M. Yaşar İşcan,[1] Ph.D.; Susan R. Loth,[1] B.A.; and Ronald K. Wright,[2] M.D.

Age Estimation from the Rib by Phase Analysis: White Females

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ABSTRACT: Metamorphosis at the sternal extremity of the rib has already been established as a reliable indicator of age at death. Using a sample of white males, it was shown that an accurate estimation of age can be made by direct examination of the bone itself. However, because of sexual differences in hormonal production and dimorphism in the skeleton, the present study was carried out to develop an appropriate standard for age determination from the sternal rib in white females. The sample consisted of 86 ribs of known age, sex, and race. Observations were made at the costochondral junction with special attention to pit formation (its shape and depth), changes in the walls and rim surrounding it, and overall bone density and texture. Based on changes in these areas, the ribs were separated into nine phases (0 through 8). The most rapid metamorphosis occurred in Phases 1 through 4 (mean ages 14-28) with changes noticeable at 3 to 4 year intervals. After mean age 28, this process slowed, considerably expanding the interval between phases to 10 to 15 years. The female ribs showed both earlier initial pit formation and a different morphologic pattern of aging as compared with males. Statistical analysis revealed that the features chosen to delineate the phases are valid predictors of age. This study has shown that the sternal rib can provide an accurate estimation of age in females spanning a mean age of 14 to 76 years.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, sternal rib, white females, age determination

Previous research [*1-6*] has demonstrated that the sternal extremity of the rib undergoes lifelong metamorphosis as a normal part of the aging process. Like Kerley [*3*], the authors [*5*] noted that these changes are discernible by direct examination of the bone itself, and, based on these observations, a phase analysis system was developed for white males using the sternal extremity of the rib as a new site for the determination of age at death in the adult skeleton [*6*]. The next question to be addressed is the possibility of differences in the aging process between males and females.

Radiographic studies have presented evidence of sexual dimorphism in both the manifestations and rate of change in the rib [*4, 7-14*]. Most of these works focused on pronounced differences in the lower ribs. Although the first rib showed greater mineralization in males, the pattern was not found to be sex specific [*4, 7*]. Elkeles [*11*] pointed out differences in the onset, and pattern of calcification between the sexes, with females showing earlier changes

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[1] Associate professor and graduate student, respectively, Department of Anthropology, Florida Atlantic University, Boca Raton, FL.
[2] Chief medical examiner, Broward County Medical Examiner's Office, Fort Lauderdale, FL.

noted by age 16. Navani et al [13] reconfirmed Fischer's observations [10] and found that in 70% of the males, calcification occurred along the superior and inferior margins of the costal cartilage, while only 11% of females exhibited this pattern. On the other hand, 76% of the females had a central pattern of bony deposition, as opposed to 12% of males. Also, females under age 20 had about 42% more mineralization than males. An extensive investigation by Semine and Damon [4] revealed that the rate of change in males increased steadily until the 40s then became more gradual, while females increased more slowly until the 40s and 50s. Furthermore, the trend they noted in women agreed with earlier findings [9,12] that mineralization of the costal cartilages is affected by gynecological disorders. Sanders [12] noted that females who had undergone hysterectomy or oophorectomy exhibited a characteristically male pattern of costochondral mineralization.

These findings are not unexpected in light of obvious differences in hormonal production and the existence of pronounced sexual dimorphism in other parts of the skeleton. This disparity in the pubic symphysis was, for example, great enough to necessitate separate standards of assessment for males and females [15,16].

With this in mind, we anticipated a similar situation in the rib [6]. Therefore the present study was designed to develop new standards for a phase analysis system that can be used for estimating age from female ribs.

Materials and Methods

To maintain uniformity with the earlier work on males [6], the same procedure was followed to collect and process ribs from females. The sternal extremity of the right fourth rib was obtained at autopsy from 86 white female forensic science cases of known age, sex, and race. All adherent soft tissues, including the costal cartilage, were removed by first soaking the specimens in water for several weeks, then gently boiling for 10 to 15 min.

The data were subjected to statistical analysis using Statistical Package for the Social Sciences (SPSS) subroutines CROSSTABS, BREAKDOWN, and ONEWAY analysis of variance [17,18]. The frequency distribution of specimens by decade can be seen in Table 1. The sample spans a range of 14 to 90 years with a mean age of 48. Individuals over the age of 50 comprised 40% of the sample. The highest concentrations of specimens were in the 20s and 40s.

Unlike the males, in which morphologic changes were not evidenced until age 17, initial observations of the females in the sample showed pronounced metamorphoses by age 16, with the first sign of change appearing at 14 years. As in the previous study [6], morphologic features were analyzed within a spectrum of nine phases (0 through 8). Specimens younger

TABLE 1—*Frequency and percentage distribution of specimens by age intervals.*

Age Intervals (in Years)	*N*	Percent
0-10	2	2.3
11-19	6	7.0
20-29	17	19.8
30-39	11	12.8
40-49	16	18.6
50-59	6	7.0
60-69	10	11.6
70-79	10	11.6
80-90	8	9.3
Total	86	100.0

than age 14 ($N = 2$) were put in the 0 phase and were not included in the statistical analysis. Earlier development, probably indicative of maturity at this site, was not unexpected and paralleled the generally younger age of maturation and cessation of growth in females [*19,20*].

As in the males, differences in shape, form, texture, and overall quality of the bone served as the basis for defining the phases. Metamorphosis in females also began with the development of an indentation (pit) in the nearly flat, billowy, or ridged medial articular surface of the rib. It is important to note the relative depth and shape of this pit, along with the appearance of the rim and walls surrounding it. This amorphous but noticeable indentation between the anterior and posterior walls deepened and took on a V-shaped appearance. As the walls became thinner, the pit widened into a U-shape, the edges of which flare with increasing age. Concurrently, the initially rounded, regular rim developed into a scalloped, but still rounded and fairly regular edge. As age advanced, the rim became increasingly irregular with sharp edges. The smooth, dense, solid bone quality and texture seen in youth thins and deteriorates, until it is very fragile, porous, and brittle in the elderly. The nine phases (0 through 8) are defined as follows.

Phase 0

The articular surface is nearly flat with ridges or billowing. The outer surface of the sternal extremity of the rib is bordered by what appears to be an overlay of bone. The rim is regular with rounded edges, and the bones itself is firm, smooth, and very solid (Plate 1: Fig. 0*a*, *b*, and *c*).

Phase 1

A beginning, amorphous indentation can be seen in the articular surface. Ridges or billowing may still be present. The rim is rounded and regular with a little waviness in some cases. The bone remains solid, firm, and smooth (Plate 1: Fig. 1*a*, *b*, and *c*).

Phase 2

The pit is considerably deeper and has assumed a V-shape between the thick, smooth anterior and posterior walls. Some ridges or billowing may still remain inside the pit. The rim is wavy with some scallops beginning to form at the rounded edge. The bone itself is firm and solid (Plate 1: Fig. 2*a*, *b*, and *c*).

Phase 3

There is only slight if any increase in pit depth, but the V-shape is wider, sometimes approaching a narrow U as the walls become a bit thinner. The still rounded edges now show a pronounced, regular scalloping pattern. At this stage, the anterior or posterior walls or both may first start to exhibit a central, semicircular arc of bone. The rib is firm and solid (Plate 2: Fig. 3*a*, *b*, and *c*).

Phase 4

There is a noticeable increase in the depth of the pit, which now has a wide V- or narrow U-shape with, at times, flared edges. The walls are thinner but the rim remains rounded. Some scalloping is still present, along with the central arc; however, the scallops are not as well defined and the edges look somewhat worn down. The quality of the bone is fairly good but there is some decrease in density and firmness (Plate 2, Fig. 4*a*, *b*, and *c*).

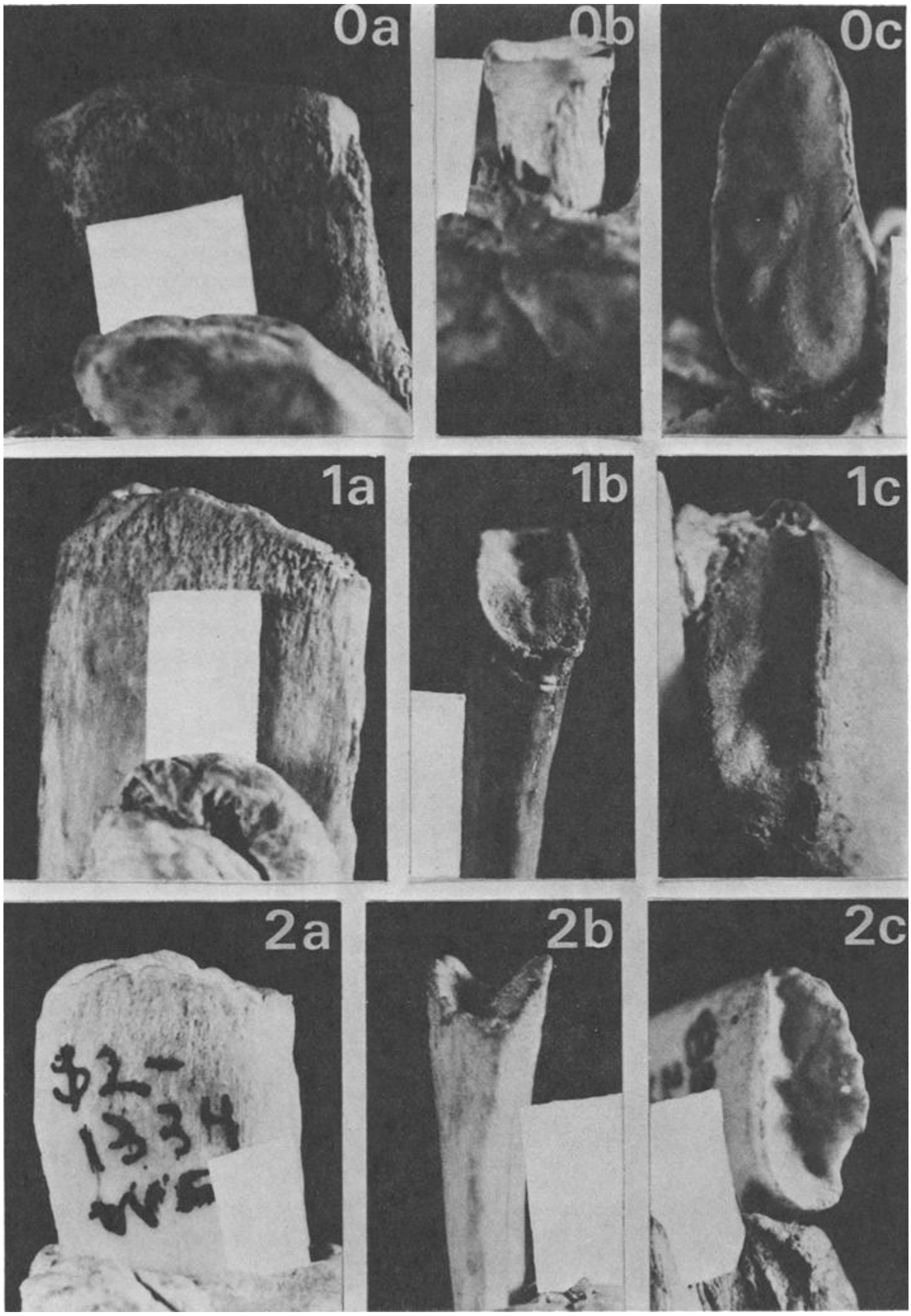

PLATE 1 (Phases 0–2)—*Phase 0: The regular, rounded rim of the articular end is bordered externally by a bony overlay (Fig. 0*a *and* b*). The medial surface of the juvenile rib is ridged or billowy with no pit formation (Fig. 0*c*). Phase 1: The still smooth, rounded, rim is now slightly wavier (Fig. 1*a*). Initial pit indentation can be seen in Fig. 1*b *and* c *with billowing still present on the articular surface. Phase 2: The rounded, wavy rim is first beginning to show some scallops forming at the edge (Fig. 2*a*). A side view of the now V-shaped pit is seen in Fig. 2*b, *while 2*c *illustrates the deepening pit surrounded by thick, smooth walls.*

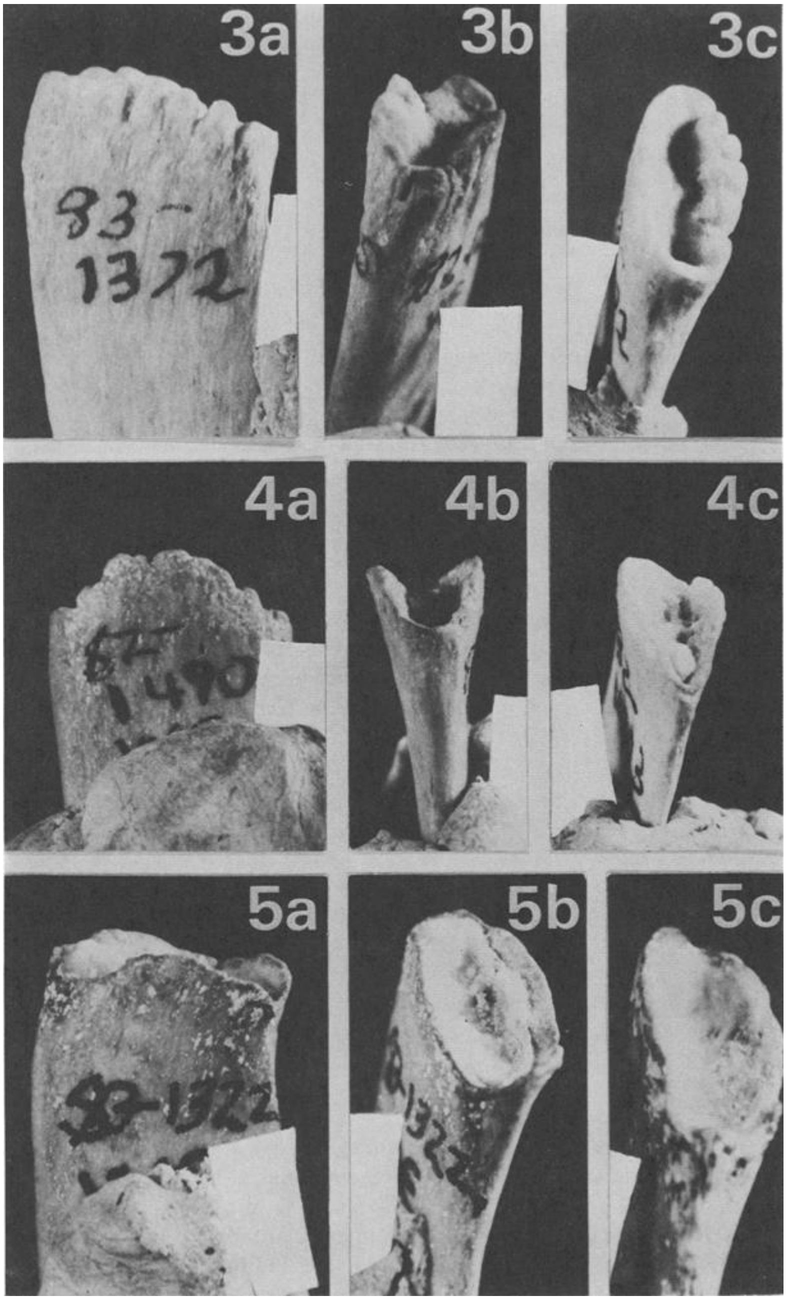

PLATE 2 (Phases 3-5)—*Phase 3: The rounded rim now exhibits a pronounced, regular scalloping patter (Fig. 3*a*). The still V-shaped pit has widened as the walls flare and thin slightly, but there is only a modest, if any, increase in depth (Fig. 3*b *and* c*). Phase 4: Figure 4*a *clearly shows the central arc. Scallops remain at the still rounded rim, but the divisions are not as pronounced and the edges look somewhat worn down. The noticeably deeper, flared V- or U-shaped pit has again widened as the walls become thinner (Fig. 4*b*). Figure 4*c *shows a small plaque-like deposit beginning to form in the pit. Phase 5: No regular scalloping remains at the now sharpening edge of the increasingly irregular rim (Fig. 5*a*). The central arc is still present. Note the smooth plaque-like deposit covering most of the interior of the pit which is now a very flared V or U with appreciably thinner walls (Fig. 5*b *and* c*).*

Phase 5

The depth of the pit stays about the same, but the thinning walls are flaring into a wider V- or U-shape. In most cases, a smooth, hard, plaque-like deposit lines at least part of the pit. No regular scalloping pattern remains and the edge is beginning to sharpen. The rim is becoming more irregular, but the central arc is still the most prominent projection. The bone is noticeably lighter in weight, density and firmness. The texture is somewhat brittle (Plate 2, 5*a*, *b*, and 5*c*).

Phase 6

An increase in pit depth is again noted, and its V- or U-shape has widened again because of pronounced flaring at the end. The plaque-like deposit may still appear but is rougher and more porous. The walls are quite thin with sharp edges and an irregular rim. The central arc is less obvious and, in many cases, sharp points project from the rim of the sternal extremity. The bone itself is fairly thin and brittle with some signs of deterioration (Plate 3: Fig. 6*a*, *b*, and *c*).

Phase 7

In this phase, the depth of the predominantly flared U-shaped pit not only shows no increase, but actually decreases slightly. Irregular bony growths are often seen extruding from the interior of the pit. The central arc is still present in most cases but is now accompanied by pointed projections, often at the superior and inferior borders, yet may be evidenced anywhere around the rim. The very thin walls have irregular rims with sharp edges. The bone is very light, thin, brittle, and fragile, with deterioration most noticeable inside the pit (Plate 3: Fig. 7*a*, *b*, and *c*).

Phase 8

The floor of the U-shaped pit in this final phase is relatively shallow, badly deteriorated, or completely eroded. Sometimes it is filled with bony growths. The central arc is barely recognizable. The extremely thin, fragile walls have highly irregular rims with very sharp edges, and often fairly long projections of bone at the inferior and superior borders. "Window" formation sometimes occurs in the walls. The bone itself is in poor condition—extremely thin, light in weight, brittle, and fragile (Plate 3: Fig. 8*a*, *b*, and *c*).

Results

The descriptive statistics showed that the mean age per phase increased from 14 years in Phase 1 to 76 years in Phase 8 (Table 2). The most rapid rate of change, detectable within a few years, was seen in the first four phases, and spanned an age range of 14 through 28. During this period, phase differentiation could be made at three- to five-year intervals. In the later phases (5 through 8), mainly representing older individuals, intervals increased to ten to fifteen years. The width of the 95% confidence interval showed a steady increase in Phases 1 through 6 then decreased slightly in Phases 7 and 8. These results suggest that change occurred at a considerably slower pace after age 28.

The results of the analysis of variance are provided in Table 3. The F ratio for this analysis reveals that the difference between phases was statistically significant at a probability level less than 0.001. Thus, the characteristics chosen to differentiate the phases could be considered valid predictors of age. The η^2 value indicated that 76% of the variation within the age variable is accounted for by the assessment of metamorphoses in the rib.

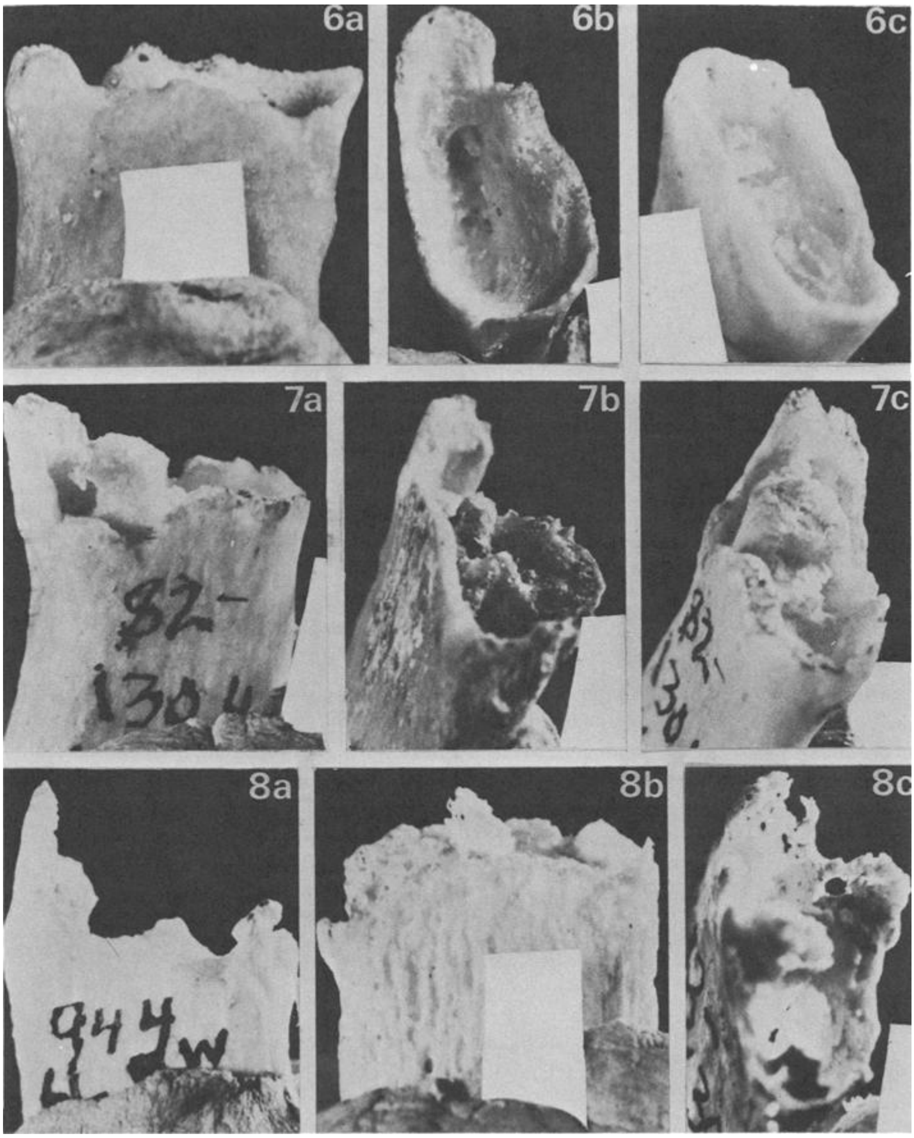

PLATE 3 (Phases 6–8)—*Phase 6: The central arc is less obvious on the sharp rim which is starting to show irregular projections of bone (Fig.* 6a*). Figure* 6b *and* c *show the noticeably deeper, wider U-shaped pit, thinning walls along with roughening inside the pit. Porosity and deterioration of bone can also be seen inside the pit. Phase 7: Figure* 7a *shows the very sharp, irregular rim and nearly obscured central arc. The depth of the flared U-shaped pit appears slightly shallower than in the preceding phase. Bony projections can be seen arising from both the rim and floor of the pit, along with evident deterioration of the bone itself (Fig.* 7b *and* c*). Phase 8: Figure* 8a *shows the extremely sharp, irregular rim with brittle projections of bone now prominent at the superior or inferior margins or both of the rib. Projections are also seen extending from the floor of the pit (Fig.* 8b*). These bony processes can be seen nearly filling the widely U-shaped pit surrounded by very thin, badly deteriorated, porous walls with "window" formation (Fig.* 8c*).*

TABLE 2—*Descriptive statistics of phases.*

Phase	*N*	Mean	SD	SE	95% Confidence Interval	Age Range, years
1	1	14.0				
2	5	17.4	1.52	0.68	15.5-19.3	16-20
3	5	22.6	1.67	0.74	20.5-24.7	20-24
4	10	27.7	4.62	1.46	24.4-31.0	24-40
5	17	40.0	12.22	2.96	33.7-46.3	29-77
6	18	50.7	14.93	3.52	43.3-58.1	32-79
7	16	65.2	11.24	2.81	59.2-71.2	48-83
8	11	76.4	8.83	2.66	70.4-82.3	62-90
Total	83	47.8	11.00	1.21	45.4-50.2	14-90

TABLE 3—*ONEWAY analysis of variance.*

Source of Variation	df	Mean Squares	*F* Ratio	η^2
Between phases	7	3996.92	33.05[a]	0.76
Within phases	75	120.92		
Total	82			

[a]Significant at $p < 0.001$ level.

Table 4 displays the results of the CROSSTABS procedure assessing the distribution of specimens by phase and age intervals. This analysis demonstrated that decades two, four, and seven spanned the most phases. However, only the 70s did not have at least 50% of individuals concentrated in one phase, thus exhibiting the greatest variability. Decades one, two, three, four, six, and eight had at least 83% of specimens in two phases or less.

The same analysis further disclosed that Phases 1 through 4 had at least 80% of specimens coming from one decade. In Phases 5, 7, and 8, 63% or more were from one decade, while Phase 6, with a maximum of only 44% in one decade, showed the highest variability. The X^2 value for the distribution of individuals by phase and age interval was statistically significant ($p < 0.001$).

Discussion

Until recently, the pubic symphysis has been considered the most reliable site for the determination of age by direct observation. However, questions have arisen regarding the accuracy of estimations from this site in both sexes [*21*]. Moreover, this situation was found to be more serious in females because of morphologic changes resulting from pregnancy and parturition. This issue was discussed informally by anthropologists at the 1984 meeting of the American Academy of Forensic Sciences, and it was also agreed that experience was very important in the use of the pubic symphysis. It has yet to be determined if one or more pregnancies can cause significant change in the appearance of the pubic symphysis regardless of age. The rib, on the other hand, is not directly subjected to the "trauma" of childbearing, and thus it is likely that intrafemale variation would not be as great. With this in mind, it may be expected that the sternal end of the rib in females would be as reliable an indicator of age as it is in males, and indeed, this has been found to be the case [*6*].

While parity may not directly alter rib morphology, the normal aging process in the female rib was sufficiently different from that observed in males to warrant the development of different standards for the determination of age. In this study, the male phase analysis tech-

TABLE 4—*Frequency distribution of phases by age intervals.*[a]

Phases	Age Intervals 14-19	20-29	30-39	40-49	50-59	60-69	70-79	80-90	Total N
8						27.3[b] 30.0[c] (N = 3)	27.3 30.0 (N = 3)	45.5 62.5 (N = 5)	11
7				6.3 6.3 (N = 1)	25.0 66.7 (N = 4)	37.5 60.0 (N = 6)	12.5 20.0 (N = 2)	18.8 37.5 (N = 3)	16
6			22.2 36.4 (N = 4)	44.4 50.0 (N = 8)	5.6 16.7 (N = 1)	5.6 10.0 (N = 1)	22.2 40.0 (N = 4)		18
5		11.8 11.8 (N = 2)	41.2 63.6 (N = 7)	35.3 37.5 (N = 6)	5.9 16.7 (N = 1)		5.9 10.0 (N = 1)		17
4		90.0 52.9 (N = 9)		10.0 6.3 (N = 1)					10
3		100.0 29.0 (N = 5)							5
2	80.0 80.0 (N = 4)	20.0 5.9 (N = 1)							5
1	100.0 20.0 (N = 1)								1
Total N	5	17	11	16	6	10	10	8	83

[a] $X^2 = 199.02$ with 49 degrees of freedom (df) (significant at $p < 0.001$ level).
[b] Row percentage.
[c] Column percentage.

nique was modified to fit the female pattern of aging, and the results indicated that the standards chosen are statistically valid, and cover a mean age range of 14 to 76 years.

The differences observed between the sexes were consistent with radiographic studies [*4,10,11,13,14*]. Female ribs began to show changes earlier than males. Although there was only one specimen between the ages of ten and fifteen years, we tentatively established Phase I based on our prior experience with the males [*6*]. The initial sign of change, beginning pit formation, was first seen at age 14 in females, in contrast to age 17 in males. Female development remained about 3 years ahead until Phase 4 when the mean age for both sexes reached 28 years. In Phases 5 and 6, females averaged about a year older than males, and this gap widened to five years in Phases 7 and 8. This discrepancy in the later phases may, at least in part, be accounted for by the greater age range (14 to 90) for females. The range for males was 17 to 85 [*6*].

Histologically, Sedlin et al [*1*] found that females showed a sharper decrease in cortical area in the rib from the second through the fifth decade. Our observations revealed that from the 20s on, ribs were thinner and less dense in females than males of the same age.

Our work also confirmed the existence of sex specific patterns of aging in the bony rib, much like those described in the aforementioned radiographic studies of the anterior rib cage. In the present study, females displayed a central arc extending from the anterior and posterior walls and bony extensions arising from the floor of the pit. In most cases, these extensions were preceded by a plaque-like deposit covering the floor of the pit. In contrast to females, the male pattern was predominantly characterized by bony projections extending from the superior or inferior margins or both of the rib. Furthermore, females showed only slight marginal projections beginning in the 60s (Phase 7), and noticeable extension of these processes did not occur with any frequency until the 70s (Phase 8). Males, however, exhibited marginal projections prominently from the late 40s onward (Phases 5 and above).

Other manifestations of morphologic differences between the sexes included the shape and depth of the developing pit at the medial articular end of the rib. In males, a consistent and continuous increase in pit depth was noted with age, attaining depths of over 14 mm in the elderly. The pit depth in females, however, showed only a very gradual and inconsistent increase until the 60s at which time depth actually decreased slightly. The depth of the pit in females rarely exceeded 5 or 6 mm. Pit shape in males advanced from the V-shape to a narrow U that continued to widen with increasing age. In females, the V first became flared before attaining a U-shape and then progressed to a moderate and then wide U with flared edges.

Further comparison of the sexes revealed that Phase 6 was, statistically, the most varied phase in both males and females, and interestingly enough, had nearly the same mean age, 50 and 51, respectively. However, variation by decade was greatest in the 30s for males and the 70s in females.

In conclusion, the sternal rib appears to be as good an indicator of age in females as it was in males. When using this technique, several matters must be considered. First, to employ this method successfully, it is necessary to determine the sex of the skeleton. Secondly, it should be kept in mind that while the phase technique does try to account for individual variation occurring as a part of the normal aging process, bone growth and remodeling are also affected by such factors as nutrition, disease, and occupational stress [*4,22-25*]. A third factor concerns the forensic science application; that is, to what extent ribs can independently or corroboratively provide a reasonably accurate estimation of age. One way to make this determination is to use an independent rib sample to be tested by physical anthropologists. The authors have administered such a test, thus far only on males, and are in the process of analyzing the data. A female test sample is now being collected to assess the accuracy and effectiveness of new standards presented in this study.

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Address requests for reprints or additional information to
M. Yaşar Işcan
Department of Anthropology
Florida Atlantic University
Boca Raton, FL 33431