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TECHNICAL NOTE

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Morphometrics of the Hyoid Bone for Human Sex Determination from Digital Photographs*

ABSTRACT: The identification of unknown remains is very important. When unknown remains are found, anthropologists first determine their sex and age. The sex of most skeletons is determined by their shape. In the hyoid bone, the shape is sex related, so it can be used forensically to determine the sex. This study focused on sex-based morphometry of the hyoid bone in Koreans using digital photographs. Hyoid bones from 52 males and 33 females were examined. For each subject, we took 34 measurements from photographs using a computer program, and the data were analyzed statistically using SPSS 11.0. Twenty-one of 34 measurements had significant sex differences ($p < 0.05$). The discriminant functions based on three measurements ($X_1 - X_3$) were as follows:

$$D = 0.238 \times X_1 + 0.571 \times X_2 + 0.191 \times X_3 - 10.734$$

The accuracy of discriminant functions is 88.2% in both groups, so these can be used to distinguish males from females in a statistically significant manner.

KEYWORDS: forensic science, hyoid bone, sex determination, morphometrics, Korean

The hyoid bone is a solitary bone that has no bony articulations but provides attachment for muscles, ligaments, and fascia of the pharynx, mandible, and cranium (1).

When a forensic anthropologist initially studies the remains of an individual, the first consideration is whether the remains are human, but determination of the sex of the individual is also an important early step. There are two major methods of sex determination: metric and nonmetric. Metric analysis, which is more precise than morphological analysis and provides statistical weight, is advantageous for forensic anthropologists who are new to the field (2).

In forensic medicine, the hyoid bone is studied for evidence of strangulation or hanging, which causes fractures. Recent studies on the shape, size, variation, and sex determination of the hyoid bone mainly used radiography and attempted to use discriminant analysis (3–6). In Korea, Chang used metric and nonmetric analysis of the hyoid bones of Koreans, and compared the result with other population groups (7).

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In this study, we measured photographs of the hyoid bones and performed discriminant analysis for sex determination after extracting the hyoid bones from cadavers used for educational purposes.

Materials and Methods

The hyoid bones of 85 Korean cadavers (52 males and 33 females) of known sex and age were extracted. The mean age of the cadavers at death was 52 years: 50.6 years for males and 54.2 years for females (Table 1).

Weights of the hyoid bones were measured using an electrical digital balance after we had carefully separated the hyoid bone from the thyroid cartilage and removed adherent tissue. We then took 33 measurements using a computer program (V-Ceph Version 3.0, Cybermed, Korea) following photography with a digital camera (COOLPIX 995, Nikon, Japan; Fig. 1).

The hyoid bone was placed on a black background and photographed from superior–inferior and the front at a distance of 55 cm (Fig. 2).

TABLE 1—*Age and sex distribution of samples.*

Age in Year	Males	Females
21–30	5	4
31–40	6	7
41–50	13	7
51–60	14	3
61–70	11	1
71 and over	3	11
Total	52	33

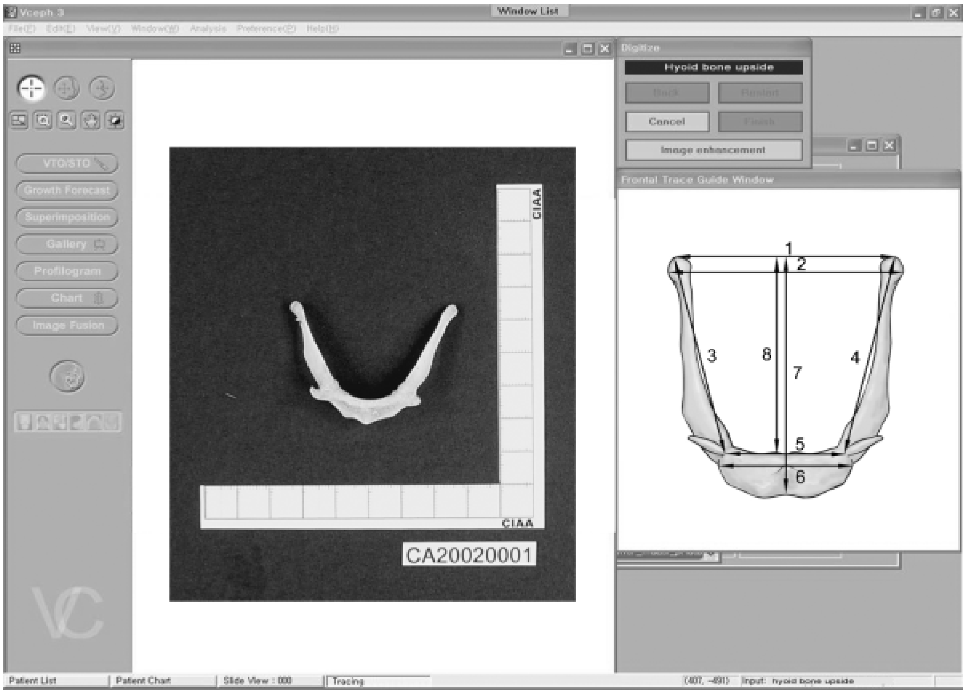

FIG. 1—*Captured image of the hyoid bone.*

After photography, 33 measurements, based on Miller et al. (4), were taken. These consisted of 21 lengths, seven widths, and five angles (Figs. 3–5, Tables 2–4).

The data were subjected to direct discriminant analysis using an SPSS (version 11.0, SPSS Inc., Chicago, IL) subroutine package.

Results

Male hyoids were larger than females in 21 of 34 measurements ($p < 0.05$). The mean weight was 2.2 g in males and 1.3 g in females ($p < 0.001$; Table 5).

The individual measurements are shown in Table 6. The second measurement showed the most prominent sex difference and the 33rd measurement showed the least. Twenty of the 33 measurements showed statistically significant sex differences by independent sample *t*-tests. These consisted of 13 length measurements, four width measurements, and three angle measurements (Table 6).

First, the variable that sets the Wilk's λ at a minimum is selected using stepwise statistics. Each step was statistically significant at $p = 0.000$. These variables consist of three measurements: the distance from the midpoint of the left side of the hyoid body to the midpoint of the right side of the hyoid body measured through its central axis (sixth measurement), the maximum width of the proximal end of the greater horn measured perpendicularly to the internal surface of the bone on the left (15th), and the length from the narrowest segment of the greater horn to a point equidistant between the distal and proximal ends of the greater horn measured through the central axis of the greater horn on the right (20th). Standardized canonical discriminant function coefficients of each

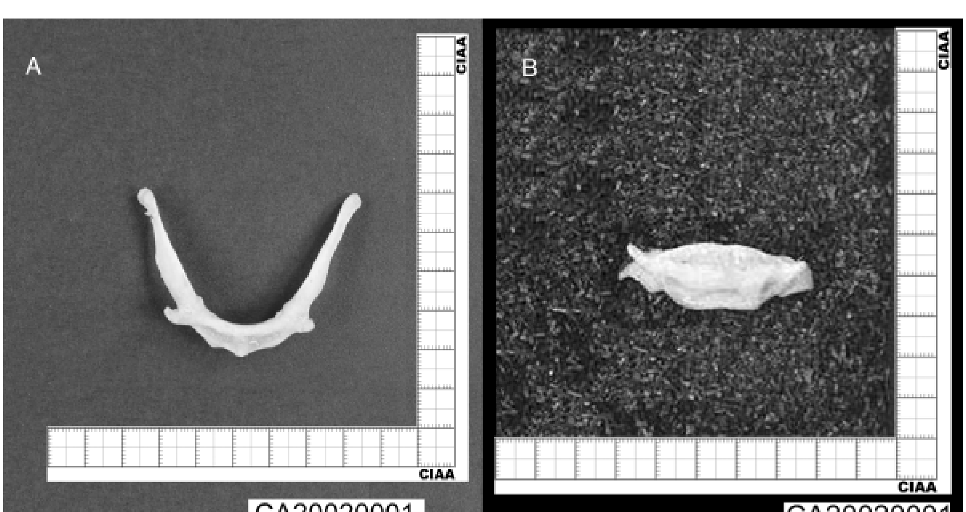

FIG. 2—*Photographs of the superior–inferior (A) and frontal (B) views of the hyoid bone.*

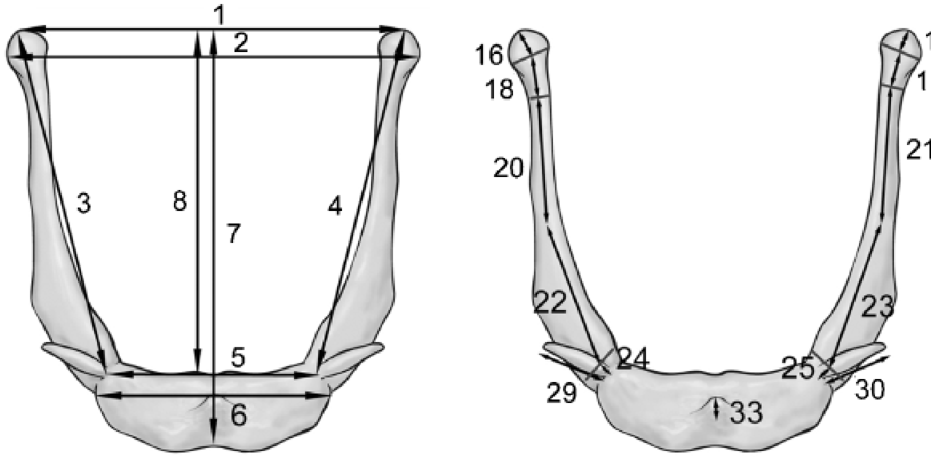

FIG. 3—*Measurement points used.*

variables were 0.577, 0.548, and 0.510, so the explanatory power of this function is similar between variables (Table 7). The canonical correlation shows a connection between the discriminant score and groups. The eigenvalue is calculated by dividing the "variance within groups" by the "variance between groups." The higher the canonical correlation and the closer the eigenvalue to one, the higher the discrimination ability. The distinction ability of the discriminant function analysis was high, with a canonical correlation of 0.72; eigenvalue was 1.078, and Wilk's λ of a canonical discriminant function was 0.000, meaning that there was a statistically significant discriminant score difference between groups. Unstandardized canonical discriminant function coefficients of variables are shown in Table 7.

The unstandardized canonical discriminant function was estimated using these three variables:

$$\text{Discriminant function}\,(D) = 0.238 \times X_1 + 0.571 \times X_2 + 0.191 \times X_3 - 10.559$$

where "X_1" is the sixth measurement, of the distance from the midpoint of the left side of the hyoid body to the midpoint of the right side of the hyoid body measured through its central axis; "X_2" is the 15th measurement, of the maximum width of the proximal end of the greater horn, measured perpendicular to the internal surface of the bone on the left; and "X_3" is the 20th measurement, of the distance from the narrowest segment of the greater horn to a point equidistant between the distal and proximal ends of the greater horn, measured through the central axis of the greater horn on the right.

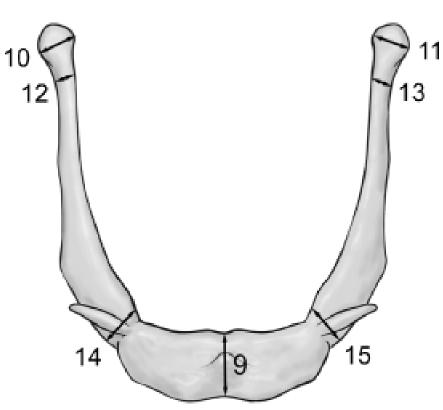

FIG. 4—*Widths measured.*

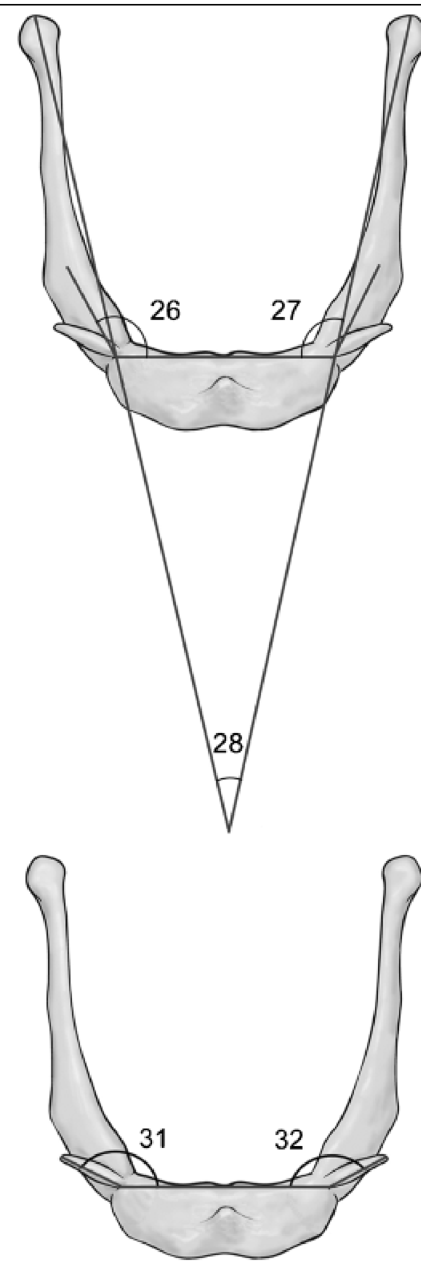

FIG. 5—*Angles measured on the hyoid bone.*

TABLE 2—*Length of osteometric measurements of the hyoid bone.*

Measurement	Description
1	Distance between the distal ends of the right and left greater horn (midpoint)
2	Distance between the distal ends of the right and left greater horn (lateral point)
3, 4	Maximum length of greater horn (Rt. and Lt.)
5	Distance from the middle of the left joint space to the middle of the right joint space measured across the body of the hyoid
6	Length of the distance from the midpoint of the left side of the hyoid body to the midpoint of the right side of the hyoid body measured through the central axis of the hyoid body
7	Perpendicular distance from the midpoint of a line drawn between the distal ends of the right and left greater horn to the midpoint of the anterior aspect of the hyoid body
8	Perpendicular distance from the midpoint of a line drawn between the distal ends of the right and left greater horn to the midpoint of the posterior aspect of the hyoid body
16, 17	Length of the distance form the distal end of the left greater horn to the midpoint of the widest segment of the distal end of the greater horn, measured through the central axis of the greater horn (Rt. and Lt.)
18, 19	Length of the distance the midpoint of the widest segment of the distal end of the greater horn to the midpoint of the narrowest segment of the greater horn, measured through the central axis of the greater horn (Rt. and Lt.)
20, 21	Length of the distance from the narrowest segment of the greater horn to a point equidistant between the distal and proximal ends of the greater horn, measured through the central axis of the greater horn (Rt. and Lt.)
22, 23	Length of the distance from the point equidistant between the distal and proximal ends of the greater horn to the widest portion of the proximal end of the greater horn measured through the central axis of the greater horn (Rt. and Lt.)
24, 25	Length of the distance from the midpoint of the proximal end of the greater horn to the midpoint of the same side of the hyoid body (not measured in bones where the greater horns are fused to the hyoid body)
29, 30	Maximum length of the lesser horn (Rt. and Lt.)
33	Length of the horn of the hyoid body

Rt., right; Lt., left.

TABLE 3—*Width of osteometric measurements of the hyoid bone.*

Measurement	Description
9	Width of the hyoid body at its midpoint, measured perpendicular to the surface of the bone
10, 11	Maximum diameter of the distal end of the greater horn, measured perpendicular to the internal surface of the bone (Rt. and Lt.)
12, 13	Minimum diameter of the distal end of the greater horn, measured perpendicular to the internal surface of the bone (Rt. and Lt.)
14, 15	Maximum width of the proximal end of the greater horn, measured perpendicular to the internal surface of the bone (Rt. and Lt.)

Rt., right; Lt., left.

Discriminant scores of each sample were calculated with this function and then compared with the sectioning point. For instance, if the discriminant score is 0.1213, it is larger than the sectioning point. Therefore, it can be concluded that this sample is a male hyoid bone. In the classification results, the hit ratio of males is 88.5%; for females, it is 87.9%, and for the original and cross-validated groups it was 88.2% (Table 8).

Discussions

The identification of skeletal and other decomposed human remains is very important for legal and humanitarian reasons. Moreover, sex and age determination is the main objective. It is generally known that male skeletons are larger than females, but this measure is not easy if there are no other skeletons to compare it with. In addition, basing sex determination on the shape of skeletal features can lead to divergent opinions according to individual experiences. Thus, an impartial metric method for sex determination is essential.

Bones of preadolescent individuals are almost useless for sex determination because the secondary sexual characteristics do not appear until the bones are remodeled under the influence of estrogens and androgens at puberty (8). We therefore excluded samples below the age of 20.

Papadopoulos et al. (3) measured the length and width of the hyoid bone, Ćerný (6) compared sex differences using discriminant function analysis, and Miller et al. (4), and Reesink et al. (5) compared sex differences using radiography. However, these studies used different landmarks and numbers of measurements. Ćerný used six measurements; Miller et al. used 31 measurements; and Reesink et al. used 13 measurements, but only three or four measurements were common. This is the first study to use digital photographs.

Male hyoids were significantly larger than females in 21 of 34 measurements. Discriminant analysis using 20 metric measure-

TABLE 4—*Angles of osteometric measurements of the hyoid bone.*

Measurement	Description
26, 27	Angle of distance from the middle of the left joint space to the middle of the right joint space measured across the body of the hyoid and length of the distance from the point equidistant between the distal and proximal ends of the greater horn to the widest portion of the proximal end of the greater horn measured through the central axis of the greater horn (Rt. and Lt.); Angle of five and 22 (23)
28	Angle of right greater horn length and left greater horn length, measured long axis of greater horn
31, 32	Angle of lesser horn and distance from the middle of the left joint space to the middle of the right joint space measured across the body of the hyoid (Rt. and Lt.)

Rt., right; Lt., left.

TABLE 5—*Mean weight of age and sex distribution of samples (unit: g, mean ± SD).*

Age (year)	Male	Female
21–30	2.1 ± 0.3	1.3 ± 0.2
31–40	2.1 ± 0.4	1.3 ± 0.2
41–50	2.2 ± 0.4	1.5 ± 0.4
51–60	2.0 ± 0.4	1.4 ± 0.2
61–70	2.2 ± 0.5	1.2*
71 and over	2.4 ± 0.4	1.2 ± 0.3
Total	2.2 ± 0.4	1.3 ± 0.4

*This is only one sample.

TABLE 7—*Discriminant function coefficients of the hyoid bone.*

Measurement	Standardized Canonical Discriminant Function Coefficients	Canonical Discriminant Function Coefficients*
6(X_1)	0.577	0.238
15(X_2)	0.548	0.571
20(X_3)	0.510	0.191
(Constant)		− 10.734

*Unstandardized coefficients.

ments (not including weight), showed a high rate of sex discrimination, with a canonical discriminant function coefficient of 0.72, an eigenvalue of 1.078, and Wilk's λ of 0.000. The sixth, 15th, and 20th measurements combined gave an accuracy of 88%. In Ćerný's (6) study, the width of the body, the height of the anterior end of the greater horn, and the length of the greater horn showed significant sex differences. That study used six measurements and showed variance in 63 functions: the rate of false classification by sex was 3.6% when the six measurements were used in multivariate analysis of variance (MANOVA). In the 1998 study by Miller et al., the accuracy of discriminant function using five measurements (second, fourth, 17th, 20th, and 29th) was 69.2% in males and 75.2% in females. In the 1999 study by Reesink et al., the accuracy of discriminant function using three measurements was 76%: these were the maximal medial height of the body, anterior–posterior thickness of the body, and the maximal transverse diameter of the body. We tried to compare the accuracy of discriminant function between our study and that of others, but there were no common measurements used as discriminant variables. Both Miller et al. (4) and Reesink et al. (5) established discriminant functions, but showed lower accuracy than this study in sex discrimination. Although Ćerný's (6) study was more accurate than the others, it used very few variables. We therefore believe that our discriminant function is more statistically useful than that of others to date.

TABLE 6—*Average and* p *values of osteometric measurements of the hyoid bone (unit: mm, mean ± SD).*

Measurement	Male ($n = 52$)	Female ($n = 33$)	p Value*
1	42.8 ± 12.3	31.6 ± 16.2	0.001
2	45.8 ± 12.8	35.4 ± 16.1	0.001
3	34.8 ± 6.0	27.6 ± 10.7	0.000
4	33.5 ± 7.3	28.0 ± 9.3	0.003
5	22.3 ± 2.3	19.3 ± 2.2	0.000
6	26.0 ± 2.5	22.4 ± 2.4	0.000
7	39.7 ± 3.2	33.9 ± 6.6	0.000
8	31.5 ± 4.5	27.0 ± 5.6	0.000
9	7.8 ± 1.6	7.1 ± 1.2	
10	4.2 ± 1.0	3.6 ± 1.6	0.037
11	3.8 ± 1.1	3.1 ± 1.3	0.010
12	2.9 ± 0.6	2.6 ± 1.1	
13	2.6 ± 0.9	2.2 ± 0.9	
14	5.5 ± 1.2	4.5 ± 1.1	0.000
15	5.5 ± 0.8	4.2 ± 1.2	0.000
16	2.0 ± 0.9	1.8 ± 1.0	
17	1.9 ± 0.9	1.6 ± 0.9	
18	3.3 ± 0.9	3.1 ± 1.3	
19	3.2 ± 1.3	2.6 ± 1.2	0.042
20	11.8 ± 2.3	8.9 ± 3.2	0.000
21	11.2 ± 3.0	9.2 ± 3.7	0.008
22	13.1 ± 2.1	10.7 ± 3.2	0.000
23	13.1 ± 1.8	11.1 ± 3.1	0.000
24	1.5 ± 0.6	1.3 ± 0.6	
25	1.4 ± 0.4	1.6 ± 0.8	
26†	112.0 ± 7.3	103.1 ± 27.7	0.031
27†	112.8 ± 6.9	104.9 ± 18.7	
28†	37.8 ± 14.0	29.3 ± 19.2	0.021
29	2.6 ± 4.4	1.1 ± 2.1	
30	1.8 ± 2.4	1.1 ± 1.9	
31†	22.3 ± 23.1	12.2 ± 20.3	0.043
32†	19.1 ± 23.4	11.8 ± 20.3	
33	0.5 ± 1.0	0.4 ± 0.8	
34‡	2.1 ± 0.4	1.3 ± 0.4	

*Statistically significant variables of measurements.
†Angles in degrees.
‡Weight in grams.

Twenty-one of our measurements showing significant sex differences have been compared with studies based on north American (4) and Korean subjects (7) (Table 9). For the study by Miller et al. (4), most measurements were smaller than in this study, but the hyoid bone was longer in males: about 10 mm. The first, fifth, 14th (15th), 19th, and 22nd measurements were larger than this study in females, but this was not statistically significant. Chang's (7) study on Koreans gave smaller measures than the ones we found here, but the length of the lesser horn in males and the seventh measurement for females was longer. We believe that the method of photography is more accurate than radiography and that the cadavers used in our study were larger than those used in Chang's study.

For Korean subjects, there have been studies on sex determination using the mandible (9), the pelvis (10), and teeth (11). For the mandible, five out of 27 measurements were used for discriminant function analysis with an accuracy of 79.6%. For the pelvis, 18 measurements were examined with an accuracy of better than 60%, but this was not useful to apply to sex determination because its precision was lower than other population groups studied and measurements to exam were more difficult than this

TABLE 8—*Probabilities of group membership of the hyoid bone.**,†

		Sex	Predicted Group Membership 1	2	Total
Original	Count	1	46	6	52
		2	4	29	33
	%	1	88.5	11.5	100.0
		2	12.1	87.9	100.0
Cross-validated‡	Count	1	46	6	52
		2	4	29	33
	%	1	88.5	11.5	100.0
		2	12.1	87.9	100.0

*88.2% of original grouped cases correctly classified.
†88.2% of cross-validated grouped cases correctly classified.
‡Cross-validation is performed only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.

TABLE 9—*Measurements of the hyoid bone compared with others (unit: mm, mean ± SD).*

Measurement	North American (1998)		Korean (1967)		This Study (2004)	
	Males ($n = 188$)	Females ($n = 127$)	Males ($n = 70$)	Females ($n = 30$)	Males ($n = 52$)	Females ($n = 33$)
1	39.8 ± 9.3	40.1 ± 8.1	41.9 ± 2.4	37.0 ± 1.2	45.1 ± 6.3	38.3 ± 7.0
2			46.0 ± 2.3	39.1 ± 4.1	48.3 ± 5.9	41.4 ± 6.1
3	28.5 ± 5.2	27.3 ± 4.4	32.3 ± 2.0	30.2 ± 1.2	35.6 ± 3.6	31.2 ± 2.8
4	21.4 ± 3.4	27.7 ± 4.3	32.2 ± 1.4	30.5 ± 1.6	34.9 ± 3.1	30.3 ± 3.0
5	20.9 ± 3.5	19.8 ± 3.0			21.9 ± 2.7	18.5 ± 3.4
6	35.2 ± 5.8	19.4 ± 3.0	23.3 ± 1.3	20.1 ± 2.0	25.5 ± 2.9	21.4 ± 3.6
7	27.3 ± 5.1	32.7 ± 4.7	38.0 ± 1.5	34.7 ± 1.1	39.4 ± 3.6	33.9 ± 4.0
8	27.3 ± 5.1	25.3 ± 4.2			31.4 ± 4.5	27.0 ± 3.7
10	3.3 ± 0.9	3.5 ± 0.8			4.4 ± 0.9	4.0 ± 0.9
11	3.3 ± 1.0	3.5 ± 0.8			3.9 ± 0.7	3.5 ± 0.5
14	5.1 ± 1.1	4.7 ± 1.0			5.6 ± 0.9	4.5 ± 0.8
15	5.0 ± 1.2	4.7 ± 0.9			5.4 ± 0.8	4.3 ± 0.9
19	3.8 ± 2.0	4.5 ± 2.2			3.2 ± 1.1	2.9 ± 0.7
20	8.3 ± 2.1	7.2 ± 2.0			11.7 ± 2.2	9.8 ± 1.6
21	8.7 ± 1.9	7.6 ± 2.2			11.6 ± 2.0	10.2 ± 1.6
22	11.4 ± 2.3	11.2 ± 2.5			12.9 ± 2.4	10.8 ± 2.3
23	11.3 ± 2.9	11.2 ± 2.3			13.1 ± 1.8	11.1 ± 3.1
26*			110.6 ± 1.9	106.5 ± 2.4	111.9 ± 7.3	109.4 ± 8.5
28*			39.6 ± 3.7	34.4 ± 2.1	40.1 ± 10.3	38.5 ± 11.6
29			7.2 ± 0.7	6.1 ± 0.7	4.9 ± 2.7	3.6 ± 1.9
34†			1.4 ± 0.4	1.0 ± 0.2	2.1 ± 0.4	1.3 ± 0.4

*Angles in degrees.
†Weight in grams.

study. For teeth, eight measurements were used for discriminant function analysis with an accuracy of 60–85%. We think that the hyoid bone is useful for sex determination in Koreans and will prove helpful in distinguishing them from other population groups.

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