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COMPARING STATURE-ESTIMATION METHODS ON MEDIEVAL INHABITANTS OF WESTERHUS, SWEDEN

ABSTRACT
In this article we compare stature estimation methods on osteological material from medieval Westerhus, Sweden. We use a recently revised anatomical technique (Raxter et al. 2006) to estimate the living stature (XSTAT) of the individuals. Other anatomical methods and various regression equations on long bone lengths are compared to XSTAT to examine their applicability to this skeletal sample and the accuracy of their estimates. We find considerable differences in estimates between techniques, especially in mean statures of tall and short stature classes based on long bone lengths. Thus we emphasize the importance of choosing the most appropriate estimation methods.

Keywords: stature estimation, anatomical method, regression equations, medieval Westerhus

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INTRODUCTION

Stature, either known or estimated from skeletal dimensions, interests biological anthropologists for several reasons. Stature is simply the most objective measure of skeletal growth. It is also needed to gain other kinds of information of human biology. Palaeopathologists estimate statures of osteoarchaeological specimens to study the temporal stature fluctuation, which reflects fluctuation in the overall health and nutritional status (Eveleth & Tanner 1990; Larsen 1995; Bogin & Rios 2003). Palaeoanthropologists estimate statures of fossil specimens to examine evolutionary trends and to use these estimations in combination with other measurements to estimate living body masses, in turn needed to assess relative brain sizes and skeletal robusticity (Ruff et al. 2005). Forensic anthropologists use stature estimates for identification purposes (Lundy 1986).

Methods used to estimate stature from skeletal dimensions include the so-called ‘anatomical method’ and the so-called ‘mathematical method’ (Lundy 1985). The anatomical method, also called Fully’s method after Georges Fully, reconstructs the stature from all the skeletal elements that contribute to the height of an individual including measurements from skull to ankle (e.g. Fully 1956; Fully & Pineau 1960). The mathematical method includes numerous regression equations to estimate stature from long bone lengths or other skeletal dimensions, e.g. calcaneal length (e.g. Pearson 1899; Trotter & Gleser 1952, 1958).

The anatomical method generally gives more accurate stature estimations than the mathematical method (Lundy 1985; Sciulli et al. 1990; Ousley 1995) because measuring the entire skeleton takes into account the inter-individual variation in the body proportions. For this reason, it is broadly applicable to both sexes and different populations. The anatomical method has been seldom used because a complete, or at least a nearly complete, skeleton is needed (Lundy 1985). This situation is now changing. This method has received an increased amount of interest lately. Researchers have been testing and revising the Fully method on skeletal remains of varying origins (Lundy 1988; King 2004; Bidmos 2005; Niskanen & Junno 2006; Raxter et al. 2006).

Although the anatomical method is preferable due to its greater accuracy, most researchers use the mathematical method, which is much easier and faster to apply because stature is estimated from the lengths of long bones, most often from the femoral length. The drawback using the mathematical method is that, although population and sex-specific equations are used, between-individual differences in body proportions are ignored and all individuals with the same long bone length are given the same stature estimate (Lundy 1985). Also, regression equations based on recent populations often provide inaccurate stature estimations for past populations due to temporal shifts in body proportions (Formicola & Franceschi 1996; Jantz & Jantz 1999). For this reason, the anatomical method is increasingly used to develop regression equations to estimate stature from the lengths of the long bones (Lundy 1983; Formicola & Franceschi 1996; Maijanen & Niskanen, in preparation).

In this study we aim to test both anatomical and mathematical stature-estimation methods on a medieval skeletal collection from Westerhus, Sweden, to estimate their applicability to the medieval Scandinavian osteological material. It is important to evaluate stature-estimation methods for past populations because incorrect stature estimations may even provide somewhat incorrect patterns of temporal trends. We follow Formicola and Franceschi's (1996) example and compare anatomically determined stature estimates with estimates provided by various regression equations. We find that regression equations (e.g. Trotter & Gleser 1952, 1958; Sjøvold 1990) commonly used to estimate statures of medieval Scandinavians often provide inaccurate estimations, especially in case of tall or short individuals.

MATERIAL AND METHODS

Measurements used in this study are from the archaeological skeletal material from Westerhus, Jämtland (Gejvall 1960). This material includes 135 fully adult individuals of which 120 were measured in 2005 and 2006 by the first author. Half (32 females and 28 males) of these 120 skeletons are complete enough for the application of the anatomical method.

The sex and age estimations by Gejvall (1960) were used in this study. The sex assessments are very likely correct for two reasons. First, we did not encounter a single case where our sex estimation differed from Gejvall's (1960). Second, as Gejvall (1960: Plate 6) has demonstrated, burial locations were different for males and females. The age range of this sample is between 25 and 60 years (average age is 40 years for both sexes).

Different regression equations have already been applied to this material. Gejvall (1960) estimated statures by using equations from Pearson (1899), Telkkä (1950) and Trotter and Gleser (1952). More recently, Werdelin used Trotter and Gleser (1952) equations, as well as the reduced major axis equations of Sjøvold (1990) to estimate statures of the Westerhus and other medieval Swedish populations (see Werdelin 1985; Werdelin et al. 2000).

The anatomical method has been applied to the Westerhus material once before. Niskanen and Junno (2006) estimated the stature of 44 individuals. In this current study we increased the sample size to 60 by including all of the individuals for which the anatomical method can be applied without including too many missing elements.

Some of the measurements used in this study were taken from Gejvall (1960) because interobserver differences were negligible, generally within 1–2 mm. These include the basion-bregma height of the braincase (BBH), the physiological length of femur (FEM2) and the lateral condyle-medial malleolus length of tibia (TIB1).

All vertebral and talo-calcaneal measurements were taken by the first author. The height of the second cervical vertebra (C2) was measured as in Raxter et al. (2006: Appendix). The vertebral body heights measured from C3–L5 include anterior height (Lundy 1988: Fig. 2), posterior height (Holliday 1995), maximum midline height (Tibbetts 1981) and maximum height anterior to pedicles (Raxter et al. 2006: Appendix). We measured the maximum anterior height of the first sacral segment (S1) as in Raxter et al. (2006: Appendix). We took two different measurements of the talus-calcaneus height (TCH): in anatomical position (Lundy 1988: Fig. 6; Raxter et al. 2006: Appendix); not in anatomical position, but between the superior part of the trochlea and the plantar part of the calcaneus (Formicola 1993).

The vertebral columns of individuals included in the study were complete or almost complete. Missing vertebral dimensions were reconstructed by regression analysis from the heights of superior and inferior vertebrae or from the other measurements of the same vertebra (see Sciulli et al. 1990; Formicola 1993). None of the individuals included had more than four missing vertebrae. Vertebrae with signs of osteophytes and lipping were included if they did not clearly affect the height of the body. In a few cases of anteriorly compressed vertebrae, the height of the compressed part was reconstructed from the height of a superior and/or an inferior vertebra if non-pathological.

Three individuals from the total number of 60 had a sixth lumbar vertebra. These individuals were included. All young adults that had completely or partly unfused epiphyseal plates were excluded as well as individuals with obvious skeletal pathologies that would affect their skeletal dimensions.

Both sides of the long bones and ankle were measured if possible and the average length or height of both left and right sides were used in the calculations. The existing one was used alone if one side was missing. All individuals with missing femur or tibia were excluded.

To attain a larger sample we reconstructed missing measurements by using sex-specific regression analysis, ratios or mean measurements. This reconstruction involved the basion-bregma height (BBH), vertebral body heights, and the talus-calcaneus height.

In case BBH was missing, we used sex-specific means (males 132.62 mm; females 127.85 mm) from Gejvall (1960: Table 17). This was necessary in the case of one male (individual number 155) and three females (individual numbers 60, 66 and 188). It was impossible to estimate BBH from other braincase height dimensions (e.g. the auricular height, as in Formicola 1993) due to incomplete cranial anatomy. We did not use regression to estimate missing BBHs because this braincase height dimension has low sex-specific correlations (males r = 0.11, N = 27; females r = 0.108, N = 29) with stature estimated by using a revised anatomical method (Raxter et al. 2006).

In case the first sacral segment (S1) was missing, its maximum anterior height was estimated

Table 1. Individuals with reconstructed vertebral heights.

Individual	Sex	Missing vertebrae	Percent missing (%)	Pearson correlation
4	M	C6, L4	8.4	0.999
53	M	C3	2.7	1.000
98b	M	T12	5.0	1.000
109a	M	C2, C7, T3, T4	19.0	0.997
115a	M	T9	4.4	1.000
120	M	T11	4.7	1.000
134	M	C2	8.1	0.998
158	M	T11	4.7	1.000
21	F	C3	2.6	0.999
38	F	T1	3.4	0.999
54	F	C6	2.6	1.000
69	F	T3	3.8	1.000
94a	F	C3, C4, T3	9.0	0.997
106	F	T11	4.8	0.999
188	F	C7	2.9	1.000
225	F	T8	4.3	1.000
226	F	L2, L3	11.4	0.997
227	F	T12	5.1	0.999

Percent missing (%) refers to percentage of missing elements of the total vertebral column length. Pearson correlation coefficient refers to the correlation between the incomplete and complete vertebral column length and thus the accuracy of estimation of missing elements.

from the anterior height of the fifth lumbar vertebra (L5) by using the following sex-specific ratios (L5/S1): males 0.8619 (N = 31); females 0.8646 (N = 42). This estimation was performed for four males (individuals 4, 115a, 139 and 164) and three females (individuals 42, 71 and 227).

We used regression to estimate the missing talus-calcaneus height (TCH) in case of three males (individuals 104, 115a and 181) and six females (individuals 24, 32, 38, 56, 82 and 106) from the sum of the physiological length of femur and the lateral condyle-medial malleolus length of tibia (FEM2 + TIB1 = FTL) because the ankle height has moderate correlations with the combined femoral and tibial lengths. The sex-specific regression equations are as follows:

Males: $TCH = 0.044 \times FTL + 36.867$ ($r = 0.428$, $N = 40$).
Females: $TCH = 0.035 \times FTL + 37.456$ ($r = 0.456$, $N = 50$).

Reconstruction of missing vertebral heights (C2–L5) was done by using regression analysis one individual at a time. 18 individuals had at least one missing vertebra (Table 1). The maximum total number of missing vertebrae was four (19.0 % missing from the total vertebral column length). If the whole vertebra was missing or none of the four vertebral height measurements could be taken, the heights of the superior and inferior vertebrae were used to estimate the height of the vertebra in question. Usually it was possible to measure at least one height of the body, in most cases the posterior height. In such cases, the missing measurement was reconstructed from three measurements: superior and inferior vertebral heights with anterior/posterior height of the body itself. We evaluated the reconstruction errors to be minimal because the Pearson correlation coefficients with complete columns were all at least 0.997. These complete column lengths based on four different vertebral height measurements are as follows:

C2L5ant (the sum of anterior heights)
C2L5post (the sum of posterior heights)
C2L5xml (the sum of maximum midline heights)
C2L5xap (the sum of maximum heights anterior to pedicles)

C2L5xap was estimated for 26 individuals from either C2L5ant or C2L5post because the maximum heights anterior to pedicles were probably incorrectly measured for many of the individuals examined in the beginning of the study. This estimation was performed by using the following sex-specific ratios:

C2L5xap/C2L5post: males 0.9979 (N = 15); females 1.0007 (N = 20)

C2L5xap/C2L5ant: males 1.0437 (15); females 1.0331 (20)

We used C2L5xap/C2l5ant ratios when possible because C2L5ant had a somewhat higher correlation ($r = 0.977$) with C2L5xap than did C2L5post ($r = 0.954$). We did not multiply the summed anterior heights (C3–L5) with 1.036 to convert them to the summed maximum heights anterior to pedicles as Raxter et al. (2006) recommended due to sex differences in the C2L5xap/C2L5ant ratio in our sample, as well as due to possible differences between populations in these ratios.

DESCRIPTIONS OF STATURE-ESTIMATION METHODS

Fully's anatomical method is based on his examinations of the World War II casualties from the concentration camp in Mauthausen, Austria. All the individuals were European males. This method estimates stature by adding together the basi-bregmatic height of the braincase (our BBH), heights of the presacral vertebrae, the anterior height of the first sacral segment, the fysiological (bicondylar) length of the femur, the bicondylar length of the tibia without spines and the articulated height of the talus and calcaneus to gain the skeletal length. Fully gave the following correction factors for soft tissue to gain the living stature: for skeletal heights of 153.5 cm or less, the factor is 10 cm; for skeletal heights from 153.5 to 165.4 cm, the factor is 10.5 cm; for skeletal heights of 165.5 cm or more, the factor is 11.5 cm (Fully 1956).

Several researchers (King 2004; Bidmos 2005; Raxter et al. 2006) have noticed that the Fully's method appears to underestimate the 'true' stature. In addition, it is not certain how Fully measured the vertebral heights, the tibial length and the articulated height of the talus and calcaneus. Thus the vertebral height has been measured in various ways by different researchers (Tibbetts 1981; Lundy 1983, 1988; Sciulli et al. 1990; Formicola 1993; King 2004).

We tested the Fully method by using three different sets of the presacral vertebral heights – the anterior height (Lundy 1988: Fig. 2), the maximum midline height (Tibbetts 1981: Fig. 1); the maximum height anterior to the pedicles (Raxter et al. 2006: Appendix) – to examine how these three different ways to measure vertebral heights affect stature estimates. We measured the articulated height of the talus and calcaneus in anatomical positioning (e.g. Lundy 1988: Fig. 6; Raxter et al. 2006: Appendix).

We also estimated statures by using anatomical methods of Formicola (1993) and Niskanen and Junno (2006). Formicola (1993) used a version of the Fully method described in Fully and Pineau (1960) by simply adding 10.8 cm to the skeletal length regardless of its length. He used the maximum midline height of vertebrae (Tibbetts 1981: Fig. 1). The articulated height of the talus and calcaneus was not measured in anatomical position as also indicated by low sex-specific foot height means provided in Formicola and Franceschi (1996: Table 1).

The anatomical method introduced by Niskanen and Junno (2006) includes the basi-bregmatic height of the braincase, the summed posterior heights of T1–L5, the physiological length of femur and the lateral condyle-medial malleolus length of tibia. The summed T1–L5 posterior height was multiplied by 1.503 to convert it to the promontory-basion length of a living individual. The summed femoral and tibial length was multiplied by 1.015 to convert dry bone lengths to corresponding green lengths. Sex-specific additions (males 14.0 cm; females 13.55 cm) include foot heights (males 7.0 cm; females 6.55 cm), the promontory-acetabular height (6.5 cm) and the scalp thickness (0.5 cm). This version of the anatomical method has not been tested on samples with known statures.

In addition to the above-mentioned methods, we used a technique introduced by Raxter et al. (2006). They tested the Fully method on skeletons of both males and females and both black and white Americans of known cadaveric statures, adjusted to living statures, from the Terry Collection. They measured the articulated talus and calcaneus in anatomical position and took two different vertebral height measurements: the anterior midline vertebral height and the maximum vertebral height anterior to the pedicles. They confirmed that the original Fully method underestimates living statures due to too small soft-tissue correction factors by determining that the average age-corrected soft-tissue addition for their sample should be 12.4 cm rather than 10.2 cm based on Fully (1956) applied to their sample. In addition, they found the maximum heights of the vertebrae (measured wherever anterior to the pedicles) to provide more reliable stature estimations than the anterior midline vertebral heights regardless of sex and ancestry. Based on their findings, they introduced a revised anatomical method to estimate statures of skeletal specimens. This revised method provides accurate stature estimates for both sexes, individuals of different body proportions (e.g. white and black Americans), as well as for tall and short individuals without directional bias.

For the above reasons, we are convinced that Raxter et al's (2006) revision of the Fully method provides the most accurate stature estimations available unless the entire skeleton is articulated, dimensions of dry bones are converted to corresponding wet dimensions, and appropriate additions are made for the scalp, joint cartilage and foot sole thicknesses. For this reason, we use stature estimates provided by this revised method as substitutes for true mean statures (unknown for the medieval people for an obvious reason) of samples or subsamples (e.g. subsamples composed of short and tall same-sex individuals) for comparison with those based on other methods. We do not assume that this method necessarily provides correct statures for individuals due to inter-individual variation in the total amount of soft tissue (especially intervertebral disk thickness) and posture.

Our aim was to determine the maximum adult stature prior to age-related stature decline. We applied the age-adjusted Equation 1 (here XSTAT) in Raxter et al. (2006) as if all the individuals were 20 years of age because Figure 1A in Raxter et al. (2006) indicates that the younger the individual, the greater the underestimation of stature. Thus the equation used to gain the ana-

Table 2. Means, standard deviations and range of the skeletal dimensions.

	BBH	C2L5xap	S1	FEM2	TIB1	TCH	SKH	XSTAT
Males								
X	13.15	51.09	3.39	46.87	37.44	7.33	159.27	172.27
S.D.	0.57	3.17	0.26	2.62	2.22	0.35	7.60	7.67
Range	11.50-13.90	45.14–56.19	2.73–3.78	41.80–52.65	32.05–41.15	6.65–8.30	142.53–174.89	155.37–188.02
% SKH	8.3	32.1	2.1	29.4	23.5	4.6	--	--
Females								
X	12.82	47.50	3.20	42.27	34.02	6.43	146.24	158.67
S.D.	0.45	2.10	0.25	1.96	1.93	0.33	5.71	5.76
Range	12.20–14.10	43.54–51.54	2.75–3.60	36.60–45.75	28.80–37.60	5.85–7.20	132.44–156.50	144.74–169.01
% SKH	8.8	32.5	2.2	28.9	23.3	4.4	--	--

BBH = basion-bregma height, C2L5xap = the sum of maximum heights of vertebrae anterior to pedicles, S1 = height of the first sacral segment, FEM2 = physiological length of femur, TIB1 = lateral condyle-medial malleolus length of tibia, TCH = talus-calcaneus height in anatomical position. % SKH refers to the percentage of the mean of a skeletal element or elements of the total skeletal height (SKH). XSTAT = anatomically determined maximum adult stature provided by a modification of Equation 1 from Raxter et al. (2006), XSTAT = 1.009 x Skeletal height - 0.0426 x 20 + 12.1, males add 0.31 cm and females deduct 0.14 cm.

tomically determined maximum stature (XSTAT) is as follows:

XSTAT = 1.009 x Skeletal height - 0.0426 x 20 + 12.1 (Raxter et al. 2006, Equation 1)

We adjusted statures for both males and females according to the prediction errors provided in Raxter et al. (2006: Table 3) for white males and white females by adding 0.31 cm to the male stature and by deducting 0.14 cm from the female stature. This correction for sex and race biases of stature estimation should provide the most correct sex-specific mean maximum statures for our individuals.

We believe that this reconstruction of young-adult statures for all individuals in our sample is reasonably accurate. After all, the mean age of individuals in our sample is 40 (age range 25–60) and all individuals that exhibited vertebral pathologies affecting the stature estimation have been eliminated. Therefore, the actual age-related stature decline in our sample, affecting mainly those over 40 years of age (there were 27 of these), was mostly due to reduced height of intervertebral disks and postural changes.

We estimated statures also with Raxter et al's (2006) Equation 1 by taking the estimated age at death into account and with their Equation 2 without the age-adjustment. These equations are as follows:

Equation 1 = 1.009 x Skeletal height - 0.0426 x age + 12.1

Equation 2 = 0.996 x Skeletal height + 11.7

In the case of Equation 1, we adjusted statures for both males and females as in calculating XSTAT.

Beside the anatomical method, stature was calculated also by using different regression equations based on long bones, femur and tibia. We used sex-specific formulae of Telkkä (1950), Trotter and Gleser (1958) and Boldsen (1984), as well as formulae independent of sex from Sjøvold (1990). Telkkä's equations are based on Finnish males and females from the collection of Department of Anatomy at University of Helsinki. Boldsen's formulae are based on a medieval Danish population from central Jutland. The formulae of Trotter and Gleser (1958: Table 12) for white males are based on the Korean War casualties and they are still most widely used in stature estimation of Euroamerican and European males. The formulae used for females are based on the Terry Collection material and they are modified by Jantz (1992) from the original formulae of Trotter and Gleser (1952). Sjøvold (1990) based his equations on published literary sources of various white populations.

Not all researchers have provided regression equations to estimate stature from combined

Table 3. Comparison of statures estimated by different versions of the anatomical method.

	Males	D	Females	D
N	28		32	
XSTAT	172.3		158.7	
Fully (C2L5ant)	167.6	4.7	154.8	-3.9
Fully (C2L5xml)	170.8	-1.4	157.0	-1.7
Fully (C2L5xap)	169.8	-2.5	156.3	-2.4
Formicola (1993)	170.1	-2.2	156.8	-1.9
Niskanen & Junno	172.7	0.5	159.5	0.8
Equation 1	171.4	-0.9	157.9	-0.8
Equation 2	170.3	-1.9	157.4	-1.3

Difference (D) calculated as Estimated stature - XSTAT (in cm). Niskanen & Junno = Niskanen & Junno 2006; Equations 1 & 2 from Raxter et al. 2006

lengths of the femur and tibia. Therefore the mean statures provided here are averages of those provided by the femoral and tibial lengths. We wanted to take into account inter-individual variation in limb-segment proportions. Estimations based on different parts of anatomy are commonly used to provide the most probable estimation. For example, Ruff et al. (1997) averaged body mass estimations based on the bi-iliac breadth/stature method and the femoral head size to estimate body masses of Palaeolithic people.

RESULTS AND DISCUSSION

We consider that XSTAT is the best approximation of the maximum living stature in this sample. Thus we use it as a reference for stature estimates provided by other anatomical methods and the various regression equations. The means and percentages of skeletal elements are presented in Table 2. The percentage shows the proportion of the elements compared to skeletal height (SKH) calculated with C2L5xap.

Comparison of statures reconstructed by using different measurements of the presacral vertebrae and anatomical techniques (Table 3) reveals considerable differences. The summed anterior heights provide predictably the shortest statures. Assuming that the XSTAT provides correct mean statures, the application of the Fully method (as described in Fully 1956) underestimates the male statures by 4.7 cm and female statures by 3.9 cm, which is somewhat more than estimation errors reported by King (2004) and Raxter et al. (2006). In any event, this finding implies that regression equations based on anatomical statures and long bone lengths for estimating living statures of South African Negro provided by Lundy (1983) underestimate true statures by several centimetres.

In this sample, the application of the maximum midline height produces slightly taller and probably more accurate mean maximum statures than the application of the maximum height anterior to pedicles used by Raxter et al. (2006) when using Fully's original method. It is thus possible that Fully (1956) may have used the maximum midline height.

Fully and Pineau's (1960) equation, as applied by Formicola (1993), underestimates the male and female statures by 2.2 and 1.9 cm, respectively. Based on this finding, regression equations based on anatomical statures and long bone lengths for the Neolithic Period Europeans provided in Formicola and Franceschi (1996) probably provide statures that are somewhat too low.

The method used by Niskanen and Junno (2006) is the only anatomical method that provides taller maximum mean statures than XSTAT, although this overestimation is less than one centimetre (males 0.5 cm; females 0.8 cm). The accuracy of this method is surprising considering that the method was based on information (e.g. that of intervertebral disk thicknesses) provided by various literacy sources (references are provided in Niskanen & Junno 2006).

We assume that Raxter et al's (2006) Equation 1, which takes the actual age into account, provides the closest approximations of the mean statures of the people buried at Westerhus at the time of death. These mean statures (Equation 1) are naturally somewhat lower than the means of the maximum adult statures of the same individuals before age-related stature decline.

Raxter et al's (2006) Equation 2, which does not include age-adjustment, underestimates statures of young adults quite considerably (1.9 cm in the case of males and 1.3 cm in the case of females). This underestimation is predictable since the mean age of individuals included in Raxter et al. (2006) was 54 years. This relatively old mean age undermines the applicability of this equation to many archaeological materials due to low life expectancy, and thus younger mean age at the time of death, of most prehistoric and early historical populations. However, this equation would be very useful in forensic anthropology.

Table 4. Comparison of stature estimates by regression equations. Difference calculated as Estimated stature - XSTAT (in cm).

	Males			Females		
	Tall	Short	All	Tall	Short	All
N	14	14	28	16	16	32
XSTAT	178.1	166.4	172.3	163.1	154.2	158.7
Telkkä (1950)	-2.1	2.6	0.2	-2.3	1.9	-0.2
T&G*	-0.3	3.4	1.5	-0.7	1.5	0.4
Boldsen (1984)	-1.8	1.5	-0.2	-1.1	1.0	-0.1
Sjøvold (1990)	-0.3	1.9	0.8	2.4	4.2	3.3

*Trotter & Gleser (1958) in case of males and Jantz's (1992) modification of Trotter & Gleser's (1952) regression equations for white females in case of females.

Table 4 compares the sex-specific mean stature estimates provided by different regression equations with XSTAT. Individuals were further subdivided into tall and short individuals within sex-specific samples to examine the variation in the accuracy of estimates according to the stature classes (Formicola 1993; Formicola & Franceschi 1996). For example, Formicola (1993) stated that Trotter and Gleser's formulae overestimated stature for all the other stature classes except for exceptionally tall individuals. This appears to apply also to the medieval inhabitants of Westerhus.

Equations provided by Telkkä (1950) provide accurate mean statures for both males and females. Statures of tall males and females are underestimated and those of short males and females are overestimated. Boldsen's (1984) equations provide similar results, but the under- and overestimations are smaller than in case of applying Telkkä's equations.

Trotter and Gleser's (1958) equations provide accurate statures for tall males, but overestimate those that have either average or short stature. In case of short males, this overestimation is 3.4 cm. Equations for females (Jantz 1992) provide more accurate estimations than those for males. Those of tall females tend to be underestimated and those for short females overestimated.

Since least-squares regression equations artificially narrow the range of variation, actual stature differences between the tallest and shortest same-sex populations were very likely somewhat more (based on Table 4). This bias is even greater when comparing very tall and short individuals and results in an underestimation of the total stature range of archaeological individuals.

Sjøvold's (1990) reduced major equations for males performed better than those of Trotter and Gleser (1958), especially in the case of individuals of average or short stature. These equations performed quite poorly in the case of females probably because females were underrepresented in Sjøvold's (1990) dataset by consistently overestimating statures of females of both stature classes.

CONCLUSIONS

The different versions of the anatomical method give varying estimates for the Westerhus sample. Compared to the anatomically determined maximum height (XSTAT), Fully's (1956) original method with anterior vertebral heights produces the most inaccurate estimates. The most accurate estimates were gained by using methods of Niskanen and Junno (2006) and Raxter et al. (2006, Equation 1). However, it is necessary to continue studying the anatomical method and its modifications with different materials, especially with materials with known stature.

Based on these estimations, it is clear that for both sexes, the mean statures of a sample can be estimated quite accurately (within 1 cm) with the regression equations except Trotter and Gleser (1958) for males and Sjøvold (1990) for females. It should be emphasized that when individuals or subsamples instead of the entire population are considered the variation of the mean stature affects the accuracy of the estimates. The stature of shorter individuals tends to be overestimated and taller individuals underestimated.

In any case, care should be taken of which formulae to choose. In our study the equations of Telkkä (1950) and Boldsen (1984) gave more accurate mean statures for entire samples of both sexes than those of Trotter and Gleser and Sjøvold. This is predictable since they are based on Fennoscandian data and more precisely Boldsen's equations are based on a medieval population from Denmark. However, all least squares regression equations provide underestimations of the total range of stature variation.

An obvious solution to the problem above is to apply an anatomical method (ideally Raxter et al. 2006) whenever possible or appropriate reduced major axis regression equations. The anatomically determined statures can be used to develop population and/or period specific reduced major axis regression equations (e.g. Formicola & Franceschi 1996). This study of the Westerhus material will continue by developing new regression equations for the medieval Scandinavian material (Maijanen & Niskanen, in preparation).

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REFERENCES

Bidmos, M.A. 2005. On the non-equivalence of documented cadaver lengths to living stature estimates based on Fully's method on bones in the Raymond A. Dart Collection. *Journal of Forensic Sciences* 50(3): 501–506.

Bogin, B. & Rios, L. 2003. Rapid morphological change in living humans: Implications for modern human origins. *Comparative Biochemistry and Physiology*, Part A, 136: 71–84.

Boldsen, J. 1984. A statistical evaluation of the basis for predicting stature from lengths of long bones in European populations. *American Journal of Physical Anthropology* 65: 305–11.

Eveleth, P.B. & Tanner, J.M. 1990. *Worldwide Variation in Human Growth*, 2nd ed. Cambridge University Press, Cambridge.

Formicola, V. 1993. Stature reconstruction from long bones in ancient population samples: an approach to the problem of its reliability. *American Journal of Physical Anthropology* 90: 351–8.

Formicola, V. & Franceschi, M. 1996. Regression equations for estimating stature from long bones of Early Holocene European samples. *American Journal of Physical Anthropology* 100: 83–8.

Fully, G. 1956. Une nouvelle méthode de détermination de la taille. *Annales Médecine Légale* 36(5):266-273.

Fully, G. & Pineau, H. 1960. Détermination de la stature au moyen du squelette. *Annales Médecine Légale* 40: 145–54.

Gejvall, N.-G. 1960. *Westerhus: Medieval Population and Church in the Light of Skeletal Remains*. Håkan Ohlsson Boktryckeri, Lund.

Holliday, T.W. 1995. *Body Size and Proportions in Late Pleistocene Western Old World and the Origins of Modern Humans*. Ph.D. dissertation. University of New Mexico.

Jantz, R.L. 1992. Modification of the Trotter and Gleser female stature estimation formulae. *Journal of Forensic Sciences* 37(5): 1230–5.

Jantz L.M. & Jantz R.L. 1999. Secular change in long bone length and proportion in the United States, 1800-1970. *American Journal of Physical Anthropology* 110: 57–67.

King, K.A. 2004. A test of the Fully anatomical method of stature estimation. *American Journal of Physical Anthropology Supplement* 38: 125.

Larsen, C.S. 1995. Biological changes in human populations with agriculture. *Annual Review of Anthropology* 24: 185–213.

Lundy, J.K. 1983. Regression equations for estimating living stature from long limb bones in the South African Negro. *South African Journal of Science* 79: 337–8.

Lundy, J.K. 1985. The mathematical versus anatomical methods of stature estimate from long bones. *The American Journal of Forensic Medicine and Pathology* 6(1): 73–5.

Lundy, J.K. 1986. Physical anthropology in forensic medicine. *Anthropology Today* 2(5): 14–17.

Lundy, J.K. 1988. A report on the use of Fully's anatomical method to estimate stature in military skeletal remains. *Journal of Forensic Sciences* 33: 534–9.

Maijanen, H. & Niskanen, M. in preparation. New regression equations to estimate stature of medieval Scandinavians from long bone lengths.

Niskanen, M. & Junno, J.-A. 2006. The reconstruction of body size and shape of the Paleolithic Period Europeans. In V.-P. Herva (ed.), *People, Material Culture and Environment in the North: Proceedings of the 22nd Nordic Archaeological Conference, University of Oulu, 18–23 August 2004*: 310–20. Faculty of Humanities, University of Oulu, Oulu.

Ousley, S. 1995. Should we estimate biological or forensic stature? *Journal of Forensic Sciences* 40(5): 768–73.

Pearson, K. 1899. Mathematical contributions to the theory of evolution: on the reconstruction of the stature of prehistoric races. *Philosophical Transactions of the Royal Society* 192: 169–244.

Raxter, M.H., Auerbach B.M. & Ruff C.B. 2006. Revision of the Fully technique for estimating statures. *American Journal of Physical Anthropology* 130: 374–84.

Ruff, C.B., Niskanen, M., Junno, J.-A., & Jamison, P. 2005. Body mass prediction from stature and bi-iliac breadth in two high latitude populations, with application to earlier higher latitude humans. *Journal of Human Evolution* 48: 381–92.

Ruff, C.B., Trinkaus, E. & Holliday, T.W. 1997. Body mass and encephalization in Pleistocene *Homo*. *Nature* 387: 173–6.

Sciulli, P.W., Schneider K.N. & Mahaney M.C. 1990. Stature estimation in prehistoric Native Americans of Ohio. *American Journal of Physical Anthropology* 83: 275–80.

Sjøvold, T. 1990. Estimation of stature from long bones utilizing the line of organic correlation. *Human Evolution* 5(5): 431–47.

Telkkä, A. 1950. On the prediction of human stature from the long bones. *Acta Anatomica* 9: 103–17.

Tibbetts, G.L. 1981. Estimation of stature from the vertebral column in American blacks. *Journal of Forensic Sciences* 26(4): 715–23.

Trotter, M. & Gleser, G. 1952. Estimation of stature from long bones of American whites and Negroes. *American Journal of Physical Anthropology* 10: 463–514.

Trotter, M. & Gleser, G. 1958. A re-evaluation of estimation of stature based on measurements of stature taken during life and of long bones after death. *American Journal of Physical Anthropology* 16: 79–123.

Werdelin, L. 1985. The stature of some medieval Swedish populations. *Fornvännen* 80: 133–41.

Werdelin, L., Myrdal, J. & Sten, S. 2000. Patterns of stature variation in medieval Sweden. *Hikuin* 27: 293–306.