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TECHNICAL NOTE

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Determination of Sex for the 12th Thoracic Vertebra by Morphometry of Three-dimensional Reconstructed Vertebral Models

ABSTRACT: Thirty-three linear measurements and two ratios were derived from 102 12th thoracic vertebrae of the Digital Korean database at the Catholic Institute for Applied Anatomy. Of 35 linear traits, 23 were sexually dimorphic. We created 23 discriminant function equations that predicted sex with 62.7–85.3% accuracy. The analysis using combinations of two factors gave higher accuracies: most equations with accuracies over 80% included at least one measurement involving the coronal diameter of the vertebral endplate. Using stepwise method of discriminant function analysis, three variables predicted sex with 90.0% accuracy: the coronal diameter of the superior endplate of the vertebral body, the ratio of anterior to middle height of the body, and the length of the left mammillary process and pedicle. Coronal dimensions of the vertebral body represented the major sex difference. These equations will help forensic discrimination of the sex of this vertebra among Koreans.

KEYWORDS: forensic science, forensic anthropology, sex determination, thoracic vertebra, Korean

The statistical examination of metrical data from human skeletal remains for determining sex has a long history in physical anthropology (1). Such analyses build on visually oriented studies—using directly observable anatomical markers to estimate sex—by providing methods that can be applied to a great variety of skeletal remains. Determination of sex is directly dependent upon the presence or absence of certain anatomical markers. However, the typical materials with which the physical anthropologist and archaeologist deal are seldom complete skeletal elements. In such contexts, it is prudent to devise analytical methods that are not compromised by specimen fragmentation (2). In addition, statistical analyses provide more replicable results and more reliable and quantifiable estimations than visual estimates (3).

Because statistical analyses tend to follow visually oriented studies of an element, they commonly focus on the same bone. For example, visual tests that use anatomical attributes of the skull to estimate sex have been followed by statistical applications that use not only the same bone, but also use the same attributes. This analytic pattern seems to be changing. A few authors have taken into account some elements that do not possess directly observable anatomical indicators of sex, such as the humerus (4,5), the femur (6–8), the scapula (9,10), the metacarpals of hand (11), the talus or calcaneus (12–17), the first cervical vertebra (18), and the 12th thoracic and 1st lumbar vertebrae (19).

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The lower thoracic and lumbar vertebrae are often preserved well in archaeological skeletal assemblages and forensic contexts, because of their weight-bearing function and relative density. Even when bone preservation is problematic for the axial skeleton, the 12th thoracic vertebra can be readily distinguished because of its unique morphology. The lower thoracic and lumbar vertebrae are highly sexually dimorphic according to work by Pastor (19) on the Spitalfields and Terry samples. However, reliable metric methods on vertebrae are still in need of development, because it has been widely acknowledged that ancestral and regional variations in skeletal elements need to be considered when producing specific standards for accurate determination of sex. This study focused on the 12th thoracic vertebra of Koreans to refine methods and to determine ethnic-specific numerical values of these parameters. Then, the purpose of this study is to examine the utility of the 12th thoracic vertebra in sex determination in a Korean population.

Materials and Methods

A total of 102 three-dimensional 12th thoracic (T12) vertebral models of Korean subjects (52 male and 50 female) were obtained from the Digital Korean database in the Catholic Institute of Applied Anatomy. The Digital Korean database consists of three-dimensional models of whole skeletons of Koreans, which are reconstructed with computer tomographic images of 1-mm axial thickness of high resolution obtained from 52 male and 50 female cadavers donated to Catholic Institute of Applied Anatomy during 2003. None of the vertebrae used possessed any pathological condition. The mean age of the subjects at death was 50.7 years (range 21–60) for men and 53.7 years (27–60) for women. The mean height was 166.1 cm (159.0–178.0) for men and 156.4 cm (146.0–166.0) for women.

Thirty-three linear measurements, as listed by Berry et al. (20) and Cheng et al. (21), were taken using three-dimensional

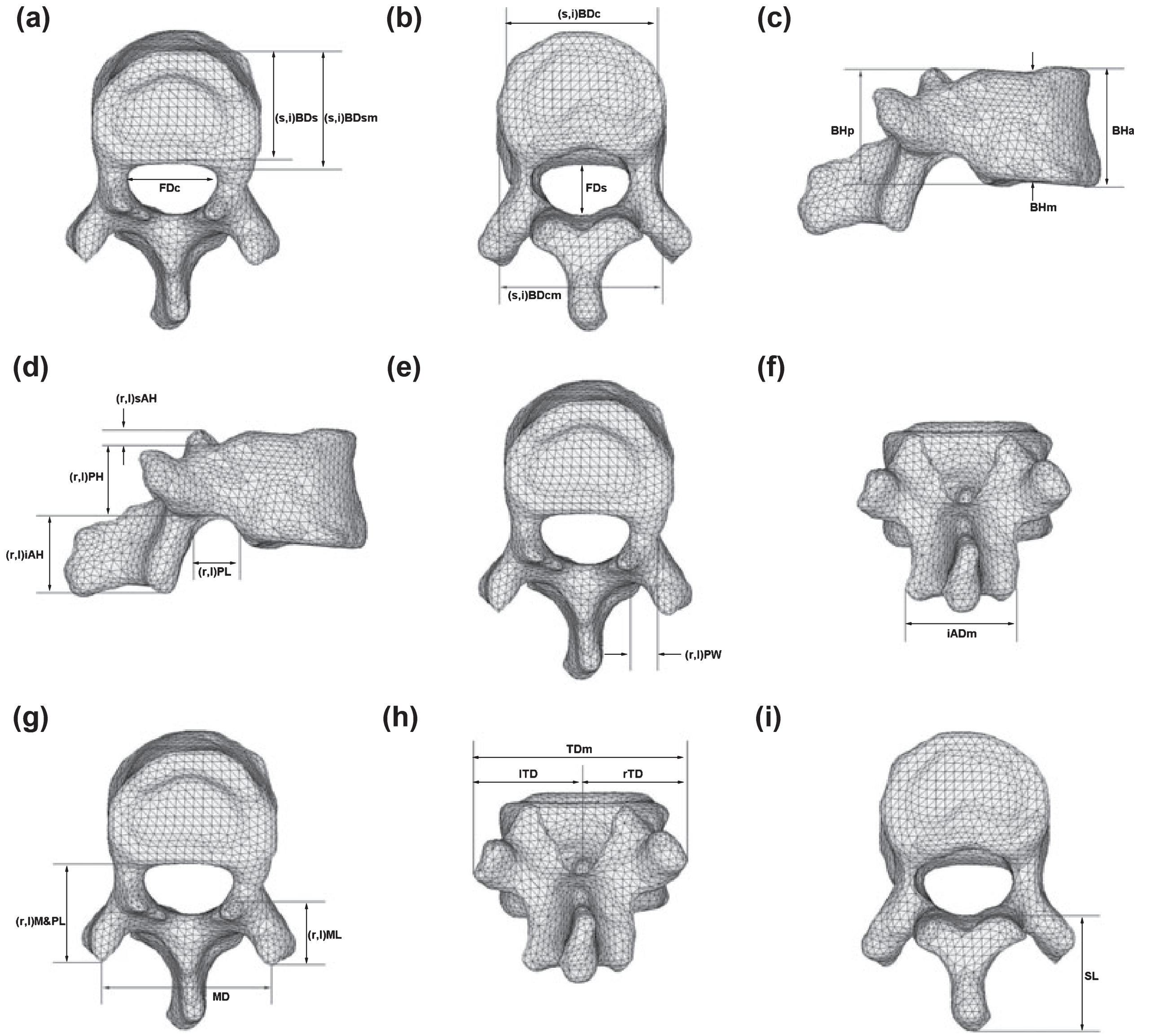

FIG. 1—*Three-dimensional views of the 12th thoracic vertebra. The various measurements determined in the present study are indicated and further explained in the nomenclature in Table 1. (a)–(c) show the measurements of the vertebral body and foramen, and (d)–(f) show the measurements of the pedicle and articular process. (g) demonstrates the mammillary process, (h) demonstrates the transverse process, and (i) demonstrates the spinous process [(a),(e), and (g) are superior views; (b) and (i) are inferior views; (c) and (d) are right lateral views; (f) and (h) are posterior views].*

morphometry software (Hyperworks version 7.0, Altair Engineering, Troy, MI) by the same operator. The nomenclature for the measured parameters is presented graphically in Fig. 1 and is listed in Table 1. Using these linear measurements, two ratios for the heights of vertebral body were calculated.

The sagittal and coronal diameters of endplates in the vertebral body were measured at the plane bisecting the body (BDs and BDc, respectively) and the maximum diameters of endplates were also measured (BDsm, BDcm). All endplate diameters were also recorded at the superior and inferior ends. Vertebral height ratios were computed from the heights of the body at the anterior and posterior (Ha/Hp) and middle and posterior (Hm/Hp) parts. Sagittal and coronal diameters of the vertebral foramen (FDs, FDc) were measured on horizontal sections at the mid-level of the pedicle.

The length of the pedicle (PL) was defined as the distance between the vertebral body and inferior articular process along its long axis. The height of the pedicle (PH) was taken as the minimum height and the width of the pedicle (PW) was taken as the minimum width on horizontal sections at the mid-level of the pedicle. Heights of articular processes (AH) were measured parallel to a vertical line from the point with the same level of the vertebral notch to the apex of articular process.

Although strictly speaking there is no "mammillary process" in thoracic vertebrae, the posterior side of the transverse process of T12 has morphology similar to the mammillary process of lumbar vertebrae. This structure was therefore termed a "mammillary process" for the purpose of this study. The length of the mammillary process and pedicle (M&PL) was defined as the distance between the posterior border of vertebral body and the tip of mammillary process along the long axis of the pedicle. The length of the mammillary process (ML) was measured parallel to the sagittal axis of the vertebral body from the tip of the superior articular process to that of the mammillary process. MD was defined as the distance between the tips of the mammillary processes.

The maximum transverse process distance (TDm) was measured from the tip of the left transverse process to that of the right. The

TABLE 1—*Nomenclature for the measurements used in this study.*

Vertebral part	Symbol	Definition
Vertebral body	BDs	Sagittal diameter of endplate
	BDsm	Maximum sagittal diameter of endplate
	BDc	Coronal diameter of endplate
	BDcm	Maximum coronal diameter of endplate
	BHa	Anterior height of body
	BHm	Middle height of body
	BHp	Posterior height of body
	Ha/Hp	Ratio of BHa to BHp
	Hm/Hp	Ratio of BHm to BHp
Vertebral foramen	FDs	Sagittal diameter
	FDc	Coronal diameter
Pedicle	PH	Height of pedicle
	PW	Width of pedicle
	PL	Length of pedicle along its long axis
Articular process	AH	Height of articular process
	ADm	Maximum distance between articular processes
Mammillary process	MD	Distance between mammillary processes
	ML	Length of mammillary process along the long axis of the pedicle
	M&PL	Length of mammillary process and pedicle along the long axis of the pedicle
Transverse process	TD	Transverse process distance
	TDm	Maximum distance between transverse processes
Spinous process	SL	Length of spinal process
Prefixes used	s	Superior
	i	Inferior
	r	Right
	l	Left

TABLE 2—*Sexual dimorphism in the linear dimensions of T12.*

		Male (N = 52)		Female (N = 50)		
Vertebral part	Measurement	Mean	SD	Mean	SD	p
Vertebral body	sBDs*	31.48	3.23	27.65	2.05	0.000
	sBDsm*	34.54	3.39	30.38	2.20	0.000
	iBDs*	31.58	3.09	28.01	1.90	0.000
	iBDsm*	34.88	3.34	30.84	2.15	0.000
	sBDc*	42.28	4.05	36.07	2.21	0.000
	sBDcm*	44.13	4.51	38.23	2.27	0.000
	iBDc*	44.37	4.35	38.81	2.52	0.000
	iBDcm*	47.20	4.35	40.98	2.58	0.000
	BHa*	26.78	2.54	24.75	2.45	0.000
	BHm*	25.73	2.18	22.52	2.34	0.000
	BHp*	28.13	2.47	26.51	2.33	0.001
	Ha/Hp	0.95	0.06	0.93	0.06	0.096
	Hm/Hp*	0.92	0.07	0.85	0.05	0.000
Vertebral foramen	FDs	13.91	1.79	13.57	1.46	0.296
	FDc	19.36	2.43	18.71	2.36	0.173
Pedicle	rPH*	19.86	1.66	18.36	1.47	0.000
	lPH*	19.32	2.70	18.04	1.29	0.003
	rPW*	10.96	1.92	9.33	1.46	0.000
	lPW*	11.17	1.91	9.19	1.45	0.000
	rPL	11.13	1.40	10.91	1.47	0.438
	lPL	11.40	1.56	11.21	1.44	0.531
Articular process	riAH	18.75	2.27	18.06	2.19	0.120
	liAH	18.54	2.14	18.15	2.28	0.380
	iADm	27.35	3.71	26.18	2.49	0.063
	rsAH	4.95	1.53	4.76	1.50	0.524
	lsAH	5.49	2.29	4.55	1.41	0.015
Mammillary process	rML*	14.52	2.12	12.39	1.99	0.000
	lML*	13.90	1.97	12.31	2.17	0.000
	rM&PL*	23.14	2.43	20.99	2.05	0.000
	lM&PL*	23.03	2.10	21.25	1.54	0.000
	MD	34.45	4.14	34.73	3.84	0.726
Transverse process	rTD*	26.13	4.10	23.66	2.16	0.000
	lTD*	27.13	4.09	24.63	2.40	0.000
	TDm*	53.26	7.92	48.29	4.24	0.000
Spinous process	SL	27.82	4.64	26.16	2.81	0.032

*$p < 0.01$.

transverse process distance (TD) was defined as the distance from the tip of the transverse process to the median sagittal plane of the vertebra. The length of the spinous process (SL) was measured horizontally from the anterior border of the lamina to its tip.

The data were analyzed using SPSS version 13.0 (SPSS, Chicago, IL). Independent sample t-tests were performed to evaluate differences between means of the parameters after all data were tested for normality of distribution. All measurements with sexual dimorphism at a significant level of 0.01 in t-test were used to create discriminant equations. For each measurement with statistically significant sexual dimorphism, respective discriminant equations were calculated for sex determination using univariate, bivariate, and stepwise method of discriminant function analysis. To make the sectioning point taken as 0, the discriminant equations were modified using centroid values of male and female groups. Any measure with a value equal to or greater than 0 was classified as male, and those with values less than 0 were classified as female. All accuracies of discriminant equations were obtained by cross-validated classification.

Results

The results (means and standard deviations) of measurements and sexual differences in them are shown in Table 2 and Fig. 2. The dimensions of the vertebrae differed significantly ($p < 0.01$) between sexes except for the ratio of BHa to BHp (Ha/Hp), the diameters of vertebral foramen (FDs, FDc), PL, AH, the maximum distance between inferior articular processes (iADm), the distance between mammillary processes (MD), and SL. In general, male dimensions were larger than female.

Using univariate discriminant function analysis with 23 single variables with significant sex differences among 35 traits (33 linear measurements and two ratios), the accuracies of correct sex classification for the T12 vertebra ranged from 62.7% to 85.3% (Table 3): they were 66.7–85.3% for the dimensions of the vertebral body, 66.7–72.5% for the pedicle, 64.7–70.6% for the mammillary process, and 62.7–63.7% for the transverse process. Table 3 shows the demarking point of each variable that allows rapid sex determination. This point is defined as the average of the male and female mean measurements for each variable. Three measurements relating to the vertebral body (sBDc, sBDcm, iBDcm, and iBDc in order of accuracy) with accuracies higher than 80.0% were the most useful individual variables.

To further investigate the more useful dimensions and their effective interactions, individual pairs of data were entered into the discriminant equation. Some pairs showed high accuracies for sex classification as shown in the upper and right side of Table 4. Table 4 also displays the Pearson correlations on the lower and left side to demonstrate the strength of the relationship between pairs of measurements. Of all equations acquired by a combination of two measurements, 43.3% (101/253) had accuracies over 80.0%. Most discriminant function equations, including coronal measurements of vertebral body, had accuracies over 80.0%. The equations using the pairs of sBDcm + Hm/Hp or iBDcm + Hm/Hp were both the most accurate at 88.2%. Table 5 indicated the equations with high accuracies over 85.0% using two measurements, and these equations included one of sBDc or Hm/Hp at least.

Discriminant function equation, including multiple variables with highest accuracy, was created using the "stepwise method" approach. The coronal diameter of the superior endplate of the

TABLE 3—*Discriminant function equations and demarking points for predicting the sex of T12 when using one measurement.*

Vertebral part	Measurement	Constant	Coefficient	Accuracy (%)	Demarking point (mm)
Vertebral body	sBDs	0.368	−10.857	77.5	Female < 29.5 < male
	sBDsm	0.349	−11.304	75.5	Female < 32.4 < male
	iBDs	0.388	−11.553	74.5	Female < 29.8 < male
	iBDsm	0.354	−11.619	79.4	Female < 32.8 < male
	sBDc	0.305	−11.927	85.3	Female < 39.1 < male
	sBDcm	0.278	−11.445	82.4	Female < 41.2 < male
	iBDc	0.280	−11.627	80.4	Female < 41.5 < male
	iBDcm	0.278	−12.254	80.4	Female < 44.1 < male
	BHa	0.401	−10.314	66.7	Female < 25.7 < male
	BHm	0.443	−10.669	77.5	Female < 24.1 < male
	BHp	0.416	−11.371	71.6	Female < 27.3 < male
	Hm/Hp	16.554	−14.616	73.5	FL Female < 0.9 < male
Pedicle	rPH	0.636	−12.154	66.7	Female < 19.1 < male
	lPH	0.470	−8.775	72.5	Female < 18.7 < male
	rPW	0.585	−5.928	68.6	Female < 10.1 < male
	lPW	0.588	−5.976	70.6	Female < 10.2 < male
Mammillary process	rML	0.496	−6.526	70.6	Female < 13.2 < male
	lML	0.483	−6.318	65.7	Female < 13.1 < male
	rM&PL	0.443	−9.764	64.7	Female < 22.0 < male
	lM&PL	0.540	−11.954	68.6	Female < 22.1 < male
Transverse process	rTD	0.303	−7.546	63.7	Female < 24.9 < male
	lTD	0.297	−7.670	62.7	Female < 25.8 < male
	TDm	0.157	−7.941	62.7	Female < 50.6 < male

Accuracies are the results of cross-validation classification.

vertebral body (sBDc), the ratio of the anterior to middle height of the body (Hm/Hp), and the length of left mammillary process and pedicle (lM&PL) predicted sex with 90.0% accuracy in the following equation.

$$\text{Discriminant score} = 0.223 \times \text{sBDc} + 12.185 \times \text{Hm/Hp} + 0.213 \times \text{lM\&PL} - 24.173$$

Discussion

Significant sex differences were determined for 23 of 35 traits for the T12 vertebra in this analysis. The linear dimensions of the vertebral body, pedicle, mammillary, and transverse processes showed distinct differences between males and females and could be used as sex-determining parameters. Discriminant function analysis using single variables showed that the coronal diameters of the endplates (sBDc, sBDcm, iBDcm, and iBDc in order of accuracy) were the most effective with accuracy over 80.0% for sex determination.

Subsequently, creating discriminant equations using two of the 35 measurements 43.3%, of the 253 pairs yielded accuracies over 80.0% for sex classification. Most equations including coronal measurements of vertebral body (sBDc, sBDcm, iBDc, or iBDcm) provided accuracies over 80.0% with strong discrimination ability as single measurements. Therefore, these measures were useful to increase all other measurements' ability for sex discrimination as well as being useful single determinants. Hm/Hp was another useful factor, as most equations including this ratio gave high accuracies. Thus, the highest accuracies of 88.2% resulted from the pairs of sBDcm + Hm/Hp and iBDcm + Hm/Hp, although this measure had moderate accuracy as a single variable (Table 4).

The 35 measurements were further selected by discriminant function analysis. Only three variables—BDc, Hm/Hp, and lM&PL—came into the equation that predicted sex with 90.0% accuracy. Such equations providing high accuracy are likely to be used in contexts with fragmentary remains, because they use only one to three variables.

Pastor (19) demonstrated new methods of accurate sex assessment from the axial skeleton, based on dimensional variation of the lower thoracic and upper lumber vertebral column. This study investigated the 18th and 19th century Spitalfields documented collection (a white immigrant population) and the more contemporary Smithsonian's Terry collection. For T12, significant sex differences were determined for 7 of 12 traits in his study. In the present study, 35 linear dimensions of T12 were examined and 23 of them could be used as sex-determining parameters. This agreed with Pastor's study. Thus, the 12th thoracic vertebra should be considered for metric sex determination, especially in fragmentary forensic assemblages, as the dimensions of the vertebral body differ between females and males. However, the kinds of measurements that yielded the highest accuracy for sex determination were widely different between the two studies. In Pastor's study, sBDs–SL showed the highest accuracy at 88.9% for white males and females in the Terry collection and sBDs–sBDc gave the highest at 86.6% for black individuals. In contrast, sBDcm + Hm/Hp and iBDcm + Hm/Hp yielded the highest accuracies at 88.2% for Koreans in the present study and the equations using sBDs–SL and sBDs–sBDc had 75.5% and 85.3% accuracy, respectively. Hence, the traits of the coronal dimension of the vertebral body such as sBDc, sBDcm, iBDc, and iBDcm had more influence on sexual characteristics than the traits of sagittal dimensions in Koreans. Moreover, in Pastor's study of the Spitalfields samples, sBDc classified sex at the highest accuracy of 76.7%. This corresponded to the result of the present study in which sBDc was the most accurate determinant for sex discrimination, but with a higher accuracy of 85.3%. The disparate results might be caused by ethnic and regional differences or by other sex differences between the samples. This comparison with Pastor's historical study implies that the metric differences of vertebrae between females and males might have changed with time.

This study has two limits. The first is that measuring T12 was conducted with three-dimensional reconstructed models, not with real bones. As computer tomographic images were taken with 1-mm axial thickness of high resolution, the dimensional difference of the model from real bone is less than 1 mm. Then, the

TABLE 4—*Accuracies for sex determination and Pearson correlation coefficients when using pairs of measurements.*

	sBDs	sBDsm	iBDs	iBDsm	sBDc	sBDcm	iBDc	iBDcm	BHa	BHm	BHp	Hm/Hp	rPH	lPH	rPW	lPW	rML	lML	rM&PL	lM&PL	rTD	lTD	TDm
sBDs	1.00	74.50	79.40	**80.40**	**85.30**	**80.40**	**84.30**	**80.40**	78.40	**82.40**	79.40	**83.30**	76.50	78.40	76.50	76.50	79.40	76.50	77.50	77.50	77.50	76.50	77.50
sBDsm	**0.95**	1.00	**81.40**	**81.40**	**85.30**	**83.30**	**82.40**	**80.40**	79.40	**83.30**	76.50	**85.30**	76.50	76.50	73.50	77.50	76.50	75.50	75.50	74.50	74.50	76.50	74.50
iBDs	**0.87**	**0.87**	1.00	75.50	**84.30**	**83.30**	**81.40**	**80.40**	76.50	78.40	75.50	**85.30**	74.50	76.50	77.50	79.40	**80.40**	74.50	78.40	76.50	74.50	75.50	74.50
iBDsm	**0.88**	**0.90**	**0.96**	1.00	**85.30**	**82.40**	**82.40**	**80.40**	76.50	79.40	78.40	**83.30**	**83.30**	**82.40**	78.40	78.40	**80.40**	78.40	79.40	**83.30**	76.50	79.40	79.40
sBDc	**0.84**	**0.86**	**0.84**	**0.85**	1.00	**85.30**	**85.30**	**84.30**	**84.30**	**85.30**	**85.30**	**86.30**	**84.30**	**83.30**	**85.30**	**83.30**	**84.30**	**85.30**	**84.30**	**85.30**	**84.30**	**84.30**	**85.30**
sBDcm	**0.84**	**0.85**	**0.81**	**0.83**	**0.96**	1.00	**83.30**	79.40	**80.40**	**82.40**	**82.40**	**88.20**	**81.40**	**82.40**	**80.40**	**80.40**	**81.40**	**81.40**	**82.40**	**81.40**	**80.40**	**81.40**	**80.40**
iBDc	**0.82**	**0.83**	**0.84**	**0.86**	**0.92**	**0.93**	1.00	**80.40**	**80.40**	**82.40**	78.40	**86.30**	**80.40**	**82.40**	**80.40**	79.40	79.40	**80.40**	79.40	**82.40**	79.40	**80.40**	79.40
iBDcm	**0.83**	**0.85**	**0.82**	**0.86**	**0.92**	**0.93**	**0.96**	1.00	78.40	**84.30**	**80.40**	**88.20**	**81.40**	**80.40**	**80.40**	**82.40**	78.40	**80.40**	**82.40**	**81.40**	**81.40**	**80.40**	**81.40**
BHa	**0.35**	**0.35**	**0.41**	**0.38**	**0.47**	**0.45**	**0.43**	**0.44**	1.00	77.50	65.70	74.50	75.50	69.60	66.70	68.60	73.50	73.50	67.60	71.60	70.60	74.50	70.60
BHm	**0.33**	**0.36**	**0.43**	**0.42**	**0.53**	**0.48**	**0.47**	**0.51**	**0.80**	1.00	79.40	79.40	79.40	77.50	77.50	78.40	**81.40**	**80.40**	**81.40**	**80.40**	**81.40**	76.50	**81.40**
BHp	**0.37**	**0.37**	**0.41**	**0.37**	**0.49**	**0.48**	**0.46**	**0.46**	**0.81**	**0.74**	1.00	78.40	69.60	69.60	65.70	65.70	70.60	73.50	65.70	70.60	66.70	70.60	69.60
Hm/Hp	0.06	0.10	0.16	0.19	0.21	0.15	0.15	0.20	0.22	**0.60**	−0.09	1.00	**82.40**	75.50	**85.30**	**83.30**	**81.40**	76.50	**83.30**	**80.40**	**81.40**	**81.40**	**82.40**
rPH	**0.49**	**0.52**	**0.45**	**0.49**	**0.55**	**0.56**	**0.54**	**0.58**	**0.45**	**0.49**	**0.50**	0.13	1.00	67.60	72.50	75.50	69.60	70.60	70.60	76.50	63.70	66.70	65.70
lPH	0.15	0.25	0.17	0.18	0.24	0.23	0.21	0.24	0.29	0.38	0.28	0.22	0.38	1.00	70.60	70.60	73.50	70.60	68.60	73.50	65.70	70.60	68.60
rPW	**0.60**	**0.61**	**0.54**	**0.55**	**0.59**	**0.63**	**0.60**	**0.62**	**0.45**	**0.49**	**0.51**	0.11	**0.49**	**0.31**	1.00	70.60	67.60	68.60	73.50	72.50	64.70	67.60	66.70
lPW	**0.60**	**0.60**	**0.56**	**0.57**	**0.63**	**0.66**	**0.61**	**0.64**	**0.34**	**0.44**	**0.41**	0.16	**0.50**	**0.28**	**0.86**	1.00	74.50	72.50	73.50	74.50	70.60	69.60	69.60
rML	**0.67**	**0.66**	**0.58**	**0.57**	**0.62**	**0.62**	**0.60**	**0.60**	**0.29**	**0.32**	**0.35**	0.06	**0.49**	0.12	**0.40**	**0.52**	1.00	69.60	68.60	73.50	64.70	66.70	65.70
lML	**0.60**	**0.61**	**0.48**	**0.50**	**0.57**	**0.57**	**0.53**	**0.52**	0.26	0.20	**0.29**	−0.03	**0.36**	0.18	**0.32**	**0.38**	**0.75**	1.00	72.50	69.60	61.80	64.70	61.80
rM&PL	**0.56**	**0.53**	**0.61**	**0.55**	**0.55**	**0.55**	**0.56**	**0.55**	**0.43**	**0.37**	**0.49**	−0.03	**0.31**	0.15	**0.31**	**0.41**	**0.66**	**0.50**	1.00	63.70	68.60	68.60	70.60
lM&PL	**0.58**	**0.54**	**0.57**	**0.54**	**0.55**	**0.56**	**0.54**	**0.52**	**0.43**	**0.33**	**0.50**	−0.10	**0.28**	0.05	**0.32**	**0.37**	**0.62**	**0.63**	**0.81**	1.00	66.70	69.60	67.60
rTD	**0.64**	**0.65**	**0.65**	**0.64**	**0.61**	**0.63**	**0.67**	**0.67**	**0.46**	**0.35**	**0.53**	−0.10	**0.57**	0.25	**0.50**	**0.53**	**0.51**	**0.44**	**0.64**	**0.56**	1.00	61.80	61.80
lTD	**0.55**	**0.55**	**0.57**	**0.55**	**0.57**	**0.58**	**0.64**	**0.62**	**0.39**	**0.34**	**0.40**	0.02	**0.52**	0.27	**0.47**	**0.56**	**0.47**	**0.38**	**0.55**	**0.47**	**0.86**	1.00	61.80
TDm	**0.62**	**0.62**	**0.63**	**0.62**	**0.61**	**0.63**	**0.68**	**0.67**	**0.44**	**0.36**	**0.48**	−0.04	**0.57**	0.27	**0.51**	**0.57**	**0.51**	**0.42**	**0.62**	**0.53**	**0.96**	**0.96**	1.00

Accuracies are the results of cross-validation classification.

Note: Accuracy percentages for pairs of measurements are shown in the upper and right parts of the table. Bold characters indicate accuracy over 80%. The Pearson correlation coefficients of pairs' measurements are shown in the lower and left parts of the table. Bold characters indicate significant correlations at the 0.01 level.

TABLE 5—*Discriminant function equations with high accuracies over 85.0% when using pairs of measurements.*

Measurement 1 (coefficient 1)	Measurement 2 (coefficient 2)	Constant	Accuracy (%)
sBDc (0.309)	sBDs (−0.007)	−11.890	85.3
sBDc (0.307)	sBDsm (−0.003)	−11.908	85.3
sBDc (0.306)	iBDsm (−0.001)	−11.916	85.3
sBDc (0.444)	sBDcm (−0.141)	−11.569	85.3
sBDc (0.444)	iBDc (−0.141)	−11.631	85.3
sBDc (0.235)	BHm (0.219)	−14.472	85.3
sBDc (0.309)	BHp (−0.015)	−11.676	85.3
sBDc (0.277)	Hm/Hp (10.656)	−20.237	86.3
sBDc (0.295)	rPW (0.04)	−11.946	85.3
sBDc (0.316)	lML (−0.042)	−11.812	85.3
sBDc (0.283)	lM&PL (0.083)	−12.905	85.3
sBDc (0.328)	TDm (−0.025)	−11.548	85.3
Hm/Hp (12.585)	sBDsm (0.308)	−21.097	85.3
Hm/Hp (11.894)	iBDs (0.324)	−20.137	85.3
Hm/Hp (11.745)	sBDcm (0.249)	−20.626	88.2
Hm/Hp (11.847)	iBDc (0.246)	−20.690	86.3
Hm/Hp (10.856)	iBDcm (0.246)	−20.425	88.2
Hm/Hp (13.296)	rPW (0.415)	−15.939	85.3

Accuracies are the results of cross-validation classification.

difference could be ignored in investigation of the trend of sex difference in T12. The other is that there were few models obtained from young aged cadavers. This study would have a significance to show the trend of sex difference in T12. Nevertheless, it is needed to investigate sex differences in T12 with more samples obtained from the young and dimensional differences in T12 with aging.

Conclusion

The 12th thoracic vertebra of Korean individuals is highly sexually dimorphic. Of the 35 metric variables examined, most measurements for the vertebral body, pedicle, transverse, and mammillary processes were found to provide reasonable accuracies for sex discrimination. In particular, the coronal measurements of the vertebral body showed the major sexual differences among Koreans. This vertebra should be considered for metric sex determination, particularly for fragmentary forensic assemblages. A preliminary data set has been presented, providing numerical parameters for sex discrimination using 12th thoracic vertebra for Koreans. Moreover, the data that are obtained in one ethnic group are not necessarily applicable to others. Therefore, ethnic-specific numerical values of these parameters need to be determined.

References

1. Bass WM. Developments in the identification of human skeletal material (1968-1978). Am J Phys Anthropol 1979;51(4):555–62.
2. Holland TD. Sex determination of fragmentary crania by analysis of the cranial base. Am J Phys Anthropol 1986;70(2):203–8.
3. Meindl RS, Lovejoy CO, Mensforth RP, Don Carlos L. Accuracy and direction of error in the sexing of the skeleton: implications for paleodemography. Am J Phys Anthropol 1985;68(1):79–85.
4. Rios Frutos L. Metric determination of sex from the humerus in a Guatemalan forensic sample. Forensic Sci Int 2005;3:153–7.
5. Iscan MY, Loth SR, King CA, Shihai D, Yoshino M. Sexual dimorphism in the humerus: a comparative analysis of Chinese, Japanese and Thais. Forensic Sci Int 1998;2:17–29.
6. Ozer I, Katayama K. Sex determination using the femur in an ancient Anatolian population. Anthropol Anz 2006;64(4):389–98.
7. Asala SA, Bidmos MA, Dayal MR. Discriminant function sexing of fragmentary femur of South African blacks. Forensic Sci Int 2004;145(1):25–9.
8. Albanese J. A metric method for sex determination using the hipbone and the femur. J Forensic Sci 2003;48(2):263–73.
9. Ozer I, Katayama K, Sagir M, Gulec E. Sex determination using the scapula in medieval skeletons from East Anatolia. Coll Antropol 2006;30(2):415–9.
10. Frutos LR. Determination of sex from the clavicle and scapula in a Guatemalan contemporary rural indigenous population. Am J Forensic Med Pathol 2002;23(3):284–8.
11. Falsetti AB. Sex assessment from metacarpals of the human hand. J Forensic Sci 1995;40(5):774–6.
12. Gualdi-Russo E. Sex determination from the talus and calcaneus measurements. Forensic Sci Int 2007;3:151–6.
13. Bidmos MA, Dayal MR. Sex determination from the talus of South african whites by discriminant function analysis. Am J Forensic Med Pathol 2003;24(4):322–8.
14. Bidmos MA, Asala SA. Discriminant function sexing of the calcaneus of the South African whites. J Forensic Sci 2003;48(6):1213–8.
15. Barrett C, Cavallari W, Sciulli PW. Estimation of sex from the talus in prehistoric Native Americans. Coll Antropol 2001;25(1):13–9.
16. Introna F Jr, Di Vella G, Campobasso CP, Dragone M. Sex determination by discriminant analysis of calcanei measurements. J Forensic Sci 1997;42(4):725–8.
17. Steele DG. The estimation of sex on the basis of the talus and calcaneus. Am J Phys Anthropol 1976;2:581–8.
18. Marino EA. Sex estimation using the first cervical vertebra. Am J Phys Anthropol 1995;97(2):127–33.
19. Pastor RF Sexual dimorphism in vertebral dimensions at the T12/L1 junction. Proceedings of the 57th Annual Meeting of the American Academy of Forensic Sciences; 2005 Feb 21-26; New Orleans, LA. Colorado Springs, CO: American Academy of Forensic Sciences, 2005.
20. Berry JL, Moran JM, Berg WS, Steffee AD. A morphometric study of human lumbar and selected thoracic vertebrae. Spine 1987;12(4):362–7.
21. Cheng XG, Sun Y, Boonen S, Nicholson PH, Brys P, Dequeker J, et al. Measurements of vertebral shape by radiographic morphometry: sex differences and relationships with vertebral level and lumbar lordosis. Skeletal Radiol 1998;27(7):380–4.

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