TECHNICAL NOTE

Robert Hoppa,[1] Ph.D. and Shelley Saunders,[2] Ph.D.

Two Quantitative Methods for Rib Seriation in Human Skeletal Remains

REFERENCE: Hoppa R, Saunders S. Two quantitative methods for rib seriation in human skeletal remains. J Forensic Sci 1998; 43(1):174–177.

ABSTRACT: Accurate rib sequencing is of importance to both forensic anthropologists and human osteologists, but until recently there have been few traits used to aid in the seriation of ribs within a human burial. This study examines two measurements (head to tubercle length and superior costotransverse ligament crest height) for the purpose of aiding rib identification and seriation in human skeletal remains. A sample of 344 ribs from 43 individuals from the 19th century Anglican Church cemetery of St. Thomas in Belleville, Ontario were used for the current study. While the head to tubercle length appeared unreliable for rib seriation, the superior costo-transverse ligament crest height may provide an alternative technique for assessing rib sequence. More importantly though, the method provides a basis on which the identification of the central ribs can be made.

KEYWORDS: forensic science, thoracic cage, superior costo-transverse ligament, rib sequence, forensic anthropology

Until recently (1) there have been few traits used to aid in the seriation of ribs within a human burial. While the obvious method is to excavate and number ribs sequentially when found in situ, frequently incomplete or disturbed burials have required researchers to sequence ribs in the lab based on morphological changes. The importance of accurate rib sequencing is relevant to both forensic anthropologists and human osteologists for recording the location and distribution of regional trauma as well as for estimation of age in the adult. The fourth rib has been used as the standard for age-related metamorphosis of the sternal end (2–7) and the sixth rib has been used for histological age estimation (8–9). Although studies have suggested that these changes are essentially the same on the adjacent central ribs (10–11), the non-distinguishing features of the fourth and central ribs remain problematic. Mann (1) suggested a series of morphological traits that can be used to aid in this task. He found that ribs within an individual burial can be accurately seriated using such features as relative rib length, the size and shape of the articular facets, as well as the distance between the articular facets and rib angle, and the height of the rib heads relative to one another. In addition to these, Dudar (10) suggests that accuracy of seriation can be assessed by stacking the ribs one atop the other in anatomical position. This study is an examination of two quantitative methods for assessing rib sequence and identification in a forensic or archaeological context.

Materials and Methods

The research was conducted on adult individuals excavated from the 19th century Anglican Church cemetery of St. Thomas in Belleville, Ontario. The St. Thomas' skeletal sample consists of 577 individuals representing 37% of the total 1564 interments in the cemetery (12). Disinterment of the burials was carried out during the summer of 1989 (13). Preservation of the sample is extremely good, partly the result of the well-drained, sandy soil and the elevation of the site (12). Only 3% of the sample is of indeterminant sex or age, leaving an analyzable sample of 558 individuals. The St. Thomas' skeletal sample consists of 19th century pioneer families of European descent (primarily English and Irish) from Upper Canada (14). Even though it is a 19th century archaeological sample, recent and ongoing studies have suggested that the growth, stature and robusticity of the individuals is very similar to modern North American reference samples (15–17).

For the present study, only specimens with intact ribs from the right side were used and only ribs 2 through 9 were analyzed. Of a total sample of 857 ribs, 344 were used for the current study, representing complete sets of ribs 2 through 9 from 43 individuals.[3] This ensured that errors in the measurements were not biased by less accurate rib identification among the incomplete sets. For each individual burial, specimens were sorted into anatomical sequence for the purpose of proper identification of all ribs. Seriation was based upon multiple factors. Mann's (1) method for siding and sequencing ribs was primarily employed. These included: a comparison between the second rib and all other ribs; a progressive widening of the angle of the rib from first to 10th; a change in the body of the rib which results in a more blade-like appearance as the ribs progress from first to 12th; an increase in length of the rib from first to seventh and then a subsequent decrease in length

[1]Postdoctoral research fellow and assistant professor, Department of Anthropology, McMaster University, Ontario, Canada.
[2]Professor, Department of Anthropology, McMaster University, Ontario, Canada.
Received 2 Dec. 1996; and in revised form 20 May 1997; accepted 6 June 1997.

[3]The statistical results are the same when run on the full sample of 857 ribs. However, to ensure that the results were not biased by potential inaccuracies in rib identification from incomplete sets, the results presented here are for complete sets only.

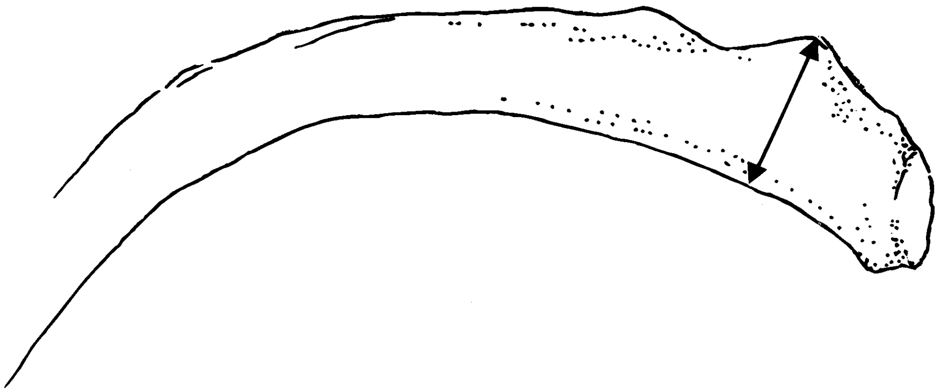

FIG. 1—*Inferior view of a right 4th rib illustrating the superior costo-transverse ligament crest height.*

from the eighth to the 12th. The seventh rib was characterized as having the maximum distance between the vertebral head and the table when laid at rest. Ribs 1, 11, and 12 are characterized as having only single articular facets (1). In addition stacking the ribs, once in anatomical sequence, as described by Dudar (10), provided a good check.

This study examines two metric variables for the purpose of aiding rib identification and seriation in human skeletal remains. The first is the head to tubercle length which was measured on ribs 2 through 8. The second, measured the distance between the inferior surface of the neck to the peak of the crest of attachment of the superior (anterior) costo-transverse ligament[4] for ribs 2 through 9 (see Fig. 1). Preliminary examinations revealed a possible pattern of increasing size of these measures with increasing rib number, and therefore a formal study was undertaken to evaluate this hypothesis. Measures were taken using sliding calipers. The crest height was measured from the inferior aspect of the neck to the most superior point of the crest. In order to independently evaluate the hypothesis these measures were not used to aid seriation.

Results and Discussion

Table 1 presents the correlation between rib number and the two metric variables, head tubercle length and superior costo-transverse crest height. Since rib number is not a continuous, normally distributed variable, Spearman's rho coefficients were calculated. As shown in Table 1, both variables demonstrate a significant ($p < 0.05$) correlation with rib number. Figures 2 and 3 present the 95% confidence intervals around the mean values of each of the two variables, by rib number. Head-tubercle length shows a nonlinear pattern with a peak maximum at the 4th and 5th ribs (Fig. 2). Superior costo-transverse crest height however, shows a very distinct pattern of increasing values up to the 7th rib (Fig. 3). Given its distinct pattern, it was apparent that the superior costo-transverse measure might be useful for distinguishing the 4th and central ribs from one another. An analysis of variance with posthoc Bonferroni statistics for evaluating the pairwise difference between ribs was calculated, the results of which are presented in Table 2. These results suggest that the mean superior costo-transverse ligament crest height for the 4th rib in particular is statistically distinct from all other analyzed ribs (pairwise mean differences are significant at $p < 0.05$). This is notable given the importance of the 4th rib for forensic anthropology. Despite these results, the overall dispersion of superior costo-transverse ligament crest height values within the sample is considerable. To further evaluate the usefulness of this trait, regression equations were fitted to the distribution. Since there was not a simple linear pattern of increase between rib number and the variable (see Fig. 3), an alternative

TABLE 1—*Correlations.*

			Rib
Spearman's rho	Correlation Coefficient	RIB	1.000
		SUP_COST	.649*
		HEAD_TUB	−.126*
	Sig. (2-tailed)	RIB	
		SUP_COST	.000
		HEAD_TUB	.036
	N	RIB	344
		SUP_COST	309
		HEAD_TUB	274

**Correlation is significant at the .01 level (2-tailed)
*Correlation is significant at the .05 level (2-tailed).

[4]The anterior costo-transverse ligament attaches to a sharp crest on the upper border of the neck of each rib and passes obliquely upward and outward to the lower border of the transverse process immediately above (16).

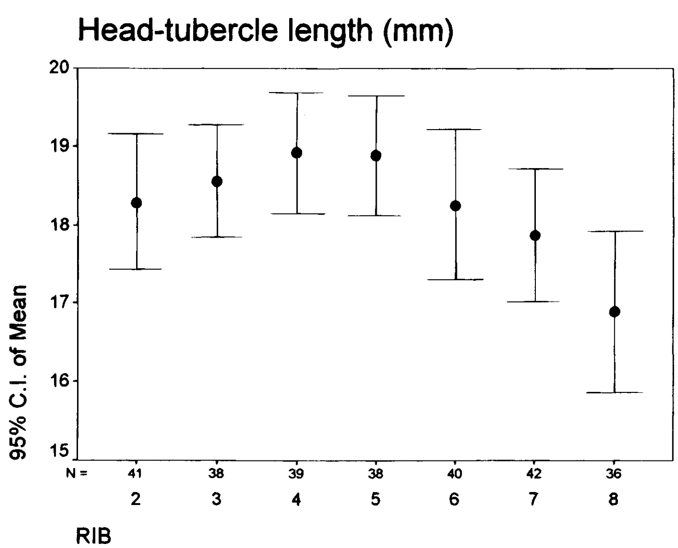

FIG. 2—*95% confidence interval for mean head-tubercle length (mm) by rib number.*

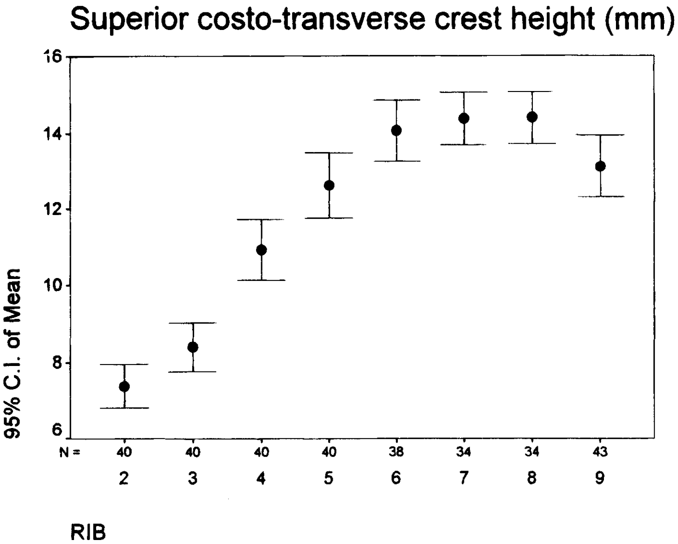

FIG. 3—*95% confidence interval for mean superior costo-transverse ligament crest height (mm) by rib number.*

model was required which exhibits a pattern of increase to a peak, followed by a decline. The quadratic model serves this purpose, and models were fit in two ways. As it is rib number that we wish to predict from the measurement, rib number was considered the dependent variable and superior costo-transverse ligament crest height the independent variable. First, a single model was fitted for the entire sample of ribs (irrespective of individual) with limited success ($r^2 = 0.446$; regression df = 2, SS = 748.29, MS = 374.15; residual df = 306, SS = 916.27, MS = 2.99; F = 124.95, $p < 0.001$). While a clear pattern for crest height is observed within the sample, the standard deviation around the mean for each rib suggested that within-individual variation may substantial. That is, while the general pattern of increase to rib 7 followed by a decrease may be valid, the actual size of the crest may be partly dependent on the individual (e.g., differences in overall skeletal size and musculature). To examine the impact of individual variability, a second set of quadratic models were generated, this time fitted independently for each individual burial. Comparisons of model residuals demonstrate better prediction compared to the total sample fitted model. The improvement is illustrated in Table 3 which presents the distribution of error (observed-predicted) for each of the two models. For the total sample fitted model 63.8% of the cases predicted within one rib while the series of individual fitted models increased to 77.7% of the sample.

Whether or not this trait is applicable across samples is difficult to assess. The implications of applying population-specific regression models are clear. However, it is unclear whether comparable variation exists in both the observed pattern and the relative presence of the trait in other population samples. While the confidence intervals for the mean estimates for each rib follow a distinct pattern, the actual distribution of measurements is considerably more dispersed than is desired for a typical analysis. However, limitations depend somewhat on the application of this measurement. First, the analysis of variance demonstrated that, despite the individual variation, the mean measure was significantly different for the 4th rib, suggesting that individual identification of the 4th rib may be possible. This may be useful for commingled samples or fragmentary specimens. However, as an aid to seriation where we do not expect to identify a single rib as compared to a total sample

TABLE 2—*Multiple Comparisons.*
Dependent Variable: Superior Costo-transverse Crest Height
Bonferroni

(I) Rib	(J) Rib	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	3	−1.0020	.509	1.000	−2.6058	.6018
	4	−3.5153*	.509	.000	−5.1190	−1.9115
	5	−5.2305*	.509	.000	−6.8343	−3.6267
	6	−6.6701*	.515	.000	−8.2949	−5.0454
	7	−6.9834*	.531	.000	−8.6565	−5.3104
	8	−7.0078*	.531	.000	−8.6809	−5.3348
	9	−5.7454*	.500	.000	−7.3210	−4.1698
3	2	1.0020	.509	1.000	−.6018	2.6058
	4	−2.5133*	.509	.000	−4.1170	−.9095
	5	−4.2285*	.509	.000	−5.8323	−2.6247
	6	−5.6681*	.515	.000	−7.2929	−4.0434
	7	−5.9814*	.531	.000	−7.6545	−4.3084
	8	−6.0058*	.531	.000	−7.6789	−4.3328
	9	−4.7434*	.500	.000	−6.3190	−3.1678
4	2	3.5153*	.509	.000	1.9115	5.1190
	3	2.5133*	.509	.000	.9095	4.1170
	5	−1.7152*	.509	.024	−3.3190	−.1115
	6	−3.1549*	.515	.000	−4.7797	−1.5301
	7	−3.4681*	.531	.000	−5.1412	−1.7951
	8	−3.4926*	.531	.000	−5.1656	−1.8195
	9	−2.2301*	.500	.000	−3.8057	−.6546
5	2	5.2305*	.509	.000	3.6267	6.8343
	3	4.2285*	.509	.000	2.6247	5.8323
	4	1.7152*	.509	.024	.1115	3.3190
	6	−1.4396	.515	.156	−3.0644	.1851
	7	−1.7529*	.531	.030	−3.4260	−7.987E-02
	8	−1.7773*	.531	.026	−3.4504	−.1043
	9	−5.149	.500	1.000	−2.0905	1.0607
6	2	6.6701*	.500	.000	5.0454	8.2949
	3	5.6681*	.515	.000	4.0434	7.2929
	4	3.1549*	.515	.000	1.5301	4.7797
	5	1.4396	.515	.156	−.1851	3.0644
	7	−.3133	.537	1.000	−2.0064	1.3799
	8	−.3377	.537	1.000	−2.0309	1.3555
	9	.9248	.507	1.000	−.6722	2.5217
7	2	6.9834*	.531	.000	5.3104	8.6565
	3	5.9814*	.531	.000	4.3084	7.6545
	4	3.4682*	.531	.000	1.7951	5.1412
	5	1.7529*	.531	.030	7.987E-02	3.4260
	6	.3133	.537	1.000	−1.3799	2.0064
	8	−2.441E-02	.552	1.000	−1.7640	1.7152
	9	1.2380	.522	.515	−.4080	2.8841
8	2	7.0078*	.531	.000	5.3348	8.6809
	3	6.0058*	.531	.000	4.3328	7.6789
	4	3.4926*	.531	.000	1.8195	5.1656
	5	1.7773*	.531	.026	.1043	3.4504
	6	.3377	.537	1.000	−1.3555	2.0309
	7	2.441E-02	.552	1.000	−1.7152	1.7640
	9	1.2624	.522	.454	−.3836	2.9085
9	2	5.7454*	.500	.000	4.1698	7.3210
	3	4.7434*	.500	.000	3.1678	6.3190
	4	2.2301*	.500	.000	.6546	3.8057
	5	.5149	.500	1.000	−1.0607	2.0905
	6	−.9248	.507	1.000	−2.5217	.6722
	7	−1.2380	.522	.515	−2.8841	.4080
	8	−1.2624	.522	.454	−2.9085	.3836

*The mean difference is significant at the .05 level.

TABLE 3—*Distribution of error of rib prediction (without direction) for the total-sample fitted model and the individual fitted models.*

	Total Sample Fitted		Individual Burial Fitted	
Error	N	Cum. %	N	Cum. %
0	125	40.6	188	61.0
1	100	73.1	74	85.1
2	57	91.6	35	96.4
3	19	97.7	10	99.7
4	5	99.4	1	100.0
6	2	100.0		
Total	308		308	

of ribs, but rather a single rib within a finite sample defined by the individual burial, individual variation may be more limiting. In this case the pattern of increase to rib seven, and then decline is generally followed within a sample of ribs from a single individual. As such, a simple ranking based on this pattern can be used either in conjunction with other techniques or in lieu of them when remains are fragmentary or poorly preserved.

Conclusions

This study has shown the potential application of two quantitative methods to tasks traditionally assigned to more qualitative techniques. While the head to tubercle length appeared unreliable for rib seriation, the superior costo-transverse ligament crest height may provide an alternative technique for assessing rib sequence. More importantly though, the method provides a basis on which the identification of the central ribs can be made. This is of particular importance for forensic anthropology, which relies on the morphometric changes of the sternal end of the fourth rib as a method for assessing chronological age. The wider application of this technique is unknown, and it is recommended that future studies examine the reliability and consistency of this trait within different population samples.

Acknowledgments

The authors would like to thank Elana Robson for assistance in the data collection and Bev Robinson for drawing Fig. 1. Two anonymous reviewers provided helpful comments and criticisms on an earlier draft of this paper. Permission to analyze the skeletal remains was given by St. Thomas' Anglican Church, Belleville. This research was supported by the Social Science and Humanities Research Council of Canada.

References

1. Mann RW. A method for siding and sequencing human ribs. J Forensic Sci 1993;38(1):151–5.
2. İşcan MY, Loth SR, Wright RK. Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. Am J Phys Anthropol 1984;64(2):147–56.
3. İşcan MY, Loth SR, Wright RK. Age estimation from the rib by phase analysis: white males. J Forensic Sci 1984;29(4):1094–104.
4. İşcan MY, Loth SR, Wright RK. Age estimation from the rib by phase analysis: white females. J Forensic Sci 1985;30(3):853–63.
5. İşcan MY, Loth SR. Determination of age from the sternal rib in white males: a test of the phase method. J Forensic Sci 1986;31(1): 122–32.
6. İşcan MY, Loth SR. Determination of age from the sternal rib in white females: a test of the phase method. J Forensic Sci 1986; 33(3):990–9.
7. Russell KF, Simpson SW, Genovese J, Kinkel MD, Meindl RS, Lovejoy CO. Independent test of the fourth rib aging technique. Am J Phys Anthropol 1993;92:53–62.
8. Dudar JC, Pfeiffer S, Saunders SR. Evaluation of morphological and histological adult skeletal age-at-death estimation techniques using ribs. J Forensic Sci 1993;38:677–85.
9. Stout SD, Paine RR. Histological age estimation using rib and clavicle. Am J Phys Anthropol 1992;87(1):111–15.
10. Dudar C. Identification of rib number and assessment of intercostal variation at the sternal rib end. J Forensic Sci 1993;38(4):788–97.
11. İşcan MY, Loth SR, Scheuerman EH. Assessment of intercostal variation on the estimation of age from the sternal end of the rib. Am J Phys Anthropol 1989;78(2):245.
12. Saunders SR, Herring DA, Sawchuk LA, Boyce G. The nineteenth-century cemetery at St. Thomas' Anglican Church Belleville: skeletal remains, parish records and censuses. In: SR Saunders, DA Herring, editors. Grave Reflections. Portraying the Past through Cemetery Studies. Toronto: Canadian Scholars Press, 1995:93–118.
13. McKillop H, Marshall S, Boyce G, Saunders S. Excavations at St. Thomas' Church, Belleville, Ontario: a nineteenth century cemetery. Paper presented to the Ontario Archaeological Society Symposium, London, Ontario, 1989.
14. Saunders SR, Herring DA, Boyce G. Can skeletal samples accurately represent the living populations they come from? The St. Thomas' cemetery site, Belleville, Ontario. In: AL Grauer, editor. Bodies of Evidence. New York: John Wiley & Sons, Inc., 1995: 69–89.
15. Saunders SR, Hoppa RD, Southern RA. Diaphyseal growth in a 19th century skeletal sample of subadults from St. Thomas' Church, Belleville, Ontario. Int J Osteoarchaeol 1993;3(4):265–81.
16. Saunders SR, Hoppa RD. Determination of sex in the human skeleton from long bone measurements. Poster paper presented at the Annual Meetings of the Canadian Society for Forensic Sciences, Toronto, Ontario, 1995.
17. Saunders SR, Hoppa RD. Sexual dimorphism of human long bones and sampling bias. Paper presented at the Annual Meetings of the American Academy of Forensic Sciences, New York, NY, 1997.

Additional information and reprint requests:
Shelley Saunders, Professor
Department of Anthropology
1280 Main Street West, Hamilton
Ontario, Canada L8S 4L9
Phone: (905) 525-9140 Fax: (905) 522-5993