Stature estimation from cranial measurements in archaeological and modern populations of Switzerland

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1. Introduction

Stature estimation is a method routinely used in forensics and anthropology; its results are of interest to a wider spectrum of sciences, e.g. archaeology, economic studies (Wurm 1982, Koepke & Baten 2005, Maat 2005, Woitek 2003). Usually it is based on complete skeletons (Fully & Pineau 1960; Raxter et al. 2008) or long bones (overview: Rösing 1988), the accuracy of these techniques lies within few centimetres. However there are a few cases e.g. mutilated bodies, poorly preserved skeletons, cranial collections, where such standards methods are not applicable. In these cases even a rough estimation of the stature can be valuable.

Aim of the present study is to develop a stature estimation algorithm based on cranial measurements and to apply it on a large ossuary cranial material; similar formulas of stature estimation based on skulls are also tested.

2. Material and Methods

• A total of 736 individuals (362 males, 374 females) from 6 archaeological populations dating to late Roman to post-Medieval Period (Table 1) were used in order to test the published formulas and to develop a new algorithm. Individual measurements of skulls (M1, M8, M17, M20, M23, M45, M48) and long bones (H1, R1, F1/F2, T1/T1b) were collected; measurements were taken after Martin (1928); stature estimation was made after Pearson (1899).

• Five different formulas (Table 2) for stature estimation from skulls were tested using the individual data of skull and long bones measurements (Table 1).

Population	n males	n females	References
Tomils, Switzerland, 11th-15th c. AD	79	75	Papageorgopoulou 2008
Westerhus, Sweden, 13th-14th c. AD	45	55	Gejvall 1960
Mannheim, Germany, 6th-7th c AD	59	58	Rösing 1975
Stetten, Germany, 7th c. AD	55	49	Konieczka & Kunter 1999
Eichstetten, Germany, 6th-7th c. AD	91	107	Hollack & Kunter 2001
Ried, Germany, 5th-7th c. AD	33	30	Kaufmann & Schoch 1983

Table 1: Populations used to test the published stature estimation formulas and to validate the proposed algorithm.

References	Population	n individuals	Data acquired from	Cranial measurements used (after Martin 1928)
Chiba & Terazawa 1998	Japan	124	dry bones (craniometrics)	M1, M23
Patil & Mody 2004	India	150	living population (cephalometric radiograph)	M1
Ryan & Bidmos 2007	South Africa	99	dry bones (craniometrics)	M1, M5, M9, M17, M45, M48
Kalia et al. 2008	India	100	living population (cephalometric radiograph)	M1, M23
Krishan 2008	North India	996	living population (craniometrics)	M1, M8, M23, M47, M66

Table 2: Published stature estimation formulas tested in the present study.

• We further developed a **new algorithm** to estimate stature from the proportions between craniometrics and stature.

The algorithm works in three steps:

(1) Selection of the two most similar neighbour populations to the examined one: The distance between the means of the observed population and the means of many reference series has to be calculated, separately for males and females. Distance is calculated as: " (observed - expected) / expected ", and summed up as total distance for M1, M8, M17, M20, M23, M45, M48 (after Martin 1928). The reference population with the smallest positive distance and the one with the smallest negative distance to the observed one are being selected.

(2) Estimations by proportions: For every measurement the stature is estimated by the mean proportion in the two reference series, by M1 for example after:

estimated stature from M1 = (((mean height of upper ref. population / mean M1 of upper ref. population) * observed M1) + ((mean height of lower ref. population / mean M1 of lower ref. population) * observed M1)) / 2 .

(3) Stature estimation: The total mean of the single calculations gives the estimated stature by skull.

For the necessary **reference series,** means of measurements of long bones and skulls were collected systematically (Table 3). Statistical analysis was made with SPSS 17.0.

Chronology	n populations	n males	n females
Neolithic Period	2	55	64
Bronze and Iron Age	3	86	53
Roman Period	11	276	202
Early Medieval Period	28	996	827
Late Medieval Period	19	1240	1046
Post-medieval Period	2	17	15
Total	65	2670	2207

Table 3: Chronologically summarised reference series used for the casewise finding of the two optimal neighbour populations.

3. Results

The six estimation methods give results varying from each other highly (Table 4-5). Compared to the stature estimation from long bones, Chiba & Terazawa 1998 and Kalia et al. 2008 give the most suitable results applied to the six validation series. The proposal made here is of similar accuracy, but shows fewer extreme deviations. Figure 1 and 2 demonstrate the application of the algorithm to the cranial material of Poschiavo.

Males	Tomils, 11.-15. c. AD	Westerhus, 13.-14. c. AD	Mannheim, 6.-7. c. AD	Stetten, 7. c. AD	Eichstetten, 6.-7. c. AD	Ried, 5.-7. c. AD	Mean δ
stature from long bones (Pearson 1899)	164.1 ±5.2	168.4 ±5.3	167.2 ±4.9	169.3 ±4.8	168.1 ±6.1	167.6 ±3.8	
Chiba & Terazawa 1998, 164.8 ±7.6 cm	167.5 ±2.5, δ +3.9 ±5.4	167.3 ±2.5 δ -1.2 ±5.1	167.5 ±3.4 δ -0.4 ±5.0	168.8 ±2.6 δ -1.2 ±3.9	165.9 ±2.6 δ -0.9 ±3.6	166.3 ±3.1 δ -1.4 ±3.7	-0.2
Patil & Mody 2005, 164.8 ±6.6 cm	173.1 ±5.7, δ +9.6 ±6.8	174.7 ±5.8 δ +5.6 ±6.3	176.7 ±7.7 δ +8.8 ±8.0	181.8 ±6.6 δ+12.6 ±5.5	173.8 ±5.1 δ+6.3 ±4.2	171.7 ±6.3 δ+4.4 ±6.1	+7.9
Ryan & Bidmos 2007, 153.3 ±5.0 cm	153.8 ±3.4 δ -10.1 ±5.5	154.3 ±2.1 δ-13.9 ±5.4	154.0 ±2.9 δ-13.7 ±4.9	155.0 ±3.7 δ-15.1 ±5.4	- - -	154.4 ±2.3 δ-12.5 ±4.6	-13.1
Kalia et al. 2008, 171.7 ±5.6 cm	171.1 ±1.8 δ +3.9 ±5.4	170.7 ±1.9 δ -1.2 ±5.1	170.8 ±2.5 δ -0.4 ±5.0	171.2 ±1.9 δ -1.2 ±3.9	169.6 ±1.9 δ -0.9 ±3.6	169.9 ±2.3 δ -1.4 ±3.7	-0.2
Krishan 2008, 172.3 ±5.3 cm	175.2 ±2.3 δ+11.5 ±5.5	174.4 ±2.1 δ +5.9 ±4.8	175.7 ±3.1 δ +7.5 ±5.0	175.9 ±3. δ+6.6 ±4.5	- - -	174.9 ±2.3 δ+8.0 ±4.9	+7.9
Studer et al. 2009	166.8 ±4.2 δ +3.1 ±5.6	166.2 ±3.9 δ -1.7 ±5.3	166.7 ±4. δ -0.9 ±5.2	163.4 ±4.9 δ -6.6 ±4.3	167.3 ±3.9 δ+0.4 ±4.4	167.3 ±4.5 δ+0.7 ±5.8	-0.8

Table 4: Comparison of different techniques for stature estimation from skull for males. The left column (yellow) shows the observed stature of the reference population, the first row (orange) the stature estimation from long bones of the examined series. Every cell gives the mean estimation for the population, and shows the individually calculated *δ* mean difference between estimation by skull and estimation by long bones; the mean difference *(δ)* shows the accuracy, its standard deviation gives the precision of the estimations. The right column (green) shows the mean difference *(δ)* for every method over the six validation series.

Females	Tomils, 11.-15. c. AD	Westerhus, 13.-14. c. AD	Mannheim, 6.-7. c. AD	Stetten, 7. c. AD	Eichstetten, 6.-7. c. AD	Ried, 5.-7. c. AD	mean δ
stature from long bones (Pearson 1899)	152.6 ±3.8	155.9 ±4.8	157.5 ±4.3	156.3 ±4.2	157.6 ±5.4	157.4 ±4.2	
Chiba & Terazawa 1998, 153.0 ±6.9 cm	153.5 ±1.7 δ +0.4 ±4.1	152.7 ±1.7 δ -3.1 ±4.2	153.0 ±1.8 δ -5.3 ±4.0	154.1 ±1.8 δ -2.5 ±4.8	151.7 ±2.5 δ -5.6 ±4.3	153.3 ±1.3 δ - 0.2 ±4.9	-2.7
Patil & Mody 2005, 150.6 ± 4.9 cm	164.2 ±5.8 δ+11.3 ±6.7	165.7 ±5.5 δ+10.0 ±5.4	167.0 ±5.7 δ +8.2 ±5.9	171.0 ±6.5 δ+14.0 ±6.1	162.8 ±7.1 δ+4.5 ±6.3	162.4 ±5.7 δ+5.7 ±6.9	+9.0
Ryan & Bidmos 2007, 143.1 ±6.9 cm	145.5 ±2.3 δ -7.4 ±4.6	145.0 ±3.2 δ-10.3 ±4.0	145.1 ±4.0 δ-13.1 ±4.8	147.0 ±2.5 δ-9.7 ±5.3	- - -	144.1 ±3.4 δ-11.8 ±4.4	-10.5
Kalia et al. 2008, 155,7 ±5,3 cm	156.0 ±0.3 δ+0.4 ±4.0	155.7 ±0.3 δ-3.1 ±4.2	156.0 ±0.3 δ-5.3 ±4.0	156.2 ±0.3 δ -2.4 ±4.8	155.8 ±0.5 δ -5.6 ±4.3	156.0 ±0.3 δ -3.9 ±4.3	-3.3
Krishan 2008*	- - -	- - -	- - -	- - -	- - -	- - -	-
Studer et al. 2009	152.0 ±3.2 δ-1.1 ±4.6	157.2 ±4.3 δ+1.9 ±4.6	155.6 ±4.1 δ-2.7 ±4.7	154.4 ±4.3 δ -2.8 ±6.1	156.0 ±5.6 δ -0.8 ±5.0	156.7 ±3.4 δ -0.2 ±4.9	-1.0

Table 5: Comparison of different techniques for stature estimation from skull for females. The left column (yellow) shows the observed stature of the reference population, the first row (orange) the stature estimation from long bones of the examined series. Every cell gives the mean estimation for the population, and shows the individually calculated *δ* mean difference between estimation by skull and estimation by long bones; the mean difference *(δ)* shows the accuracy, its standard deviation gives the precision of the estimations. The right column (green) shows the mean difference *(δ)* for every method over the six validation series; (* only for males).

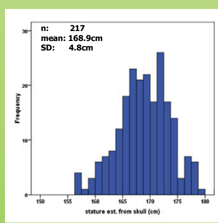

Fig. 1: Stature estimation for the males in the ossuary of Poschiavo after Studer et al. 2009.

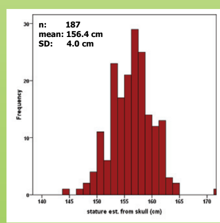

Fig. 2: Stature estimation for the females in the ossuary of Poschiavo after Studer et al. 2009.

Fig. 3: The ossuary of Poschiavo.

4. Discussion

Applying the different formula to the six validation series shows, that the formula published by Chiba & Terazawa 1998 and Kalia et al. 2008 give results significantly closer to the expected stature than the formulas of Patil & Mody 2005, Ryan & Bidmos 2007 and Krishan 2008. Besides that, the resulting estimations reflect the mean stature of their reference population to a high degree. Therefore the choice of reference population is a decisive step. Most formulas tend to reduce the SD for the populations to an unrealistic small span. The new algorithm gives plausible results with a low mean error and more plausible standard deviations.

5. Conclusions

Estimation of stature from skull is possible within some limits of accuracy compared to estimations from long bones. Our new algorithm gives plausible results and could be adapted easily to other areas of the world by using an adequate collection of reference series.

References

*(All references related to material **(Table 1 & 3)** on request from the author: **Catherine.Studer @ stud.unibas.ch**)*

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