J Forensic Sci, Nov. 2005, Vol. 50, No. 6
Paper ID JFS2005058
Available online at: www.astm.org

TECHNICAL NOTE

Selma Uysal RM,[1] M.D.; Dilek Gokharman,[1] M.D.; Mahmut Kacar,[1] M.D.; Işıl Tuncbilek,[1] M.D.; and Uğur Kosar,[1] M.D.

Estimation of Sex by 3D CT Measurements of the Foramen Magnum

ABSTRACT: The purpose of this prospective study is to investigate the value and accuracy of the measurements of the foramen magnum (FM) by using three-dimensional computed tomography (3DCT). Cases were randomly selected among 100 patients (48 males, 52 females) who had temporal CT in the Radiology Department. Seven measurements of the foramen magnum on 3D images, modified from the nine lines previously defined by Giles and Elliot were made. Using Fisher's linear discriminant functions test, the length and width of right condyle and width of FM diameters were found to be statistically different in each sex ($p < 0.001$) with 81% accuracy. To our best knowledge, this is the first report studying 3DCT measurements of FM, resulting with a sex determination accuracy rate of 81%. CT/3DCT can be reliably used in further investigations to provide basis for anthropometric and forensic issues.

KEYWORDS: forensic science, forensic anthropology, foramen magnum, computed tomography, sex determination, three-dimensional reconstruction

Sex determination of unidentified human remains is very important in forensic medicine, medicolegal cases and forensic anthropology. The identification of sex from adult human skeletal remains is highly reliable if the complete skeleton is available for analysis. Krogman reported close to 100% accuracy of sex determination, in 750 intact skeletons (1). On the other hand, finding a wholly intact skeleton is not always likely. For this reason, it has become more important to develop sex discriminant functions for each bone (2,3) For example, the maximum sex determination accuracy of the whole skull alone was found to be 90% (1).

It is very well known that for unidentified skeletons, sex determination is sometimes difficult. Sometimes the process may be extremely complicated especially when presented fragmented bones (2–5). The sex discriminant value of the foramen magnum has always attracted attention although its importance is a controversial subject in the archaeological and anthropological literature (6–10). Previous research evaluates made about the value of the foramen magnum in species designation and sex discrimination (6).

The purpose of this study is to evaluate whether measurements of the foramen magnum are useful for sex determination in fragmented skulls by using three dimensional computed tomography (3D CT), and if so, to investigate the resultant accuracy.

Methods

Individuals included in the study were randomly selected from a Turkish population among a group of patients who had temporal bone CT for several reasons in the Radiology Department. The study was made prospectively and patients with congenital or acquired disease causing probable cranial deformities were excluded from the study. The foramen magnum was measured in a total of 100 patients (48 males and 52 females), age range: 18–83 years (mean age: 42 years). The probable errors due to asymmetry/obliquity in axial 2 mm-collimated CT images were excluded by making the measurements on 3D volume-rendered images. Measurements were made on a Pronto Hitachi CT. Seven measurements, modified from the nine variables previously defined by Giles and Elliot (9), were made (two measurements were not used because of nonvisualisation by 3D CT). Measurements were made by a senior radiologist (S.U.) using sliding callipers graduated to 0.1 mm. The metric parameters were as follows (Figs. 1, 2);

1. Length of occipital condyle (LC): The maximum length of condyle along the long axis from the edges of the articular surface
2. Width of occipital condyle (WC): The maximum width of condyle from the articular edges along a line perpendicular to the long axis (Length and width of occipital condyle line were measured for each side)
3. Minimum intercondylar distance (MnID): The minimum distance between the medial edges of the articular surfaces of the condyles
4. Maximum bicondylar distance (MBD): The bicondylar breadth; the maximum distance between the lateral edges of the articular surfaces of the condyles
5. Maximum medial intercondylar distance (MID): The intercondyler breadth; the maximum distance between the medial articular margins of the condyles
6. Length of the foramen magnum (LFM): The maximum internal length of the foramen magnum along the midsagittal plane

[1] Department of Radiology, Ankara Training and Research Hospital, Ankara, Turkey.
Received 10 Feb. 2005; and in revised form 20 May 2005; accepted 4 June 2005; published 14 Sept. 2005.

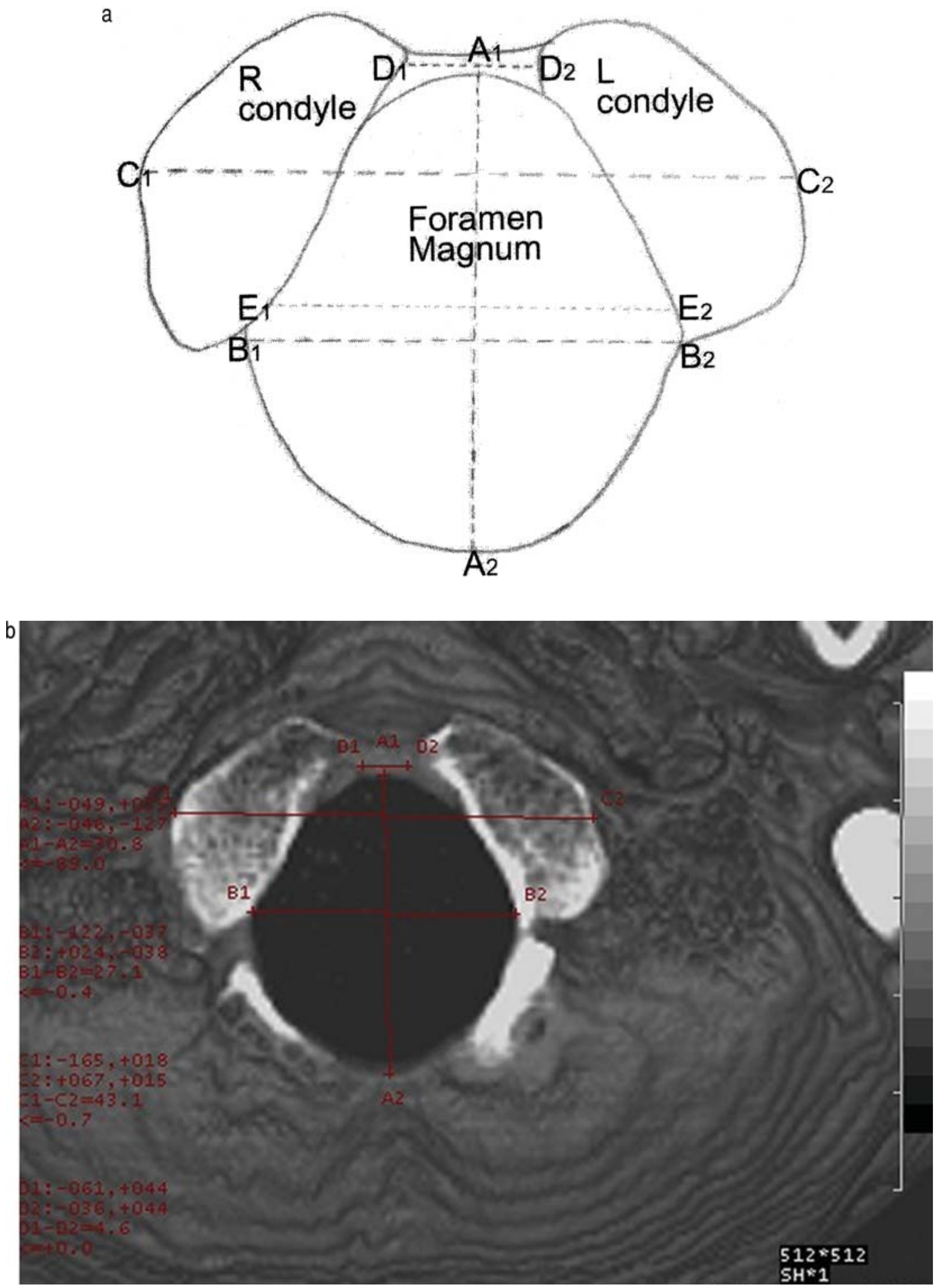

FIG. 1*a* and *b—The five lines showing LFM (A_{1-2}), WFM (B_{1-2}), MBD (C_{1-2}), MnID (D_{1-2}) and MID (E1–2) illustrated as seen from the cranial base (Fig. 1a) and on 3DCT (Fig. 1b).*

7. Width of the foramen magnum (WFM): The maximum internal width of the foramen magnum perpendicular to the midsagittal plane.

Results

Statistical analysis was made on SPSS for Windows 11.5 version by using Fisher's linear discriminant functions. $P < 0.001$ values were accepted as statistically significant. For each measurement, the minimum and maximum diameters were obtained and mean values with standard deviations for both sexes were calculated (Table 1). Although all dimensions were larger in the male, there was a statistically significant difference between males and females for both length (mean: 22.8 mm for males and 20.8 mm for females) and width (mean: 12.5 mm for males and 11.8 mm for females) of right condyle and width of the foramen magnum (mean:30.8 mm for males and 28.9 mm for females) ($p < 0.001$) (Table 2).

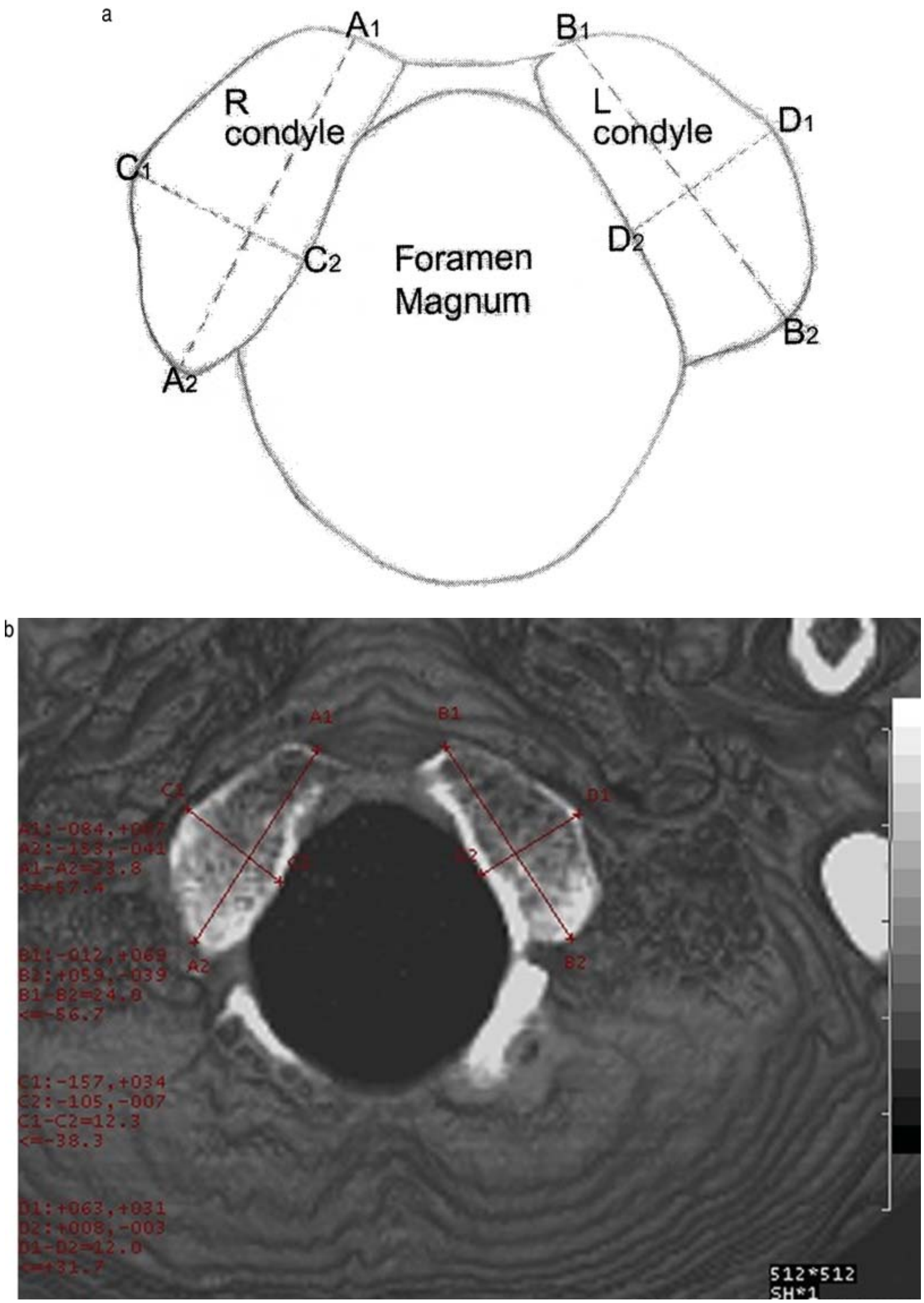

FIG. 2*a* and *b—The four lines showing LRC (A_{1-2}), LLC (B_{1-2}), WRC (C_{1-2}) and WLC (D_{1-2}) for both condyles seen from the cranial base with illustration (Fig. 2a) and on 3DCT (Fig. 2b).*

The resultant formula of Fisher's linear discriminant function analysis is as follows;

$$\begin{aligned} D_{\mathrm{male}} &= [(8.227\mathrm{xLRC}) + (6.885\mathrm{xWRC}) \\ &\quad + (5.817\mathrm{xWFM})] - 227.181 \\ D_{\mathrm{female}} &= [(7.529\mathrm{xLRC}) + (6.477\mathrm{xWRC}) \\ &\quad + (5.467\mathrm{xWFM})] - 196.519 \end{aligned}$$

Thus, in an unidentified skull, while these 3 measurements are installed in the formula, the resultant larger numerical value implies the sex with an accuracy of 81% (Tables 3, 4).

Discussion

Sex determination is used in forensic medicine, medicolegal cases and forensic anthropology. There are mainly two approaches; the first is based on visual assessment of the shape or relative

TABLE 1—*The minimum and maximum diameters.*

Descriptive Statistics[a]

Category	N	Minimum	Maximum	Mean	Std. Deviation
Male					
LRC	48	19.80	29.0	22.8365	1.96644
WRC	48	9.70	15.20	12.5594	1.35398
LLC	48	16.75	30.10	22.7271	2.26291
WLC	48	6.40	15.50	12.5011	1.56981
MnlD	48	3.90	8.20	5.6021	.97222
MID	48	20.90	32.20	26.6875	2.48512
MBD	48	34.60	52.75	46.8229	3.20248
LFM	48	32.90	42.65	37.0833	1.93730
WFM	48	27.60	37.65	30.8365	2.04156
Valid N (listwise)					
Female					
LRC	52	17.15	23.75	20.8596	1.37620
WRC	52	9.05	18.65	11.8012	1.48699
LLC	52	11.55	24.00	20.5827	2.24171
WLC	52	9.75	14.40	11.7779	1.05582
MnlD	52	3.20	6.80	4.9114	.82560
MID	52	18.50	35.10	24.6885	2.82233
MBD	52	37.65	51.20	43.9817	2.84240
LFM	52	29.40	39.60	34.8702	2.63110
WFM	52	22.00	35.10	28.9327	2.43990
Valid N (listwise)					

[a] No statistics are computed for one or more split files because there are no valid cases.

TABLE 2—*As shown in the table, among seven variables in the analysis, LRC, WRC and WFM were significant as determinants of sex.*

Canonical Discriminant Function Coefficients

	Function
	1
LRC	.460
WRC	.269
WFM	.230
(Constant)	−20.147

Unstandardized coefficients.

TABLE 3—*Fisher's linear discriminant function analysis demonstrating the statistically significant three lines.*

Classification Function Coefficients

	Category	
	Male	Female
LRC	8.227	7.529
WRC	6.885	6.477
WFM	5.817	5.467
(Constant)	−227.181	−196.519

Fisher's linear discriminant functions.

proportions of sexually dimorphic features and the second is a metric approach (11). The metric approach is more objective and less dependent on observer experience. Its replicability is high and it is more amenable to statistical analysis facilitating between-sample and between-study comparisons. However, it depends on identifiable and unambiguous osteometric landmarks (12).

TABLE 4—*The accuracy of the function analysis.*

Classification Results*

		Category	Predicted Group Male	Predicted Group Female	Total
Original	Count	male	38	10	48
		female	9	43	52
	%	male	79.2	20.8	100.0
		female	17.3	82.7	100.0

* 81.0% of original grouped cases correctly classified.

The sex determination procedure is easy when the skeletal integrity is complete, whereas it may be extremely difficult while handling fragmented bones. When using the innominate component of the adult human pelvis alone, the accuracy was reported to be 90–100%, making it the most preferred bone for sex determination (13). Giles and Elliot have remarked that "next to the pelvis, the skull is the most easily sexed portion of the skeleton" (9). These authors have developed a discriminant-function technique that utilized cranial measurements in intact skulls, with 82–89% accuracy in predicting the sex (9). A problem arises, however, if a skull is fragmentary. The study of Catalina-Herrera et al. has revealed significant differences between sagittal and transverse diameters of the foramen magnum with these parameters being larger in male than in female skulls (7). Previous work by Holland suggests that the measurements of the region of occipital condyles and the foramen magnum are useful for determining the sex, with an accuracy of 70–90% (10). In his report, he has used nine lines for measuring the foramen magnum.

In this present study, we used seven variables modified from those of Holland's (two lines were not included because of nonvisualisation by 3D CT) and made the measurements by 3D CT in a living human population. In the reviewed literature, we could find only one study using CT for the measurement of the foramen magnum in control subjects (8). But in that study no sex differences were evaluated. In our study only three metric diameters of the foramen magnum (WFM, LRC and WRC) were statistically significant in sex determination with an accuracy rate of 81%, approximating the rate of Holland. We think that the addition of other variables does not increase the accuracy rate.

The factors decreasing our accuracy rates may be due to probable methodological differences, as Holland (10) made manual measurements in human skulls compared to our measurements in a living human population by 3D CT. Also, we have to keep in mind that there are some intermediate characteristics in each sex with social and populational differences as well.

We found that the right condylar length and width were statistically more significant than the left condylar dimensions in defining sex determination. In previous reports, condylar measurements and intercondylar differences were not underlined. To our knowledge, this is a new finding which may lead to further studies. The intercondylar differences may be explained by the right hand dominance of the population as a hypothesis.

Reviewing published literature, we identified only one study concerning CT measurements of the foramen magnum in unidentified skulls. To our best knowledge, this is the first report studying 3D CT measurements of the foramen magnum with a resultant sex discriminant accuracy of 81%. Radiological support should provide easier measurements improving the reliability of statistical analysis. CT/3D CT can be accurately used in further investigations to provide basis for anthropometric and forensic issues.

Acknowledgments

Special thanks to Yılmaz Selim Erdal, Anthropologist- Hacettepe University and Nursel Türkmen, M.D., Forensic Medicine-Uludağ University.

The study was in accordance with the Helsinki Declaration of 1975 and informed consent was received from each patient.

References

1. Krogman WM. The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas, 1973. (From the reference of MacLaughlin SM, Bruce MF The accuracy of sex identification in European skeletal remains using the Phenice characters. J Forensic Sci 1990;35:1384–92.
2. Introna F, Di Vella G, Campobasso CP, Dragone M. Sex determination by discriminant analysis of calcanei measurements. J Forensic Sci 1997;42:725–8. [PubMed]
3. Wescott DJ. Sex variation in the second cervical vertebra. J Forensic Sci 2000;45:462–6. [PubMed]
4. Holland TD. Use of the cranial base in the identification of fire victims. J Forensic Sci 1989;34:458–60. [PubMed]
5. İşcan MY, Miller-Shaivitz P. Discriminant function sexing of the tibia. J Forensic Sci 1984;29:1087–93. [PubMed]
6. Shaeffer MS. Brief communication: foramen magnum-carotid foramina relationship: Is it useful for species designation? Am J Phys Anthropol 1999;110:467–71. [PubMed]
7. Catalina-Herrera CJ. Study of the anatomic metric values of the foramen magnum and its relation to sex. Acta Anat 1987;130:344–7. [PubMed]
8. Sendemir E, Savcı G, Cimen A. Evaluation of the foramen magnum dimensions. Kaibogaku Zasshi 1994;69:50–2. [PubMed]
9. Giles E, Elliot O. Sex determination by discriminant function analysis of crania. Am J Phys Anthropol 1963;21:53–68. [PubMed]
10. Holland TD. Sex determination of fragmentary crania by analysis of the cranial base. Am J Phys Antropol 1986;70:203–8.
11. Kurihara Y, Kurihara Y, Ohashi K, Kitagawa A, Miyasaka M, Okamoto E, et al. Radiologic evidence of sex differences: Is the patient a woman or a man? AJR 1996;167:1037–40. [PubMed]
12. MacLaughlin SM, Bruce MF. The accuracy of sex identification in European skeletal remains using the Phenice characters. J Forensic Sci 1990;35:1384–92. [PubMed]
13. Kelley MA. Phenice's visual sexing technique for the os pubis: a critique. Am J Phys Antropol 1978;79:117–20.

Additional information and reprint requests:
Selma Uysal, RM, M.D.
Fakülteler mah. Dirim Sok. Savaş Apt. 15/13
06590, Cebeci/ Ankara
Turkey
E-mail: uysalselma@yahoo.com