Metric assessment of the foramen magnum for sex determination in adults and subadults

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1. Introduction

The basal region of the human skull is robust and well protected by soft tissues and tends to withstand inhumations (Graw, 2001; Gapert et al., 2009) and physical insults (Holland, 1989). Osteometric studies have tried to evaluate the skull base and especially the foramen magnum (FM) as indicator of sex in adults (e.g. Gapert et al., 2009; Günay et al., 2000; Uysal et al., 2005) and subadults (Veroni et al., 2010). However, in most studies (Gruber et al., 2009) the full potential of the method was prohibited due to the small sample size.

Aim of the present study is to assess the use of FM for sex determination on a large European and non-European dataset and to demonstrate the potentials and the limits particularly on subadults, poorly preserved or cremated skeletons.

2. Material and Methods

Discriminant functions (DFA): **555 (296 males, 259 females)** dry skulls from the ossuary of Poschiavo (18th century, Grisons, Switzerland; Papageorgopoulou et al. 2010).

value = (m7 * 0.145950593562103) + (m16 * 0.31358247364222) - 14.2704696491778 . [1]
value = (m7 * 0.385252865348475) - 13.4033062372623 . [2]
value = (m16 * 0.412288351276398) – 12.0906917250254. [3]
(the cutpoint of all = 0)

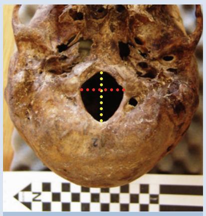

Fig. 1. Sagittal (yellow line) and transverse (red line) diameter of the foramen magnum.

- The **sagittal** (FML/M7) and the **transverse** (FMB/M16) diameters of the FM were obtained after Martin (1928) (Fig.1).
- Measurements taken: 4 experienced observers; absolute technical error **(TEM)** and relative technical error of measurement **(rTEM)** were calculated on 105 randomly selected skulls after Gapert et al., 2009.
- **3900 (2118 males, 1782 females)** FML and **1100 (596 males, 504 females)** FMB from **47 archaeological populations (10 mil. BC - 2 mil. AD),** including Howells 1973, 1996 world dataset, were collected from the authors themselves and from published data.
- FM index was computed as FML/FMB after Muthukumar et al., 2005.
- Area of FM was computed as: 3.14159 * ((FML + FMB) /4)^2.
- Capacity of the skull was estimated after Pearson, as published in Martin and Saller (1957).
- FMB and FML of 46 subadults from Poschiavo were also measured (Fig. 2).
- All statistics were calculated by SPSS 19.0.

Fig. 2. The ossuary of Poschiavo in the oratorio of St. Anna (Grisons, Switzerland, 18th c. AD) with 637 human skulls. Registration of the skulls by the Archaeological Service of Grisons.

3. Results and Discussion

➢ Intra-observer error differences between the four observers both for FML and FMB (non-parametric Kruskall-Wallis-test, FML: chi^2 1.628, sign. 0.653; FMB: chi^2 5.161, sign. 0.160) and between the inter- and the intra-observer error were not significant (FML: chi^2 0.469, sign. 0.493; chi^2 0.590, sign. 0.442).

Table 1. Mean and standard deviation of FML measurements collected; the number of individuals is restricted to sexed adults. The last column shows the significance of the difference between males and females after a T-test.

FML	males			females			t-test
	mean ±std.dev.	n	min.-max.	mean ±std.dev.	n	min.-max.	sign.
Europe*	36.3 ±2.9	1191	21 - 39	34.7 ±2.7	1018	24 - 48	0.000
Asia	36.5 ±2.4	439	30 - 44	34.8 ±2.3	283	27 - 44	0.000
America	36.9 ±2.6	201	30 - 45	35.4 ±2.5	188	30 - 42	0.000
Africa	36.3 ±2.6	241	30 - 43	34.5 ±2.5	253	27 - 42	0.000
Australia	36.4 ±2.3	330	30 - 42	34.5 ±2.3	282	28 - 40	0.000
FMB							
Europe	30.4 ±2.6	883	21 - 39	28.9 ±2.5	750	22 - 40	0.000

* Europe: St. Anna, Ossuary, Poschiavo, Switzerland, 17th-19th c. AD; Wallis, ossuary, Switzerland, 17th -19th c. AD; Badener, anatomical collection, Germany, 16th-18th c. AD; Westerhus, cemetery, Sweden, 13th -14th c. AD; Tomils, cemetery, Switzerland, 11th-15th c. AD; Zwentendorf, cemetery, Austria, 10th -11th c. AD; Alattyan, cemetery, Hungrary, 7th-8th c. AD; Stetten, cemetery, Germany, 7th c. AD; Oerlingen, cemetery, Switzerland, 7th c. AD; Munzingen, cemetery, Germany, 7th c. AD; Ried-Mühlehölzli, cemetery, Switzerland, 5th-7th c. AD; Linz, cemetery, Austria, 4th c. AD; Pully Chamblandes, cemetery, Switzerland, 4 mil. BC; Sondershausen and Bruchstedt, cemeteries, central Germany, 5 mil. BC; Taforalt, Marocco, cemetery, 10-7 mil. BC; Moita do Sebastião, cemetery, Portugal, 10-7 mil. BC; Vlasac, cemetery, Serbia, 10-7 mil. BC. Non-European populations from Howells 1973, 1996 world dataset.

Table 2. Percentages of correct classifications for sex determination based on DFA for FM; n: cases correctly classified; N: total number of cases; %: percent of correctly classified cases; CI: confidence interval. Summary table for all skeletal series, grouped according to geographical origin.

	DFA FML and FMB		DFA FML		DFA FMB	
	n/N	%	n/N	%	n/N	%
Europe	1039/1619	64.2	1363/2238	60.9	1040/1643	63.3
Asia			481/722	66.6		
America			247/389	63.5		
Africa			306/484	63.2		
Australia			405/612	68.0		
Total	1039/1619	64.2	2802/4445	63.0	1040/1643	63.3
95% CI		61.8-66.5		61.6-64.5		60.9-65.6

Table 3. Comparison of the size of the FM between children, juveniles and adults in Poschiavo, by mean and standard deviation for FML and FMB. There were no significant differences (Kruskal-Wallis-test).

Poschiavo	FML		FMB	
	n	mean ± SD	n	mean ± SD
adults (21+)	576	34.7 ±2.6	579	29.3 ±2.5
early adults (18-21)	5	35.4 ±1.5	5	28.8 ±1.5
juvenile (14-18)	9	35.7 ±1.4	9	28.8 ±1.6
infans II (7-14)	25	34.4 ±2.8	25	28.0 ±2.2

➢ FML, FMB and FM area show small, but significant differences between sexes in all European and non-European populations (Table 1); similar results were shown by Catalina-Herrera, 1987; Gapert et al. 2009.

➢ The index of FM (ca. 1.2) is lower in males than in females, but the differences are significant only on the large samples (>150 individuals).

➢ In larger samples the correlation between FML and FMB was significant for both sexes, but low (Spearman's rho ca. 0.32 - 0.56).

➢ Skull capacity, FML and FMB were positive correlated. In Poschiavo this correlation is significant, but always weaker than rho = 0.28. The other series show similar tendencies.

➢ The new DFA predicted the correct sex in Poschiavo and the collected series in 64.2% (CI 61.8-66.5%) of all cases (Table 2).

➢ When Gapert's DFA (2009) was applied, the degree of correct classifications was 62.9% for FML (CI 60.5-65.2%), 63.0% for FMB (CI 60.6- 65.3%) and 61.1% for both FMB and FML (CI 59.1-63.1%).

➢ There are no significant differences (Kruskall-Wallis-Test) in the size of the FM between infans II, juvenile, early adults, and adults (Table 3), as suggested also by Gruber et al. 2009 and Veroni et al., 2010.

4. Main Outlook

Success of sex determination from FM by means of DFA is not high, but has proved stable on a large worldwide dataset. Under special conditions like cremated, mutilated or subadult individuals FM could be used as predictor of sex on wide-ranging skeletal material.

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