TECHNICAL NOTE

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A Multivariate Method for Classifying Third to Seventh Cervical Newborn Vertebrae Using Bone Measurements

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ABSTRACT: This research provides a method to classify human newborn (9 to 10 lm) third to seventh cervical ossification centers. Nine linear measurements on the cervical neural arch were defined from 35 human neonates. Four discriminant functions were performed using the stepwise method. The model classifies 82.8% of grouped cases and 77.9% of cross-validated cases correctly. The model is useful in cases with isolated or commingled remains during anthropological or forensic investigations.

KEYWORDS: forensic science, forensic anthropology, forensic osteology, newborn bones, newborn vertebral column, newborn cervical vertebrae, fetal bone measurements, immature bone identification, discriminant analysis

Text

When isolated or commingled newborn human vertebral bones are encountered during anthropological or forensic investigations, the osteologist is faced with the task to identify them. If all of the cervical vertebrae are present, it is a relatively simple matter to arrange them into the proper order, but a single cervical vertebra 3 to 7 will always be problematic. Newborn bone cervical remains are so different from adult ones that they become difficult to identify. Ossification centers of human fetal and newborn cervical vertebrae anatomical details were described by Castellana and Kósa (1). An initial newborn 3 to 7 vertebral assessment can be done by means of morphological features of bones. The present document offers a discriminating method among newborn third to seventh cervical ossification centers by using bone measurements in order to complement and help such previous vertebral identification. The application of present results could be of great interest in anthropology and forensic osteology fields.

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Materials and Methods

Measurements were taken on a skeletal sample of 35 human neonates (17 male, 16 female, and 2 of unknown sex) of 9 to 10 lunar months (28 days each lunar month). The specimens were selected from the fetal-newborn collection in the Department of Forensic Medicine of the Albert Szent-Györgyi Medical University (Szeged, Hungary). Nine linear dimensions (by sliding caliper with vernier 1/10 mm) were defined to describe morphological variation (Table 1). Measurements are shown in Fig. 1. No pathological skeletons were used. SPSS (Release 8.0.1) was used to generate canonical discriminant functions. A stepwise discriminant analysis was chosen to select an optimal set of discriminating variables (2). The analysis was performed using the number of cases by group shown in Table 2. The exact sample composition for each function varied due to difference in preservation and element representation.

Results

The assumptions of multivariate normality and the homogeneity of covariance matrices were evaluated using the Q-Q plots and Box's M tests. Q-Q plots for each variable indicate no major departures from normality; they were basically linear. Results of Box's M ($M = 75.144$, $F = 1.166$, $p = 0.178$) does not demonstrate the heterogeneity. A single pooled variance-covariance matrix can represent all five groups.

For each group of variables, the mean (X) and standard deviation (SD) were calculated (Table 2). The metric pattern of group means gives us some useful data in order to identify cervical neural arch. From third to seventh neural arches, an increase of sagittal dimensions (Measurements 1, 3, 5, 6, and 8) and a decrease of transverse dimensions (Measurements 2, 4, 7, and 9) can be seen. Thus, C3 is shorter and wider than C7. Decrease of transverse dimensions lies in the gradual anterior displacement of the inferior articular facet, which is flatted in the third neural arch and almost vertical in the seventh one (1): Measurement 2 includes this facet. Such anterior displacement goes with an extension of facet length (Measurement 6) and a shortening of its width (Measurement 7). Moreover, superior articular facet gradual fusion with the transverse process—which begins in C3 and finishes in C7 (1)—can be observed in the decrease of involved transverse dimensions (Measurements 4 and 9) and in the extension of the facet length (Measurement 8). On the other hand, the gradual increase of the length (Measurement 3) and pos-

TABLE 1—*Definition of measurements.*

Measurement	Description
1. Maximum length of the neural arch	From the most anterior point in the transverse process to the most posterior one in the lamina. It provides an idea of the size of the ossification center.
2. Maximum width of the neural arch	Distance between the most lateral point of the superior articular facet to the most distant point in the anterior process (pedicle). The measurement shows the position of the inferior articular facet, which gets vertical from C3 to C7.
3. Length of the lamina	From the most anterior point of the superior articular facet to the most posterior one in the lamina. The measurement provides an idea of the anterior displacement of the superior articular facet from C3 to C7.
4. Width of the neural arch	Distance from the lateral point of the ossification center located between the superior and inferior articular facets, to the most distant one in the anterior process (pedicle).
5. Height of the lamina	Maximum dimension measured in the most posterior part of the lamina. It normally coincides with the longitudinal axis of the lamina.
6. Length of the inferior articular facet	Distance between the most distant points in the inferior articular facet measured in its sagittal axis. Place the arms of the caliper perpendicular to the bone.
7. Width of the inferior articular facet	Distance between the most distant points in the inferior articular facet measured in its transverse axis. Measured perpendicular to its length.
8. Length of the superior articular facet	Distance between the most distant points in the superior articular facet measured in its sagittal axis.
9. Width of the superior articular facet	Distance between the most distant points in the superior articular facet measured in its transverse axis. Measured perpendicular to its length.

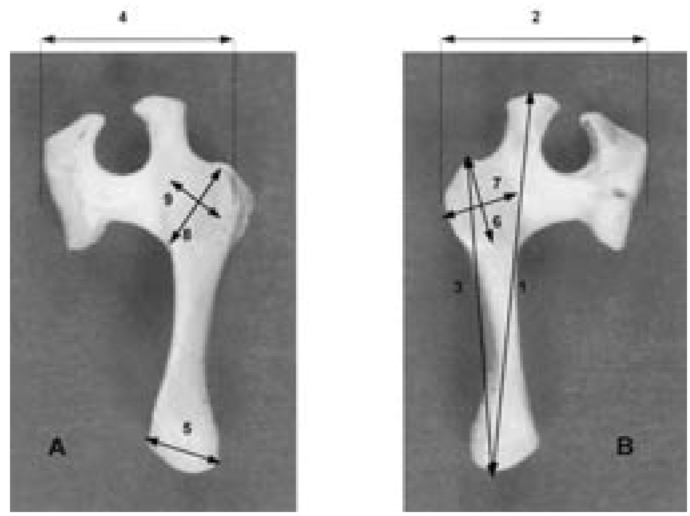

FIG. 1—*Newborn cervical neural arch measurements (see description in Table 1): A: Superior view. B: Inferior view.*

terior height (Measurement 5) of the lamina makes the neural arch larger as descending in the cervical column. This increased length compensates the reduction of the transverse process, and this situation produces an equivalent neural arch length (Measurement 1) among cervical groups studied. This is to say, there are no significant differences among the neural arch length group means (Wilks' lambda near to 1) (Table 3). Low Wilks' lambda values indicate great disparity among groups, so the length of the neural arch is not a good discriminator. The other variables are adequate for the analysis (Table 3). Five measurements were introduced in the analysis (F to enter = 3.84, F to remove = 2.71) to produce four discriminant functions (Table 4). The unstandardized coefficients plus the constant can be used to derive a discriminant score on an unknown newborn vertebra. The relative importance of each variable to the

TABLE 2—*Description statistics for third to seventh cervical neural arch measurements.*

		Cervical Neural Arch				
		Third	Fourth	Fifth	Sixth	Seventh
		Number of Individuals in the Analysis				
Measurement		$N = 33$	$N = 32$	$N = 33$	$N = 33$	$N = 32$
1. Max length of the neural arch	*X*	16.266	16.641	16.897	16.930	16.647
	SD	1.495	1.429	1.498	1.615	1.823
2. Max width of the neural arch	*X*	9.550	9.563	9.336	9.094	8.916
	SD	0.696	0.597	0.596	0.657	0.850
3. Length of the lamina	*X*	13.362	14.306	15.024	15.918	16.181
	SD	1.471	1.186	1.272	1.403	1.824
4. Width of the neural arch	*X*	9.034	9.128	8.955	8.800	8.459
	SD	0.767	0.627	0.549	0.511	0.481
5. Height of the lamina	*X*	3.522	3.338	3.624	3.794	4.534
	SD	0.443	0.476	0.506	0.531	0.480
6. Length of the inferior facet	*X*	4.803	5.119	5.461	5.673	5.966
	SD	0.357	0.456	0.560	0.521	0.474
7. Width of the inferior facet	*X*	3.772	3.662	3.452	3.415	0.297
	SD	0.398	0.392	0.380	0.343	0.425
8. Length of the superior facet	*X*	3.634	4.025	4.618	5.512	6.256
	SD	0.486	0.486	0.553	0.580	0.717
9. Width of the superior facet	*X*	3.644	3.706	3.427	3.245	2.950
	SD	0.418	0.450	0.405	0.317	0.352

TABLE 3—*Wilks' lambda (U-statistic) and univariate* F *ratio.*

Measurement	Wilks' Lambda	*F*	Significance
1. Max length of the neural arch	0.997	0.924	0.452
2. Max width of the neural arch	0.875	5.612	0.000
3. Length of the lamina	0.654	20.733	0.000
4. Width of the neural arch	0.864	6.200	0.000
5. Height of the lamina	0.578	28.668	0.000
6. Length of the inferior facet	0.574	29.092	0.000
7. Width of the inferior facet	0.831	7.955	0.000
8. Length of the superior facet	0.256	113.877	0.000
9. Width of the superior facet	0.663	19.930	0.000

discriminant function may be gaged by the size of the standardized coefficient when the sign is ignored. The most contributive measurement to the first function was the superior facet length. This function accounts for 93.3% of the variance in the discriminating variables. The largest standardized coefficients of the second function were the lamina length and width and explain an additional 6.2% of the variance. The last two functions explain the remaining 0.5% of the variance and describe the residual differences. The clas-

TABLE 4—*Discriminant function coefficients and standardized coefficients.*

	Function 1	Function 2	Function 3	Function 4
UNSTANDARDIZED COEFFICIENTS				
3. Length of the lamina	0.242	−0.564	−0.358	−0.489
5. Height of the lamina	0.495	2.219	−1.237	0.356
7. Width of the inferior facet	−0.912	1.487	2.934	−1.459
8. Length of the superior facet	1.512	−0.404	1.090	0.986
9. Width of the superior facet	−1.979	−1.317	−0.959	3.079
Constant	−2.842	1.281	−2.301	−4.085
Percent of variance	93.3	6.2	0.4	0.1
STANDARDIZED COEFFICIENTS				
3. Length of the lamina	0.350	−0.816	−0.518	−0.707
5. Height of the lamina	0.242	1.084	−0.604	0.174
7. Width of the inferior facet	−0.354	0.577	1.138	−0.566
8. Length of the superior facet	0.863	−0.231	0.622	0.563
9. Width of the superior facet	−0.774	−0.515	−0.375	1.204

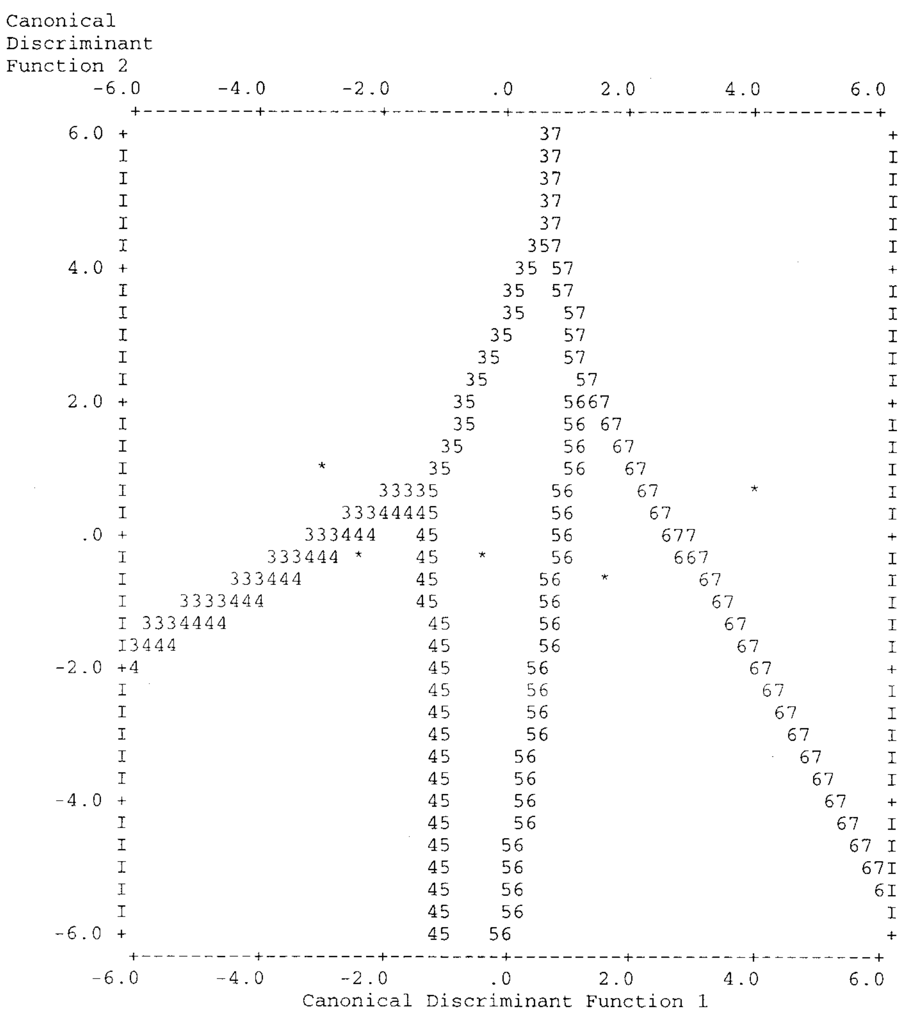

FIG. 2—*Territorial map. Symbols that represent frontiers between regions of the five cervical groups: 3 = third cervical; 4 = fourth cervical; 5 = fifth cervical; 6 = sixth cervical; 7 = seventh cervical. *Indicates a group centroid.*

TABLE 5—*Classification coefficients and results.*

	Third Cervical	Fourth Cervical	Fifth Cervical	Sixth Cervical	Seventh Cervical
			Classification Coefficients		
3. Length of the lamina	2.721	3.571	4.238	4.723	4.503
5. Height of the lamina	2.598	0.119	1.502	1.205	5.811
7. Width of the inferior facet	12.420	9.283	6.951	6.140	5.219
8. Length of the superior facet	−0.194	1.551	3.936	7.709	10.383
9. Width of the superior facet	6.942	8.029	3.738	−0.404	−6.046
Constant	−60.084	−62.349	−63.658	−72.556	−83.380
		Original percent of perdicted group membership (cross-validated percent in parentheses)			
Third cervical	78.8 (75.8)	21.2 (24.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Fourth cervical	15.6 (15.6)	75.0 (75.0)	9.4 (9.4)	0.0 (0.0)	0.0 (0.0)
Fifth cervical	0.0 (6.1)	6.1 (9.1)	87.9 (75.8)	6.1 (9.1)	0.0 (0.0)
Sixth cervical	0.0 (0.0)	0.0 (0.0)	15.2 (18.2)	78.8 (69.7)	6.1 (12.1)
Seventh cervical	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	6.3 (6.3)	93.8 (93.8)
		Original percent of cases correctly classified: 82.8% (cross validated: 77.9%)			

TABLE 6—*Discriminant functions 1 and 2 evaluated at group centroids.*

	Centroids	
	Function 1	Function 2
Third cervical	−3.014	0.896
Fourth cervical	−2.310	−0.448
Fifth cervical	−0.352	−0.404
Sixth cervical	1.693	−0.708
Seventh cervical	3.941	0.699

sification coefficients are given for the five variables (Table 5). These are used to test the adequacy of the derived functions by classifying the cases used to produce the functions and comparing predicted group membership with actual group membership. It does yield a measure of the classification results; 78.8% of third cervical were classified correctly, 75.0% of fourth cervical were classified correctly, 87.9% of fifth cervical were classified correctly, 78.8% of sixth cervical were classified correctly, and 93.8% of seventh cervical were classified correctly. An 82.8% of "grouped" cases were correctly classified. Application of the cross-validation method gives a 77.9% of validated cases correctly classified.

The territorial map shown in Fig. 2 plots the first discriminant function against the second and attempts to divide the plot into regions for each vertebral group scores (i.e., the region delimited by Number 3 corresponds to the area of third cervical vertebra scores). After computing the first two discriminant function values of an unknown vertebra, the group membership can be established by placing the intersection point of both values in the map. The asterisks indicate the group centroids corresponding to first and second discriminant functions (Table 6).

Discussion

Newborn bone measurements and discriminant analysis have been classically used to establish demographic characteristics such as age and sex (3–6). Measurements of the ossification centers have never been used in human newborn identification. We have presented four discriminant functions, which can be used to predict the cervical group 3 to 7 of a neonatal vertebra. It is discouraging that the functions provide relatively low discriminating abilities: only fifth and seventh cervical show accuracy levels of original percent of predicted group membership of above 80%. Cross-validation decreases the accuracy to the 70 to 75% range. Notwithstanding that, when a forensic anthropologist is asked to examine commingled fetal or newborn bones during the course of paleodemographic reconstruction, it may be necessary to use cervical discriminant functions to do an individual assignment. Such cases may be unusual, but they do occur. The present work contributes to the diagnosis of human newborn skeletal remains in both the forensic and anthropological context. Lacking other criteria, the new defined measurements of cervical neural arch ossification centers may be used to estimate a classification of a newborn vertebra.

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