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Determination of Age from the Sternal Rib in White Males: A Test of the Phase Method

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ABSTRACT: The effectiveness of a given age determination technique can better be assessed by testing the standards on unknown specimens. A test of this nature was carried out to evaluate the authors' previously published phase method for age estimation from the sternal extremity of the rib. A sample of 15 test ribs was judged by 25 physical and forensic anthropologists with varying levels of education and experience. The judges were asked to match the rib to the phase it most closely resembled by comparing it with the photographs from the original study. The results indicated that interobserver error based on experience was minimal, and nearly all of the participants averaged within one phase of the ideal. Variation appeared to be greater among the ribs than among the judges, yet no consistent association could be made between this variation and factors such as cause of death, antemortem medical history, drug or alcohol abuse, and occupation.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, sternal rib, age estimation, sternal rib, interobserver error, white males

Determination of age at death from adult skeletal remains is a major concern for physical and forensic anthropologists. Available methods using gross morphology of the skeleton have focused on pubic symphyseal metamorphosis and cranial sutural closure [*1*]. Recently, based on Kerley's initial observations [*2*], İşcan and associates [*3-5*] introduced the sternal extremity of the rib as another viable site for age estimation. They analyzed rib metamorphosis with two techniques: component analysis and phase analysis. The component analysis system was developed by associating the changes observed in three areas (components) of the sternal rib including pit depth, pit shape, and rim and wall configurations with the age at which they are found to occur [*3*]. The phase analysis technique delineated these metamorphoses at the sternal rib into nine phases of progression with age [*4*].

The success of a given technique depends largely on the representativeness of the sample from which the standards are derived. The specimens used in the study from which the phase technique was developed reflected a cross section of the general population [*4*]. It consisted of white males with a mix of socioeconomic backgrounds, professions, and health/disease status, ranging in age from 3 to 85 years. Thus, it was felt that the standards established by the authors would provide an all encompassing, widely applicable basis for this system of age determination from the rib [*4*].

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The method must also be designed to minimize variation between individual observers. While the question of the representativeness of the sample is statistical in nature and can be assessed accordingly, interobserver variation is a subjective matter, and, thus, more difficult to assess. The procedure most commonly used by anthropologists to evaluate this problem involves presenting an unknown test sample to a group of individuals of known educational background and experience and comparing the results [*6, 7*]. The phase technique was tested by participants attending a conference of forensic scientists. The purpose of this paper is to present and analyze the results of this evaluation.

Materials and Methods

To test the accuracy and ease of application of the phase method, along with interobserver error, a sample of 15 white male ribs collected from a medical examiner's office was brought to the 1984 Annual Meeting of the American Academy of Forensic Sciences held in Anaheim, CA. The ribs were presented randomly to the judges and were labeled only with the medical examiner's case number when the test was administered. Later, to simplify the analysis of data after the test, the ribs were renumbered R1 to R15 in ascending age order. Figure 1 illustrates these specimens in chronological order from youngest (11 years) to oldest (78 years).

Twenty-five of the individuals attending the anthropology section of the conference volunteered to act as judges (J1–J25). They ranged from undergraduate students to Ph.D.s and M.D.s with over 20 years of experience in physical and forensic anthropology or forensic medicine. Each was asked to assign the 15 unknown ribs to a phase by simply comparing them with the photographic plates consisting of three views of prototype ribs at each of the nine phases (0–8) that were used in the study describing this technique [*4*]. The judges were asked to write down the phase number of the photographs that each specimen most closely resembled. No other instructions were given, including the phase descriptions that would normally accompany the photographs and would be used in the actual age determination process.

The authors also evaluated the unknown ribs in the same manner as the judges, using only the photographs, before the actual ages were obtained from the medical examiner's records. Each rib was assigned to an "ideal phase" based on its recorded age. The ideal phase was the one in which the specimen's age came closest to the calculated mean age per phase lying within the 95% confidence interval. The test results were then compared to this ideal phase. An analysis was also carried out to correlate the relative effectiveness of this method with the experience and educational background of the judges.

Results

Table 1 presents pertinent data on the ribs in the test sample along with descriptive statistics from the original study in which the age determination technique was developed [*4*]. It can be seen that the test sample ranged in age from 11 to 78 years with a median age of 52. This table also shows the authors' estimated phase for each rib without prior knowledge of the age of the specimen. The ideal phase column lists the phase to which each rib would be assigned on the basis of its actual (known chronological) age.

For the purpose of comparison, the right half of Table 1 lists the mean age, confidence interval, and the age range of the ribs comprising each phase in the initial study. None of the test specimens were in Phase 3, and therefore, it is not listed in this table. Comparison of the authors' estimated phase with the actual phase indicated that out of fifteen ribs, two ribs were underestimated by one phase (R6, R9), two by two phases (R11, R12), and one specimen (R8) was overestimated by one phase. With the exception of R6 (age 34) all the disputed ribs were over 50.

The estimates made by the judges, who were divided into doctoral and predoctoral groups, were compared with the ideal phase and the mean deviation between the two appears in Table 2.

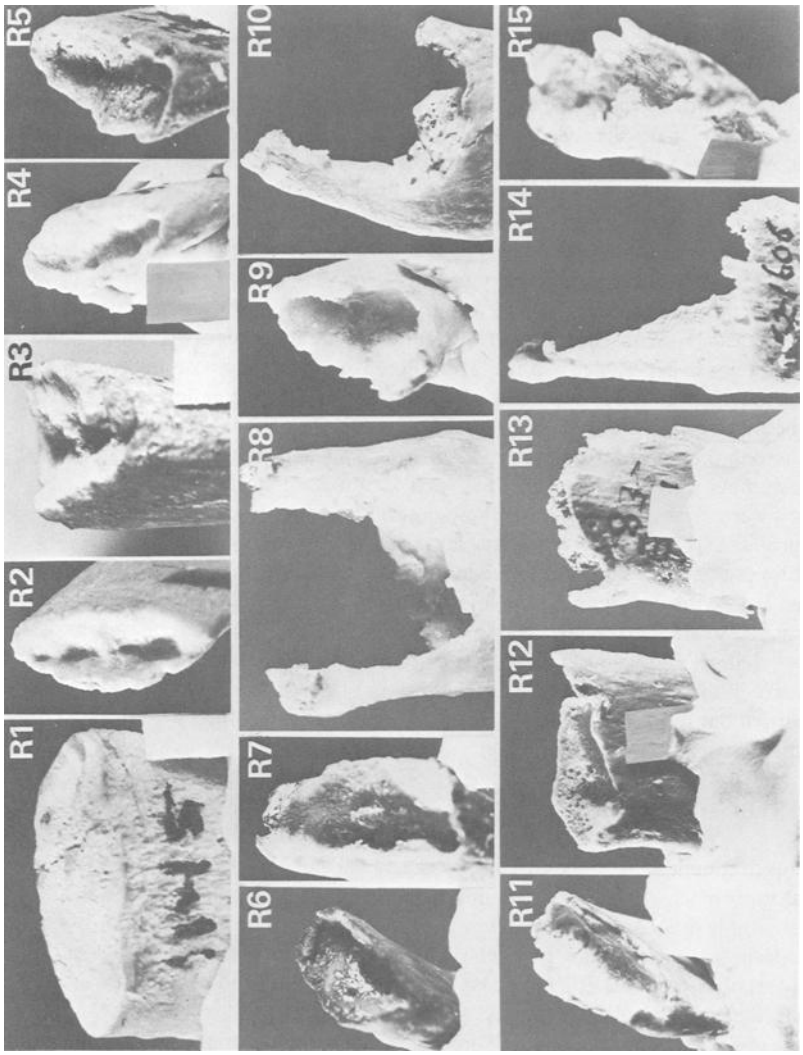

FIG. 1—*The test specimens, R1–R15, are illustrated in chronological age order. Specimens R1, R2, R4, R10, and R14 were estimated most accurately (within 0.4 phase), while R5, R11, R12, and R15 were misjudged by more than 1 phase. R15, which does not show the typical morphological characteristics of Phase 8, illustrates the importance of the texture and bone quality descriptions that appear in the phase definition instructions. R8, which would ideally be in Phase 6, was almost identical, morphologically, to the prototype for Phase 7, and nearly all the judges assigned it accordingly.*

TABLE 1—*Actual age, authors' evaluation of test specimens, and descriptive statistics of the phases based on the original study.*

Test Specimens				Original Study[a]			
Rib No.	Authors' Estimated Phase[b]	Age	Ideal Phase[c]	Mean Age	SD	95% Confidence, Interval of Mean	Actual Age Range
R1	0	11	0	>17.0			
R2	1	18	1	17.3	0.50	16.5-18.0	17-18
R3	2	20	2	21.9	2.13	20.8-23.1	18-25
R4	2	23	2				
R5	4	27	4	28.2	3.83	25.7-30.6	22-35
R6	4	34	5	38.8	7.00	34.4-42.3	28-52
R7	5	43	5				
R8	7	52	6	50.0	11.17	44.3-55.7	32-71
R9	6	55	7				
R10	7	55	7	59.2	9.52	54.3-64.1	44-85
R11	5	58	7				
R12	5	64	7				
R13	8	73	8				
R14	8	75	8	71.5	10.27	65.0-78.0	44-85
R15	8	78	8				

[a]Modified from İşcan et al [4], Table 2.
[b]Determined by authors without prior knowledge of age.
[c]Ideal phase as determined by confidence interval in Table 1.

A score of 0, for example, indicates that a judge evaluated the rib as being in the ideal phase, a −1 means that a judge underestimated the age by one phase, and a +1 shows an overestimation of one phase. The mean deviation, calculated as the absolute total of raw phase deviations divided by the number of judges per case, are listed separately for the doctoral and predoctoral groups (Table 2). The overall deviation appears at the bottom of the same table. It is clear that certain ribs were correctly assessed by nearly all of the judges, while others were missed by almost everyone. In 11 of the 15 test ribs, the estimates of the judges as a group fell within 1 phase of ideal, and all the judges estimated the 11-year-old specimen correctly as Phase 0, that is, below the age of 17 years. Specimens R12 and R15 were the only ribs misjudged by an average of 2 phases or more, and both were over age 60. On the average, only 1 rib (R5) under the age of 58 was missed by more than 1 phase.

The last two columns in Table 2 rate the individual performance of the judges. Fifteen of the twenty-five judges averaged within one phase of the ideal, and only one judge (J18) deviated more than 1.5 phases from ideal. The judges' performance was also analyzed on the basis of their academic level. The average for those judges with doctoral degrees was within 0.92 of the ideal phase. The mean deviation for the predoctoral group was somewhat higher at 1.06.

While deviation is expressed in terms of the raw difference between the judges' estimated phase and the ideal phase (Table 2), deviation in years can be calculated as the difference between the mean age for the estimated phase and the actual age of the specimen which appears in Table 1. For example, J13 underestimated R3 (actual age 20) by 1 phase as Phase 1 (mean age 17), therefore, the deviation in years is 3. Where phase was overestimated the difference in years is calculated by subtracting the actual age of the rib from the mean age of the estimated phase. For example, J25 estimated R12 (actual age 64) as Phase 8 (mean age 72); thus, the deviation is 8 years. The higher the phase, the greater the age difference between phases becomes. The mean age difference between Phases 1 through 4 is approximately three years per phase. This increases to about ten years per phase in Phases 4 through 8 and is accounted for by a wider 95% confidence interval.

TABLE 2—*Deviation of judges' (J) estimates of the test ribs (R) from the ideal phase.*

	Test Ribs															Judges' Deviation:	
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15		
	23[a]	23	23	23	23	23	21	23	21	23	22	22	21	20	21		
Judges	0[b]	1	2	2	4	5	5	6	7	7	7	7	8	8	8	Total	Mean
AUTHORS	0	0	0	0	0	−1	0	+1	+1	0	−2	−2	0	0	0	7	0.47
JUDGES WITH DOCTORAL DEGREES																	
J1	0	0	0	0	+1	−2	0	+1	−2	0	−4	−2	0	−1	−3	16	1.06
J2	0	0	0	0	0	+1	−2	+1	+1	+1	0	−1	0	0	−1	8	0.53
J3	0	−1	0	−1	−2	−1	0	+1	−2	0	−2	−4	−1	−1	−3	19	1.27
J4	0	+1	−1	0	−1	0		+1	+1	0	+1	−4	−2	−1	−3	16	1.14
J5	0	0	0	0	−1	0	0	+1	0	0	−1	−3	0	0	−2	8	0.53
J6	0	0	0	−1	−3	−2	−2	+1	0	0	−4	−2	−2	0	−4	21	1.40
J7	0	0	0	0	−1	−2	0	+1	0	0	0	−2	0	0	−2	8	0.53
J8	0	−1	−1	0	0	0	0	+1	0	0	−1	−2	−3	0	−3	12	0.80
J9	0	0	−1	0	−2	+1	−1	−1	0	0	−2	−3	0	0	−4	15	1.00
J10	0	0	−1	0	−2	+1	0	+1	−1	0	−5	−2	0		−5	18	1.29
J11	0	0	−1	−1	0	−2	0	+1		+1	−1	−4		−1	−3	15	1.15
J12	0	0	−2	−1	−1	0	−1	+1	−1	0	−3			0	−3	13	1.00
J13	0	0	−1	0		+2	+2	+1	0	0	0	−1	0	0	−4	11	0.79
J14	0	+1	0	0	+1	0	−1	+1	−1	+1	−1	−3	−1	0	−2	13	0.87
J15	0	0	−1	0	−2	0	0	+1	+1	0	−1	−3	0			9	0.69

J16	0	−1	−1	0	−1	0	−1	+1	−1	0	−1	−1	−2	0		10	0.71
Total	0	5	10	4	18	14	10	16	11	3	27	37	11	4	42		
Mean	0	0.31	0.63	0.25	1.20	0.88	0.67	1.00	0.73	0.19	1.69	2.31	0.79	0.29	3.00		0.92
JUDGES WITHOUT DOCTORAL DEGREES																	
J17	0	0	0	+3	0		0	+1	0	0			0	0	−1	5	0.42
J18	0	0	−1	0	−2	−2	−3	0	−4	−2	−3	−4	−1	0	−4	26	1.73
J19	0	0	0	0	−2	+1	0		−1	0	−3	−2	0	0	−3	12	0.86
J20				0		0		+1		0		−2	0		−4	7	1.00
J21	0	0	−1	0	−2	+1		+1	0		−2			−1	−3	11	1.00
J22	0	0	0	+1	−2	0	0	+1	0	+1	0	+1	−1		−5	12	0.86
J23	0	0	−1		−2	−2				0	−2	−3		0		10	1.11
J24					−2		−2	+1				−2	0			7	1.40
J25	0	0	0	−1	−2	−2	+2	+1	+1	0	+1	+1	0	−1	−5	17	1.13
Total	0	0	3	5	14	8	7	6	6	3	11	15	2	2	25		
Mean	0	0	0.43	0.71	1.75	1.14	1.17	0.86	1.00	0.43	1.83	2.14	0.29	0.33	3.57		1.06
OVERALL DEVIATION:																	
Total	0	5	13	9	32	22	17	22	17	6	38	52	13	6	67		
Mean	0	0.22	0.57	0.39	1.39	0.96	0.81	0.96	0.81	0.26	1.73	2.36	0.62	0.30	3.19		0.97

[a]This row indicates the number of judges who tested each specimen.

[b]This row lists the ideal phase in which the rib would be placed as determined by the 95% confidence interval based on its known age. The values below each ideal phase indicate the judges deviations from the ideal phase number. For example, −1 signifies that a particular judge assessed the rib one phase younger than the ideal phase, 0 overestimation.

Table 3 shows the overall deviation for each test rib, that is, how many phases they were over- or under-estimated. The middle portion of the same table presents the percentage of over-, exact, and under-estimation of each rib. Again, the most accurately estimated ribs were R1, R2, R4, R10, and R14, while the most problematic ones were R12 and R15. It can also be seen that when deviation occurred it tended to be in the direction of underestimation. The last row shows that for nine of the ribs, 80% or more of the estimates fell within one phase of ideal.

The available antemortem history appears in Table 4. The last column of the table indicates that the estimation of age in R5, R12, R11, and R15 exceeded the mean deviation from the ideal phase found for the total sample. Of these cases, only R5 and R12 had a history of alcohol abuse. However, the other alcoholic individuals (R10, R13) were estimated quite accurately, as was R7, a known diabetic. There was also no consistent pattern of deviation for those individuals with cardiovascular disorders. Two cases (R11, R15) were underestimated by more than one phase while the other two (R7, R9) were within one phase of ideal.

The occupation and body height and weight of the specimens are also noted in Table 4 and were checked for any obvious association with the estimated phase age. While keeping in mind that postmortem weight might be less and stature somewhat greater than the antemortem values, no clear-cut association could be made with the overall deviation of the estimates. There also appeared to be no obvious association between occupation and the accuracy of age determination for the individuals in this test sample.

Discussion

There are a number of factors that must be considered when evaluating a method to estimate age from the skeleton. In the case of the rib, these factors include the principles underlying the development of the phase technique, whether age determination is affected by the antemortem health and occupation of the decedent, and finally, the importance of the educational level of the judges (differences between those with doctoral and predoctoral degrees).

In order to put the test results in their proper perspective, it is important to understand how the phase technique was developed. In the authors' original study establishing the phase technique, statistical analysis revealed that 85% of the variation with age was accounted for by the criteria chosen to differentiate and define the phases [*4*]. The 95% confidence interval of the mean age per phase increased from about 1.5 years in Phase 1 (mean age = 17) through 8 years in Phase 5 (mean age = 39) to 13 years in Phase 8 (mean age = 72). This indicated two things: rapid metamorphosis in younger individuals and wider variation with increasing age. Therefore, precise delineation of morphological changes would be more difficult in the later phases, especially after Phase 4. Thus, younger ribs were more likely to be effectively estimated by the judges, while the more subtle changes in the older groups might have been more clearly differentiated by the added explanation provided in the original study.

Furthermore, the variability found in older specimens increased the possibility of misassigning an individual whose rib formation was outside the description of the phase to which the rib would have been assigned on the basis of its age alone. It must be kept in mind that the mean age per phase was calculated in the original study by averaging the ages of individuals showing similar features at the sternal extremity of the rib, and thus, those at the extremes of the actual age range of each phase would be classified as either a phase older or younger if assigned by known age rather than appearance.

It is important to emphasize that the judges tested this method without the detailed instructions that normally would accompany the photographic plates. Thus, it is not surprising to observe that the judges focused their attention on those characteristics of the rib most obvious in the photographs, especially the shape of the rim and pit. The instructions point out and describe which formations and features define the phases. More importantly, they include vital details that must be considered and are not visually obvious in a photograph, such as texture and sharpness of edges. For example, the authors rated specimen R6 (Fig. 1) as Phase 4, but

TABLE 3—*Total number of cases under-, correct, and over-estimated.*

Deviation from Ideal Phase	Test Ribs														
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
	23	23	23	23	23	23	21	23	21	23	22	22	21	20	21
−5											1				3
−4									1		2	4			5
−3					1		1				3	5	1		8
−2			1		11	7	3		2	1	4	8	3		3
−1		3	11	5	5	1	4	1	5		6	3	4	6	2
0	23	18	11	16	4	9	11	1	9	18	4		13	14	
+1		2		1	2	5		21	4	4	2	2			
+2						1	2								
+3				1											
+4															
+5															
% ESTIMATES:															
Under		13	52	22	74	35	38	4	38	4	73	91	38	30	100
Correct	100	79	48	70	17	39	52	5	52	78	18		62	70	
Over		8		8	9	26	29	91	19	17	9	9			
±1 phase	100	100	96	96	49	65	71	100	86	96	55	23	81	100	10

TABLE 4—*Cause of death and relevant medical history from death certificate.*

Rib Number	Age	Cause of Death (Medical History)	Occupation	Height, ft-in.[a]	Weight, lbs[a]	Overall Deviation
R1	11	accidental hanging (unknown)	student	4'11"	80	0
R2	18	gunshot (unknown)	student	5'10"	133	0.22
R3	20	auto accident (unknown)	auto mechanic	6'2"	158	0.57
R4	23	auto accident (unknown)	telephone installer	5'11"	204	0.39
R5	27	auto accident (chronic alcoholism)	waiter	5'10"	158	1.39
R6	34	gunshot (unknown)	army soldier	5'7"	154	0.96
R7	43	ACHD[a] (diabetes)	stage hand	6'0"	258	0.81
R8	52	gunshot (unknown)	drug store manager	5'9"	166	0.96
R9	55	ACHD (unknown)	store manager	5'9"	170	0.81
R10	55	G.I. hemorrhage (chronic alcoholism)	unemployed	5'7"	142	0.26
R11	58	ACHD (unknown)	college dean	5'9"	160	1.73
R12	64	chronic alcoholism (chronic alcoholism)	security guard	5'8"	140	2.36
R13	73	chronic alcoholism (chronic alcoholism)	unknown	5'8"	138	0.62
R14	75	suicide (unknown)	retired	6'0"	194	0.30
R15	78	ruptured aortic aneurysm (unknown)	retired	5'6"	154	3.19

[a]Height and weight data are obtained from the death certificate or autopsy reports and may not be the same as the antemortem values. 1 ft = 30 cm, 1 in. = 25.4 mm, and 1 lb = 0.45 kg.

with the instructions would have properly judged at Phase 5 because, while the shape of the rim and pit was similar to both photographs, the edge of the rim was sharp to the touch—a major feature distinguishing the progression from Phase 4 to Phase 5 [*4*].

The consideration of texture is especially significant in judging older specimens. The oldest rib (78 years) in the test sample (Fig. 1, R15) was rated at least 1 phase, and in most cases 2 to 4 phases, younger by all of the judges except the authors. Visually, the rim configuration and pit shape of this specimen could be matched with photographs of Phases 5 through 7 but the extreme fragility and almost paper thinness of the bone would, according to the instructions, have limited the choices to Phases 7 and 8.

Specimen R8 was notable in that nearly everyone (including the authors) judged it as Phase 7 instead of its ideal Phase 6. As can be seen in Fig. 1, R8, which was from a 52-year-old individual, clearly looks much more like the photographic example of Phase 7, and would have been classified as such if it had been part of the original study. This would not have been anomalous, because while the 95% confidence interval of the mean for Phase 7 was 54 to 64 years, the actual age range of specimens used to compute the mean age for that phase was 44 to 84. Furthermore, the mean age for either Phase 6 or Phase 7 would have correctly placed this individual in his fifties.

This test of the phase method supported the findings of the original study by showing that the metamorphic markers delineating the phases are clearer below Phase 4 and become more subtle with increasing age. When variation in the phases was originally evaluated statistically, it was found that Phase 6 was the most varied, followed by Phases 5 and 7 [*4*]. This is consistent with the results of the present test.

In any technique for the determination of age from the skeleton, the standards must be broad enough to account for the effects of disease or substance abuse occurring in the population at large. With this in mind, as we stated before, the study sample was representative of the general population, and included all individuals regardless of their medical history and involvement with drug or alcohol abuse. While it has been observed that long-term drug or alcohol abuse and hormone therapy may affect the accuracy of macroscopic skeletal aging criteria [*8-10*], the authors found no consistent association between drug or alcohol abuse and misjudgment of age in this test. Two alcoholics were underestimated by about two phases, while the other two were estimated very accurately, one almost exactly (R10).

The results of this test also yielded no apparent connection between correct age assessment and occupation, cause of death, and antemortem disease status. It is difficult to assess this problem because of the limited amount of information, especially pertaining to medical history, and duration of pathology or substance abuse, available on medical examiner's cases. It is known that occupational differences can cause morphological variation in the skeleton [*11-13*]. However, the association between the aging process and occupationally related activity has not been clearly demonstrated. The sample used in this study showed a variety of occupations, but if there was any influence it could not be detected nor directly attributed to a particular job in this relatively small group.

The experience of the judges must also be considered. This test indicated that variation is much wider among specimens than observers. It was found that interobserver error, based on the educational level and years of experience of the judges, was minimal. In fact, in several cases, judges with predoctoral degrees and recent Ph.D.s had more success than some judges with 15 years of postdoctoral experience. This contrasts with Suchey's findings of considerable interobserver error between individuals determining age from the pubic symphysis [*7*].

In conclusion, variation in age related changes in the rib is undoubtedly similar to that found in other bones of the skeleton. However, this test indicated that the variation between individuals is still within an expected range. Because so many factors may contribute to this problem, it is extremely difficult to pinpoint a single cause from the background information obtained on the specimens in the test sample. The present study suggests that age can be successfully estimated to within a phase of the actual age of the rib. Furthermore, the accuracy of age determination from the rib was not seriously affected by the experience and academic background of the judges, in contrast to techniques using the pubic symphysis and cranial sutures [*7, 14*].

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