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Correlation between the Postmortem Stature and the Dried Limb-Bone Lengths of Korean Adult Males

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The postmortem stature was measured in 57 Korean adult males (age range: 20~86 years old, mean: 52.3 years old) in supine position. After dissection of the corpses, we measured the maximum length of the remaining limb-bones (humerus, radius, ulna, femur, tibia and fibula). The correlation coefficients between the stature and each limb-bone length were calculated. Simple regression equations for estimating stature from each limb-bone length and multiple regression equations from the combination of limb-bone lengths were also obtained.

Key Words: Dried limb-bone, stature, correlation coefficient, regression equation, simple regression, multiple regression, Koreans

Human limb-bones have been used for stature estimation in forensic fields since the 19th century. Numerous reliable regression equations have been developed by the previous investigators on various populations (Stevensen, 1929; Breitinger, 1938; Stewart, 1940; Telkkä, 1950; Dupertuis and Hadden, 1951; Trotter and Gleser, 1952a, 1952b; Keen, 1953; Allbrook, 1961; Genoves, 1967; Trotter and Gleser, 1977). Populations on which these equations were based, included European-Caucasian, American-Caucasian, African-American, Africans, Mesoamericans and a heterogeneous group of Mongolians.

Limb-bone length is not the only useful information for stature estimation. Other bones, such as metacarpal bones (Musgrave and Harneja, 1978), fragmented limb-bones (Steel and McKern, 1969), clavicle (Singh and Sohal, 1952; Jit and Singh, 1956) and scapula (Olivier and Pineau, 1957) were investigated for the same purpose. Particularly, radiographically measured metacarpal bone length is used for estimating children's stature as well as adults' (Himes *et al.* 1977). But limb-bone equations are still the most commonly used in stature estimation.

For Koreans, there have been several equations for estimating stature, but they were based on radiological data. In forensic fields, these equations or other populations' equations are still used for personal identification. The aim of this study was to

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obtain simple and multiple regression equations for estimating the stature of Korean adult males using the postmortem statures and each dried limb-bone length (humerus, radius, ulna, femur, tibia and fibula).

MATERIALS AND METHODS

The statures of 57 Korean male cadavers at the Department of Anatomy, Yonsei University College of Medicine, Seoul, Korea, were measured in the supine position with a scaled strap to the nearest 0.1 cm. After measuring, the dissections were performed. The remaining limb-bones were gathered in dried states. On an osteometric board, the maximum lengths of the humerus, radius, ulna, femur, tibia and fibula were measured three times each to the nearest 0.1 cm.

The ages of the subjects ranged from 20-86 years (mean 52.3, standard deviation 16.6); and statures ranged from 147-178 cm (mean 163.1, standard deviation 7.1). The statistical methods used in this paper were as follows: paired t-test for the comparison of right and left limb-bone length; linear regression analysis for estimating stature; and analysis of variances (ANOVA) for comparison of the estimates from different equations. The statistic package used was SPSS.

RESULTS

There was no statistical significance in the differences between right and left limb-bone length based on paired t-test (Table 1).

Since there was no statistical significance in the differences between right and left bone length, regression analysis was performed with right bone length only. Table 2 shows the results of simple regression analysis for estimating stature using each limb-bone as an independent variable. The regression coefficients of all limb-bone lengths proved to be statistically significant ($p<0.01$). Among the measured lengths, the maximum femur length showed the largest R-square and F-ratio (Table 2).

ANOVA was performed for the comparison of 5 different stature estimates including the estimates obtained from this study. Differences between the stature estimates were shown to be statistically

Table 1. Comparison between the right and left limb-bone length

Limb-bones	No. of cases	Means	SD	Minimum	Maximum
Humerus					
Right	44	30.2	1.2	27.4	32.5
Left	44	30.1	1.2	27.3	32.1
Radius					
Right	40	22.9	1.3	19.6	24.8
Left	40	23.0	1.3	19.9	24.9
Ulna					
Right	43	24.6	1.3	21.0	26.7
Left	43	24.7	1.3	21.3	26.7
Femur					
Right	49	43.2	1.9	39.6	48.3
Left	49	43.1	1.9	39.5	48.2
Tibia					
Right	44	35.2	2.1	31.5	39.5
Left	44	35.2	2.0	31.4	39.4
Fibula					
Right	42	34.3	1.9	31.1	37.3
Left	42	34.3	1.9	31.2	37.3

unit: cm, No.: number, SD: standard deviation significant (P<0.01). Among the limb-bone lengths, maximum humerus length was the variable which showed the highest F-ratio. Mean absolute differences (MAD) of limb-bones (estimated statures minus observed statures) were smallest in Koreans, except those of the radius and tibia. This shows that the estimates obtained from this study were the most accurate for Koreans (Table 3).

Table 2. Simple regression equations on each limb-bone length

	N	S	R-square	F-ratio
Humerus	44	4.30×H*+33.32±4.92	0.51	43.7*
Radius	40	3.89×R*+74.12*±4.62	0.54	44.7*
Ulna	43	3.74×U*+70.78*±4.97	0.51	42.5*
Femur	49	2.93×F*+36.88**±3.96	0.67	94.1*
Tibia	44	2.54×T*+73.38*±4.23	0.61	64.9*
Fibula	42	2.55×FB*+74.49*±4.23	0.58	55.6*

unit: cm, N : cases, * : $p < 0.01$, ** : $p < 0.001$
S: estimated stature, H: maximum humerus length
R: maximum radius length, U: maximum ulna length
F: maximum femur length, T: maximum tibia length
FB: maximum fibula length

Table 3. Comparison of the stature estimates between the different regression equations (simple regression)

Limb bones (No. of cases)	Authors(1997)	Pearson (1898)	Trotter and Gleser (1952a)			F-ratio
	Koreans	European Whites	American Whites	Mongolians	American Blacks	
Humerus (44)	163.05 (3.89)	157.83 (6.13)	165.16 (4.29)	164.05 (4.24)	62.66 (4.19)	26.0**
Radius (40)	162.99 (3.79)	160.63 (4.13)	165.75 (4.40)	162.87 (3.77)	161.17 (3.96)	7.9**
Ulna (43)	162.91 (3.95)	--	165.74 (4.60)	163.17 (3.95)	160.88 (4.32)	4.5**
Femur (49)	163.51 (3.22)	162.56 (3.49)	166.04 (4.24)	165.49 (3.98)	163.20 (3.35)	5.9**
Tibia (44)	162.78 (3.73)	162.43 (3.36)	167.27 (5.17)	165.57 (4.17)	162.57 (3.41)	8.9**
Fibula (42)	161.84 (3.11)	--	164.61 (3.89)	162.77 (3.15)	159.81 (3.69)	3.6**

unit: cm, No.: number, ( ) : mean absolute difference (MAD)
** : $p < 0.01$ on ANOVA

Correlation coefficients were also obtained from the stature and each limb-bone length to analyze the relationship between the bone lengths and to select independent variables for estimating the stature. All the correlation coefficients were above 0.6 ($p<0.05$). Among the correlation coefficients for all limb-bone lengths, those of the radius and ulna were the largest; whereas the smallest were those of the humerus and fibula. It was noted that the correlation coefficients of lower limb-bone length with stature were larger than that of upper limb-bone length (Table 4).

Multiple regression analysis on estimating the stature was performed using the combination of

Table 4. Correlation coefficients between the stature and each limb-bone length

	S	H	R	U	F	T	FB
S	1.00	0.72	0.72	0.71	0.80	0.77	0.76
H		1.00	0.87	0.87	0.76	0.72	0.65
R			1.00	0.99	0.78	0.81	0.74
U				1.00	0.77	0.81	0.76
F					1.00	0.83	0.81
T						1.00	0.93
FB							1.00

cases: 40, all correlation coefficients: $p<0.05$
S: stature, H: maximum humerus length, R: maximum radius length
U: maximum ulna length, F: maximum femur length
T: maximum tibia length, FB: maximum fibula length

Table 5. Regression equations from the combination of limb-bone lengths (multiple regression)

limb bones	S	R-square	F-ratio
H-F	$2.21 \times F^{*} + 1.73 \times H^{**} + 16.08 \pm 3.84$	0.72	49.8*
H-R-F-T	$1.86 \times H - 0.48 \times R + 1.49 \times F + 1.21 \times T + 17.53 \pm 4.09$	0.72	14.2*
H-R-F	$1.60 \times H + 0.52 \times R + 2.15 \times F + 10.32 \pm 3.92$	0.72	23.9*
H-R-T	$2.01 \times H - 0.47 \times R + 2.30 \times T^{*} + 32.21 \pm 4.19$	0.69	19.7*

unit: cm, *: $p < 0.05$, **: $p < 0.01$, S: estimated stature
H: maximum humerus length, R: maximum radius length
F: maximum femur length, T: maximum tibia length

Table 6. Comparison between estimated statures from the combinations of limb-bone lengths in 4 populations (multiple regression)

Authors (1997) Korean		Pearson (1898) Europe whites	Dupertuis and Hadden (1951) American whites	Dupertuis and Hadden (1951) American blacks	
H-F	H-R-F-T	H-R-F-T	H-R-F-T	H-R-F-T	F-ratio
162.98 (2.97)	163.08 (2.87)	159.98 (4.61)	167.58 (5.18)	163.27 (3.30)	26.0**

unit: cm, ( ): mean absolute difference (MAD)
H-F: estimated stature from the combination of humerus and femur
H-R-F-T: estimated stature from the combination of humerus, radius, femur and tibia
** : $p < 0.01$ on ANOVA

limb-bone lengths as independent variables. As seen in Table 5, the model using the combination of femur and humerus length was the most accurate in estimating stature. The multiple regression analysis using the combination of 4 limb-bone lengths (humerus, radius, femur and tibia) was performed to compare this result with previous studies, and ANOVA was performed with the 5 estimates of statures; 2 estimates from this study and 3 estimates from different populations. There were statistically significant differences among them. While the MAD was the smallest for the estimates using the combination of humerus, radius, femur and tibia, this model was not statistically significant. Thus the estimates using humerus and femur lengths seemed to be the most accurate model (Table 6).

DISCUSSION

Ever since Pearson (1898) has estimated height from limb-bones, many regression equations of stature estimation have been developed. The measuring methods and bones used to obtain the regression equations of each previous investigators were different as follows: The maximum lengths of humerus, femur, tibia and fibula, and the physiologic lengths of radius and ulna were measured (Telkkä, 1950); The maximum lengths of humerus, ulna, tibia and femur were measured (Dupertuis and Hadden, 1951); The regression formulas from the data of the maximum lengths of humerus, radius, ulna, femur, tibia, the oblique length of femur, and the interarticular length of tibia were induced (Trotter and Gleser, 1952b); The remarkable differences were found among the estimated statures from the various human populations due to racial differences (Keen, 1953; Genoves, 1958).

According to this study and others, there were the racial differences in adult mean heights and limb-bone lengths between populations. For example, the mean height of Korean adult males was greater than that of Mexicans (Romero, 1952). Each limb-bone length was smaller than that of American Whites (Trotter and Gleser, 1952a). And the correlation coefficients of all the limb-bone lengths were less than those of American Whites (Appendix). Therefore, to compare the regression equations, the equations induced from the same population as the subject should be chosen.

To obtain the stature estimations, multiple regression analysis which utilized the combination of bone lengths was used as well as simple regression analysis. When the multiple regression analysis method is applied to the data with large correlation coefficients, the inevitable problem of multicollinearity arises (Afifi and Clark, 1990a). To prevent this problem, the other commonly used method is to either use the data which have low correlation coefficients or alter the data used (Afifi and Clark, 1990b). In this study, we chose the data with rela-

Appendix. Correlation coefficients between stature and each limb-bone length of American whites

	S	HR	RR	UR	FR	TR	FBR
S	1.00	.78	.72	.75	.87	.86	.86
HR			.77	.79	.85	.82	.82
RR				.91	.73	.80	.81
UR					.76	.83	.85
FR						.87	.87
TR							.96
FBR							
Mean	173.9	33.6	25.2	27.1	47.2	37.8	38.1
SD	6.6	1.7	1.3	1.3	2.4	2.2	2.1

Trotter and Gleser (1952a, cases: 545), unit: cm, S: stature
SD: standard deviation, S: stature, HR: right maximum humerus length
RR: right maximum radius length, UR: right maximum ulna length
FR: right maximum femur length, TR: right maximum tibia length
FBR: right maximum fibula length

tively low correlation coefficients to induce the regression equation since all correlation coefficients were above 0.7 (Table 4). We first chose the data with the highest correlation coefficients to the stature of the subjects. Then we performed multiple regression analysis with the data which had the relatively small correlation coefficients to the previously selected data. After considering the statistical significances of the coefficients of the determination (R-squares) and F-values, we were able to induce the 4 appropriate equations (Table 5).

Comparison of the coefficients of the determination (R-squares) obtained from simple regression analysis and the coefficients of the determination (R-squares) from multiple regression analysis showed that R-squares from the simple regression analysis were smaller than those of multiple regression analysis (Table 2,5). This in turn showed that the combination of bone lengths is preferable in stature estimation than the length of a single bone. The length of a single bone, however, can be a viable datum in stature estimation using a respective equation, provided that the coefficient of determination is factored in (Table 2).

It was determined that the coefficients of determination were not so high and were statistically insignificant in this study. And we investigated the regression which used the combination of four categories (humerus, radius, femur and tibia) for the purpose of comparing the results from different population subjects. In this equation, MAD was lower than the equation using two categorical combinations (humerus and femur). Of the compared estimated statures, that of American Whites was found to be most deviant from the stature of Koreans (Table 6).

In conclusion, we found that the differences of measured statures and the statistically determined statures were the lowest in the equation formulated for this paper. It was noted that the regression equations in this study would be more reliable to use for a Korean adult male than any other foreign regression equations. We could not formulate the regression equations of Korean females since there were not enough dried limb-bones to make equations. In the future, we will collect the dried limb-bones of Korean females and make regression equations and perform sex comparisons.

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