TECHNICAL NOTE

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Sex Variation in the Second Cervical Vertebra*

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ABSTRACT: The second cervical vertebra can be used to estimate sex with 83% accuracy in unidentified human skeletal remains. Reported here are the necessary statistics, based on 8 dimensions taken from 400 second cervical vertebrae, for the computation of customized discriminant functions. Discriminant function equations developed using variables selected in a stepwise procedure are also presented here as an example of the usefulness of this bone in estimating sex.

KEYWORDS: forensic science, forensic anthropology, skeletal anatomy, vertebra, sexual dimorphism, discriminant analysis

Medicolegal investigations of unidentified human skeletal remains demand a variety of methods for correctly estimating sex. Most metric studies of skeletal sexual dimorphism have focused on bones that manifest obvious gross size differences while avoiding those that do not (1–5). However, physical anthropologists are frequently summoned to provide a reliable estimation of the sex of unknown individuals represented by only a few bones. Therefore, exploration of sex differences in less commonly used bones is also needed.

The present study focuses on the usefulness of the second cervical vertebra for estimating sex. The means and variances of a "calibration" sample are provided as well as the pooled within-group covariance matrix. These statistics provide the information necessary for physical anthropologists to develop customized discriminant functions for complete or fragmentary second cervical vertebrae. An example of this bone's usefulness is illustrated with discriminant function equations developed using a stepwise procedure.

Materials and Methods

Specimens from the Hamann-Todd and Terry anatomical collections are utilized in the present study as a "calibration" sample. Eight dimensions of the second cervical vertebra were measured to the nearest 0.1 mm using digital sliding calipers and recorded for 100 black and 100 white specimens of each sex ranging in age from 20 to 79. For bilateral structures the left side was recorded. The dimensions measured (Fig. 1) are defined as follows: 1) Maximum Sagittal Length (XSL): The sagittal length of the vertebra from the most anterior point on the body to the posterior edge of the spinous process. 2) Maximum Height of the Dens (XDH): The height from the most inferior edge of the anterior border of the body to the most superior point on the dens. 3) Dens Sagittal Diameter (DSD): The maximum sagittal (anteroposterior) diameter of the dens. 4) Dens Transverse Diameter (DTD): The diameter of the dens measured perpendicular to the sagittal diameter. 5) Length of Vertebral Foramen (LVF): The internal length of the vertebral foramen measured at the inferior edge of the foramen in the median plane. 6) Maximum Breadth Across the Superior Facets (SFB): The maximum breadth between the superior articular facets as measured from the most lateral edges of the superior facets. 7) Superior Facet Sagittal Diameter (SFS): The maximum sagittal diameter of the superior articular facet. 8) Superior Facet Transverse Diameter (SFT): The maximum transverse diameter of the superior articular facet measured perpendicular to the sagittal diameter.

Being able to reliably replicate measurements is vital to any metric study, and therefore tests for intraobserver and interobserver error were conducted. To test intraobserver error, 20 vertebrae were subjected to two separate measurement trials, and the difference was utilized to calculate a percentage of intraobserver error (6,7). An independent researcher was also summoned to measure these 20 vertebrae to test interobserver error. The independent researcher was provided with no instructions on measurement techniques except for the written definitions provided above.

A multivariate analysis of variance (MANOVA) procedure was performed for the main effect of sex, race and skeletal collection and the interaction of sex and collection and sex and race. The MANOVA procedure evaluates the relationship of the continuous dependent variables to the independent classification variables (i.e., sex, race, and collection). The interaction effect is computed to test the hypothesis that the relationships are the same among groups defined by the main effects. In other words, the interaction tests if the relationship between one of the main effect groups and the dependent variables is changed by another main effect variable.

Discriminant function analysis, a procedure that maximizes within-group differences, was utilized to evaluate the effectiveness of the second cervical vertebra at estimating sex and race. A stepwise procedure was utilized for variable selection. The stepwise procedure selects a subset of variables based on the squared partial correlation and the significance level from an analysis of covariance that has the greatest amount of discriminating ability. Evaluation of the discriminating ability of the variables selected was then conducted using a crossvalidation procedure. This procedure classifies each individual case based on a discriminant analysis run on

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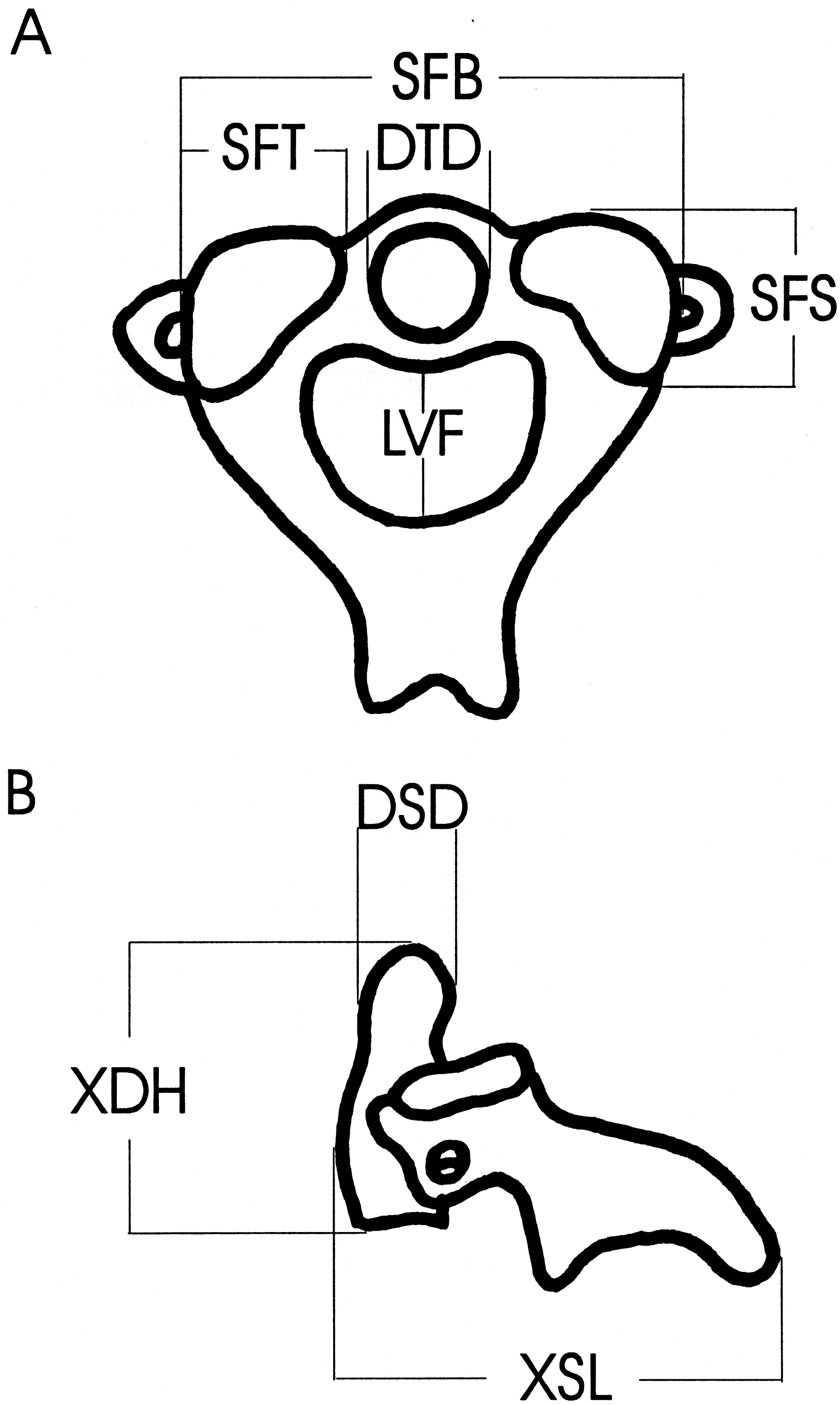

FIG. 1—*Line drawing of the second cervical vertebra from a superior view (A) and a lateral view (B) illustrating measurements used in this study.*

all other cases. In other words, the case being classified is omitted and a new discriminant analysis is conducted to classify it. In this way, the case being classified does not influence the discriminant analysis used to classify it.

Results

The results of the intraobserver and interobserver tests (Table 1) indicate that overall the measurements used in this study are replicable. The average percentage intraobserver error and interobserver error is 1.3 and 1.7%, respectively. Only DSD exhibits a relatively high intra- and interobserver error.

Simple statistics are presented in Tables 2 and 3 for females and males respectively, and the variance-covariance matrix is found in Table 4. These statistics can be utilized by forensic anthropologists to develop customized discriminant function equations that fit their particular needs.

The result of the MANOVA suggest that the Hamann-Todd and Terry collections do not differ significantly in the way sexual dimorphism is expressed in the second cervical vertebra, and therefore they could be pooled as a calibration sample. Since the Terry collection sample consists of whites only, the effect of race and collection could not be tested.

For the calibration sample, significant correlation was found for the main effect of race. The only variable to show a non-significant race effect was SFS. However, the overall interaction effect of sex and race was not significant. That is, while there are race differences in the second cervical vertebra, the pattern of sexual dimorphism does not differ significantly between blacks and whites. For this reason, and because the second cervical vertebra can only be used to discriminate between blacks and whites with marginal accuracy (73%), blacks and whites were pooled for the evaluation of sexual dimorphism.

Significant results were found for the main effect of sex in all variables, but only a single canonical axis was significant. The first canonical axis, which is primarily associated with size, accounts for 67% of the variation and displays a high loading for the XSL, XDH, SFB, and SFT variables.

Stepwise selection was employed to develop models of measurements displaying the maximum amount of discrimination ability. The maximum sagittal length (XSL) is by far the best single variable for estimating sex with an R-square value of 0.41, meaning that XSL accounts for 41% of the total variation in the model. The consecutive addition of SFS, SFT, LVF, and XDH only raises the R-square value to 0.46 (Table 5).

TABLE 1—*Intra-observer and inter-observer error results.*

		Percent Error*		Absolute Range (mm)	
Var	N	Intra	Inter	Intra	Inter
XSL	20	0.52	0.72	0.0–0.8	0.0–1.0
XDH	20	0.30	0.74	0.0–0.9	0.0–1.7
DSD	20	3.44	3.95	0.0–1.5	0.0–1.8
DTD	20	0.85	1.20	0.0–0.5	0.0–0.7
LVF	20	2.01	3.04	0.0–1.2	0.0–1.5
SFB	20	0.18	0.22	0.0–0.4	0.0–0.3
SFS	20	1.75	2.14	0.0–1.2	0.0–1.8
SFT	20	1.12	1.78	0.0–0.6	0.0–1.1

$$\text{*Percent Error} = \frac{\Sigma|Xi_1 - Xi_2|/n *100}{(X_1 + X_2)/2}.$$

TABLE 4—*Pooled within-sex covariance matrix.**

Var	XSL	XDH	DSD	DTD	LVF	SFB	SFT
XSL	6.64						
XDH	3.52	7.11					
DSD	0.81	1.18	0.89				
DTD	0.95	1.12	0.42	3.49			
LVF	1.30	0.50	0.23	0.10	3.37		
SFB	3.36	3.46	0.61	0.72	0.61	6.60	
SFT	1.12	1.70	0.22	0.17	−.13	2.23	2.22

* Degrees Freedom = 393.

TABLE 5—*Stepwise selection summary.*

Step	Var	Partial R^2	F Statistic	Prob>F Lambda	Wilks' Lambda	Prob.
1	XSL	0.4114	275.411	0.0001	0.5886	0.0001
2	SFS	0.0488	20.177	0.0001	0.5598	0.0001
3	SFT	0.0221	8.848	0.0031	0.5475	0.0001
4	LVF	0.0015	4.559	0.0334	0.5411	0.0001
5	XDH	0.0088	3.472	0.0632	0.5364	0.0001

TABLE 2—*Simple statistics for females.*

	Pooled Females			White Females			Black Female		
Var	N	Mean	SD	N	Mean	SD	N	Mean	SD
XSL	199	47.42	2.41	100	47.68	2.41	99	47.14	2.39
XDH	200	36.07	2.67	100	37.01	2.61	100	35.11	2.39
DSD	200	10.78	0.94	100	11.13	0.86	100	10.41	0.88
DTD	200	10.02	1.16	100	10.52	1.27	100	9.51	0.75
LVF	199	16.14	1.58	100	16.64	1.64	99	15.61	1.34
SFB	200	43.44	2.47	100	43.92	2.13	100	42.96	2.70
SFS	200	17.08	1.35	100	17.11	1.26	100	17.06	1.44
SFT	200	15.87	1.37	100	16.02	1.45	100	15.71	1.27

TABLE 3—*Simple statistics for males.*

	Pooled Males			White Males			Black Males		
Var	N	Mean	SD	N	Mean	SD	N	Mean	SD
XSL	198	51.70	2.72	98	52.36	2.42	100	51.06	2.85
XDH	199	39.33	2.64	99	40.01	2.27	100	38.67	2.82
DSD	200	11.48	0.95	100	11.86	0.86	100	11.11	0.89
DTD	200	10.37	0.99	100	10.85	0.87	100	9.90	0.86
LVF	196	16.35	1.69	96	16.98	1.58	100	15.74	1.57
SFB	200	46.75	2.66	100	47.40	2.53	100	46.09	2.64
SFS	200	18.54	1.50	100	18.59	1.28	100	18.49	1.69
SFT	200	17.43	1.60	100	17.57	1.65	100	17.30	1.55

TABLE 6—*Discriminant analysis equations for predicting sex from the second cervical vertebra.*

	Number of Variable in Model				
	1	2	3	4	5
Maximum Sagittal Length (XSL)	0.6488	0.5836	0.5490	0.5882	0.5343
Superior Facet Sagittal Diameter (SFS)		0.4359	0.3234	0.2987	0.3005
Superior Facet Transverse Diameter (SFT)			0.3021	0.2796	0.2142
Length of Vertebral Foramen (LVF)				−0.1694	−0.1671
Maximum Height of the Dens (XDH)					0.1183
Constant	−32.159	−36.6899	−38.0016	−36.3804	−37.1515
Male Mean	1.39	1.57	1.64	1.68	1.70
Sectioning Point	0.0	0.0	0.0	0.0	0.0
Female Mean	−1.39	−1.57	−1.64	−1.68	−1.70
Calibration Sample					
Males Classified Correctly	80.3%	81.8%	85.6%	81.2%	80.6%
Females Classified Correctly	83.1%	85.1%	80.3%	85.1%	83.4%
Total Correctly Classified	81.7%	83.4%	82.9%	83.1%	82.0%

Discriminant function equations were calculated, with the prior probabilities set equal, using those variables selected by the stepwise procedure (Table 6). When tested on the calibration sample employing a cross-validation procedure, the percent of males and females correctly classified ranged from 81.7 to 83.4%.

Discussion

While the second cervical vertebra would never be used for the estimation of sex in fairly complete skeletons, it can be used to correctly classify sex with nearly the same level of accuracy of other traditionally used single bones (1,2,4,5,8,9). The femur, for example, can be used to estimate sex with about 85% accuracy (1). From the results in Table 6, it is apparent that the combination of XSL and SFS provide the greatest sex discriminating ability in the second cervical vertebra. The addition of other variables does not add any significant discriminating ability.

The measurements used in this study are replicable. Only DSD and LVF exhibit moderately high percent error. The dimension DSD was not selected in the stepwise procedure, and LVF adds little to the discriminating ability of the second cervical vertebra. The two most important measurements (XSL and SFS) have very low intraobserver and interobserver error.

The pattern of sexual dimorphism does not differ significantly between blacks and whites, but for both males and females, the mean is greater in whites than in blacks for all dimensions recorded. Furthermore, whites appear to exhibit a slightly greater amount of sexual dimorphism than do blacks. To explore this difference, discriminant analyses were calculated separately on whites and blacks (Table 7). Sex was correctly classified 89% of the time for whites and only 81% for blacks. Furthermore, although there are three variables in common, stepwise variable selection differs slightly for blacks and whites. In consecutive order, variable selection for whites was XSL, SFB, DSD, DTD, and LVF. For blacks XSL, SFT, LVF, and SFB were selected consecutively.

Because of this race difference, the discriminating ability of the second cervical vertebra is reduced when blacks and whites are pooled. Ideally, discriminant functions for estimating sex would be developed separately for blacks and whites. When the means for all variables are examined, it is apparent that black males and white females are the most closely aligned groups. Therefore, in the pooled black/white sample, white females and black males are more frequently misclassified than black females or white males.

TABLE 7—*Dicriminant analysis results by race for selected functions.*

	Equation Number*		
	1	2	5
Black			
Male	76.0%	77.0%	78.1%
Female	82.8%	79.8%	84.9%
Total	79.4%	78.4%	81.5%
White			
Male	86.7%	83.7%	88.7%
Female	83.3%	86.3%	90.1%
Total	85.0%	85.0%	89.4%

* Equations from Table 5.

While this is a problem, in most medicolegal cases involving fragmentary skeletons the forensic anthropologist is not going to know the race of an unidentified human skeleton. Race could be estimated using the second cervical vertebra first, but this estimation is not going to be highly reliable. For this reason, the discriminant functions used here based on a pooled black/white sample is probably the most useful for the practicing forensic anthropologist.

In conclusion, when forensic scientists are confronted with incomplete human skeletal remains, the second cervical vertebra can be used to correctly classify sex with nearly the same level of accuracy of other traditionally use single bones. This paper provides forensic scientists with several calculated discriminant functions and the necessary statistics to develop customized discriminant functions to meet the needs of their specific medicolegal cases.

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