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Identification of Rib Number and Assessment of Intercostal Variation at the Sternal Rib End

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ABSTRACT: A technique for the identification of anatomical rib number is presented here. Preliminary tests indicate that with experience, percent accuracy for identification may approach 100%. This technique was then applied to a skeletal collection where rib number was not documented in order to determine the effects of intercostal variation on the application of rib four age-at-death estimation standards [*2,3*] to other ribs. Spearman rank correlations between rib four and ribs three through nine range from 0.89 to 0.91. No significant differences were found between ribs conforming to or deviating from the phase observed on rib four. There is a significant proportion of deviations falling below the phase set by rib four, however these deviations are not statistically associated with rib number and are usually within one phase. These results indicate that rib four standards can be cautiously applied to other sternal ends when rib four is not preserved.

KEYWORDS: forensic science, rib human identification, age-at-death estimation

Problems associated with the quality of preservation of human skeletal remains may cause considerable difficulties when forensic investigators attempt to identify individuals. Areas on bones used to estimate age-at-death are particularly vulnerable to postmortem environmental effects.

Concern has been expressed regarding İşcan and coworker's [*1–4*] morphological rib end age-at-death estimation technique because of its reliance on the fourth right sternal end as its standard. Cargill and Suchey [5] assessed the sternal rib end technique over a two year period involving 32 Southern California forensic cases. Of these cases, age could only be estimated in 12.5% of the cases by the rib standards. The problem was the difficulty in identifying the right fourth rib. Cargill and Suchey found that a number of their cases involved disarticulation of the skeleton with subsequent commingling and/or fragmentation of the rib cages. Carnivore activity also complicated the application of rib morphological standards.

İşcan and colleagues [*6*] have addressed this problem by a preliminary assessment of intercostal variation of sternal rib ends three through five. The results of their analysis indicate that,

> In the majority of cases, all three ribs [numbers 3,4,5] fell into the same phase, and where differences were observed, they tended to be relatively minor. In conclusion, it appears likely that age can be accurately assessed from these adjacent ribs using the present standards. [6:245]

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Even though ribs three through five can be used with the fourth rib standards, this still does not solve the problem of which rib end to assess in a jumbled mass of disarticulated ribs. What is required is a full assessment of intercostal variation to determine if fourth rib standards can be applied to other ribs. Unfortunately, most skeletal collections do not retain the proper orientation of the ribs. It is thus necessary to first develop a method of identifying each rib.

This paper presents a technique to identify rib number, and tests this technique on archaeological remains where rib number was documented in situ. This rib identification method is then used to determine rib number on a larger sample, and the effect of intercostal variation at the sternal end is assessed.

Part I: The Rib Identification Technique

The identification of ribs, defined as the determination of anatomical orientation according to side (left or right) and number, has only recently been addressed [*7*]. Gray [*8*], Moore [*9*], and Steele and Bramblett [*10*] list traits for the identification of the atypical ribs (1,2,10,11, and 12). Ribs three through nine have been variously called the central, the typical or the common type. Differences among these typical ribs have been described as changes in length, curvature, and twisting of shafts. Steele and Bramblett [*10*] have observed that:

> Although these variations in the ribs can be recognized when viewing a set of ribs from one individual, the ribs did not differ enough from one another for these features to be diagnostic [10:140]

Materials and Methods

Prehistoric skeletal remains from the Late Archaic Hind site AdHk-1 [*11,12*], were used as a study sample in order to test the identification technique described here. The sample consists of seven fully articulated individuals (3 females, 4 males), age range 15 to 59 years old [*11*]. The material is generally in excellent condition and the archaeological recovery was exceptionally thorough. The ribs themselves were individually tagged at the time of excavation as to side orientation (right or left) and sequential order (1 through 12).

These identification tags were removed by an assistant (H. Stalker) and replaced with coded tags. A separate key-code for identifying each rib was not revealed until two trials of the rib identification technique were complete. The rib set for each individual was then commingled to remove any side or sequential order. Each rib set remained autonomous, there was no commingling of individuals' ribs. Trials consisted of applying the technique to each of the commingled rib sets. Trial one was conducted for each of the rib sets in one day and the data were removed. The rib sets were commingled a few days later and Trial two was completed in one day. The key-code was then broken, coded ribs identified, and errors tabulated. Percent accuracy was calculated as follows: each misidentification resulted in misclassification of two ribs, thus each misclassification pair was treated as a single error. The total errors for each rib were divided by the total number of ribs of that type (anatomical number and side). The percent error was then subtracted from 100 for percent accuracy.

The Technique

The identification of ribs into proper anatomical order is based on a few morphological features of the atypical ribs, and slight differences to the shaft characteristics. The atypical ribs (1,2,10,11,12) each exhibit unique morphological features [*8–10*] and may thus be

identified separately (see Fig. 1). The typical ribs three through nine, each possess similar structure but express individual differences in length, angle in the horizontal and vertical plane, and twisting of the superior external border (see Fig. 2).

Encountering normal morphological variability in tubercles and articular facets of atypical ribs ten through twelve may hinder their identification. This may be corrected by including the ribs in question into the analysis of the typical ribs.

Typical Ribs

Each typical rib has a head, a neck, a tubercle and a shaft or body. The head of a rib presents two articular facets separated by the crest of the head. These facets articulate with the corresponding vertebrae [9]. The neck is located between the head and the tubercle. The tubercle of a rib faces postero-inferiorly to articulate with the transverse process of the corresponding vertebra. The shaft of a rib is thin, angled in the horizontal and vertical plane, and twisted in the vertical plane. On the internal surface of the shaft at the inferior margin, is the costal groove which transmits the intercostal vein, artery, and nerve [9]. This results in a thin sharp inferior border. Orienting the rib in the horizontal plane with the head nearest the observer, the sternal end away, and the costal groove inferior, observe if the rib shaft arches to the right at the head end (a right rib) or arches to the left at the head end (a left rib).

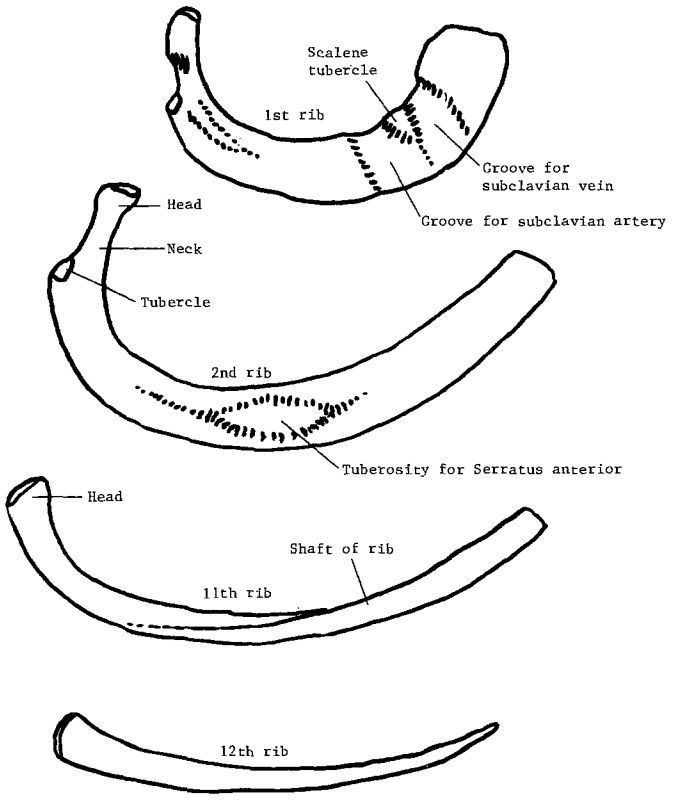

FIG. 1—*The atypical ribs (1,2,10,11,12) each exhibit unique morphological features and may thus be identified separately.*

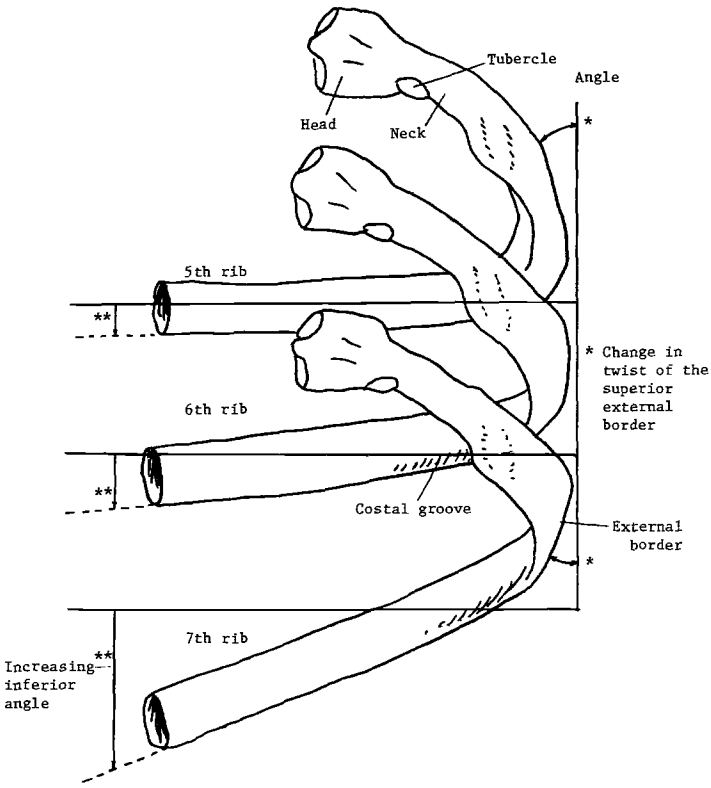

FIG. 2—*The typical ribs (three through nine) each possess similar structure but express individual differences in length, increasing inferior angle, and change in twist of the superior external border.*

Identification of the typical ribs involves the careful observation of slight morphological changes to the angle of the rib in the horizontal and vertical plane, and the twisting of the superior external border in the vertical plane. Moving in a cranial-caudal direction along the thoracic cage, each successive rib will demonstrate a slight increase in its horizontal angle (more open), a trend towards increasing the inferior angle in the vertical plane (points more down, see Fig. 2), and a change in the twist of the superior external border (border approaches the vertical plane). Typical ribs increase in length to a maximum at rib seven, and then diminish thereafter [*8*,*9*]. The usefulness of this last trait for identification is dependent on rib completeness, more so than the other traits where all that is required is the head, neck and angle portion of the shaft. Nevertheless, it has been observed by the author that the more complete a rib set is, the easier it is to identify.

The first step in the identification of typical ribs is to orient all ribs into right or left categories. The next step is to identify the 1st and 2nd ribs according to the atypical features associated with each [*8–10*]. Identification of the 10th, 11th and 12th atypical ribs may be hindered by normal morphological variation in atypical features. If this occurs, these atypical ribs should be included in the following typical rib comparison procedure.

The identified second rib is compared to each unidentified rib of the same side category (left or right) for changes in the morphological traits outlined earlier. The second rib is placed on the superior surface of an unidentified rib, with rib heads and tubercles aligned vertically. This is the common reference point for ribs as all must articulate with the vertebral column. The angle in the horizontal and vertical planes, and twist differences

of the superior external borders between the two ribs should be observed. This is done in turn for each unidentified rib of the same side category. The unidentified rib that most closely matches the morphology of the second rib is identified as the third rib. This procedure is now repeated with the third rib being compared to the remaining unidentified ribs, and so on, each step identifying the next rib in a cranial-caudal direction. It may be helpful to remember that typical rib shafts increase in length to a maximum at rib seven, and then diminish thereafter.

Double-checking the results can be accomplished by "stacking" the ribs. Starting at rib 9, place the 8th rib on the superior border of rib 9, making sure rib heads and tubercles are aligned in the vertical plane for each successive rib added to the stack in a cranial direction. The stacking procedure should require no adhesives if one has properly identified the ribs. The stack should fit together like a puzzle, with the twist of the superior external border, and horizontal and vertical angles of each successive rib being only slightly different from that of the preceding rib.

At this point if one or more ribs are missing then observe the stack. The missing rib(s) can usually be identified as "filling" a place in the stack where one rib does not sit properly on the superior surface of the other. This is due to the non-successive ribs' horizontal and vertical angles not being slight differences from each other, as successive ribs would possess. These missing ribs can be identified by number because the remaining stack has been identified.

Results

Tables 1 and 2 summarize that percent accuracy for side classification (right or left), identification of ribs one through five (including rib six in Trial 2), and identification of ribs nine through twelve is 100%. Problems in identification of the middle ribs (six through eight) occurred in Trial 1, but improved in Trial 2. Errors associated with misidentification were not side specific (4 errors both sides Trial 1).

Discussion

The increase in percent accuracy in Trial 2 may be due to a familiarity with the ribs to some extent, but is most likely a result of more experience with the identification

TABLE 1—*Test of the rib identification technique, Trial 1.*

Burial ID and sex	% Accuracy side right or left	% Accuracy[a] identification rib number and errors
3 f	100%	100%
10 m	100%	100%
14 f	100%	100%
18a f	100%	100%
19 m	100%	91.7% rib 6, 7 right
20 m	100%	83.4% rib 6, 7 right & 7, 8 left
22 m	100%	91.7% rib, 7, 8 left
Total	100%	100% ribs 1–5 right and left
		85.7% rib 6 right and left
		71.4% rib 7 right and left
		85.7% rib 8 right and left
		100% ribs 9–12 right and left

[a]% Accuracy was calculated as follows: each misidentification resulted in misclassification of two ribs, thus each pair of misclassifications was treated as a single error. The total errors for each rib were divided by the total number of ribs of that type (anatomical number and side). Percent error was then subtracted from 100 for percent accuracy.

TABLE 2—*Test of the rib identification technique, Trial 2.*

Burial ID and sex	% Accuracy side right and left	% Accuracy[a] identification rib number and errors
3 f	100%	100%
10 m	100%	100%
14 f	100%	100%
18a f	100%	100%
19 m	100%	100%
20 m	100%	91.7 rib 7, 8 left
22 m	100%	100%
Total	100%	100% ribs 1–6 right and left 93% ribs 7, 8 right and left 100% ribs 9–12 right and left

[a]% Accuracy was calculated as follows: each misidentification resulted in misclassification of two ribs, thus each pair of misclassifications was treated as a single error. The total errors for each rib were divided by the total number of ribs of that type (anatomical number and side). Percent error was then subtracted from 100 for percent accuracy.

technique. Results of Trial 1 were not released till Trial 2 was complete. Thus the fact that the errors of Trial 1 were corrected in Trial 2 *before* errors were made known lends weight to the conclusion that, with experience, ribs can be identified very accurately.

Only one misidentification was repeated in Trial 2, and that was Burial 20, ribs 7 and 8 left side. The seventh rib was missing the portion of the shaft immediately distal to the angle of the rib, making correct identification difficult.

The ribs of Burial 19 were fragmentary and required several hours to reconstruct to a state where they could be used with the identification technique. Results from this individual burial were surprising in that only one misidentification occurred in Trial 1 and no errors in Trial 2. Thus even fragmented rib cages, albeit rather complete fragmented ones, can be used for age estimation techniques following proper reconstruction and identification.

This modest preliminary study has many limitations. Trends observed between trials would benefit greatly from an increased sample size. This can only be accomplished if future skeletal disinterments involve the proper labeling of ribs on removal from resting places. The applicability of this technique to samples of other biological populations is also unexplored.

Nevertheless, it is encouraging that accuracy for side determination as well as the identification of ribs one through six was 100%. This last point is important when one recalls that İşcan's technique implements the right fourth rib for its standard.

Part II: Intercostal Variation at the Sternal Rib End

The accurately identified ribs can now be used to apply the rib morphological age estimation technique. The identification of ribs using the technique outlined above is still not an ideal solution to the problem of sternal rib end intercostal variation. Ribs that are very fragmented, or incomplete cannot be identified with the technique and thus fourth rib standards cannot be applied with confidence. Clearly there is a need to document the range of variability with respect to the morphology of other sternal rib ends. What error would be introduced by the application of fourth rib standards [*1–4*] to unidentifiable sternal rib ends?

Materials and Methods

The sample used to investigate intercostal variation at the sternal rib end is comprised of cadaveral material from anatomy teaching facilities of Southern Ontario and archae-

ological remains from the Hind site (southwestern Ontario), and the St. Thomas Anglican Church site (Belleville, Ontario) collections. The cadaveral sample is comprised of 25 rib cages from thirteen males and twelve females. The ribs were labeled according to number as they were removed. The archaeological sample is also comprised of 25 rib cages. Nineteen males and six females are represented (see Fig. 3). These ribs were not identified as to number or side during disinterment. Anatomical identification for the archaeological ribs was determined by utilizing the identification technique outlined earlier. Individuals were rejected from inclusion in the sample if the fourth rib was poorly preserved, or if the ribs were incomplete and/or very fragmentary.

Rib number one was not included in this investigation because of fundamental differences from other ribs in the form and function of its sternal end. The joint capsule surrounding the first manubrio-costal articulation is synchondrodial in nature (lacks a joint cavity). All other sterno-costal articulations are diarthrodial, possessing joint cavities [*13*]. Ribs ten through twelve were not included because they were too difficult to remove from cadavers.

All right ribs from all individuals were coded and commingled by an assistant (P. Berti) and a blind assessment of intercostal variation was completed by the author. Fourth right rib standards for white males and white females were applied to the respective male and female individuals. The use of white age-at-death estimation standards with an unknown biological population will not affect the results of an assessment of intercostal variation

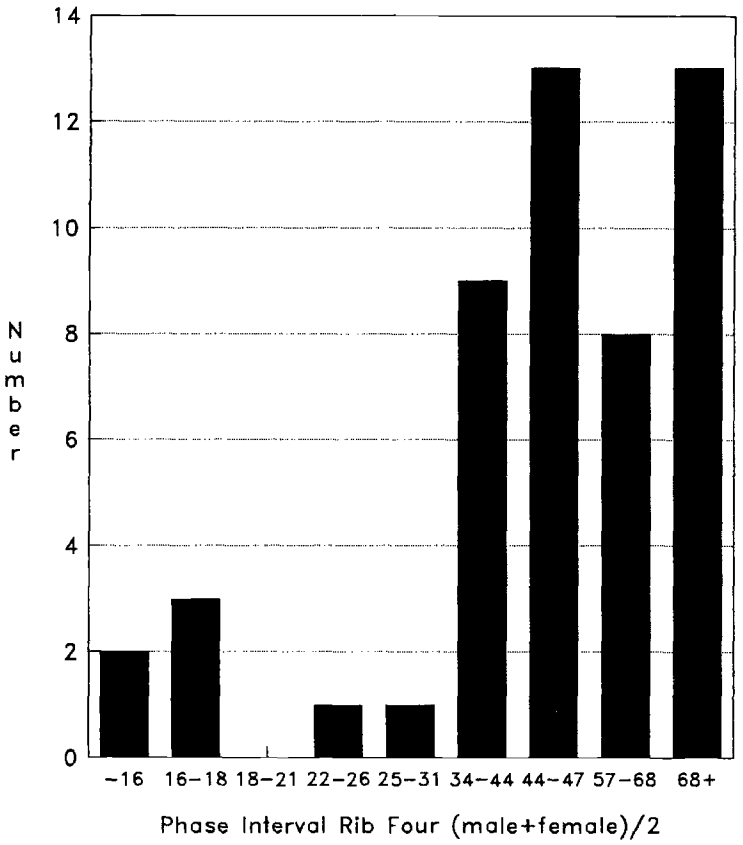

FIG. 3—*Demographic profile of sample used to determine intercostal variation.*

because age-at-death estimation is not being tested. Single ribs were drawn at random from the commingled collection, assigned an estimated age-at-death phase, which was recorded with the code, and removed from the collection. Only after phases had been assigned to all ribs was the code broken and each rib identified with the other ribs of the respective rib sets.

Results

Spearman rank correlation coefficients (r) were derived for the total sample and for each sex. Spearman's r was calculated from the phase assigned to each rib and the phase assigned to rib four for each individual. Deviations in sternal rib end phase assignments (for ribs 2 to 3 and 5 to 9) from the phase assigned to the fourth rib for each individual were tabulated. A Chi-square test of association was run to test the null hypothesis that: the differences observed in the percentage of deviations and conformations for each rib relative to rib four are not associated with rib number. A Chi-square test of goodness of fit tested the null hypothesis that: there is no difference in the proportion of deviations falling above or below the phase assigned to rib four.

Spearman's rank correlation for the combined sample (see Fig. 4) yielded r-values ranging from a low of 0.89 for rib seven to a high of 0.91 for rib five. Standard errors for the r-values averaged 0.035 for the entire sample. Female r-values range from 0.88 for rib two, to 0.95 for rib five. The male r-values range from 0.90 for rib seven to 0.93 for rib three.

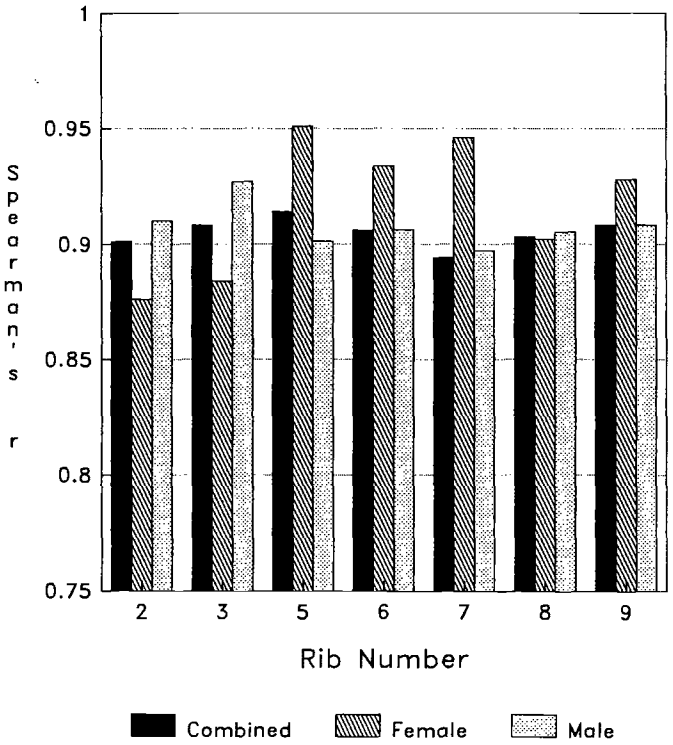

FIG. 4—*Spearman rank correlations: combined, female and male samples.*

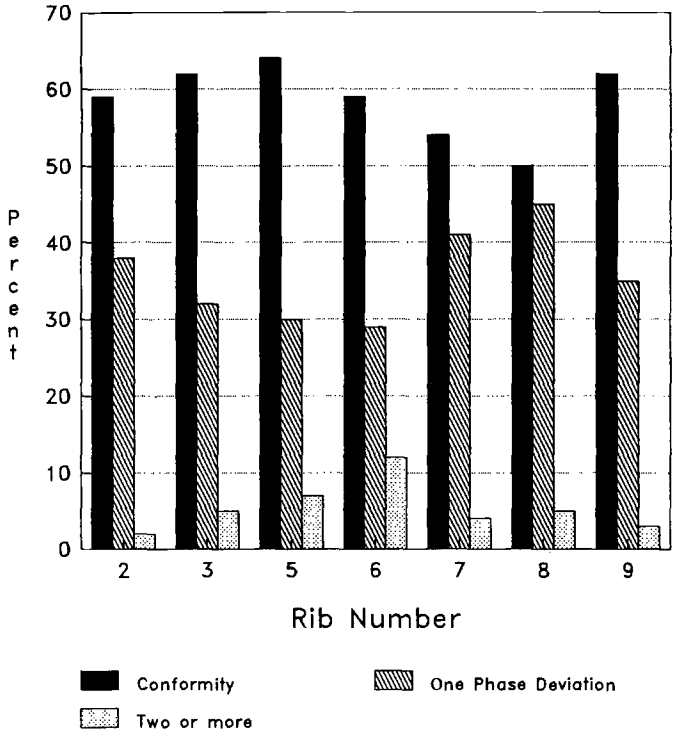

FIG. 5—*Conformity and deviation from phase assigned to rib four.*

Total conformations to the phase assigned to rib four for each rib were calculated. Rib eight conformed the least at 50% of the time, whereas rib five conformed the most at 64% (see Fig. 5). Total deviations and deviations by one phase from the phase assigned to rib four were calculated. All deviations were within one phase 87.6% of the time.

The Chi-square test of association failed to reject the null hypothesis. No significant differences exist between individual ribs conforming to, or deviating from, the phase assigned to rib four. The Chi-square test of goodness of fit rejected the null hypothesis; thus there is a significant ($0.05 < p < 0.025$) proportion of deviations below the phase assigned to rib four.

An additional Chi-square test of association tested the hypothesis that: the differences observed in the proportions of deviations above and below the phase assigned to rib four are not associated with rib number. This test failed to reject the null hypothesis. Thus the significant proportion of deviations falling below the phase assigned to rib four (as determined by the Chi-square goodness of fit test) is not associated with anatomical rib number.

Discussion

A significant proportion of deviations fall below the phase assigned to rib four. These deviations are not statistically associated with rib number, and are usually within one phase of the phase assigned to rib four (see Fig. 5). There are no significant differences in the proportion of non-fourth ribs conforming to the phase assigned to rib four. This, as well as the strong positive correlations for each rib, suggest that the fourth rib standards

can be cautiously applied to ribs two through nine when rib number cannot be identified, or when rib four is not preserved.

Conclusions

Preservation difficulties experienced by researchers applying the sternal rib end technique may be reduced by the ability to apply the fourth right rib standards to any typical rib. Less rigorous identification of skeletal material is thus acceptable now that more than one rib end may be used to indicate age-at-death. Due to the preliminary nature of this study, it must be cautioned that non-fourth ribs deviate from the phase assigned to rib four by 36% to 50%. Deviations are however within one phase 87.6% of the time. It is recommended then, that when rib location is known, or when it is possible to reconstruct and identify commingled ribs with the rib identification technique, that the fourth right rib be used with appropriate standards for sex and race.

Acknowledgments

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