

Sex determination using upper limb bones in Korean populations

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Abstract: The purpose of this research is to establish metric standards for the determination of sex from the upper limb bones of Korean. We took a set of eleven measurements on each of 175 right sides of adult skeletons chosen at Korean sample. Classification accuracy dropped only one or two individuals when only vertical head diameter of humerus is used. Variables in relation with maximal length were less accurate than head diameter of humerus. Two variables were selected by the stepwise procedure: maximal length of humerus, vertical head diameter of humerus. The combined accuracy was 87%. This study of modern Korean skeletons underscores the need for population-specific techniques, not only for medicolegal investigations, but also for the study of population affinities and factors affecting bone configurations.

Key words: Sex determination, Upper limb bone, Partial measurements, Korean

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Introduction

Sex determination of unidentified skeletal remains from crime scenes or excavation sites is an important component for identification in forensic anthropology. Of the human skeleton, the humerus often remains in good condition and is especially favorable for metric sex determination [1]. The length of the humerus, among the long bones of the human body, is a good predictor, but the vertical head diameter of this bone is also an accurate predictor of gender [2, 3]. For this reason, numerous studies and metric methods have emerged from upper limb bones (ULB) with humerus analyses based in Varanasi [4], prehistoric central California [1], the Terry

collection [5], China, Japan, Thailand [6], South Africa [7, 8], Spain [9], Germany [10], Guatemala [11], the Dart collection [11, 12], the island of Crete [2, 13, 14], Chile [3], Turkey [15], Greece [16], America [17], and the Eastern Adriatic coast [18]. Non-metric studies involving the ULB have also been performed in Canada [19] and Japan [20].

Interestingly, the size of the ULB varies distinctly by regional population. For example, humerus lengths are different between the European and American populations. Asians, too, have been shown to exhibit significant regional differences [6]. Within various Asian populations, the discriminant value of humerus size has been determined for the Chinese, Japanese, and Thai populations [6]. However, humerus, radius, and ulna values have yet to be determined for the Korean population. Sex determination reports have been published for the pelvic bone [21], skull [22, 23], corpus callosum [24, 25], hyoid bone [26], thyroid cartilage [27], and mandible [28, 29] in Korean sample populations.

Involving only fragmentary or incomplete remains, sex can be determined by quantitative metric analysis, although

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with somewhat lower accuracy. Additionally, the ULB unearthed in the forensic field are often fragmented. Thus, the discriminating values from such ULB have been derived from not only complete bone, but also fragmented humeri in Korea. Therefore, the purpose of this research is to establish accurate metric standards for sex determination based on humerus, radius and ulna measurements in the Korean population, as well as to compare the size and sexual dimorphism to studies from other regions.

Materials and Methods

The ULB lengths and partial bone lengths were measured for 175 right side of adult Korean cadavers (100 men, 75 women) between 42 to 95 years of age (mean, 72.2 years; standard deviation, 13.7 years). The ULB were removed from fresh cadavers. Articulate cartilage was removed using a surgical knife. No bones with obvious pathologies or healed fractures were included, and all measurements were taken using an osteometric table (EGO, Seoul, Korea), digital calipers (Mitutoyo, Tokyo, Japan) and measuring tape (Komelon, Busan, Korea) (Fig. 1).

Eleven variables were taken: maximum length of clavicle includes distance between acromial end and sterna end, circumference at middle of shaft of clavicle (CMS), maximum length of humerus includes distance between trochlea and the proximal extremity of humeral head (MLH), maximum diameter of humeral head (MDH), epicondylar breadth of humerus (EB), condylar breadth of humerus, transverse diameter of humeral head (TDH), vertical diameter of humeral head (VDH), maximum length of radius includes

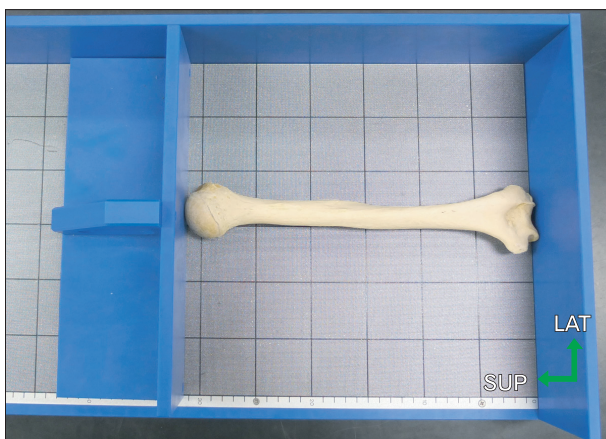


Fig. 1. The measurement method using osteometric table. LAT, lateral; SUP, superior.

distance between styloid process and the proximal extremity of radial head, maximum length of ulna includes distance between styloid process and the proximal extremity of ole-

Table 1. The measurement of humerus, radius and ulna

Variable	Measurement
MLC	Maximum length (clavicle)
CMS	Circumference at midshaft (clavicle)
MLH	Maximum length (humerus)
MDH	Maximum diameter of head (humerus)
EB	Epicondylar breadth (humerus)
CB	Condylar breadth (humerus)
TDH	Transverse diameter of head (humerus)
VDH	Vertical diameter of head (humerus)
MLR	Maximum length (radius)
MLU	Maximum length (ulna)
LCSU	Least circumference of shaft (ulna)

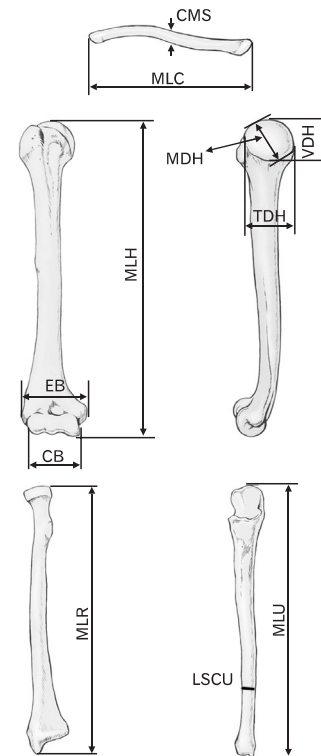


Fig. 2. Variables used for sex determination. CB, condylar breadth of humerus; CMS, circumference at middle of shaft of clavicle; EB, epicondylar breadth of humerus; LCSU, least circumference of ulna shaft; MDH, maximum diameter of humeral head; MLC, maximum length of clavicle includes distance between acromial end and sterna end; MLH, maximum length of humerus includes distance between trochlea and the proximal extremity of humeral head; MLR, maximum length of radius includes distance between styloid process and the proximal extremity of radial head; MLU, maximum length of ulna includes distance between styloid process and the proximal extremity of olecranon; TDH, transverse diameter of humeral head; VDH, vertical diameter of humeral head.

cranon, least cricumference of ulna shaft (LCSU) (Table 1, Fig. 2).

Statistical analysis was performed using SPSS ver. 17.0 (SPSS Inc., Chicago, IL, USA) for Windows. Means and standard deviations of the results of individual factors were calculated and statistically analyzed to identify any significant differences.

Results

Table 2 represents the mean length and standard deviation

Table 2. Means±SD of measured variables

Variable	Male	Female
MLC	151.5±9.4	138.2±10.5
CMS	39.0±0.4	34.0±0.4
MLH	302.7±16.7	277.9±15.1
MDH	45.4±2.6	40.7±2.5
VDH	45.2±2.7	40.2±2.4
TDH	42.1±2.3	38.5±2.7
EB	59.3±4.3	54.5±3.3
CB	42.2±2.8	38.0±2.4
MLU	247.7±13.4	225.9±14.2
LCSU	36.0±0.4	33.0±0.3
MLR	231.1±14.6	207.5±12.3

Values are presented as mm. MLC, maximum length of clavicle; CMS, circumference at middle of shaft of clavicle; MLH, maximum length of humerus; MDH, maximum diameter of humeral head; VDH, vertical diameter of humeral head; TDH, transverse diameter of humeral head; EB, epicondylar breadth of humerus; CB, condylar breadth of humerus; MLU, maximum length of ulna; LCSU, least cricumference of ulna shaft; MLR, maximum length of radius.

Table 3. Demarking point separating males from females

Variables	Demarking point (mm)	Wilks' Lambda	F-ratio	Significance
MLC	F<144.3<M	0.722	44.946	0.000
CMS	F<39.0<M	1.000	0.001	0.971
MLH	F<289.5<M	0.652	70.393	0.000
MDH	F<43.0<M	0.569	100.049	0.000
VDH	F<42.7<M	0.547	109.264	0.000
TDH	F<40.3<M	0.666	66.086	0.000
EB	F<56.8<M	0.754	43.447	0.000
CB	F<40.1<M	0.639	76.250	0.000
MLU	F<236.6<M	0.635	73.537	0.000
LCSU	F< 35.0<M	0.841	24.238	0.000
MLR	F<219.6<M	0.609	80.909	0.000

MLC, maximum length of clavicle; F, female; M, male; CMS, circumference at middle of shaft of clavicle; MLH, maximum length of humerus; MDH, maximum diameter of humeral head; VDH, vertical diameter of humeral head; TDH, transverse diameter of humeral head; EB, epicondylar breadth of humerus; CB, condylar breadth of humerus; MLU, maximum length of ulna; LCSU, least cricumference of ulna shaft; MLR, maximum length of radius.

of Korean ULB for each of the given variables. All of the values were larger for males than for females, and these differences were statistically significantly. The absolute values for all variables ranged from 3.0 mm to 24.8 mm between males and females.

Table 3 presents the discriminant function coefficient of the ULB dimensions for the Korean sample. The functions are displayed based on a single variable. Females are indicated when the discriminant score is lesser than the demarcation point, and males are indicated when the discriminant score is higher. For example, a VDH size of 45 mm would be identified as a male because the diameter is greater than the 42.7 mm function coefficient.

In Table 4, the accuracy of sex determination for the ULB size is represented. In general, the value for humerus breadth was a better predictor than the value of humerus length. The best predictor for sex determination is VDH (87.0%) and the worst predictive value is CMS (60.3%). Specifically, the variables for humeral head including (MDH, VDH, and TDH) were predictive for sex.

Table 5 depicts a stepwise discriminant analysis of the variables for MLH and VDH. The cutoff point was set to zero. If the product of the predictor variable and its coefficient are added to the constant and yield a value of >0, the individual is classified as male, whereas a sum of <0 indicates a female.

Discussion

Forensic experts are often faced with a single specimen

Table 4. Percentage of correctly classified cases

Variable	Correctly classified (%)		
	Male	Female	Average
MLC	84.7	56.3	75.3
CMS	59.2	62.5	60.3
MLH	85.7	70.8	80.8
MDH	86.7	79.2	84.2
VDH	89.8	81.3	87.0
TDH	84.7	79.2	82.9
EB	77.6	68.8	74.7
CB	83.7	81.3	82.9
MLU	83.7	77.1	81.5
LCSU	70.4	72.9	71.2
MLR	86.7	72.9	82.2

MLC, maximum length of clavicle; CMS, circumference at middle of shaft of clavicle; MLH, maximum length of humerus; MDH, maximum diameter of humeral head; VDH, vertical diameter of humeral head; TDH, transverse diameter of humeral head; EB, epicondylar breadth of humerus; CB, condylar breadth of humerus; MLU, maximum length of ulna; LCSU, least cricumference of ulna shaft; MLR, maximum length of radius.

from which he or she must draw conclusions about the specimen's origin. In some cases, it may even be necessary to establish whether remains belong to a specific person when the identity is suspected based on circumstantial evidence. Multiple studies have shown that the ULB is a useful bone for metric sex determination. Such studies also demonstrate the differences in ULB dimensions between populations, potentially resulting from environmental factors such as nutrition, physical development, and genetic factors [11]. Our study is important because it is the first to analyze sex-specific differences in a Korean population sample.

Previous studies indicate that there are population differences between our Korean sample and other populations. The mean lengths of all variables were similar among the different Asian populations. However, Asian ULB sizes are generally smaller than most other populations, with the exception of Guatemala (Table 6). The MLH study from Steyn and Iscan [7] used a South African white sample population

whose dimensions (335.0 mm in males and 309.0 mm in females) are larger than that of Koreans by approximately 32.0 mm in both sexes. The t-test showed that all measurements used in the present study were significantly higher in men than in women ($P < 0.05$) (Table 6).

A comparison of the results of the present study with those from other studies' skeletal long bones demonstrates that the same variables are especially valuable. In the LCSU, Spain [9] attained 91.1% accuracy, while our study achieved 60.3% accuracy. Thus, LCSU is a better predictor of sex in the Spanish study sample than the Korean sample (Table 7).

In the other studies, the classification rate is variable: 79.5–89.5% in Prehistoric Central California; 77.9–93.3% in Chinese, Japanese, and Thai populations; 84.0–91.0% in South African white and black populations; 80.6–90.4% in Germans; 83.0–95.5% in Guatemalans; 85.1–89.9% in Cretans; 87.0% in Chileans; and 74.7–87.0% in Koreans. The general effective single variables, as determined by direct discriminant analysis

Table 5. Stepwise discriminant function analysis

Discriminant equation	Sectioning point	Significance
$0.024 \times \text{MLH} + 0.288 \times \text{VDH} - 19.741$	0	0.000

MLH, maximum length of humerus; VDH, vertical diameter of humeral head.

Table 7. Comparison Safont et al. [9] with this study about percentage of correctly

	Percentage of correctly classified (%)	
	Safont et al. [9]	Present study (2013)
LCSU	91.1	60.3

LCSU, least circumference of ulna shaft.

Table 6. Comparison mean length of each variables with other studies

	Population	MLH		EB		TDH		VDH		MLR		MLU	
		M	F	M	F	M	F	M	F	M	F	M	F
Singh and Singh [4]	Varanasi	313.9	279.8	61.4	52.7	-	-	-	-	-	-	-	-
Dittrick and and Suchey [1]	Prehistoric Central California	324.1	304.0	62.2	56.4	43.6	38.7	47.0	41.7	-	-	-	-
Holman and Bennett [5]	Terry collection	329.12	302.18	-	-	-	-	-	-	248.2	227.8	265.5	245.0
Iscan et al. [6]	China	313.7	283.6	60.4	52.3	-	-	44.9	39.7	-	-	-	-
	Japan	297.4	276.9	59.8	52.1	-	-	44.1	39.1	-	-	-	-
	Thai	300.6	278.9	60.3	52.1	-	-	44.4	38.2	-	-	-	-
Steyn and Iscan [7]	South African	335.0	309.0	64.3	55.9	-	-	-	-	-	-	-	-
	White												
	South African Black	328.0	294.0	61.4	53.3	-	-	-	-	-	-	-	-
Mall et al. [10]	German	334.0	307.0	66.0	58.0	-	-	50.0	44.0	246.0	220.0	265.0	238.0
Rio Frutos [11]	Guatemala	298.8	271.2	58.3	49.3	-	-	43.4	37.4	-	-	-	-
Barrier and L'Abbe [12]	South African	-	-	-	-	-	-	-	-	255.7	240.0	273.8	249.2
Kranioti and Michalodimitrakis [14]	Cretan	321.3	293.4	61.7	54.4	-	-	46.4	41.2	-	-	-	-
Charisi et al. [16]	Greece	327.1	297.5	61.5	53.5	-	-	47.6	40.8	240.6	212.8	261.8	230.0
Basic et al. [18]	Eastern Adriatic Coast	328.0	304.2	63.5	56.7	-	-	46.9	41.7	-	-	-	-
Present study (2013)	Korea	302.7	277.9	59.3	54.5	42.1	38.5	45.2	40.2	231.1	207.5	247.7	225.9

MLH, maximum length of humerus; EB, epicondylar breadth of humerus; TDH, transverse diameter of humeral head; VDH, vertical diameter of humeral head; MLR, maximum length of radius; MLU, maximum length of ulna; M, male; F, female.

Table 8. Comparison of percentage of sex determination with single measurements

		TDH	VDH	EB	MLH	MLU	MLR
Dittrick and Suchey [1]	Prehistoric Central California	89.5	89.0	85.2	79.5	-	-
Iscan et al. [6]	Chinese	-	80.5	77.9	-	-	-
	Japanese	-	87.3	89.9	-	-	-
	Thai	-	90.4	93.3	-	-	-
Steyn and Iscan [7]	South African White	-	84.0	89.0	-	-	-
	South African Black	-	91.0	88.5	-	-	-
Mall et al. [10]	German	-	90.4	88.5	80.6	87.0	89.1
Rios Frutos [11]	Guatemalan	-	95.5	91.1	83.0	-	-
Kranioti and Michalodimitrakis [14]	Cretan	-	89.9	85.1	85.1	-	-
Ross and Manneschi [3]	Chile	-	87.0	-	-	-	-
Present study (2013)	Korean	82.9	87.0	74.7	80.8	81.5	82.2

Values are presented as percentage. TDH, transverse diameter of humeral head; VDH, vertical diameter of humeral head; EB, epicondylar breadth of humerus; MLH, maximum length of humerus; MLU, maximum length of ulna; MLR, maximum length of radius.

Table 9. Comparison of demarking point with other studies

	Population	MLH	VDH	EB
Iscan et al. [6]	Chinese		F<42.60<M	F<56.80<M
	Japanese		F<41.90<M	F<56.40<M
	Thai		F<42.40<M	F<57.50<M
Steyn and Iscan [7]	South African White		F<46.04<M	F<60.06<M
	South African Black		F<40.74<M	F<57.46<M
Kranioti and Michalodimitrakis [14]	Cretan	F<307.39<M	F<43.79<M	F<58.03<M
Basic et al. [18]	Eastern Adriatic Coast	F<247.00, 385.00<M	46.00<M	F<53.00, 65.00<M
Present study (2013)	Korean	F<289.5<M	F<42.70<M	F<56.80<M

MLH, maximum length of humerus; VDH, vertical diameter of humeral head; EB, epicondylar breadth of humerus; F, female; M, male.

of all population, were VDH and EB except EB of Korea. Additionally, these 2 variables were significantly different between populations (Table 8).

The demarcation points of South African whites were bigger than those determined by other studies. However, the demarcation points of the Eastern Adriatic Coast sample were similar. These differences between populations could be the result of environmental factors affecting bone growth, such as nutrition, physical development, or genetic factors (Table 9).

In conclusion, we describe a specific standard for sex determination in the Korean population using ULB. This study of modern Korean skeletons underscores the need for population-specific techniques, not only for medicolegal investigations, but also for the study of population-specific attributes and factors affecting bone characteristics.

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