

Evaluation of the Rib Seriation Using Analysis of Quantitative Methods in Koreans

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Abstract : Rib seriation has not been used to identify individual human skeletal remains in Koreans. Accurate rib seriation is important for determining rib number and for establishing an individual's age at death. The aim of this study was to use a previously published quantitative method to correctly predict rib sequencing in Koreans.

We used complete rib sets of 54 individuals and measured three variables: AFTAL (articular facet of the tubercle-to-angle length), HAFL (head-to-articular facet length), and SCTCH (superior costo-transverse crest height).

AFTAL and SCTCH were more useful than HAFL for predicting rib seriation, and AFTAL produced the simplest equation for determining sex. In the ranking, the cumulative percentage of AFTAL was 79% with an error of 0, and the range of seriation error was ± 4 . Compared to other studies using European measures, AFTAL showed greater accuracy of rib seriation in this study of Korean ribs. In fact, both AFTAL and AFTAL with SCTCH accurately predicted rib 4 in 94% of cases.

AFTAL was the most accurate, and use of both SCTCH and AFTAL yielded better results than either alone. Thus, the high accuracy and predictive ability showed that this method is useful for measuring rib seriation in Koreans.

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Key words : Rib seriation, Typical rib, Sex determination, Quantitative method, Korean

Introduction

Rib number identification is important to forensic

anthropologists and human osteologists for several reasons: (1) identify the location of stab or puncture marks and gunshot wounds to the thoracic region; (2) identify the sequence of ribs in commingled assemblages; and (3) establish the age at death using cartilaginous and osseous changes in the sternal end of the ribs (Mann 1993). Accurate rib seriation is crucial for identifying the typical ribs, ribs 3 to 10, because of the

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difficulty in identifying these ribs (İşcan et al. 1984a, b, İşcan et al. 1985, İşcan et al. 1987).

Rib seriation has been studied in two ways; morphological characterization and metric analysis (Dudar 1993, Mann 1993, Hoppa and Saunders 1998, Owers and Pastor 2005). In the morphological characterization method, the differences between the typical ribs can be described in terms of length, curvature, and twisting of shafts (Dudar 1993). The morphological characterization method is difficult to apply to ribs that are fragmented or warped (Owers and Pastor 2005). Hoppa and Saunders (1998) and Owers and Pastor (2005) described a quantitative method using metric analysis for identifying rib numbers. Metric analysis is gaining favour within the discipline as more forensic anthropologists are asked to provide statistical weight to their opinions and because this method is more easily used by less experienced forensic anthropologists (Reichs 1998).

There is no available study of ribs that has an applied method for identifying rib sequences and sex in Koreans. We applied methods from previous studies for rib assessment and sex determination in Korean bones. The purposes of this study were to assess rib seriation and determine sex using three quantitative methods and then test their applicability in Koreans.

Materials and Methods

The sample comprised complete dry ribs of 54 individuals (39 males and 15 females) for which sex and age at death (16~88 years) were known. We used specimens with complete sets of ribs 2 through 9 and applied the method of Owers and Pastor (2005). We measured each of the three variables twice with digital vernier calipers (MyCAL Absolute 500-652, Kawasaki, Mitutoyo, Japan). We analysed rib seriation and sex determination, and used the data to identify rib 4. The three variables were as follows (Fig. 1):

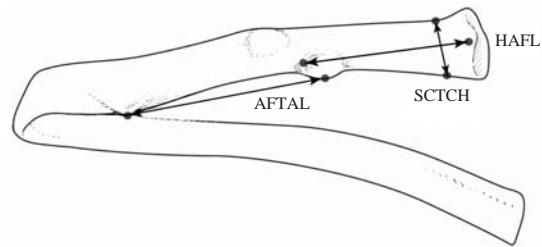


Fig. 1. Schematic drawing of the ribs showing the measurements. AFTAL, articular facet of the tubercle-to-angle length; HAFL, head-to-articular facet length; SCTCH, superior costotransverse crest height.

1. The articular facet of the tubercle-to-angle length (AFTAL)—the distance from the most vertebral edge of the articular facet of the tubercle to the angle, a roughened oblique line on the external surface of the rib, which is the attachment site for the iliocostalis muscle.
2. The head-to-articular facet length (HAFL)—the distance from the medial edge of the head to the most lateral border of the articular facet, which is always clearly identifiable.
3. The superior costo-transverse crest height (SCTCH) measured on the neck of the rib—the maximum distance from the inferior surface of the neck of the rib to the peak of the rib crest.

The values for the three metric variables were analysed using SPSS (version 13.0, SPSS Science, Inc., Chicago, IL, USA).

Results

The variables were easy to measure because their precise locations were easily determined. We measured each of the three metric variables twice and obtained Cronbach's alpha values greater than 95% for all measurements, indicating very high intraobserver reliability. We used two methods to assess bilateral asymmetry—those of Auerbach and Ruff (2006) and Čuk et al. (2001)—

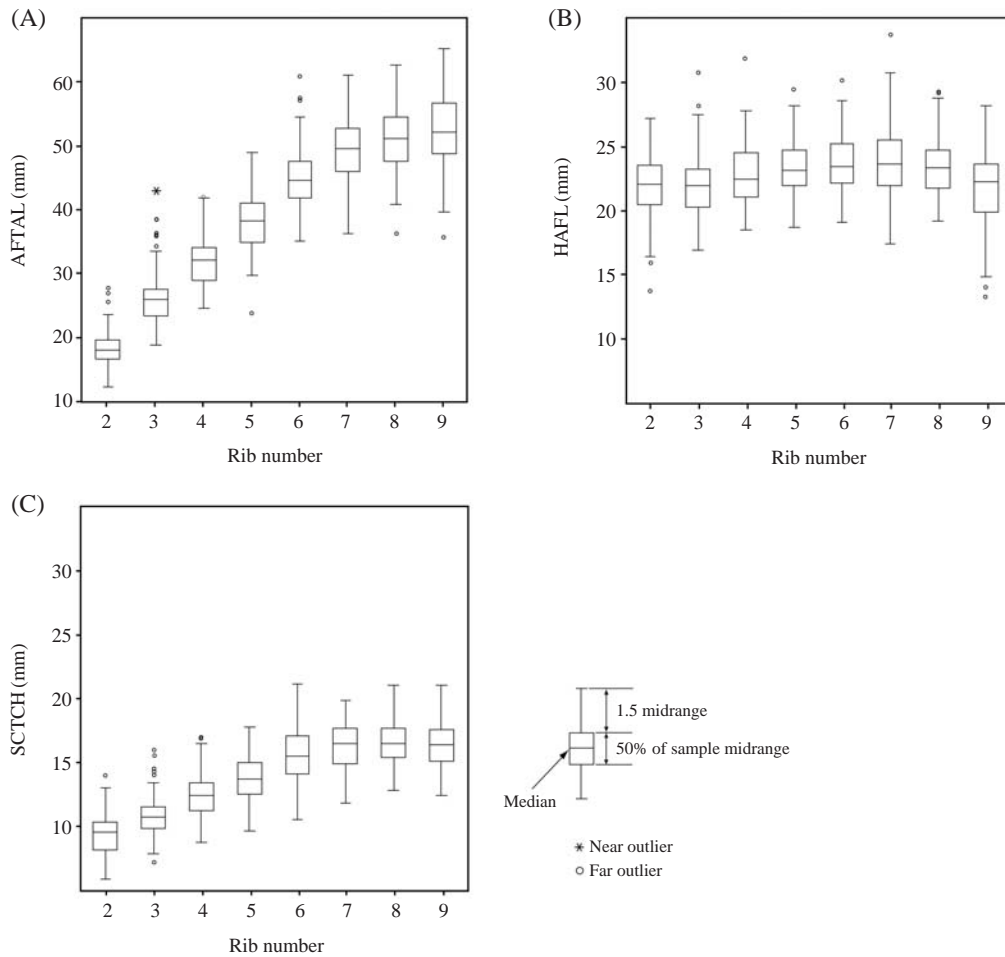


Fig. 2. Box-and-whisker plots of the three variables. A, articular facet of the tubercle-to-angle length (AFTAL); B, head-to-articular facet length (HAFL); C, superior costotransverse crest height (SCTCH).

and obtained similar results. Furthermore, we analysed the data using the paired t test. Most measurements did not differ significantly between the right and left sides ($p > 0.05$), except for the SCTCH in ribs 6, 8, and 9.

Fig. 2 shows that the actual spread was large and that the measurements for several individuals fell outside the range of all variables. AFTAL generally increased in size with rib number, HAFL changed little over the sequence of ribs, and SCTCH increased from rib 2 to 8. The three variables of each rib differed significantly

between the sexes in independent sample t tests ($p < 0.05$), but the sex did not affect the results.

1. Articular Facet of the Tubercle to Angle Length (AFTAL)

The values for AFTAL also tended to increase from rib 2 to 9 (Fig. 2). Analysis of variance was performed on the AFTAL measurements to test whether AFTAL is independent from rib number. The result was signifi-

Table 1. Results from analysis of variance of measurements of ribs

	Sum-of-squares	df	Mean-squares	F-ratio	<i>P</i>	<i>R</i> ²
AFTAL rib	114,589.481	7	16,369.926	781.363	0.000	0.871
AFTAL error	16,460.376	800	20.950			
HAFL rib	512.267	7	73.181	12.246	0.000	0.089
HAFL error	4,783.189	800	5.979			
SCTCH rib	5,455.181	7	779.312	243.504	0.000	0.678
SCTCH error	2,560.321	800	3.200			

Table 2. Results of regression analysis of measurements of ribs

	Variables	B	SE B	T	Sig.	F-ratio	Adjusted <i>R</i> ²
AFTAL	AFTAL	-0.300	0.063	-4.736	0.000	1477.163	0.846
	(AFTAL) ²	0.013	0.002	7.717	0.000		
	(AFTAL) ³	0.000	0.000	-7.962	0.000		
	(constant)	3.878	0.707	5.486	0.000		
HAFL	HAFL	-0.131	0.169	-0.771	0.441	7.047	0.015
	(HAFL) ³	0.000	0.000	1.437	0.151		
	(constant)	6.644	2.627	2.529	0.012		
SCTCH	SCTCH	-2.924	0.569	-5.139	0.000	517.947	0.658
	(SCTCH) ²	0.289	0.043	6.761	0.000		
	(SCTCH) ³	-0.008	0.001	-7.270	0.000		
	(constant)	10.849	2.439	4.448	0.000		
AFTAL +SCTCH	AFTAL	0.140	0.004	33.424	0.000	2173.571	0.843
	SCTCH	0.122	0.017	7.164	0.000		
	(constant)	-1.645	0.146	-11.297	0.000		

cant ($F=781.363$, $p<0.001$) (Table 1) indicating that AFTAL was directly related to rib number. Post hoc tests (Tukey's test) demonstrated that the mean differences for rib pairs (7, 8) and (8, 9) were not significant. Regression analysis showed a significant relationship between AFTAL and rib number ($F=1477.163$, adjusted $R^2=0.846$) (Table 2). The probability test of regression used the Durbin-Watson statistic, which was 1.014. The regression equation was as follows:

$$Y = \text{AFTAL} \times (-0.300) + (\text{AFTAL})^2 \times 0.013 + 3.878.$$

We used Spearman correlations to compare the actual rib seriation with the rib seriation predicted using this equation in complete rib sets. The actual and predicted rib seriations correlated significantly ($r=0.960$,

$p<0.001$). We tested ranking in an individual set from this equation. These rankings were compared with those obtained by numbering the ribs using the actual rib seriation. The cumulative percentages in Table 3 indicate the proportion of ribs correctly seriated for a given acceptable error. Using AFTAL, 79% of ribs were seriated correctly, with an error of 0 and range of seriation error of ± 4 . The rib number was correctly predicted for AFTAL about 80% of the time, indicating fairly correct identification.

2. Head to Articular Facet Length (HAFL)

The mean HAFL values differed from those for AFTAL and SCTCH. HAFL values increased to rib 7,

Table 3. Distribution of error of prediction for rib sequence of measurements

Error	AFTAL		HAFL		SCTCH		AFTAL+SCTCH	
	N*	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%
0	638	79.0	93	11.5	386	47.8	612	75.7
1	128	94.8	153	30.4	243	77.8	148	94.1
2	36	99.3	144	48.3	95	89.6	38	98.8
3	4	99.8	92	59.7	51	95.9	8	99.8
4	2	100.0	116	74.0	19	98.3	2	100.0
5			113	88.0	9	99.4		
6			63	95.8	4	99.0		
7			34	100.0	1	100.0		
Total	808		808		808		808	

*Number of ribs seriated correctly
Cum.%, Cumulative percentage of correctly seriated ribs.

decreased to rib 9, and were nearly flat for ribs 1, 2, and 9. HAFL values for ribs 8 to 9 decreased more than those of the other ribs (Fig. 2). The Spearman coefficient was 0.136 ($p < 0.001$), a weaker correlation with rib number than others. The adjusted R^2 from the analysis of variance was 0.089 (Table 1), and post hoc analysis showed no significant difference between ribs. (F for regression=7.047, adjusted $R^2=0.015$) (Table 2). The Durbin-Watson statistic was 1.361. The equation was as follows:

$$Y = \text{HAFL} \times (-0.131) + 6.644.$$

Unlike AFTAL and SCTCH, HAFL was a weak predictor of correct rib seriation. The distribution of error of rib prediction for HAFL was much less encouraging. Using HAFL, rib number was correctly predicted in only 11.5% of cases, with an error of 0 (Table 3).

3. Superior Costotransverse Crest Height (SCTCH)

SCTCH generally increased in size with rib number: increasing to rib 7 and nearly flat from ribs 7 to 9 (Fig. 2). The F-ratio of analysis of variance was 243.504 and R^2 was 0.678, indicating a significant relationship between SCTCH and rib number ($p < 0.001$), as observed for the other variables (Table 1). The probability

matrix revealed significant mean differences for all possible pairs chosen from ribs 2 to 9, whereas SCTCH was not significant for the rib pairs (6, 7), (7, 8), (7, 9), and (8, 9). The F-ratio of regression was 517.947, and the adjusted R^2 was 0.658, indicating a significant relationship between SCTCH and rib number (Table 2). The Spearman correlation coefficient was 0.793 and the Durbin-Watson statistic showed 1.121. The regression equation of SCTCH was as follows:

$$Y = \text{SCTCH} \times (-2.924) + (\text{SCTCH})^2 \times 0.289 + (\text{SCTCH})^3 \times (-0.008) + 10.849.$$

The cumulative percentage of SCTCH was 47.8% with an error of 0 (Table 3).

4. AFTAL and SCTCH

The correlation with rib number was higher for AFTAL and SCTCH than for HAFL. We also analyzed use of AFTAL and SCTCH together. The Spearman correlation coefficient calculated for these traits showed a significant correlation with rib number ($r = 0.844$, $p < 0.001$). The F-ratio of regression was 2173.571 and the adjusted R^2 was 0.843. The regression equation was:

$$Y = \text{AFTAL} \times 0.140 + \text{SCTCH} \times 0.122 - 1.645.$$

The distribution of error of predicted rib seriation is

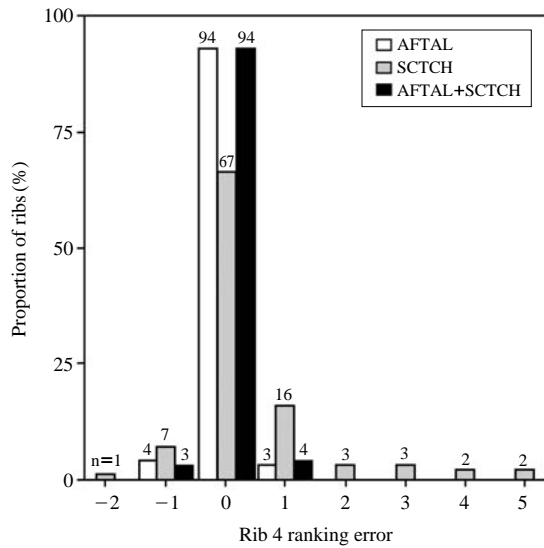


Fig. 3. Ranking-error comparison for rib 4. Numerals above the bar show the numbers as proportions of ribs. AFTAL, articular facet of the tubercle-to-angle length; HAFL, head-to-articular facet length; SCTCH, superior costotransverse crest height; AFTAL+SCTCH, the articular facet of the tubercle-to-angle length was calculated together with the superior costo-transverse crest height.

shown in Table 3. The cumulative percentage was 75.7 % with an error of 0; the cumulative percentage was similar to that derived using AFTAL. Assuming an error of ± 1 in predicted rib number as acceptable, the cumulative percentage accuracy was 94.1%.

5. Identification of rib 4 using ranking

The fourth rib is often used for establishing age at death. Fig. 3 shows that rib 4 was identified correctly using the variables. Rib 4 was correctly identified in 94% of cases using ranked AFTAL values, 66% of cases using SCTCH, and 94% of cases using AFTAL with SCTCH. This indicates that AFTAL alone or AFTAL with SCTCH are useful for identifying rib 4 (Fig. 3). HAFL was not effective in identifying rib 4 because it was a poor predictor of rib seriation in this study.

6. Sex determination

Discriminant function analysis was calculated three ways based on rib numbers and variables. For AFTAL of all ribs, the ability of the discriminant function was 0.417, Wilks's lambda was 0.826 ($p < 0.001$), and the discriminant variable was rib 4 only (Table 4). The accuracy of the discriminant function analysis was 75.2%. Using HAFL of all ribs, the accuracy was 75.2 %, and the discriminant variables were ribs 2 and 7. In SCTCH of all ribs, the discriminant variables were ribs 2 and 4, and the accuracy was 86.1%. In AFTAL with SCTCH of all ribs, the discriminant variables were ribs 2, 3, 4, and 7, and the accuracy was 89.1%, which is the highest of the values calculated. Using each variable from ribs 2 to 4, the discriminant variables were AFTAL of rib 4, HAFL of rib 2, and SCTCH of ribs 2 and 4, and the accuracy was 88.1%. The accuracy of AFTAL with SCTCH was the highest of all the variables, and the discriminant variable of AFTAL was the simplest to obtain and had acceptable accuracy.

Discussion

Accurate rib seriation is necessary to identify the patterns of thoracic skeletal trauma such as healed fractures and gunshot or stab wounds in commingled samples (Mann 1993, Hoppa and Saunders 1998, Owers and Pastor 2005). The atypical ribs - ribs 1, 2, 11 and 12 - are clearly distinguishable, but the typical ribs have similar features and are difficult to distinguish. Among the typical ribs, ribs 4 and 6 have been used to estimate age (Hoppa and Saunders 1998), although others have evaluated the histomorphometry of ribs 5, 7, and 11 for use in age estimation (Crowder and Rosella 2007). Studies of accurate numbering of the typical ribs have used the morphological method and metric method. Mann (1993) compared the second rib with all

Table 4. Discriminant function coefficients of ribs

Measurements		Standardized canonical discriminant function coefficients	Canonical discriminant function coefficients*	Sectioning point	Accuracy
AFTAL of all ribs	rib 4 (constant)	1.000	0.288 -9.194	-0.5	75.2%
HAFL of all ribs	rib 2 rib 7 (constant)	0.737 0.513	0.344 0.214 -12.669	-0.6	75.2%
SCTCH of all ribs	rib 2 rib 4 (constant)	0.656 0.529	0.517 0.368 -9.364	-0.9	86.1%
AFTAL +SCTCH of all ribs	SCTCH of rib 2 SCTCH of rib 4 SCTCH of rib 7 AFTAL of rib 3 AFTAL of rib 7 (constant)	0.637 0.622 -0.313 0.382 0.424	0.502 0.433 -0.186 0.101 0.086 -13.897	-1.2	89.1%
Ribs 2 to 4	SCTCH of rib 2 SCTCH of rib 4 HAFL of rib 2 AFTAL of rib 4 (constant)	0.476 0.437 0.465 0.474	0.375 0.304 0.213 0.136 -16.283	-1.2	88.1%

*Unstandardized coefficients.

other ribs. The metric method has been used recently to correctly sequence ribs (Hoppa and Saunders 1998, Owers and Pastor 2005). Hoppa and Saunders (1998) used two variables, the SCTCH and HAFL, on nineteenth-century Irish and English samples. Owers and Pastor (2005) devised three variables by adding the AFTAL to the two variables used by Hoppa and Saunders (1998) on eighteenth-century Parisian samples.

We studied the bilateral asymmetry of the ribs prior to taking measurements. Humans are unique among primates in terms of the magnitude of directional bilateral asymmetry exhibited in both use and size of the upper limbs, and in their tendency to favour the right side. Recent studies show that the right arm is more developed than the left (Čuk et al. 2001, Auerbach and Ruff 2006). İşcan and colleagues used the right fourth rib to establish age; other studies used the right side (İşcan et al. 1984a, b, İşcan et al. 1985, İşcan et al.

1987). Other studies noted that the ribs are not weight bearing and generally exhibit minimal side asymmetry in normal individuals (Dudar 1993, Crowder and Rosella 2007). We tried to test the rib data using the paired t test. According to these theories we found that the right ribs do not differ statistically from the left ribs ($p > 0.05$), and that sex did not affect the result. For this reason, we did not consider the side and sex of samples.

Our observed values are similar to those in other reports (Hoppa and Saunders 1998, Owers and Pastor 2005). However, our HAFL values (Fig. 4) are longer than those of Hoppa and Saunders (1998). Some ribs were larger than those reported by others except for AFTAL of ribs 2 to 4, as reported by Owers and Pastor (2005). AFTAL and SCTCH were more suitable for rib seriation using our equations. HAFL was similar for most ribs and weakly correlated to rib number. We tried to measure the three variables separately and combined

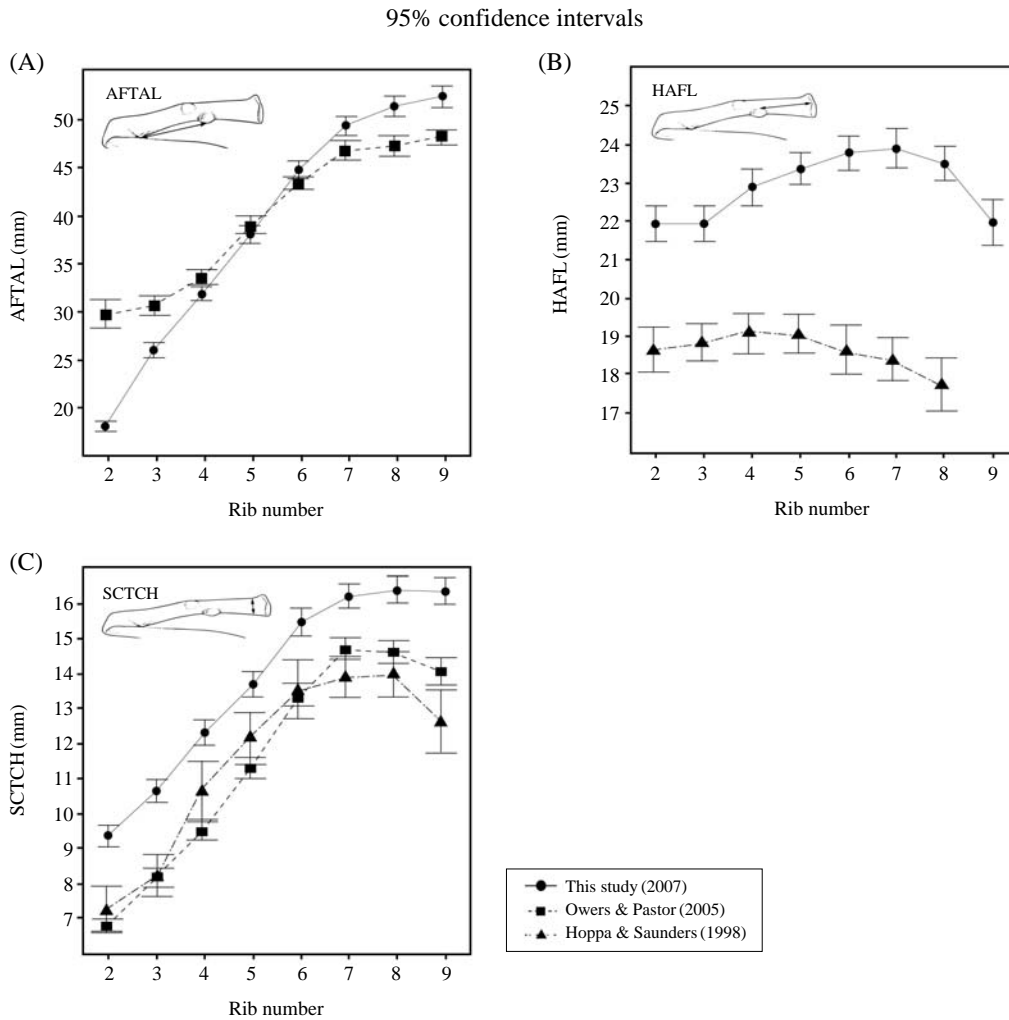


Fig. 4. Comparison of the results with those of other studies. A, articular facet of the tubercle-to-angle length (AFTAL); B, head-to-articular facet length (HAFL); C, superior costotransverse crest height (SCTCH).

and we found that AFTAL alone and AFTAL with SCTCH together were best for sequencing the ribs correctly. The regression equation showed adjusted R^2 values of 0.843 for AFTAL with SCTCH, which indicates that 76% of the ribs were seriated correctly.

Table 5 compares our data with those other studies. In our study, the adjusted R^2 was higher for AFTAL (0.871) than for SCTCH (0.678). In contrast, Hoppa

Table 5. Comparison of results from analysis of variance of measurements with those from other studies

	Hoppa R & Saunders S (1998)		Owers SK & Pastor RF (2005)		This study (2007)	
	<i>P</i>	R^2	<i>P</i>	R^2	<i>P</i>	R^2
AFTAL			<0.001	0.74	0.000	0.871
HAFL	—	—			0.000	0.08
SCTCH	<0.001	0.446	<0.001	0.83	0.000	0.678

Table 6. Comparison of the distribution of error of predicted rib sequence with those from other study

Error	AFTAL (Cum.%)		HAFL (Cum.%)		SCTCH (Cum.%)	
	Owers & Pastor (2005)	This study (2007)	Owers & Pastor (2005)	This study (2007)	Owers & Pastor (2005)	This study (2007)
0	49	79.0	27	11.5	55	47.8
1	81	94.8	57	30.4	80	77.8
2	92	99.3	74	48.3	93	89.6
3	95	99.8	85	59.7	98	95.9
4	98	100.0	92	74.0	99	98.3
5	98		97	88.0	99	99.4
6	99		99	95.8	100	99.0
7	100		100	100.0		100.0

Cum.%, Cumulative percentage of correctly seriated ribs.

and Saunders (1998) reported only SCTCH (adjusted $R^2=0.45$), and Owers and Pastor (2005) reported adjusted R^2 values of 0.74 for AFTAL and 0.83 for SCTCH. Our results show that AFTAL correlates highly with rib number in Koreans, whereas SCTCH appears to be more valuable than AFTAL in Europeans. The common feature in our data and those of other studies (Hoppa and Saunders 1998, Owers and Pastor 2005) is the reliability of using AFTAL and SCTCH for rib seriation. Table 6 shows the comparison of the distribution of predicted rib sequencing using the data of Owers and Pastor (2005) and our data. AFTAL was a good predictive variable for rib sequencing in both studies. In particular, the cumulative percentage of AFTAL in our study was 79%, which indicates high accuracy for the correct rib sequence. Our data and previous data suggest that, for identifying the correct rib sequence, AFTAL is the best variable in Koreans (78%) and SCTCH is the best variable in Europeans (55%). The ranking error comparison showed that rib 4 was correctly identified in 86% of cases using SCTCH in the Owers and Pastor study (2005). We correctly identified rib 4 in 94% of cases using ranked AFTAL values and AFTAL with SCTCH, and in 66% of cases using SCTCH alone. This suggests that the predicted rib sequencing and rib 4 are easier to distinguish in Koreans than in European when ribs are commingled.

Hoppa and Saunders (1998) measured two variables to examine nineteenth-century Irish and English samples and reported that SCTCH may provide an alternative technique for assessing rib sequence. Owers and Pastor (2005) measured three variables using eighteenth-century Parisian samples and found that the SCTCH and AFTAL traits are reasonably accurate for identifying the typical ribs. We measured three variables in modern Koreans and found that AFTAL was the best variable for correct rib sequencing. SCTCH in the ranked rib seriation was more accurate when used together with AFTAL than when used alone. We propose that the difference between our data and those of others reflects the differences in sample populations and periods. In addition, we used complete rib samples whereas others used complete and incomplete sets.

Owers and Pastor (2005) suggested that AFTAL and SCTCH were good variables for rib seriation. In this study, the cumulative percentage of AFTAL was 79% with an error of 0, and AFTAL with SCTCH was 75.7%. Rib 4 was correctly identified using ranked AFTAL values and AFTAL with SCTCH in 94% of cases. The accuracy of AFTAL with SCTCH was the highest of all the variables, suggesting that AFTAL and SCTCH are the best variable for rib seriation and sex determination.

The results of this and other studies can be used to

number ribs sequentially when the ribs are fragmented or poorly preserved. This method can be applied to Koreans and is probably more useful for identifying rib 4 and determining sex in Koreans than in Europeans. The mean values of HAFL and SCTCH are greater in Koreans than in Europeans, and these measures may be useful for differentiating between Koreans and Europeans. Our method also has the advantages of being simple and easy to use in the field and laboratory.

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양적 방법을 이용한 한국인 갈비뼈의 갈비뼈순서맞추기의 평가

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간추림 : 한국인 유골을 이용한 신원확인에서 갈비뼈순서맞추기는 시도된 적이 없었다. 정확한 갈비뼈순서맞추기는 갈비뼈 순서의 유추와 사망당시의 나이추정에 중요한 역할을 한다. 이 연구의 목적은 기존에 증명된 양적 방법을 이용하여 한국인 갈비뼈의 정확한 순서를 추정할 수 있는지 평가하는 것에 있다.

54명의 완벽한 갈비뼈들을 이용하여 3개의 항목을 계측하였다. 계측항목은 갈비뼈 결절의 관절면에서 갈비뼈각까지의 거리(AFTAL), 갈비뼈머리에서 관절면까지의 거리(HAFL), 그리고 위갈비가로능선높이(SCTCH)이다.

AFTAL과 SCTCH 항목이 갈비뼈순서를 추정하는 데 있어 HAFL 항목보다 더 유용하였으며 AFTAL 항목은 성별판별을 위한 판별식들 중 정확도가 높으며 가장 간단한 방정식을 만들 수 있었다. AFTAL 항목을 이용한 갈비뼈순서의 유추는 정확한 순서를 유추할 확률은 79%이었으며 갈비뼈순서 유추의 오류범위는 ± 4 이었다. 유럽인을 대상으로 한 다른 연구와 비교하면 한국인을 대상으로 한 연구결과가 더 정확도가 높았다. 이 연구에 사용된 넷째 갈비뼈의 정확한 유추는 AFTAL 항목과 AFTAL과 SCTCH 항목을 같이 사용하여 실시한 방법이 94%로 가장 높았다.

AFTAL 항목이 갈비뼈순서를 유추하는 데 있어 가장 정확도가 높았으며 SCTCH 항목의 경우 이 항목만을 이용한 경우보다 AFTAL 항목을 같이 사용하는 경우가 정확도가 높았다. 이러한 높은 정확도와 유추력은 한국인의 갈비뼈순서맞추기에 양적 방법이 유용하다는 것을 알 수 있다.

찾아보기 낱말 : 갈비뼈순서맞추기, 전형적인 갈비뼈, 성별판별, 양적 방법, 한국인