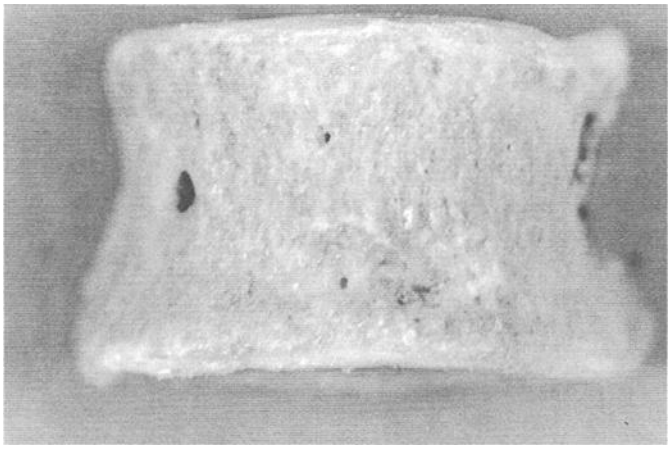

FIG. 6—*Complete union (Stage 3). Anterior view T4.*

the line between the epiphysis and centrum is somewhat wider, deeper, and slightly roughened and coarse. The difference between a line in the recent union phase (Stage 2) and a scar in a completely united epiphysis (Stage 3) is illustrated in Fig. 5. If any portion of the surface shows an indentation or groove but not a scar, it should be recorded as recent union (Stage 2), not complete union (Stage 3). The use of low magnification in addition to gross examination may help distinguish between these two stages in cases where there may be some confusion.

Beginning osteophytic lipping should not be confused with a vertebral ring epiphysis groove or scar. Early lipping is characterized by bone that extends or begins to slightly hang over the edge of the surface of the centrum. Epiphyseal rings rest purely upon the surfaces of the centra and do not extend beyond the margins (Figs. 7a and 7b).

Scoring for the progress of union in this study was modified from that of McKern and Stewart [*11*]. McKern and Stewart used the following five stages: "0" for no union, "1" for one-quarter union, "2" for one-half union, "3" for three-quarters union, and "4" for complete union. In their analysis, McKern and Stewart noted that by age 20 years, complete union is evident only in the first, and last five thoracic vertebrae (T1, and T8 through T12). After age 20 years, up until age 24 years, "there is a definite and consistent lag throughout the age groups in the region between T2 and T7, but especially in segments T4 and T5. Thus, it is important to examine these segments for the last signs of epiphyseal union in the presacral spine (p. 101)." McKern and Stewart's five stage scoring method does not adequately account for the "last signs" of vertebral ring activity. Stage 3 (three-quarters union) does not distinguish between union still in progress and almost complete union. Similarly, Stage 4 (complete union) does not distinguish between recently completed union and union that has been complete for some time. Buikstra et al. [*14*] reported data on epiphyseal union of the cervical vertebrae for 32 black females from the Terry Collection. They used a slightly different scoring method from that of McKern and Stewart [*11*], though their method likewise did not distinguish union still in progress from almost complete union, or recently completed union from long-time union.

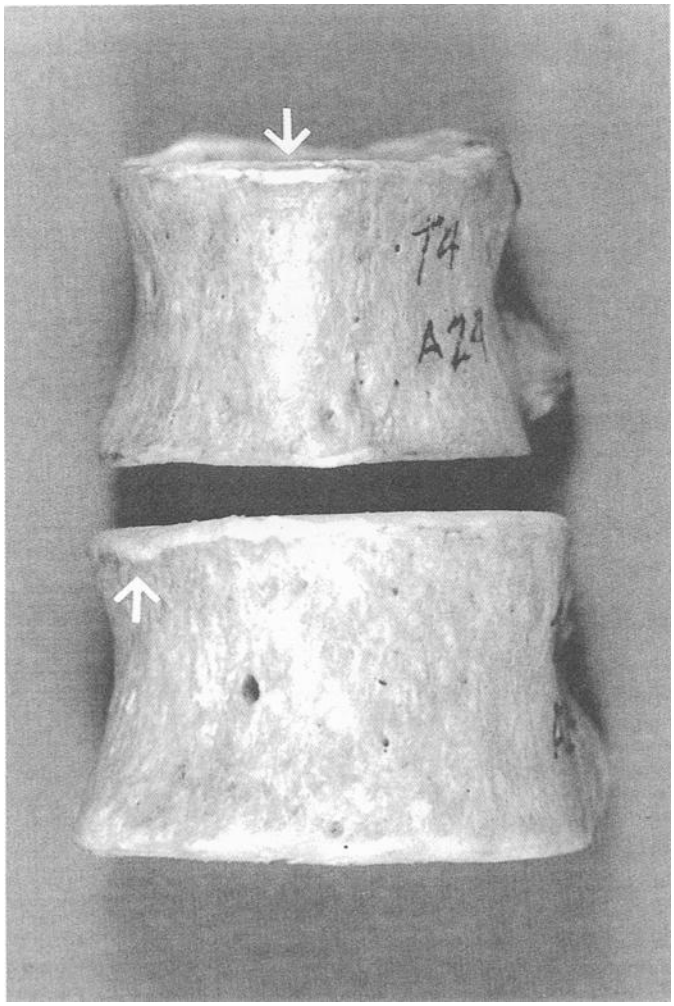

FIG. 7a—*Complete union (Stage 3) with beginning osteophytic lipping. Anterior view* (top) *T4 and* (bottom) *T8.*

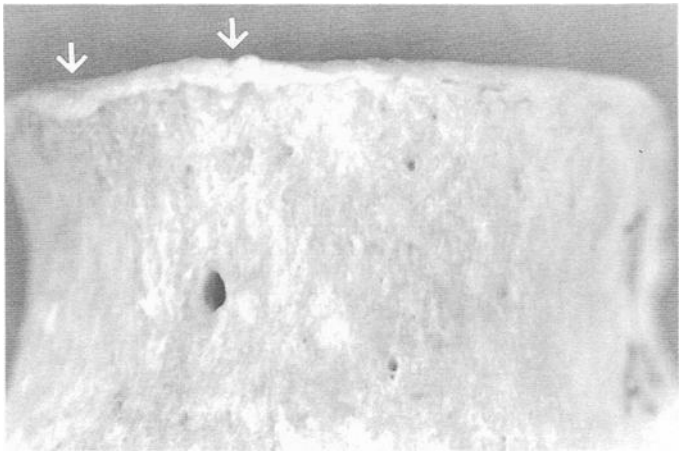

FIG. 7b—*Complete union (Stage 3) with beginning osteophytic lipping. Closeup anterior view T8.*

One modification of the stages of union in this study was made by incorporating the stage of almost complete or recent union (Stage 2). Beginning union and progressing union were both included in one stage (Stage 1), as this particular period of activity seems to occur over the course of only a few months. As union nears completion, progress slows; thus almost complete union and recent union were included in one stage (Stage 2). Almost complete union and recent union (Stage 2), however, seem to differ—by a couple of years—from union that has been complete for some time (Stage 3). Hence, Stage 2 permitted an extension of the time period for which activity of the vertebral ring epiphyses was observed. For example, although recent union is in effect complete union, it differs in that it represents *newly* complete union as opposed to union that has been complete for some time. Inclusion of Stage 2 permitted more detailed age information to be extracted from the sample because the ages for which epiphyseal union were observed had been extended to include individuals older than 25 years. Since recent union was seen in many of the vertebrae from individuals between 25 to 27 years, the usefulness of this scoring method is expanded beyond that of earlier methods [*11,14*].

Results and Discussion

Statistical Analyses

Three sets of data from the original sample of 55 were discounted due to uncertainties of identity. Statistical analyses were thus performed on data collected from 52 individuals (5 black females,

TABLE 1—*Analysis of variance vertebral ring epiphyseal union.*

Source	df	Sum of Squares	Mean Square	F-Value	Prob > F
Model	4	954.500,85	238.652,1	36.245	0.0001
Error	42	276.515,99	6.583,71		
C Total	46	1231.016,84			
Root MSE		2.565,87	R-square		0.7754
Dep Mean		22.647,16	Adj R sq		0.7540
C. V.		11.329,79			

16 white females, 3 black males, and 28 white males). An analysis of variance test indicated an overall correlation (r-square value) of 0.78 ($P < .0001$), between stages of epiphyseal ring union of all vertebrae and known age at death, for females and males combined. A standard deviation of 2.566 years (see Table 1, root MSE) was determined by calculating the square root of the variance (square root of MSE, where MSE is the mean square error—which is equivalent to the pooled estimator of the variance—the variance for females and males combined). Thus, stages of vertebral ring epiphyseal union varied by age within a range of plus and minus 2.566 years at the 99.9% confidence level ($P < .0001$).

Observational Analyses

Table 2 and Fig. 8 show the age distribution of stages of epiphyseal union for all vertebral centra examined, with females and males combined. Percentages were calculated by counting the number of epiphyses observed for females and males in a particular age category and dividing that number by the total number of epiphyses found in each stage of union. Complete union was found in 30% of the epiphyses for 17 to 18 year olds. Complete union was found in 18% and 22% of the epiphyses for individuals in the 19 to 20, and 21 to 22 year age categories, respectively. The relatively high percentage of completely united epiphyses for 17 to 18 year olds resulted from one individual, aged 18 years, who showed complete union from T3, superior, to L2, inferior. No other individuals between the ages of 19 to 22 years showed as many completely united epiphyses as the individual noted above, thus this early maturation most likely represents an anomaly.

All of the epiphyses for 27 to 28 year olds were completely united. Epiphyses for individuals 29 years and older however, were 99.4% complete with only one epiphysis showing recently completed union. Upon reexamination of this specimen, it was found that what was originally documented as recently united may in effect be complete union with a scar. None of the other epiphyses for this particular individual showed scarring. This demonstrates the confusion in some cases between recent union and complete union with a persisting scar.

Tables 3 and 4 show data for the stages of union for all the superior and inferior ring epiphyses of the vertebrae examined for each individual in the female (Table 3) and male (Table 4) portions of the sample. A blank indicates the absence of a particular vertebral specimen. Noteworthy observations from Tables 3 and 4, concerning timing of union and ages for the various stages, are described below. The following observations pertain to individuals and their particular vertebral ring epiphyses, and are summarized in Table 5.

Stage 0 (early phase)—There was no attachment of epiphyseal rings in any vertebrae before the age of 14 years in females, and before the age of 16 years 4 months in males.

Stage 0 (late phase)—The oldest female to show Stage 0 in any vertebrae was age 17 years 3 months (T4 and T5, inferior). The oldest male to show Stage 0 in any vertebrae was age 20 years 8 months (T3 and T5, inferior; and T6, superior and inferior).

Stage 1 (early phase)—Beginning union was first seen in two females, age 14 years. One 14 year old female showed beginning union in T1, superior and inferior; T8, inferior; T10, superior and inferior; and T12, superior. A second 14 year old female showed beginning union in T1 through T4, all superior. The youngest male to show beginning union was age 16 years 4 months (L1, inferior).

Stage 1 (late phase)—The oldest female to show Stage 1 in any vertebrae was age 19 years 11 months (in all vertebrae with the exception of T11, which was absent from the sample). The oldest male to show Stage 1 in any vertebrae was age 20 years 8 months (T1, inferior; T2, superior and inferior; T3, superior; T4, superior and inferior; T5, superior; and T7, superior and inferior).

Stage 2 (early phase)—The youngest female to show Stage 2 (almost complete union) in any vertebrae was age 17 years 3 months (T1, superior and inferior; T2, superior, through T4, superior; T7 and T8, inferior; and T9, superior, through L2, inferior, with the exception of L1 which was absent). The youngest male to show Stage 2 in any vertebrae was age 17 years 8 months (T10, inferior; and T11, superior).

TABLE 2—*Age distribution of stages of vertebral ring epiphyseal union (in %).*

Age (In years)	N (Total Variables: superior and inferior ring epiphyses)	Stage 0 (No union)	Stage 1 (Beginning or progressing union)	Stage 2 (Almost complete or recent union)	Stage 3 (Complete union)	I (Number of individuals)
16 and under	232	95	5	0	0	9
17–18	124	6	34	30	30	5
19–20	209	2	17	63	18	8
21–22	143	0	0	78	22	6
23–24	134	0	0	34	66	5
25–26	176	0	0	26	74	7
27–28	164	0	0	74	100	6
29 and over	163	0	0	0.6	99.4	6
Total	1345					52

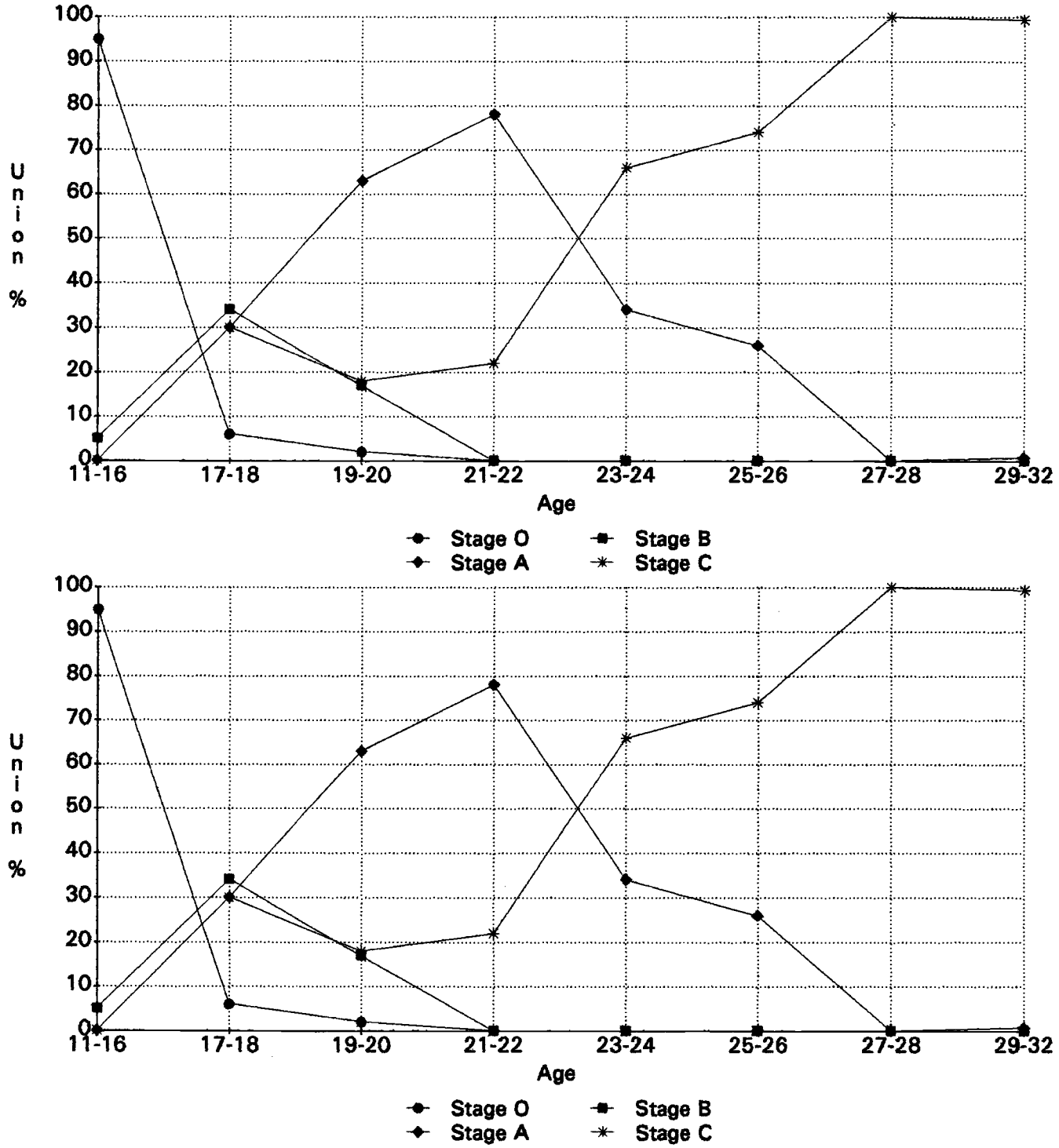

FIG. 8—*Vertebral ring union age distribution graph percentages of epiphyses in various stages of union according to age.*

Stage 2 (late phase)—The oldest female to show recent union in any vertebrae was age 26 years 10 months (T2, superior, to T3, inferior; and T4 through T6, all superior). The oldest male to show recent union in any vertebrae was age 26 years 4 months (T8 and T9, superior). This observation for males is provided after reanalysis of the one epiphysis, mentioned earlier, which was originally documented as Stage 2 (recent union), but later thought to be Stage 3 (complete union with a persisting scar), in a male age 29 years 3 months.

Stage 3 (early phase)—The youngest female to show complete union in any vertebrae was age 18 years (T3, inferior, to L2, inferior). The youngest male to show complete union in any vertebrae was age 18 years 9 months (T6 and T7, superior; T10, inferior, to T12, superior; and L1, superior and inferior).

Stage 3 (late phase)—The youngest female to show completely united ring epiphyses in *all* the vertebrae was age 25 years. The

TABLE 3—*Vertebral ring epiphyseal union stage data for females.*

AGE	RACE	T1-S	T1-I	T2-S	T2-I	T3-S	T3-I	T4-S	T4-I	T5-S	T5-I	T6-S	T6-I	T7-S	T7-I	T8-S	T8-I	T9-S	T9-I	T10-S	T10-I	T11-S	T11-I	T12-S	T12-I	L1-S	L1-I	L2-S	L2-I
12.58	W		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.00	W	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0				
14.00	W	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.25	W	2	2	2	1	2	1	2	0	1	0	1	1	1	2	1	2	2	2	2	2	2	2	2	2			2	2
18.00	B		2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
19.33	W		2	2	2	2	2	2	2	2	2	2	2	2	3	2	3	2	2	2	2	2	2	2	2	2	2	2	
19.92	W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1
21.75	W	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
22.50	W	3	2			2	2	2	2	2	2	2	2							3	2	2	2	2	2				
22.92	W		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
25.00	W					3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
25.17	B	3	3	3	3	3	3	3	3	2	2	2	2	2	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3
25.42	W	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
25.83	W	3	3	2	2	3	3	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
26.17	W					3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
26.83	B	3	3	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
27.08	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
27.75	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
28.67	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
30.00	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
31.75	W			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

TABLE 4—*Vertebral ring epiphyseal union stage data for males.*

AGE	RACE	T1-S	T1-I	T2-S	T2-I	T3-S	T3-I	T4-S	T4-I	T5-S	T5-I	T6-S	T6-I	T7-S	T7-I	T8-S	T8-I	T9-S	T9-I	T10-S	T10-I	T11-S	T11-I	T12-S	T12-I	L1-S	L1-I	L2-S	L2-I
11.25	W		0	0		0	0	0		0			0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.42	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.92	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
15.33	W			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.08	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
16.33	W	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
17.67	W						1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	3	3	3	3	
18.00	W		0	1	0	0	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18.75	B					2	2	2	2	2	2	3	2	3	2	2	2	2	2	2	3	3	3	3	2	3	3		
19.67	W		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	3	2	3	3	3	2
19.92	W				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
20.33	W		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	3	2	3	
20.50	W		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
20.67	W	2	1	1	1	1	0	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
20.75	W		2	2	3	2	2	2	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
21.25	W		2	2	2	2	2	2	2	3	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
21.67	W	3	3	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	3	3				
22.42	W						2	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	
23.25	W	2	3	2	2	2	2	2	2	2	2	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3
23.42	W		2	2	2	2	2	2	2	3	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	2	3	3
23.92	W	3	3	3	3	2	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
24.17	W		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
24.42	W			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3		
26.33	W		3			3	3	3	3		3	3	3	3	3	2	3	2	3		3	3	3	3	3	3			
28.00	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
28.25	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
28.50	B		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
29.08	W		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
29.25	W	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
30.42	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
32.58	W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

TABLE 5—*Vertebral ring epiphyseal union summary stage observations.*

	Stages and Descriptions	Age: Females	Age: Males
Stage 0			
(early)	No epiphyseal attachment	under 14 years	under 16 years 4 months
(late)	Oldest individual to show Stage 0 (no epiphyseal attachment) in any vertebrae	17 years 3 months	20 years 8 months
Stage 1			
(early)	Youngest individual to show epiphyseal attachment in any vertebrae	14 years	16 years 4 months
(late)	Oldest individual to show Stage 1 (progressing union) in any vertebrae	19 years 11 months	20 years 8 months
Stage 2			
(early)	Youngest individual to show Stage 2 (almost complete union) in any vertebrae	17 years 3 months	17 years 8 months
(late)	Oldest individual to show Stage 2 (recent union) in any vertebrae	26 years 10 months	26 years 4 months
Stage 3			
(early)	Youngest individual to show Stage 3 (complete union) in any vertebrae	18 years	18 years 9 months
(late)	Age of first appearance of complete union of all epiphyses	25 years	24 years 2 months

youngest male to show completely united ring epiphyses in *all* the vertebrae was age 24 years 2 months.

Timing and Rate of Union

There were no statistically significant differences in either the *timing* or *rate* of union between females and males, most likely due to the relatively small sample size. Observations showed, however, that females exhibited more advanced union than males for all of the aforementioned categories except Stages 2 and 3, late phase (oldest age of recent union, and complete union of all epiphyses, respectively). Observations of Stage 2, late phase, indicated that although union began earlier in females, males "caught up" before Stage 3, late phase (complete union of all epiphyses). There were no females between ages 23 to 24 years in the sample, therefore the possibility remains that complete union of all vertebral epiphyses may take place in females during these ages. The finding that union began earlier in females than in males is consistent with other studies in which females exhibit skeletal growth and changes in morphology before males [*2–9*].

Similarities or differences attributed to race were not known, given the small sample size. Although Buikstra et al. [*14*] report data for epiphyseal union of the cervical centra for black females, racial or secular comparisons were not made between their study and this study of thoracic and the first two lumbar vertebrae, since different vertebrae were examined. Moreover, the timing and sequence of union between cervical, and thoracic and the first two lumbar vertebrae may differ. Furthermore, comparisons of cervical vertebrae from black females with thoracic and lumbar vertebrae from a largely white sample may not be accurate, whether or not differences are found.

Sequence of Union

Statistical analyses showed no significant differences in the sequence of union from T1 to L2, whereas observational analyses indicated that the sequence of union was somewhat comparable to that found by McKern and Stewart [*11*]. Similar to McKern and Stewart's findings, union in some individuals began and advanced in the lower thoracic vertebrae (T8–T12), and in some cases in T1, earlier than in the middle thoracic vertebrae (T2–T7). Contrary to McKern and Stewart's findings, the fourth and fifth thoracic vertebrae were not always the last to complete union. The sequence of union of the first two lumbar vertebrae did not differ markedly from the lower thoracic vertebrae. Again, these findings represent a trend observed in the data collected and were not statistically significant, most likely due to the relatively small sample size.

There were no significant differences regarding the sequence of union between the superior and inferior ring epiphyses, either for a particular vertebra, or among all the vertebrae for a given individual. The superior *or* the inferior ring epiphysis, of one vertebra, may exhibit a more advanced stage of union than the other. For example, in the two 21 year old males, the 21.25 year old showed Stage 3 for T5, superior; and Stage 2 for T5, inferior. The 21.67 year old showed the reverse—Stage 2 for T5, superior; and Stage 3 for T5, inferior (see Table 4). Nevertheless, both the superior and inferior epiphyses of any one vertebra exhibited the same stage of union more often than not.

There was much internal variation concerning the sequence of union among each individual in the sample. The vertebrae, therefore, were not divided into subunits, such as T1, T2 to T9, and T10 to L2, since no definite pattern was found in the sequence of union. Effective age estimation would best be accomplished by comparing *all individual* vertebrae available with the data provided in Tables 3, 4, and 5. Inasmuch as *incomplete* vertebral columns are often recovered, forensic anthropologists may find these data useful.

Interobserver Bias Test

Four student observers with varying levels of training in osteology participated in a preliminary test for interobserver bias. Twenty-seven sets of vertebral centra were selected for analysis. Most of the specimen sets were chosen at random, although this sample was checked to be sure that each of the four stages of epiphyseal ring union were represented. At least one set of vertebrae for each of the four stages of union was present. Each observer was given a brief verbal explanation of the stages of union and instructed on how to document the various stages. Total instruction time was approximately 15 minutes for each student observer.

An analysis of variance test showed that overall mean observations documented by the student observers correlated highly with the original findings. Mean reliability was between 0.96 to 0.99. The purpose of this test was to provide some early insight into the replicability of the aging method presented. Further studies specifically designed to measure interobserver reliability were not the focus of this research, but will be conducted in the near future.

Conclusions

When compared with other later-fusing epiphyses, vertebral ring epiphyseal union was found to correlate well with age ($r = 0.78$, $p < .0001$). There was less variability in epiphyseal union of the superior and inferior vertebral centra than in union of the first two sacral elements and medial clavicles, for example [*11,3*]. A preliminary test for interobserver bias demonstrated the potentially high replicability that can be achieved. Current data are supplied for males, and are available for the first time for females.

No single age determination method alone has been shown to effectively predict age with 95% confidence within a narrower range than ten years. Results of this study indicated that age can be estimated from vertebral ring epiphyseal union with 99.9% confidence within a range of plus and minus 2.566 years (or roughly 5 years), yet a larger sample size may show greater variability which could increase this range. The use of multiple skeletal age indicators, however, provides the best estimate. The data presented for vertebral ring epiphyseal union supply information intended for use with observations from other skeletal age indicators. This age determination method aids in narrowing broad age estimations, and its future use remains promising.

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