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PAPER

ANTHROPOLOGY

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Age Estimation Using Thoracic and First Two Lumbar Vertebral Ring Epiphyseal Union

ABSTRACT: Union of the vertebral centra or "ring" epiphyses occurs during adolescence and early adulthood, providing valuable age at death information. We present a system for estimating age based on the timing and pattern of vertebral ring union. Data from 57 known individuals aged 14–27 years were used to establish age ranges for various patterns of union in females and males. Female age ranges were more well defined with less overlap in patterns of union than male age ranges. The age ranges are accompanied by descriptions of the stages of union observed that aid in applying this method. A test of interobserver error in scoring stages of union demonstrated strong consistency among three observers (r = 0.91–0.97). Estimating age by observing all stages documented resulted in 78%, 88%, and 100% accuracies using vertebral data alone. We encourage the continued use of this method, in conjunction with other age indicators.

KEYWORDS: forensic science, forensic anthropology, age estimation, age determination, skeletal growth, skeletal maturation, epiphyseal union, epiphyseal fusion, vertebrae

Fusion of the superior and inferior epiphyses, or "ring" epiphyses, of the thoracic and first two lumbar vertebral centra has been established as a viable method of skeletal age estimation in teenagers and young adults (1–4). In 1957, McKern and Stewart first reported the use of vertebral rings in aging young adult American males, noting that full fusion was generally reached by the middle 20s (1). In 1995, Albert and Maples published vertebral ring union data collected from a sample of known individuals at autopsy. They modified the McKern and Stewart epiphyseal union scoring method to better extract age information during the critical years between the early and late 20s, specifically by noting the difference between recent fusion and union that has been complete for some time. Albert and Maples also reported for the first time data for female thoracic and first two lumbar vertebral ring epiphyseal union, where females were shown to mature slightly earlier than males (3).

The utility of the vertebral rings in age estimation was further demonstrated on two cases of unknown identity in 1999 (4). The strengths of this method of age estimation for teenagers and young adults was further corroborated in 2005 by cervical vertebral ring union data collected from a sample from the Hamman-Todd Collection, housed at Case Western Reserve University in Ohio (5). Correlations between stages of vertebral ring union and known age at death were high, and a similar pattern of sex differences in fusion progression and timing was found in females and males, with females showing an earlier initiation of union activity when compared to males (age 12 years for cervical vertebral ring epiphyses, 14 for thoracic vertebrae, when compared to age 16 years for males for both cervical and thoracic vertebrae). No study found any significant differences attributed to population affinity.

Vertebral ring union as an age estimation method has been popularized over the years (6,7) and appears to be in relatively widespread use. Here, we provide a timely update. The purpose of this study is to expound on this age estimation method by examining the progress, timing, and pattern of fusion of the vertebral ring epiphyses in another known human skeletal sample, to further validate the efficacy of this method. Moreover, to increase the utility of this method and address questions of interobserver bias for practitioners examining skeletal remains, a method of assigning an estimated chronological age range based on individual vertebral ring union data is provided.

Methods

Sample

Three examiners with experience in skeletal age estimation participated in data collection. For Examiner 1, the sample comprised 57 known individuals from the Robert J. Terry skeletal collection, housed at the Smithsonian Institution in Washington, DC. There were 23 females (21 of African-American descent and two of European descent) and 34 males (28 of African-American descent and six of European descent) ranging in chronological age at death from 14 to 27 years (Fig. 1). For Examiners 2 and 3, two individuals were unavailable for analysis; thus, the sample was reduced to 55 individuals—the same 23 females and 32 of the 34 males available to Examiner 1. The three examiners independently collected vertebral ring epiphyseal union data from all 12 thoracic and the first two lumbar vertebral centra, superior and inferior, where applicable.

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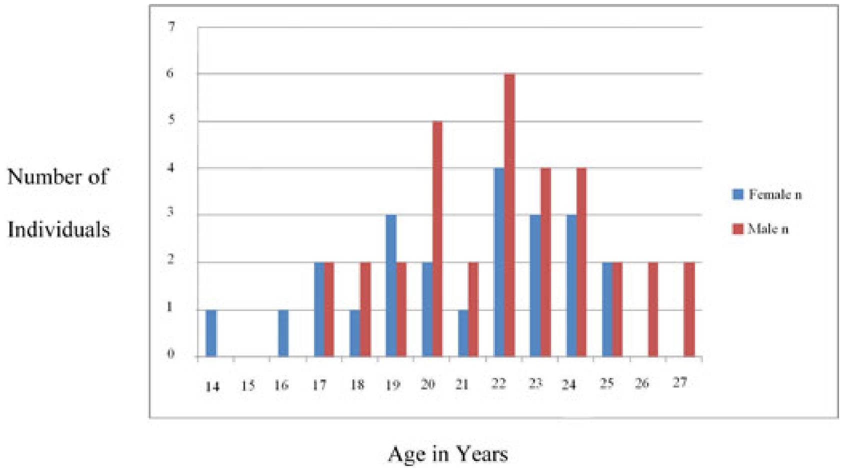


FIG. 1—*Sample distribution.*

Vertebral Ring Epiphyseal Union Scoring

Epiphyseal union data were scored using the four-stage method developed by Albert and Maples (2,3), modified from McKern and Stewart (1). The four stages are 0 for no union, 1 where union is beginning or progressing, 2 for almost complete (more than 50% epiphyseal fusion) or recent union (full epiphyseal fusion with the persistence of grooves), and 3 representing full fusion that has been complete for some time. One of the key features of the Albert and Maples four-stage epiphyseal union scoring method is that there is a distinction between recently completed union (Stage 2) and union that has been complete for some time (e.g., at least several months; Stage 3). This modification from McKern and Stewart (1) allows for better distinguishing individuals in their early to middle 20s from individuals in their middle 20s and older.

Figure 2 illustrates the appearance of a thoracic vertebra where no union has taken place, Stage 0. The surface of the centrum is bare, and in some lower vertebrae, the surface may appear billowy along the anterior aspect, both superiorly and inferiorly (Fig. 3 where the centrum is bare). Figure 3 represents Stage 1 where union is beginning. If any part of the vertebral ring epiphysis is adherent, then the ring is considered to be in the beginning union stage. Stage 1 also encompasses union that is actively progressing as seen in Fig. 4. Beginning and progressing union are included in one stage because of the relatively short time span—roughly a few months—between the start of fusion and actively progressing fusion. The short time span does not greatly affect age estimation, therefore precluding the need for separate stages.

Union in progress (Stage 1) is characterized as having a clear gap between the epiphysis and centrum along any part of the centrum surface when viewed anteriorly and laterally. The length and width of the gap largely determines the difference between progressing union (Stage 1, wider gaps) and almost complete union (Stage 2, narrower gaps). It is noteworthy that there is individual variation in epiphysis thickness and gap width. Figures 4 and 5 illustrate the difference in gap width as it relates to union in progress and union nearing completion. A distinction is made between epiphyses actively fusing, Stage 1, from those nearing completion,

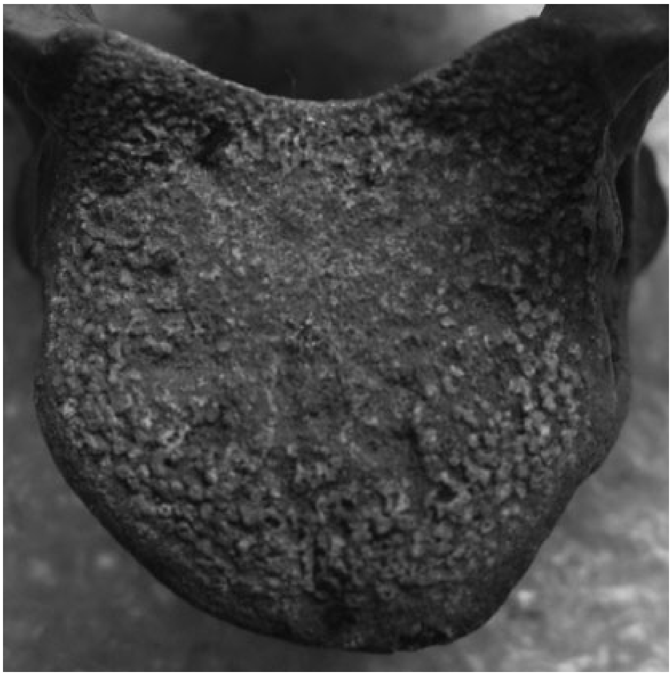


FIG. 2—*Stage 0, no union, T3 superior, male aged 20 years.*

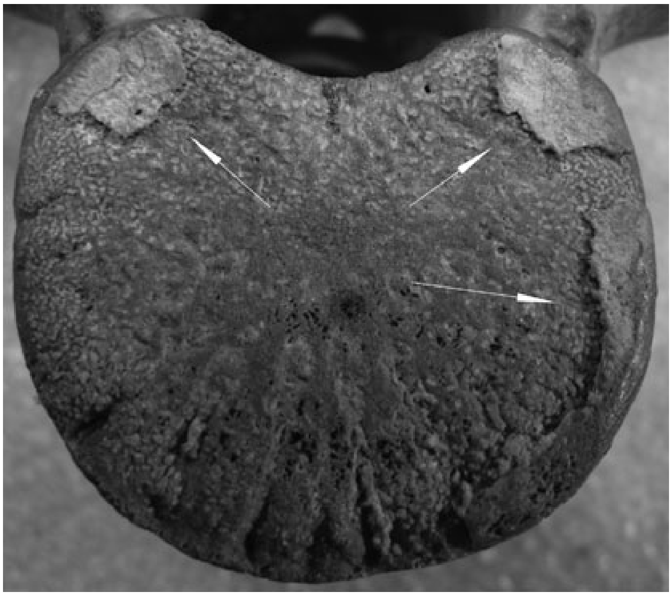


FIG. 3—*Stage 1, beginning union, L1 superior, male aged 22 years.*

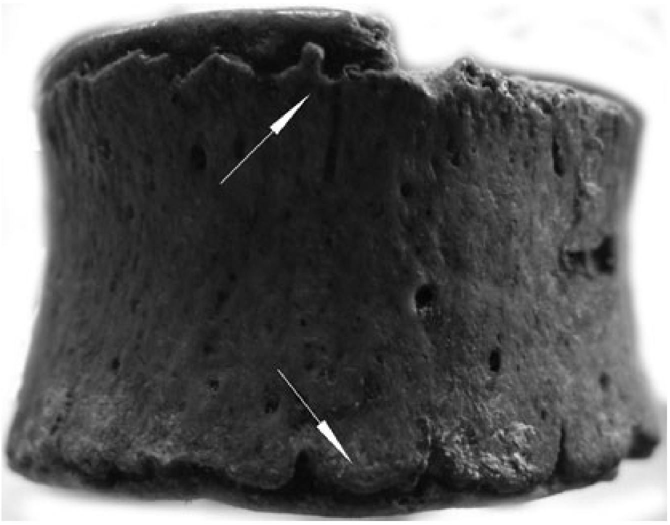


FIG. 4—*Stage 1, progressing union, T9 superior and inferior, male aged 20 years.*

Stage 2, because a longer interval of time seems to pass between active union and union that is almost complete—where fusion activity appears to slow down. As mentioned earlier, Stage 2 also includes recently complete union, which is marked by a faint line or groove between the epiphysis and centrum (Fig. 6). The appearance of this line or groove may be confused with union that has been complete for a few months to years but yields a scar that persists (i.e., a line where the epiphysis and centrum fused; Fig. 7). Care must be taken in distinguishing newly complete union with a groove or slight indentation from union that has been complete for some time (Fig. 8), which is smooth to the touch, but may appear to have depth. For a more complete explanation of vertebral ring epiphyseal union documentation and age estimation guidelines, please see the BoneClones® reference vertebral cast-set and accompanying instructional manual (7).

Analyses

Vertebral ring union data were statistically analyzed using MS Excel 2007 and SAS version 11 (SAS Institute, Inc., Cary, NC).

FIG. 5—*Stage 2, almost complete union (superior) with Stage 3, complete union (inferior), T7, male aged 19 years.*

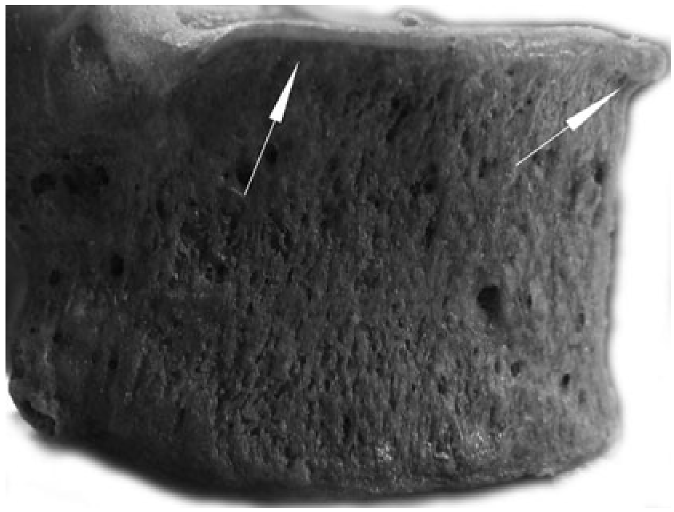


FIG. 7—*Stage 3, complete union, T4 superior and inferior, with a scar and beginning osteophytic lipping (superior), female aged 24 years.*

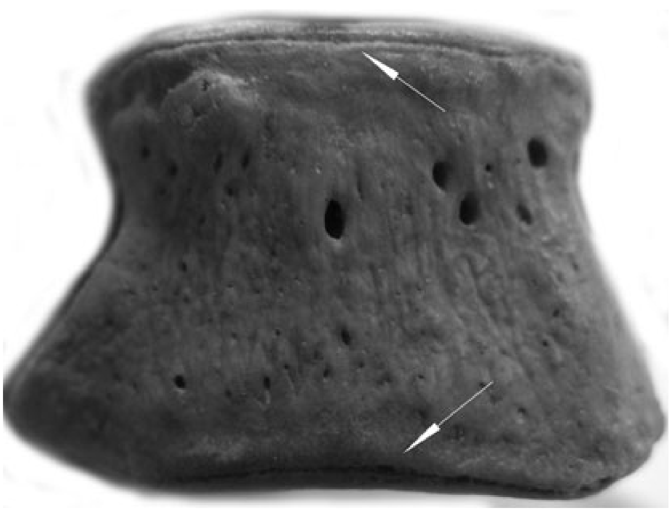


FIG. 6—*Stage 2, almost complete union (inferior) and recent union (superior), T1, female aged 20 years.*

FIG. 8—*Stage 3, complete union, T11 superior and inferior, female aged 25 years.*

We assessed how well vertebral ring union correlated with age and tested for sex and ancestry differences as well as interobserver bias. We also noted findings from observational analyses of the raw data.

Results and Discussion

General Findings

Data collected by Examiner 1 were considered baseline information. Data collected by Examiners 2 and 3 represented interobserver bias in the method, and their results were compared to findings from Examiner 1. Inasmuch as stages of vertebral ring union were documented for as many as 28 epiphyses per individual in the sample (i.e., the superior and inferior centra of 12 thoracic and first two lumbar vertebrae), we computed one vertebral ring epiphyseal union mean value per individual in the sample, for each of the three examiners' data, and compared the findings. Overall, based on Examiner 1's data, a Pearson's correlation showed that vertebral ring epiphyseal union mean values were fairly highly correlated with known age at death ($r = 0.78$, $p < 0.05$). For females, the correlation was higher ($r = 0.87$), and for males, it was slightly lower ($r = 0.71$). This finding was most likely because of the age distributions of the two sexes in the sample.

A two-sample F-test for variances was run on MS Excel and yielded an F-ratio of 1.22; the female and male sample differed significantly in terms of the age distributions, with there being in the sample a greater number of older males than females, and a greater number of younger females than males (Fig. 1 and Table 1).

When vertebral ring mean values were compared among the three examiners, they were found to be highly correlated, from $r = 0.91$ to 0.97 (Table 2). However, because there were differences among the three examiners in scoring each specific epiphysis of each vertebral centra in each individual in the sample, an ANOVA test was run to assess how scoring vertebral ring union varied among the three examiners. Results showed no significant differences in mean values among the three examiners (Table 3).

TABLE 1—*F-test two-sample for variances.*

	Female Age	Male Age
Mean	20.82608696	21.91176471
Variance	9.241106719	7.598039216
Observations	23	34
d.f.	22	33
F	1.216248884	
P(F<=f) one-tail	0.299001247	
F Critical one-tail	1.873468167	

TABLE 2—*Vertebral ring epiphyseal union mean values correlated among three examiners.*

	Examiner 1	Examiner 2	Examiner 3
Sexes combined			
Examiner 1	1		
Examiner 2	0.929518904		
Examiner 3	0.933751698	0.952283812	1
Females			
Examiner 1	1		
Examiner 2	0.907897381	1	
Examiner 3	0.937899047	0.973304132	1
Males			
Examiner 1	1		
Examiner 2	0.929518904	1	
Examiner 3	0.933751698	0.952283812	1

Examiner, Sex, and Ancestry Findings

Using SAS version 11, the PROC GLM procedure, a general linear mixed model, analyzed differences between examiners, and sex and ancestry in the sample, with sex and ancestry being fixed effects and examiner deemed a random effect. Results indicated that sex and ancestry can be considered without the interaction effect. Significant sex differences were found on the superior surface of the first thoracic vertebra (T1-S), the inferior surface of the ninth thoracic vertebra (T9-I), and on T11-I, T12-I, L1-I, and L2-I ($p < 0.05$). Note that these were mostly on the lower vertebrae. Sample sizes were too small to permit adequate analyses of ancestry.

There were significant differences ($p < 0.05$) between examiners at sites T1-S, T1-I, T2-S, T9-I, and L1-S. While each of these findings—sex, ancestry, and examiner differences—prompted further analyses, explained in the following sections, overall they did not necessarily greatly affect the accuracy of using vertebral ring epiphyseal union data in ascribing an estimated age range that reflected actual known age of individuals in the sample.

Upper, Middle, and Lower Vertebrae

As sex differences were found mainly on the lower vertebrae, mean values for epiphyseal union were calculated separately for upper (T1–T5), middle (T6–T9), and lower (T10–L2) vertebrae for each individual in the sample to determine what impact, if any, these had on age. An ANOVA test yielded no significant

TABLE 3—*ANOVA of vertebral ring epiphyseal union mean values.*

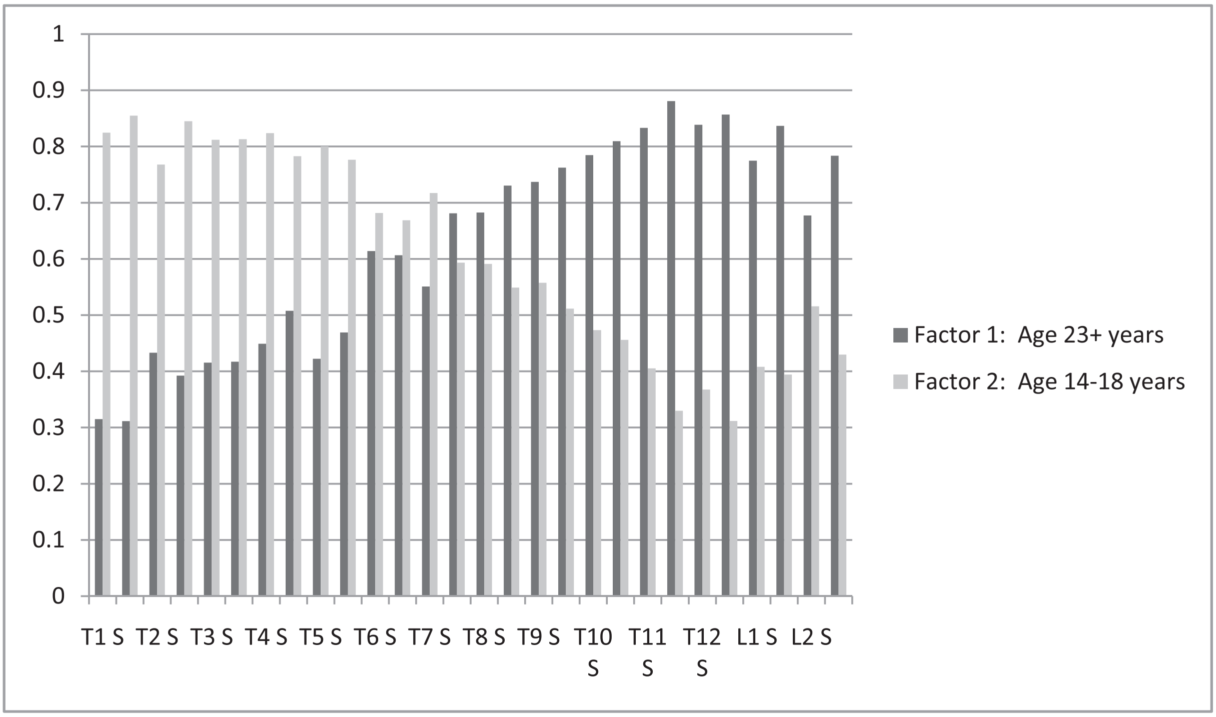
ANOVA single factor						
Summary						
Groups	Count	Sum	Average	Variance		
Examiner 1	57	124.4254	2.182902	0.765833		
Examiner 2	55	111.8753	2.034096	0.487337		
Examiner 3	55	102.6414	1.866207	0.315177		
ANOVA						
Source of Variation	SS	d.f.	MS	F	p-Value	F crit
Between Groups	2.809039	2	1.404519	2.671477	0.072159	3.051127
Within Groups	86.2224	164	0.525746			
Total	89.03144	166				

differences between upper, middle, and lower vertebral ring epiphyseal union mean values. More revealing than mean values, however, were raw data observations of stages of union assigned to each epiphysis; these showed that for individuals experiencing active union at the time of death, the lower vertebrae tended to exhibit more advanced stages of union than the upper and middle vertebrae of the same individual, with the exception of T1 occasionally. To test these observations, a factor analysis was performed using SAS version 11.

Using a principal components basis with a varimax rotation, two factors emerged using eigenvalues greater than one rule (Table 4 shows factor loadings). Factor 1 showed that the lower vertebrae, T10 to L2, were more similar in terms of stages of union assigned. Observations of the raw data (e.g., viewing the stages of union, 0 through 3, assigned for each individual epiphysis for each individual in the sample) indicated that the greater similarities in stages of union for females and males in the lower vertebrae were likely because of older age, age 23 years and older, where stages for all

TABLE 4—*Factor loadings.*

Vertebral Epiphysis	Factor 1: Age 23+ years	Factor 2: Age 14–18 years
T1 S	0.31508	0.82473
T1 I	0.31132	0.85492
T2 S	0.43297	0.76782
T2 I	0.39228	0.84501
T3 S	0.41539	0.81195
T3 I	0.41718	0.81302
T4 S	0.4491	0.82379
T4 I	0.50771	0.78288
T5 S	0.42231	0.80043
T5 I	0.46925	0.77639
T6 S	0.61388	0.68168
T6 I	0.60647	0.66891
T7 S	0.55089	0.7171
T7 I	0.68124	0.59337
T8 S	0.68259	0.59103
T8 I	0.73044	0.54907
T9 S	0.73704	0.55766
T9 I	0.76233	0.51163
T10 S	0.78477	0.47338
T10 I	0.80947	0.45606
T11 S	0.83307	0.40533
T11 I	0.8808	0.32973
T12 S	0.83868	0.36756
T12 I	0.85676	0.31178
L1 S	0.77486	0.40811
L1 I	0.83681	0.39441
L2 S	0.67743	0.51568
L2 I	0.7836	0.42985



individuals were 2 or 3; for individuals 24 years and older ($n = 15$), all epiphyses were coded Stage 3, complete union. While older age (23+ years) appeared to have more of an influence on the lower vertebrae (T10–L2), Factor 2—younger age (14–18)—had more of an influence on the upper vertebrae (T1–T5).

Factor 2 showed that the upper vertebrae, T1–T5, were more similar in terms of stages of union assigned. Raw data observations indicated greater similarities in stages of union among both females and males with regard to the upper vertebrae compared to the middle and lower vertebrae in individuals aged 14–18 ($n = 9$); there were more of Stage 0 and 1 and a few Stage 2. The middle vertebrae, T6–T9, showed the least amount of similarity in stages of union; there was greater variability in union—a larger mix of Stages 1, 2, and 3—for females and males aged 19–21 ($n = 16$), peak ages of epiphyseal union activity, when compared to the rest of the sample.

Results from the factor analysis (Table 4) corroborated results of earlier studies to the extent that the sequence of union was noted as appearing to occur from the "ends" of the presacral vertebral column toward the middle (1–4). In this study, the lower end seemed to be more advanced than the upper end, yet the middle vertebrae were last to unite as previous studies have found (1–4).

Findings and Age Estimation Guidelines

Inasmuch as the overall age estimation range assigned is deemed more important than incongruence regarding specific epiphyses, age estimation guidelines were developed based on observations of the raw data, as well as the vertebral ring epiphyseal union mean values, collected by Examiner 1. We calculated the percentages of vertebral ring epiphyses in the various stages of union for each individual in the sample, which was separated by sex, because previous analyses indicated differences in the timing of union between females and males. For each individual in the sample, the percentages of epiphyses in each stage of union were calculated by dividing the total number of epiphyses in each stage of union by the total number of epiphyses examined.

TABLE 5—*Distribution of stages of vertebral ring epiphyseal union by age for females.*

Age in Years	% Stage 1	% Stage 2	% Stage 3	% Stage 4	Vertebral Ring Epiphyseal Union Mean
14	0	29	71	0	1.71
16	0	100	0	0	1.00
17	71	21	7	0	0.36
17	36	50	14	0	0.79
18	45	33	22	0	0.78
19	0	7	93	0	1.93
19	0	36	64	0	1.64
19	0	0	69	31	2.31
20	0	29	71	0	1.71
22	0	0	64	36	2.32
20	0	0	86	14	2.14
21	0	0	86	14	2.14
22	0	4	82	14	2.11
22	0	4	96	0	2.04
22	0	0	100	0	2.00
23	0	0	0	100	3.00
23	0	0	71	29	2.29
23	0	0	73	27	2.27
24	0	0	79	21	2.21
24	0	0	25	75	2.25
24	0	0	0	100	3.00
25	0	0	50	50	2.50
25	0	0	39	61	2.61

The distribution of percentages of epiphyses in the various stages of union was used to group individuals into age ranges as vertebral ring union mean values alone did not explain the patterns of dispersal of the stages of union across the ages or the ages of first or last appearance of particular stages of union (Tables 5 and 6). The dispersal of stages of union combined with the vertebral ring union mean values is integral to using these data ultimately for age estimation purposes in unknown individuals. Results of the age groupings are presented below. Guidelines for age estimation based on these results are shown in Tables 7 and 8 for females and males, respectively. Later, we discuss the results of a test of the accuracy of these age estimation guidelines using the data collected by Examiners 2 and 3.

Findings for females ($n = 23$) are presented first (Table 5), with findings for males ($n = 32$) discussed secondly (Table 6). For females aged 14–18 ($n = 5$), epiphyses were in Stage 0 (no union), Stage 1 (beginning or progressing union), and/or Stage 2 (almost complete union or recent union). Stage 3 (complete) epiphyses were absent (i.e., not yet attained). The vertebral ring union mean values ranged from 0.36 to 1.71. Stage 0 was present in three individuals (two aged 17 and one aged 18) yet was surpassed (i.e., epiphyses were Stage 1 or beyond) in two individuals (aged 14 and 16). Stage 1 was present in all individuals in this age group, with one individual (aged 16) showing all epiphyses in Stage 1. Stage 2 was present as young as age 14. Stage 2 was absent in one individual aged 16 and present in the three remaining individuals in this age range (two females aged 17 and one aged 18).

Females between the ages of 19 and 22 ($n = 10$) had vertebral ring epiphyses in Stages 1, 2, and/or 3. Vertebral ring union mean

TABLE 6—*Distribution of stages of vertebral ring epiphyseal union by age for males.*

Age in Years	% Stage 0	% Stage 1	% Stage 2	% Stage 3	Vertebral Ring Epiphyseal Union Mean
17	39	32	29	0	0.89
18	36	50	14	0	0.79
18	0	75	25	0	1.25
19	0	56	44	0	1.44
19	0	0	93	7	2.07
19	0	4	82	14	2.11
20	21	71	8	0	0.88
20	0	0	82	18	2.18
20	25	71	4	0	0.79
20	0	0	7	93	2.93
21	0	0	54	46	2.46
21	4	57	39	0	1.36
22	0	0	54	46	2.46
22	0	21	79	0	1.79
22	0	0	96	4	2.04
22	0	0	43	57	2.57
22	0	0	64	36	2.36
22	36	64	0	0	0.64
23	0	0	21	79	2.79
23	0	0	82	18	2.18
23	0	0	56	44	2.46
23	0	0	79	21	2.21
24	0	0	0	100	3.00
24	0	4	75	21	2.18
24	0	0	93	7	2.07
24	0	0	79	21	2.21
25	0	0	32	68	2.68
25	0	0	61	39	2.39
26	0	0	14	86	2.86
26	0	0	29	71	2.71
27	0	0	0	100	3.00
27	0	0	0	100	3.00

TABLE 7—*Vertebral ring union age estimation guidelines for females.*

Age Range in Years	Vertebral Ring Union Mean Value Range	Description
14–18	0.36–1.71	Stage 0 may persist up through age 18 years
		Stages 0, 1, 2 prevalent
		Stage 2 appears as young as age 14 years
		Stage 3 absent
19–22	1.64–2.32	Stage 0 surpassed
		Stage 1 less frequent, may persist up through age 22 years
		Stage 2 typically more prevalent than Stages 1 and 3
		Stage 3 may appear as young as age 19 years
		Stage 3 may be absent up through age 22 years
		Stage 3 in all epiphyses does not appear yet
23+	2.21–3.00	Stages 0 and 1 surpassed
		Stages 2 and 3 prevalent, or all Stage 3

values ranged from 1.64 to 2.32, overlapping slightly with females aged 14–18 (0.36–1.71). Stage 0 was surpassed in all individuals; there were no epiphyses in Stage 0. Stage 1 was present (five out of ten individuals) or surpassed (five out of ten individuals). Stage 2 was present in all ten individuals in this age range. Stage 3 was attained in five of the ten females aged 19–22. Stage 3 appeared as young as age 19 in one individual while remaining absent in two individuals aged 22.

Females aged 23–25 ($n = 8$) had vertebral ring epiphyses in Stages 2 and/or 3. Vertebral ring union mean values ranged from 2.21 to 3.00. Stages 0 and 1 were surpassed in all individuals in this age group. Stage 2 persisted in six of the eight individuals in this age group, with the oldest aged 25. Stage 2 was surpassed by two individuals whose epiphyses were all Stage 3 (one female aged 23, the other aged 24). Table 7 shows female age estimation guidelines derived from these findings (summarized in Table 5).

Findings for the males ($n = 32$) and their distribution of stages of vertebral ring epiphyseal union across the various ages are shown in Table 6. There was a high degree of variation in the timing of fusion of vertebral ring epiphyses in the male sample; thus, age groupings overlap. These overlapping age groupings account for variability and ensure accuracy in age estimation which is discussed shortly.

Males aged 17–22 ($n = 18$) showed epiphyses in Stages 0, 1, 2, and/or 3. Vertebral ring union mean values ranged from 0.64 to 2.93. Stage 0 was present in five of 18 males in this age group, persisting up through age 22 in one individual. Stage 1 was present in ten individuals; it was surpassed in eight individuals, the youngest aged 19. Stage 2 was present in all individuals except for one 22-year-old whose epiphyses were all Stages 0 or 1. Stage 3 was present in nine individuals. The youngest age at which Stage 3 was present was 19, and the oldest age where Stage 3 was not yet attained was 22. Stage 3 in all epiphyses was not yet present.

Males aged 23–26 ($n = 12$) had vertebral ring epiphyseal union mean values (2.07–2.86) that overlapped fairly considerably with males aged 17–22 (0.64–2.93) as many of the epiphyses were distributed across Stages 2 and 3. For males aged 23–26, Stage 0 was surpassed in all individuals. Stage 1 was surpassed in all individuals except one 24-year-old. Stage 2 was present in all individuals except for one 24-year-old who showed Stage 3 in all epiphyses. Stage 2 persisted up through age 26. Stage 3 was present in all individuals. The remaining two males in the sample were aged 27 and both showed Stage 3 in all epiphyses. Many of the males from ages 19–26 showed similar distributions of stages of union and corresponding vertebral ring union mean values. Thus, when we developed the guidelines for use in male age estimation (Table 8), we established an age grouping of 19–26 to account for the variability in ages at which certain stages of union progressed which overlaps with the age grouping of 17–22. Similarly, because complete union in all epiphyses was seen as young as age 24 years, our last age grouping for males is 24 years and older, which also shows overlap with the 19–26 year age range.

Testing Accuracy

The guidelines for estimating age from vertebral ring epiphyseal union established from the analyzed data collected by Examiner 1 (Tables 7 and 8) were tested on the data collected by Examiners 2 and 3. Percentages of epiphyses in the various stages of union for each individual in the sample were calculated for data collected by Examiners 2 and 3. In a blind test (i.e., knowing the sex but not the age), the distribution of epiphyses in the various stages of union along with vertebral ring union mean values was assessed, and based on the guidelines shown in Tables 7 and 8, ages were estimated. The estimated ages were then compared to the known ages and the results are presented below.

For females, the estimated age ranges from Examiner 2's data corresponded to known age correctly in 100% of the sample (all 23 females). Results were lower for Examiner 3's data—estimated ages corresponded to known age in 78% of the female sample. In five out of 23 cases examined, the age range was underestimated. All were determined to be in the estimated age range of 14–18, where the actual ages were 19 (2 individuals), 20, 22, and 24 years. In the five cases, none of the epiphyses were scored as Stage 3 by Examiner 3; however, Examiners 1 and 2 scored several epiphyses as Stage 3 for each of these individuals. Given the guidelines for

TABLE 8—*Vertebral ring union age estimation guidelines for males.*

Age Range in Years	Vertebral Ring Union Mean Value Range	Description
17–22	0.64–2.93	Stage 0 may persist through age 22 years
		Stage 0 may be surpassed from age 18+ years
		Stage 1 appears at age 17 and may be prevalent
		Stage 2 may be surpassed from age 19+ years
		Stage 3 first appears as young as age 19 years, but may be absent up through age 22 years
19–26	0.88–3.00	Stage 0 may persist up through age 22 years; it is surpassed from age 23+ years
		Stage 1 may persist up through age 24 years; it is surpassed from age 25+ years
		Stages 2 and 3 only may be prevalent between ages 19 and 26 years
		Stage 2 may be surpassed as early as age 24 years
		Stage 3 is present or absent between ages 19 and 22 years; from age 23+ years it is present
24+	2.21–3.00	All Stage 3
		Stage 3 in all epiphyses appears as young as age 24 years

females shown in Table 7, the presence of an epiphysis in Stage 3 places an individual in the 19 years and older age range as opposed to the age range of 14–18 years. Thus, the ages of individuals for whom no Stage 3 existed were underestimated. This finding obviates the challenge of discerning recently completed union with its slight groove (Stage 2) from complete union (Stage 3) where a scar may persist. Similar results were found for males.

For males, the estimated age ranges from Examiner 2's data corresponded to known age correctly in 100% of the sample (all 32 males). Estimated age ranges from Examiner 3's data were accurate for 88% of the sample (28 out of 32 males). The issue of underestimation was noted. In four cases out of 32, the estimated age range was lower than the actual age. In three cases, none of the epiphyses were scored as Stage 3 by Examiner 3, whereas both Examiners 1 and 2 had scored Stage 3's. Examiner 3 estimated the ages for these three cases in the range of 17–22 years, where the actual ages were 24 (two individuals) and 25 (one individual). Had there been Stage 3's, the estimated age ranges would have been 19–26 years, which would have incorporated the known ages. In one case, Examiner 3 scored Stage 2, whereas both Examiners 1 and 2 scored all epiphyses as Stage 3. The presence of Stage 2 led to the estimated age range of 19–26 years where the actual age was 27 (Stage 2 surpassed, all epiphyses Stage 3). Practitioners are encouraged to be confident in assigning Stage 3 (complete union) when a scar persists yet are cautioned not to overlook the recent union in Stage 2 where a groove (i.e., slight indentation) is found. Careful discernment between recently complete union with its groove (Stage 2) and union that has been complete for a time (Stage 3 with a scar perhaps) is important for obtaining a high degree of accuracy in age estimation with this method.

Conclusions

Results of this study showed that although there is a good deal of variability in the rate and timing of fusion of vertebral ring epiphyses, their union activity correlates well with known age at death and there is good agreement between observers using the four-stage method modified by Albert and Maples (3,4). That females exhibited maturity at earlier ages with males catching up in the early to middle 20s and beyond is comparable to research findings from other skeletal and dental studies (8). The utility of this method is enhanced by an explanation of the pattern and array of epiphyses in their various stages of union that practitioners may expect to see when observing the vertebrae for use in age estimation.

The guidelines for age estimation using vertebral ring epiphyseal union developed in this study show promise in assisting practitioners in assigning an estimated chronological age range at death that accurately reflects actual age at death in years. Moreover, for the age range researched for this study (teens to late 20s), other skeletal and dental methods used to estimate age are often accurate to within 2–3 years of the actual age at death (9). The vertebral ring epiphyses fare comparably.

As always, the use of multiple skeletal age indicators in estimating age at death is considered a best practice. This method of estimating age via observations of vertebral ring epiphyseal union may be especially useful in conjunction with age observations of sacral fusion, which is most active between the ages of 20 and 30 (10). We support the use of vertebral ring epiphyseal union data whenever possible as a means to help narrow otherwise broader age estimation ranges.

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