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Examination of Variation in Sternal Rib End Morphology Relevant to Age Assessment*

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ABSTRACT: The morphology of the sternal end of the right fourth rib has been proffered as an accurate age assessor in skeletonized individuals of both sexes. This technique was tested for its applicability on left and right II, III, V–IX. Tests were performed between phase scores obtained from right and left ribs; right rib IV phase scores and scores obtained from the others in the right rib series; and between right rib IV scores and a composite score composed of the average of an individual's phase scores (omitting rib IV). Left ribs IV–IX were found not to vary significantly from their right counterparts. Although only right rib II was found to vary significantly from rib IV, use of the other ribs in the series should be undertaken with caution due to questions concerning their statistical significance. A composite score is therefore recommended for use instead.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, age assessment, sternal rib

Age estimation can be a critical part of forensic anthropological investigations. Unfortunately, age determination is also one of the more difficult aspects of the investigation of death of a skeletonized individual. While there have been a number of fairly accurate techniques developed to estimate age, each requires relatively fragile bones such as the pubis (1–6). Another method, cranial suture closure (7,8) has been repeatedly criticized because of the high variability between individuals in closure times (3,9,10). Microscopic analysis of structures within long bone cortical segments is another valuable technique (11,12). However, this technique requires specialized equipment, highly trained workers, and a great deal of time. Imperfect preservation can also make it difficult to assess age using current techniques.

Reasoning that the ribs may be recovered in skeletonized forensic contexts, when other diagnostic elements may not be available, İşcan et al. (13,14) suggested an evaluation of the age-related morphological changes in the sternal end of the right fourth rib. İşcan et al. (13,14) employed a phase analysis system that illustrates the morphological changes that occur in the sternal extremity of the rib due to the process of aging. Although the ribs may not have a higher preservation rate than the other skeletal features commonly utilized in age assessment, they do add one more possible technique in the assessment of age of imperfectly preserved individuals.

Their method involves nine phase classifications (grades 0–8), encompassing ages ranging from younger than 17 years to 85 years for males and younger than 13 years to 85 years of age for females. Changes described by the technique include alterations in the shape, form, texture, and bone density of the sternal end, with special attention paid to the depth of the pit that emerges in the sternal extremity. In younger individuals (phase 1), this pit can be described as an amorphous indentation, which may still retain the billowy surface seen in phase 0. As the individual ages however, this pit becomes wider and deeper, first assuming a V-shape between anterior and posterior walls (phases 2 and 3) then gradually increasing in width and assuming a U shape (phases 3–8). Through time the edge of the pit also becomes more irregular, with bony growths extending from its superior and inferior borders, and the rib itself becomes increasingly brittle and porous. In the final phase (8) bony growths are often observed in the rib floor or no floor is present at all (13,14). It has been postulated that the "deepening" of the pit is actually a buildup of periosteally produced bone on the sides of the ribs. The thinning of the bone and erosion of the pit floor may be due to endosteal resorption (13). Commercially available casts of the "typical" morphological expressions for each phase were produced to aid in the age assessment process (15). Photographs of the "typical" ribs are also available for those without access to the casts (13,14). Observers score sternal end morphology by reading the descriptions of each phase, and complement this information with the use of rib casts or photographs of the "typical" ribs.

This technique has been independently tested and found to be accurate on other populations, and when applied by other researchers (16). It has also been tested favorably in comparison to other established techniques (17). In addition to forensic contexts, this method has been shown to be accurate in paleodemographic applications (18,19). İşcan et al. (13,14) theorized that the technique would be applicable to ribs III and V and therefore age estimations from these ribs would not significantly differ from those obtained by the right fourth rib. This hypothesis was later supported by a test of the accuracy of age obtained by ribs III and V from a modern autopsy sample (20). This research is promising as it proffers ribs III and V for age estimation analyses. However, it does not fully alleviate the problems inherent in the study of incomplete skeletal remains.

One of the main difficulties of the İşcan et al. (13,14) technique is the difficulty in determining which rib is the fourth in cases

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where few of the ribs in the series are present. Although there are techniques for sequencing ribs (21,22), they are only applicable when a number of ribs in the series are present. The availability of ribs III and V for use in the technique does not completely assuage this problem. The applicability of the technique to the other ribs in the series was tested on a small combined archaeological and cadaver sample (22). The technique was found to be applicable in this study; however, the small sample size precludes any definitive understanding of the applicability of the technique to the other ribs in the series. An additional problem is that the individual may only have the left rib present and the technique was only devised for and tested on the right fourth rib. It has not been tested for its applicability with left ribs. Therefore this technique cannot be used at all if either the right fourth rib cannot be recognized or is absent. However, İşcan et al. (13) theorized that there would be no significant difference in the accuracy of the technique if performed on the left as opposed to the right side.

To allay these problems the authors applied the İşcan et al. (13,14) aging technique to ribs II through IX on both the right and left sides in order to examine its applicability to the other ribs in the series. This study not only tests their theory on the applicability of the method to both sides of the body, and reevaluates its application to ribs III and V, it also examines whether similar age related differences exist in rib II and ribs VI–IX. The null hypotheses in this analysis are that there are no significant differences in scores obtained from the right and left rib series. There are no significant differences between scores obtained from right rib IV and the other ribs in the series. Our final hypothesis is that the average of an individual's phase scores across the series is not significantly different from right rib IV phase scores. The goal of this research is to aid in the determination of age by widening the availability of rib age assessment for imperfectly preserved individuals.

Materials and Methods

Ribs II through IX were scored by the İşcan et al. (13,14) technique for 231 individuals from the Smithsonian's National Museum of Natural History's Terry Collection, five individuals from the Maxwell Museum's Documented Collection at the University of New Mexico, Albuquerque, and 13 individuals from the William M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville. The low numbers of individuals from the collections from the University of New Mexico and the University of Tennessee are due to poor preservation of rib ends and time constraints. The demographic information for this sample is compiled in Table 1. The Terry Collection is composed of 1,728 anatomical specimens, most of whom died at the turn of the century. The Maxwell Museum's Documented Collection is comprised of 206 New Mexican individuals, most of whom donated their bodies to the University of New Mexico from 1974 to the present. The William M. Bass Donated Skeletal Collection encompasses individuals from a range of socioeconomic backgrounds and ancestries. It was collected from 1981 to 1995. At the time of death, information was noted as to the sex, age, ancestry, and metric variation of the individual.

TABLE 1—*Distribution of sample by age and ancestry.*

Age Category	White Females	White Males	Black Females	Black Males	Total Females	Total Males
10–19	0	1	4	2	4	3
20–29	3	5	13	10	16	15
30–39	7	13	11	10	18	23
40–49	7	11	11	10	18	21
50–59	11	13	11	11	22	24
60–69	10	15	10	10	20	25
70+	10	10	10	10	20	20
Total	48	68	70	63	118	131

The ribs were sorted using the technique described by Bass (21). Males and females, determined by documentation provided at time of death of the individual, were scored separately following the methodology described by İşcan et al. (13,14). The ribs housed at the University of New Mexico, Albuquerque were scored using the casts developed by İşcan and Loth (15), while the ribs at the Smithsonian and the University of Tennessee, Knoxville were scored using photographs of the casts published by İşcan et al. (13,14). All of the ribs analyzed were scored by the first author to minimize observer error. Fifteen individuals selected randomly from the Maxwell Museum's Documented Collection were scored twice to enable the evaluation of intraobserver error. First and second observations of the individuals in the intraobserver error study were separated by a period of at least one week. Pair-wise t-tests were performed to test for intraobserver error. The p-values obtained were then corrected for multiple comparisons by the Šidák correction technique (23).

To aid in the determination of increased and possibly differential variation in the rib series due to age, individuals in the sample were divided into seven age categories: 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, and, 70+. Between 3 and 25 individuals of each sex were selected from each category for study in the present analysis. The number of rib scores from the right rib series that differ from the scores obtained from the right fourth rib were tabulated by rib number and age category and converted into percentages. These percentages are referred to as the percentages of difference for the purposes of this study. The minimal sample size in each age category was not always ideal for statistical analysis, therefore these percentages were calculated to aid in the examination of possible differential variation due to age.

Wilcoxin signed rank tests were performed to test for significant differences between observed phase scores (based on the right fourth rib) and the phase score obtained from the other ribs in the series. These tests form the basis for this analysis. The scores obtained from the right ribs were tested against those obtained from the left ribs. Right rib IV was tested against: right ribs II, III, V–IX, left ribs II and III, and the average score of an individual's rib series (excluding right rib IV). The variables of sex and ancestry were also assessed for significance between right rib IV and the other right ribs and between right rib IV and left ribs II and III.

Results

There was no significant intraobserver error in fourth rib scores obtained from either the right or left rib series. Only two of the right series p-values (for ribs V and VI) are significant before Šidák correction, and they are barely significant (0.0463 and 0.0437 respectively). Left ribs II, VI, and VII are significant before the Šidák correction (p-values of 0.0271, 0.1745, and 0.0111, respectively), but after the correction they are well above the 5% significance level (Table 2). Although the t-test may not be the best statistical test, it is more powerful than the Wilcoxin test and therefore would tend to find false significance. Since none of the tests demonstrate significant p-values this is not a problem for these tests. The majority of differences between scores were only by one phase score.

TABLE 2—*Intraobserver error.*

Test	Right Rib *p*-Value	Šidák (*n*-1 = 8)	Left Ribs *p*-Value	Šidák (*n*-1 = 8)
rib II v. rib II’	0.6761	0.999	0.0143	0.1091
rib III v. rib III’	0.5016	0.9962	0.0581	0.3805
rib IV v. rib IV’	0.1911	0.8166	0.8605	1.0
rib V v. rib V’	0.0463	0.3159	0.0122	0.0935
rib VI v. rib VI’	0.0437	0.3006	0.0714	0.4469
rib VII v. rib VII’	0.1039	0.5842	0.2006	0.8332
rib VIII v. rib VIII’	1.0	1.0	0.7685	1.0
rib IX v. rib IX’	0.2894	0.9350	0.0138	0.1049

* Significant at $p < 0.05$.

TABLE 3—*Wilcoxin of right versus left ribs.*

Rib #	Asymp. Sig
II	0.005*
III	0.002*
IV	0.318
V	0.340
VI	0.941
VII	0.433
VIII	0.544
IX	0.312

* Significant at $p < 0.05$.

The results from the test of scores obtained from left as opposed to the right ribs are illustrated in Table 3. Only the scores obtained from left ribs II and III were significantly different from those obtained from the right ribs (*p*-values of 0.005 and 0.002, respectively). When left rib II and III scores differed from their counterparts in the right rib series the left ribs typically yielded older phase scores (Table 4). Due to these results left ribs II and III were also analyzed in tests between right rib IV and the other right ribs in the series. Comparisons were made among the entire sample, as well as among groups defined by sex and ancestry.

TABLE 4—*Side differences in aging in ribs II and III.*

Rib #	% Left Older	% Right Older
II	31.4	16
III	24.8	11.6

The results of the tests between right rib IV and the other ribs are shown in Table 5. These results indicate that scores obtained from right rib II and left rib III from the entire sample are significantly different from those obtained from right rib IV. Scores from right ribs II and III are significantly different for females (Whites and Blacks combined). Right rib VI and left rib III of the males of the entire sample are significantly different from right rib IV scores.

When analyzed by ancestry (sexes combined) right rib II scores from the Whites and left rib III from the Blacks in the sample are significantly different from those of right rib IV (Table 5). When broken down further by sex, White males demonstrate no significant differences for any rib score. Right rib V is significantly different from right rib IV in White females, right rib II is significant for Black females and right rib VI is significant for Black males.

Due to the apparent variation in rib scores the right rib IV phase scores were tested against the average of an individual’s phase scores among the right and left ribs (omitting right rib IV). The results indicate that the average of an individual’s phase scores is not significantly different in either the right or left rib series (*p*-values of 0.430 and 0.355, respectively) (Table 6).

Tabulation of the percentage of differences in scores obtained from the right rib series in comparison to right rib IV scores reveals a high level of inaccuracy (Tables 7 and 8). For females, rib VIII was the least accurate (different from rib IV 54.4% of the time). The most accurate rib for females is rib V (different 37.6%). The

TABLE 6—*Wilcoxin in test of right rib IV versus averages of left and right sides.*

Side	*p*-Value
Right	0.430
Left	0.355

* Significant at $p < 0.05$

TABLE 7—*Percentage of scores by right rib # that differ from right rib IV scores.*

Rib #	Female %	Male %
II	50.6	47.7
III	43.9	41.5
V	37.6	36.9
VI	40.4	36.1
VII	43.3	46.2
VIII	54.4	47.7
IX	43.6	45.8

TABLE 5—*Probabilities obtained from Wilcoxin signed rank test for paired differences.*

Test	Total Sample	Sample Females	Sample Males	Total Whites	White Males	White Females	Total Blacks	Black Males	Black Females
Right IV v. Right II	**0.004***	**0.001***	0.446	**0.018***	0.132	0.59	0.089	0.601	**0.008***
Right IV v. Right III	0.217	**0.034***	0.614	0.701	0.502	0.180	0.188	1.0	0.104
Right IV v. Right V	0.286	0.072	0.790	0.282	0.602	**0.027***	0.699	0.929	0.693
Right IV v. Right VI	0.527	0.128	**0.013***	0.428	0.239	0.793	0.985	**0.033***	0.088
Right IV v. Right VII	0.671	0.504	0.250	0.777	0.607	0.833	0.750	0.260	0.493
Right IV v. Right VIII	0.704	0.414	0.172	0.215	0.249	0.591	0.484	0.453	0.148
Right IV v. Right IX	0.636	0.407	0.158	0.409	0.157	0.461	0.919	0.592	0.607
Right IV v. Left II	0.316	0.906	0.166	0.576	0.300	0.660	0.407	0.346	0.674
Right IV v. Left III	**0.011***	0.295	**0.009***	0.181	0.055	0.710	**0.027***	0.074	0.135

* Significant at $p < 0.05$.

TABLE 8—*Percentage of scores by age group that differ from right rib IV scores.*

Age Group	Female %	Male %
10–19	28.57	57
20–29	54.36	55.9
30–39	43.11	43.28
40–49	47.7	50.75
50–59	40.84	40.97
60–69	45.69	42.76
70+	47.91	23.14

TABLE 9—*Total number of ribs scored by rib category.*

Rib #	Male Total	Female Total
II	111	91
III, V–IX	693	624
Composite	804	715

most variable ribs for males in the sample are ribs VIII and II (both differed 47.7%), and the least is rib VI (36.1%) (Table 7). The most variable age group for females is 20–29 year olds (different 54.36%), the least is 10–19 year olds (28.57%). The least accurate age group in males is 10–19 year olds (57%); the most accurate age grouping is 70+ year old individuals (23.14%) (Table 8).

Table 9 illustrates the total number of ribs scored in each rib category (II, III, V–IX, and composite). 47.7% of the male right rib II phase scores, 14.2% of ribs III, V–IX phase scores, and 5.2% of composite rib scores differed from right rib IV phase scores. The majority of male right rib scores only differed by one phase (38.7%, 9.8%, and 4.8%, respectively) (Table 10). The same general pattern is true for the females in the sample. 56.9% of female right rib II phase scores, 13.3% of ribs III, V–IX phase scores, and 5.6% of composite scores differed from their respective rib IV phase scores (Table 11). As was true in the male sample, the majority of differences in rib scoring are exhibited in rib II phase scores. In both males and females the most accurate (least different) scores were obtained by the composite scoring technique.

TABLE 10—*Maximum number of phase scores away from right rib IV phase scores for right ribs II-III, V-IX, males.*

# of Scores	Rib II	%	Rib III, V–IX	%	Composite	%
1	43	38.7	68	9.8	39	4.8
2	9	8.1	21	3	3	0.3
3	1	0.9	2	0.2	0	0
Total	53	47.7	91	14.2	42	5.2

TABLE 11—*Maximum number of phase scores away from right rib IV phase scores for right ribs II–III, V–IX, females.*

# of Scores	Rib II	%	Rib III, V–IX	%	Composite	%
1	31	39.2	63	10.1	37	5.1
2	12	15.1	15	2.4	3	0.42
3	2	0.2	5	0.8	0	0
Total	45	56.9	83	13.3	40	5.6

Discussion

Our null hypothesis that there is no significant difference between the right and left rib series is partially supported. Right and left ribs IV–IX do not yield significantly different results. However, ribs II and III are significantly different on the right and left sides of the series. This indicates that in general both halves of the ribcage are subjected to the same stress levels. Torsional stress from the twisting of the abdomen may only affect one side per incident (depending on which direction one is twisted), but unless twisting consistently involves only one direction, torsional stress will be equal on both the left and right ribs. However, there may be increased stress on ribs II and III relating to handedness. The differential and heightened movement involved in the repeated favoring of one arm over the other may result in different stress levels and differential aging of right and left ribs II and III.

These results also partially support our hypothesis of finding no significant difference between right rib IV phase scores and those obtained from the other ribs. Phase scores from right ribs III–IX and left rib II are not significantly different from those of right rib IV. However, right rib II in the total sample, in the females of the total sample, Black females, and in Whites (sexes combined), did yield significantly different phase scores from right rib IV. Right rib III in the females of the total sample, and right rib V in White females are also significant. The right sixth rib in the males of the total sample and Black males, and the left third rib in the total sample, total male sample and total Black sample also demonstrate significant differences. The high percentages of difference between phase scores of ribs II, III, and V–IX, and right rib IV superficially support the high degree of variability in accuracy in rib scores shown through the Wilcoxin tests. However, the majority of differences in rib scores are found in right rib II and left rib III scores, and regardless which ribs are analyzed, scores generally only differ by one phase score.

Statistical analysis reveals that the average of an individual's phase scores in either the right or left rib series is not significantly different from the score obtained from the right rib IV only. This supports our null hypothesis that a composite phase score yields the same phase scores as the right fourth rib.

Analysis of the percentages of difference within scoring in age groups is highly variable. The most variable phase scores were obtained from the younger age groups in both sexes. However, the least variable age groups were opposite in the sexes. Individuals in the 70+ year old age category for male individuals and 10–19 year old age category for female individuals exhibited the least amount of variation between rib series phase scores and right rib IV phase scores. This indicates that there is no clear pattern of variation among age groups between the sexes.

Any variation in aging within the rib series may be the result of differential stress on the ribs in the series. Ribs I–VI are closely and directly attached to the sternum by cartilage and thus may be subjected to increased muscular stress from the movement of the arms and upper body (24,25). The upper half of the rib series is the only segment that demonstrated significant *p*-values. This may be the result of differential stress on the lower (VII–XII) ribs as opposed to the upper (I–VI) ribs. The ribs in the upper half of the ribcage may be subjected to more tensile and torsional stress than those in the lower half (ribs VII–X). Due to their greater degree of attachment to the sternum, the upper ribs may experience more torsional stress through the twisting of the abdomen during body movement. This movement may result in the pulling of the cartilage away from the sternal end of the rib. Ribs II–VI may also be subjected to tensile stress through respiration. This could be due to the pulling of the sternal end of the rib and the sternum by the cartilage with the expanding of the lung due to inhalation. During inhalation the ribcage in males is expanded by as much as 10 cm at the approximate level of ribs IV and V (24,25). This expansion could increase stress levels on these and their surrounding ribs, over the other ribs in the series. This hypothesis of differential stress between the ribs in the series causing differential aging is tentative at best, and there may of course be other factors contributing to the variation seen in rib series aging.

There are three types of rib movement, which have been likened to the movement of a pump handle, bucket handle, and spreading caliper. The pump handle movement is the anteroposterior expansion of the thorax. In this movement the upper ribs pivot around their vertebral articulations, which raise their anterior ends attached to the sternum. The bucket handle movement involves the expansion of the thorax laterally. In this case ribs II–VII swing laterally (like a bucket), rotating around both their sternal and vertebral articulations. The last movement, spreading caliper movement, affects the false ribs (VIII–X) and the floating ribs (XI–XII). In this movement, the sternal ends of the right and left ribs are pulled away from each other. In addition to these movements, both the ribs and the costal cartilage of ribs attached to the sternum change in shape. The ribs themselves become straighter and longer during inhalation, and the cartilage also straightens (24,25). Although one or more of these movements affect all of the ribs, the upper ribs are affected by the majority of the movement types in addition to the stresses involved in respiration.

Conclusions

Right and left ribs IV–IX exhibit age related changes at the same rate and phase scores obtained from them do not vary significantly from each other. Statistical analysis indicates that right ribs III, V–IX scores from the entire sample do not vary significantly from the right fourth rib phase scores. Statistically significant differences are revealed when the sample is further analyzed by sex and ancestry. The pattern of these differences is not consistent, a feature that is supported through the analysis of the percentages of difference in phase score estimations. However, scores obtained from ribs other than the right fourth typically only differ by one phase score. Due to questions of statistical significance and the accuracy of the other ribs' phase scores, the authors recommend working with caution when estimating age with ribs other than the fourth. Due to the apparent variability in the accuracy of estimations obtained from ribs other than the right fourth, a composite of rib series scores, if available, is preferable over single rib phase score analysis. These findings allow investigators a wider range of available techniques in the assessment of age of imperfectly preserved skeletal material.

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