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Osteometric Analysis of Sexual Dimorphism in the Sternal End of the Rib

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ABSTRACT: Although there have been a number of radiological studies of the entire anterior thorax, no attempt has been made to establish a method of sex determination based on direct metrical analysis of an isolated rib. The present study attempts to determine sex from the sternal end of the fourth rib. The sample (144 males, 86 females) was obtained from individuals of known age, sex, and race autopsied at a medical examiner's office. Three measurements (height, width, and sternal articular pit depth) were taken from each bone. The sample was divided into three groups: young, old, and the combined total and analyzed by means of stepwise discriminant function statistics. It was found that the accuracy of sex determination varied from 82% in the young and 89% in the old groups to 83% for the combined group. However, when a discriminant function formula developed for a different age group was used the accuracy of correct assessment diminished considerably. It was, therefore, concluded that sexual dimorphism can be detected by metrical analysis from the teens to the 70s and this dimorphism increases with age.

KEYWORDS: pathology and biology, musculoskeletal system, human identification, sternal rib, sex determination, discriminant function, aging

Sexual dimorphism in the postcranial skeleton has been successfully investigated by many physical anthropologists [*1-3*]. Yet many situations arise where it is necessary to determine sex from an incomplete skeleton. Thus, it is important to be able to determine as much information as possible from every bone.

The sternal extremity of the rib has already been established as a reliable indicator of age at death by İşcan et al [*4-6*]. In the process of developing standards for age determination from the rib, it became apparent that age-related changes were sexually dimorphic. These differences, both in rate and pattern, were sufficient to necessitate the development of separate standards for males and females. Based on these observations, the author felt that the sternal rib should be further investigated to evaluate its potential as a site for the determination of sex.

Earlier radiologic studies revealed sexual dimorphism in the ribs by focusing on the pattern of calcification of the costal cartilage and bony extensions emanating from the sternal end of the rib [*7-15*]. Male and female patterns were first established by Fischer in 1955 [*10*]. The vast majority of chest plates characterized by calcifications projecting from the superior and inferior margins of the rib were found to be male, while a centralized pattern of calcification usually belonged to a female [*10-15*]. These researchers all noted that the patterns were difficult to differentiate earlier than the 30s and became more pronounced with age. All studies of this type have also reported that a large number of cases exhibited an "indeterminate" pattern. This was found most often in younger individuals with little calcification and older ones where

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calcification was so complete that no pattern could be discerned. It is important to emphasize that all of these radiologic studies were based on an analysis of X-rays of the entire, intact sternal rib cage.

To date, there have been no publications dealing with sexual differentiation by direct examination and measurements of bony ribs. This approach, unlike radiographic techniques, can be used on completely skeletonized forensic or archaeological remains. The present study is an attempt to establish a new technique using discriminant function analysis for sex determination from the sternal extremity of the rib.

Materials and Methods

The right fourth rib was collected at autopsy from recent forensic science cases of known age, sex, and race. The sample ($N = 230$) consisted of 144 white males and 86 white females. All soft tissues, including the costal cartilage, were carefully removed from the bones.

Three measurements were taken at the costochondral junction of the rib: maximum superior-inferior height (S-I), maximum anterior-posterior breadth (A-P), and maximum pit depth (P-D). All the dimensions were taken with a coordinate caliper calibrated to the nearest 0.1 mm. S-I height was the maximum distance between the most superior and inferior points at the end of the bone. A-P breadth was also measured at the end of the rib between the most anterior and posterior points. P-D depth, as previously defined by İşcan and coworkers [*4*], referred to the maximum depth of the concavity at the medial articular surface of the rib and is taken with a depth caliper with vernier, where the distance between the bottom of the pit and top of the adjacent wall are greatest.

To control the effect of age on sexual dimorphism, the sample was analyzed in three age groups: young, old, and young and old combined. The assignment of a rib to an age group was made on the basis of its metamorphic phase as assessed by the age determination techniques established previously [*5,6*].

In these techniques, age-related metamorphosis was analyzed in nine phases (Phase 0 to Phase 8) centering on form, shape, texture, and overall quality of the bone [*5,6*]. This process was summarized as follows [*5*]:

> ... metamorphosis begins with the formation of an indentation (pit) in the medial articular surface. Special attention is paid to the depth and shape of the pit along with the walls and rim surrounding it. Initially, the pit is merely an *amorphous* but noticeable indentation in the once almost flat, *billowy* endplate. As the pit deepens, the indentation between the anterior and posterior walls takes on a *V-shaped* appearance that gradually widens into a U as the walls become thinner. With increasing age the pit becomes wider and deeper. Along with further pit development, the rim progresses from a *regular*, rounded border to a *scalloped*, but still fairly regular edge, and over the years, grows increasingly *sharp* and *irregular*. The overall texture and quality of the bone itself, dense, smooth and solid in youth, deteriorate until the bone becomes very *thin, brittle* and *porous* in the elderly (emphasis added).

Figure 1 adapted from the studies by İşcan and associates [*5,6*] illustrates representative phases for both males (Fig. 1*a, b, c, f, h, j, l, n*) and females (Fig. 1*d, e, g, i, k, m, o, p*). Metamorphic changes from Phase 1 to Phase 3 evolved from the nearly flat, billowy endplate of Phase 0 to the formation of a V-shaped pit and scalloped rim with rounded edges (Fig. 1*a–e*). In Phase 3 males, the pit had already assumed a narrow U-shape (Fig. 1*f*). The bone was solid and sturdy. The transitional phase (Phase 4) dividing the young and old groups was marked by the disappearance of scallops in males (Fig. 1*h*) and only a slight scalloping remained in females (Fig. 1*g*). The pit was still V-shaped in females (Fig. 1*i*) and moderate to wide U in males (Fig. 1*j*). Phases 5 to 8 showed increasing thinning of the walls and enlargement of the pit into a U shape (Fig. 1*i–p*). Phase 8 was differentiated by the advanced degree of deterioration in the bone. Further detail on the age-related metamorphosis was given by İşcan et al for both males [*4,5*] and females [*6*].

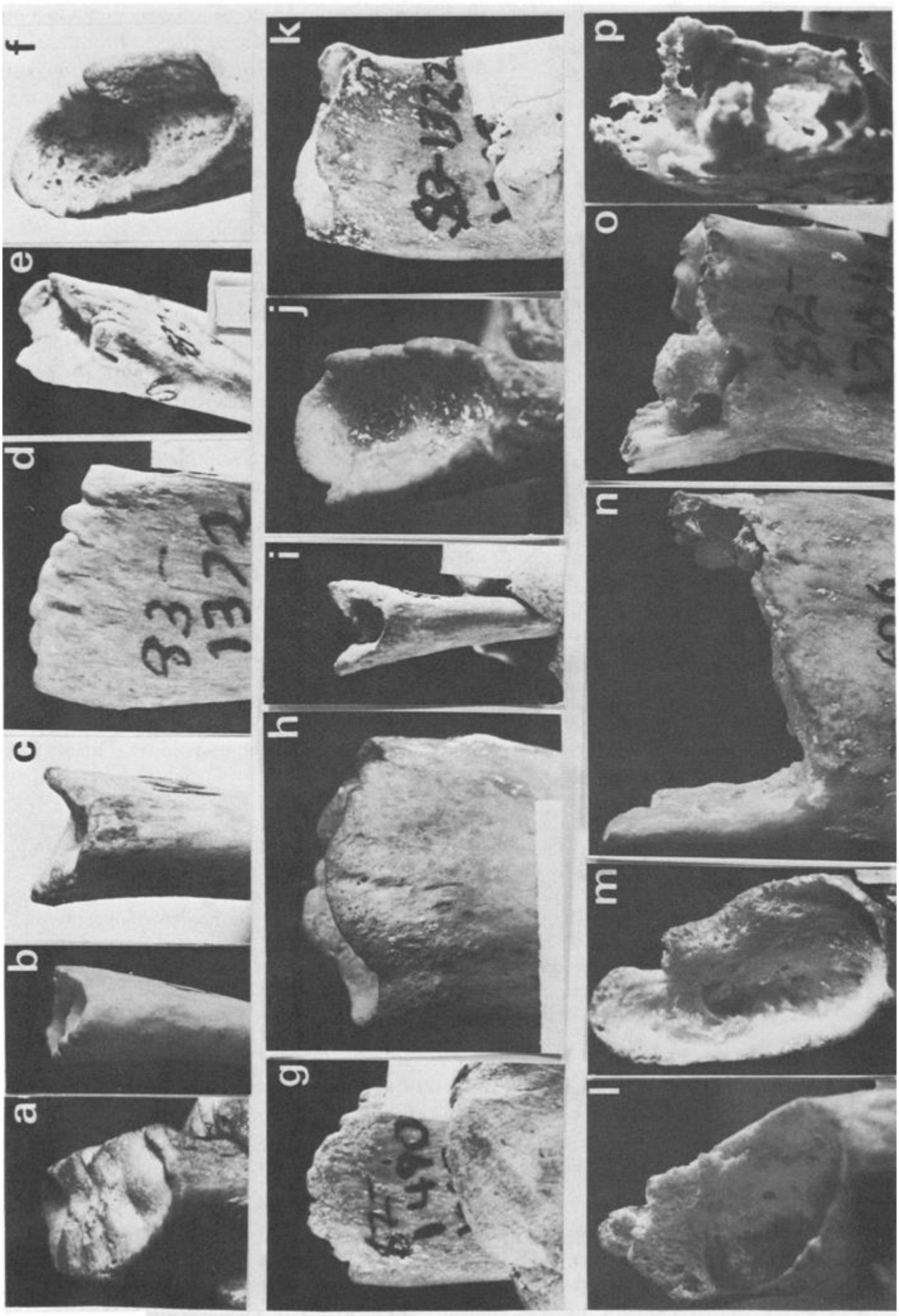
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FIG. 1—*Age-related metamorphic changes from late adolescence to late 70s in males* (a, b, c, f, h, j, l, n) *and females* (d, e, i, k, m, o, p) *to be used in the assessment for sex identification.* Young group (a-j)—(a) *The smooth, regular, rounded rim is typical of the adolescent rib. Note the billowy articular surface with no pit formation.* (b) *Rim is still smooth and rounded. The initial indentation of the pit, along with some billowing still present on the articular surface is also seen.* (c) *The scallopped rim with smooth rounded edges is first seen in this phase. The V-shaped pit surrounded by thick walls also characterizes this phase.* (d) *The rounded rim now exhibits a pronounced, regular scalloping pattern.* (e) *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.* (f) *The rim is becoming more irregular with only a little scalloping remaining. The deepening pit has taken on a narrow U-shape with fairly thick walls and rounded edges. Transitional phase* (g-j)—(g) *This rib 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.* (h) *Regular scalloping pattern is gone from the increasingly irregular rim.* (i) *The noticeably deeper, flared V- or U-shaped pit has again widened as the walls become thinner.* (j) *The bone is a moderately wide U-shaped pit with slightly thinner walls whose edges are still rounded.* Old group (g-p)—(k) *No regular scalloping remains at the now sharpening edge of the increasingly irregular rim.* (l) *Rim is slightly more irregular with a deep, moderately wide U-shaped pit and thinner walls and sharper edges. It also shows evidence of porosity and some deterioration of bone inside the pit.* (m) *The bone becomes the noticeably deeper, wider U-shaped pit with thinning walls along with roughening and porosity inside the pit. Porosity and deterioration of bone can also be seen inside the pit.* (n) *The irregular rim with long bony projections and noticeably thin, fragile walls with sharp edges are important characteristics of this phase.* (o) *The very sharp, irregular rim and nearly obscured central arc are among the specific aspects of the old age group.* (p) *The rib shows the extremely sharp, irregular rim with brittle projections of bone now prominent at the superior or inferior margins of the rib or both. These bony processes can be seen nearly filling the widely U-shaped pit surrounded by very thin, badly deteriorated, porous walls with "window" formation. (Male* [5] *and female* [6] *are adapted from İşcan et al.)*

The stepwise discriminant function program of SPSS was used for the statistical analysis [16,17]. Separate functions were calculated for specimens in the young group (Phases 1-4, mean ages 14 to 28), old group (Phases 4-7, mean ages 28 to 65) and combined group (Phases 1-7, mean ages 14 to 65). In assigning a rib to one of the groups, scallop formation and wall edges were key features to assess. If scallops were present then the rib was put in the young group. If the edge was no longer rounded and felt sharp to the touch, the rib was determined to be, at least, Phase 5. Therefore, it was included in the old group. Phase 4 (transitional) specimens were analyzed in both groups to minimize errors of assignment.

Ribs in Phase 0 ($N = 10$ males, $N = 3$ females) were excluded from the statistical analysis because they had not reached skeletal maturity. Specimens in Phase 8 representing individuals over a mean age of 71 ($N = 12$ males, $N = 11$ females) were omitted because of deterioration in bone quality.

Results

The descriptive statistics and statistical significance between the sexes, as calculated by the oneway analysis of variance (univariate F ratio), appear in Table 1. Males were larger in all dimensions, and with the exception of P-D depth in the young group ($p < 0.05$), the differences between the sexes were significant at a probability level of less than 0.001. Age difference was only significant in the combined group with females being older than males. Results of the stepwise discriminant function analyses appear in Table 2. Of the three osteometric dimensions in the analysis, two (A-P height and S-I breadth) were chosen as the optimal number of

TABLE 1—*Descriptive statistics and univariate* F *ratios.*

	Male		Female		
Variables[a]	Mean	S.D.	Mean	S.D.	*F* Ratio
Younger group					
N	46		21		
Age	24.48	4.43	23.38	5.78	0.73*[b]
A-P breadth	7.64	0.92	6.33	0.63	34.81
S-I height	16.75	1.50	13.95	1.24	55.61
P-D depth	3.58	1.26	2.79	0.95	6.43**
Older group					
N	64		61		
Age	46.27	14.14	47.75	17.48	0.23*[c]
A-P breadth	8.74	1.09	7.07	1.03	77.80
S-I height	18.62	1.80	14.99	1.58	142.80
P-D depth	5.99	1.85	3.79	1.12	63.69
Total group					
N	94		72		
Age	39.93	16.11	43.43	19.11	4.05**[d]
A-P breadth	8.24	1.17	6.91	1.03	58.30
S-I height	17.95	1.85	14.78	1.55	136.60
P-D depth	5.05	2.09	3.55	1.20	29.71

[a]All dimensions except age are in millimetres.
[b]Degrees of freedom (d.f.), 1, 65.
[c]d.f., 1, 123.
[d]d.f., 1, 164.
*Not significant.
**Significant at $p < 0.05$, all others significant at $p < 0.001$.

TABLE 2—*Summary of three stepwise discriminant function analyses.*[a]

Variable Step Entered	Wilks' Lambda	Equivalent F Ratio	Degrees of Freedom
Younger group			
1 S-I height	0.539	55.61	1, 65
2 A-P breadth	0.470	36.10	2, 64
Older group			
1 S-I height	0.463	142.81	1, 123
2 P-D depth	0.415	86.08	2, 122
3 A-P breadth	0.398	61.11	3, 121
Total group			
1 S-I height	0.546	136.59	1, 164
2 A-P breadth	0.538	70.06	2, 163

[a]Variables in the analysis include superior-inferior height (S-I), anteroposterior (A-P) breadth, and pit depth (P-D).

variables to discriminate one sex from the other by the functions for the young and combined groups. For the old group, all three dimensions significantly separated the sexes. This indicated that age exerts a sexually differential influence.

In addition to the three functions selected by the stepwise discriminant analyses, a fourth function, combining A-P height and S-I breadth was computed for the old group. All four functions are given in Table 3, along with the standardized, unstandardized (raw), and structure coefficients. The raw discriminant function coefficient was used to calculate a discriminant score. This coefficient assumes a continuum in which males are at one side and females at the other. If the score was negative a rib was classified as female, and a positive score was

TABLE 3—*Canonical discriminant function coefficients.*

Functions and Variables	Standardized Coefficients	Raw Coefficient[a]	Structure Coefficient	Group Centroids[b]
Younger group				
1 A-P breadth	0.51	0.602 005 9	0.69	+0.707
S-I height	0.75	0.523 321 8	0.87	−1.548
Constant		−12.660 070 0		
Older group				
2 A-P breadth	0.29	0.272 677 1	0.65	+1.192
P-D depth	0.36	0.232 810 7	0.58	−1.251
S-I height	0.69	0.405 758 1	0.88	
Constant		−10.142 490 0		
3 A-P breadth	0.39	0.368 967 9	0.69	+1.115
S-I height	0.79	0.464 096 8	0.93	−1.188
Constant		−10.752 480 0		
Total group				
4 A-P breadth	0.20	0.182 591 1	0.64	+0.806
S-I height	0.88	0.510 109 9	0.98	−1.053
Constant		−9.856 245 0		

[a]These coefficients are used in the calculation of a discriminant score. A score less than 0 would classify as female.
[b]Positive centroid for males, negative for females.

classified male. The larger the magnitude of a score the higher the probability was that a specimen would accurately be classified as a member of that sex group. Conversely, as the score approaches 0, the probability of misclassification increases.

Table 3 also illustrates the relative contribution (standardized coefficients) of each variable to a function. In all four functions, S-I height contributed at least 70% to the discriminant function. However, the standardized coefficients did not take into account any intercorrelation between variables. It was the structure coefficient that controlled the possibility of intercorrelation and revealed that S-I height was still the most discriminating variable. The contribution of the A-P dimension was also considerable. Moreover, both standardized and structure coefficients indicated that sex differences were primarily size dependent.

The classification accuracy for these functions appears in Table 4. It is clear that sexual dimorphism was equally detectable by the discriminant function analysis in all groups. Average accuracy varied from 82% in the young group to 89% in the old group. Females were more accurately classified than males in the young and combined groups, but not in the old group.

A test assessment of a discriminant function formula on a different age group was also carried out to determine whether, for example, the sex of young specimens can be predicted with the same accuracy from a formula developed for the old group. It should be noted that specimens whose ages were in Phase 4 were not included in this test. This was done because these Phase 4 specimens were incorporated in both age groups and, if included, would have affected the result. Table 5 shows the results of this cross-validation test. It is seen that both of the old group formulas classified most of the young male specimens as females (for example, 67.6% by Function 3). The opposite was true when the young group formula was applied to old specimens, that is, 33.3% of females were classified as males.

Discussion

While the pelvis and skull have proved to be the most reliable indicators of sex [*1*], other parts of the skeleton have also been researched with varying degrees of accuracy [*18, 19*]. Overall, this study revealed that accurate sex determination from the sternal rib could be as high as 89%. This was comparable to such highly dimorphic areas as the head and distal epiphysis of the femur, and proximal epiphysis of the tibia with correct classification rates of 90, 89, and 87%, respectively [*18, 19*].

TABLE 4—*Percentage of correct prediction for the discriminant functions.*

Functions and Variables	Total *N*	Male %	Male *N*[a]	Female %	Female *N*[a]	Average %
Younger group						
1 S-I height A-P breadth	67	80.4	37/46	85.7	18/21	82.1
Older group						
2 S-I height P-D depth A-P breadth	125	89.1	57/64	88.5	54/61	88.8
3 S-I height A-P breadth	126	87.7	57/65	85.2	52/61	86.5
Total group						
4 S-I height A-P breadth	167	81.1	77/95	86.1	62/72	83.2

[a]Represents the number of cases correctly classified in a given sex sample.

TABLE 5—*Cross-validation of sex determination formulas.*[a]

Test Group and Function	Male %	Male N	Female %	Female N	Total N^b
Younger group (using the old age group formulas)					
Function 2	26.5	9/34	100.0	11/11	45
Function 3	32.4	11/34	100.0	11/11	45
Older group (using the young age group formula)					
Function 1	100.0	53/53	66.7	34/51	104

[a]See Table 3 for the formulas and Table 4 for comparison.
[b]Total *N* excludes Phase 4 specimens in the calculation.

Specifically, this work indicated that sexual dimorphism in a single sternal rib can be assessable with some reliability. It was shown that while the rib morphology changes with age, metric analysis can successfully discriminate males and females from the teens to the 70s. Moreover, morphologic variation between the sexes was not manifest until the mid-20s by direct examination (nonmetric) of the bone itself and was not detectable radiologically until a decade later [*15*]. In this study, nearly all individuals from the teens to the 70s could be analyzed with a minimum of 82% accuracy as compared with radiologic techniques, where often more than 50% of specimens did not show a classifiable pattern of mineralization. In fact, in the most recent of these studies [*15*], it was stated that "... an indeterminate pattern of coastal mineralization is seen more often than either the typical male or female pattern" and indeed, they reported that 349 (54%) of their sample was "indeterminate."

Not only did the sternal rib compare favorably with other bones as an indicator of sex, but it was also one of the few parts of the skeleton in which dimorphism increased with age throughout most of the adult life span. Undoubtedly, there are many factors involved in this process. On the histologic level, it has been revealed that periosteal deposition of new bone continues throughout life, outpacing resorption and leading to a continuous increase in rib diameter [*20,21*]. It has also been suggested that this is at least partially responsible for some of the age-related morphologic changes reported at the sternal extremity [*4-6*]. Sedlin et al [*20*] also found that females exhibited a sharper decrease in cortical area than males from the 20s through the 50s.

Another important factor is likely to be the obvious difference in body size and muscularity between the sexes. The size difference is undoubtedly enhanced by traditionally male occupations and athletic pursuits marked by strenuous physical activity that result in increased muscle mass and, in turn, larger rib surface area. It is already known that males exceed females in several chest dimensions including the chest expansion and associated vital capacity [*22*]. Thus, even a difference in respiratory chest expansion could cause a proportionally larger increase in bone size in males. This link was first suggested by King [*23*] and supported by Semine and Damon [*14*] who found a positive statistical correlation between chest expansion and calcification at the costochondral junction.

While endocrine differences must also be considered, evidence suggests that these are more closely linked with morphologic patterns than size [*9,10,12,14*].

In the practical application of this technique, the age of the specimen and intercostal variation should be considered. If the age is approximated by the phase technique, the expected accuracy can be reliable. If the age is not estimated the formula for the combined group should be preferred. As far as the intercostal variation is concerned, this research was based on measurements of the fourth rib, and thus, intercostal variation may come into play. Size and rate of ossification are known to vary between ribs, most notably, the first and lower ones [*14,15*]. Differences in the lower ribs are more subtle, although the exact differentials have not been calculated. However, it has been suggested that adjacent ribs show relatively smaller differences [5].

There are additional problems that could be associated with this study or any study using the discriminant function or multiple regression analysis as the major method of investigation. The main problem is whether the results found in these studies can provide equally successful results if applied to a different sample. Some investigators claimed that the reliability would be less if the composition of the test sample is different from that of the original study [24,25]. Although partial answers have been given [26,27] to this question, one can never control all the parameters associated with a test sample. Secondly, it is expected that the application of the discriminant function weights computed in any discriminant function study, including this one, to additional "new data" will no doubt result in some "shrinkage" in validity.

The researcher who pursues these types of studies where some "optimization" of coefficients is involved is placed on the horns of a dilemma unless he happens to have overabundant resources. Given fixed resources for collecting a finite quantity of data, the researcher must choose between the extremes of (1) doing the best job he can of finding the most accurate estimate of the coefficients by using all the data in their computation and (2) doing a poor job of estimating the coefficients by holding out some of the data for use in a cross-validation study. In the present case, the author chose the first approach. Nonetheless, in his future work on age-related rib metamorphosis, the author is planning to test the results of the present study, to assess intercostal variation, and to identify occupational effect on the development of the rib.

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