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Body mass prediction from stature and bi-iliac breadth in two high latitude populations, with application to earlier higher latitude humans

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Abstract

Previous studies have indicated that body mass can be estimated from stature and bi-iliac (maximum pelvic) breadth with reasonable accuracy in modern humans, supporting the use of this method to estimate body mass in earlier human skeletal samples. However, to date the method has not been tested specifically on high latitude individuals, whose body form in some ways more closely approximates that of earlier higher latitude humans (i.e., large and broad-bodied). In this study, anthropometric data for 67 Alaskan Inupiat and 54 Finnish adults were used to test the stature/bi-iliac body mass estimation method. Both samples are very broad-bodied, and the Finnish sample is very tall as well. The method generally works well in these individuals, with average directional biases in body mass estimates of 3% or less, except in male Finns, whose body masses are systematically underestimated by an average of almost 9%. A majority of individuals in the total pooled sample have estimates to within $\pm 10\%$ of their true body masses, and more than three-quarters have estimates to within $\pm 15\%$. The major factor found to affect directional bias is shoulder to hip breadth (biacromial/bi-iliac breadth). Male Finns have particularly wide shoulders, which may in part explain their systematic underestimation. New body mass estimation equations are developed that include the new data from this study. When applied to a sample of earlier (late middle Pleistocene to early Upper Paleolithic) higher latitude skeletal specimens, differences between previous and new body estimates are small (less than 2%). However, because the Finns significantly extend the range of morphological variation beyond that represented in the original world-wide reference sample used

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in developing the method, thereby increasing its generality, it is recommended that these new formulas be used in subsequent body mass estimations.

Introduction

Predicting body mass (weight) from skeletal remains will always involve significant uncertainties, given the variability of soft tissue relative to hard tissue between and (over time) within individuals. Yet body mass prediction for archaeological and fossil specimens, even if only approximate, is still useful for a variety of reasons. Body mass is the most commonly used dimension for evaluating changes in the relative size of other body components, including brain size (encephalization), tooth size (megadontia), and long bone strength (robusticity). Body mass has been measured in a wide variety of other animals and related to many physiological, ecological, and behavioral variables (Calder, 1984; Schmidt-Nielson, 1984). It is thus the most relevant ''size'' measure both for placing humans into broad comparative context and for estimating such variables in earlier humans (e.g., McHenry, 1994). Geographic and temporal variation in body mass and body mass relative to stature are important in interpretating modern and earlier population affinities, as well as the effects of environmental changes on body form (Ruff, 2002; Ruff et al., 2002).

Many different approaches have been used to estimate body mass from skeletal material (Porter, 2002; Auerbach and Ruff, 2004). The most successful have relied on either a direct functional relationship between the size of a skeletal element and its support of body weight, or actual morphological reconstruction of the body. The first approach can be termed ''biomechanical,'' and the second ''morphometric'' (Ruff, 2002; Auerbach and Ruff, 2004). Although biomechanical approaches, e.g., using lower limb articular size, have proven very useful in body mass estimation (Ruff et al., 1991; McHenry, 1992; Grine et al., 1995; Ruff et al., 1997), morphometric

approaches have certain advantages, particularly when mechanical loadings relative to body size may have varied significantly (Auerbach and Ruff, 2004). Morphometric approaches generally begin by estimating stature. In some techniques body mass is then calculated assuming some relationship between stature and body mass (Mathers and Henneberg, 1995; Porter, 1995). In an alternative approach, stature estimates are combined with a measure of body breadth—bi-iliac, or maximum pelvic breadth—to calculate body mass using multiple regression (Ruff, 2000a). This approach factors in the considerable variation in relative body breadth that exists among both living and past human populations and that strongly contributes to variation in body mass (Ruff, 1994, 2002). Because of systematic differences in shoulder to hip breadth proportions in males and females (Hiernaux, 1985), different equations need to be used for the two sexes, or if sex is unknown an average between male and female estimates is taken. The stature/bi-iliac breadth method has been shown to work well in both ''normal'' and highly athletic modern individuals (Ruff, 2000a), and has been used to estimate body mass in a number of archaeological and paleontological specimens (Ruff and Walker, 1993; Ruff et al., 1997; Arsuaga et al., 1999; Rosenberg et al., 1999; Trinkaus et al., 1999a,b, 2003; Trinkaus and Ruff, 1999a,b; Ruff, 2000b; Holt, 2003).

The original anthropometric data set upon which the stature/bi-iliac method is based was world-wide in distribution, consisting of 56 sex/population means gleaned from the mid- to late 20th century literature (Ruff, 1994). Considerable variability in body size and shape was incorporated into the overall reference sample, making the method appropriate for application to a variety of different skeletal materials. However, because it was specifically selected to be world-wide, not over-representing any particular region, the

reference sample included only a limited number of higher latitude populations—sex/sample means for Alaskan ''Eskimos'' (Inupiats) and Aleuts[1], and a few northern European samples (Danish, Irish, Belgian, Czech). Among both living and earlier humans, higher latitude populations tend to be characterized by greater body mass and body breadth than lower latitude populations (Ruff, 1994). Pleistocene humans in general were larger in body size than modern living humans (Ruff et al., 1997). Thus, pre-Holocene higher latitude skeletal specimens tend to be very large in body breadth and likely body mass, near or beyond the limits of modern human population means. Such specimens include those from the middle Pleistocene sites of Atapuerca, Spain (Arsuaga et al., 1999), and Jinnuishan, China (Rosenberg et al., 1999), European and Near Eastern Neandertals (Ruff, 1994), and some Upper Paleolithic-associated modern humans in Europe (Ruff, 1994; Holt, 2003) (see Discussion). Other indirect evidence also indicates that higher latitude earlier humans had large and/or relatively broad bodies (Trinkaus et al., 1999b). Because of the great significance of such specimens to various evolutionary and adaptational arguments (e.g., Ruff et al., 1997; Arsuaga et al., 1999; Ruff, 2002; Zilhão and Trinkaus, 2002), it is important to further verify the application of body mass estimation techniques in similarly shaped modern individuals.

In the present study, body mass is estimated from stature and bi-iliac breadth in two high latitude samples from different regions of the Northern Hemisphere—Alaskan Inupiats and Finns. The overall accuracy of predictions in these samples is assessed, and deviations of estimates from predicted values are examined in relation to population affinity, sex, and body shape. New body mass estimation equations incorporating the new data are calculated and applied to several middle and late Pleistocene higher latitude specimens, with estimates compared with those from the old equations.

[1] Note that the body weight given for Aleut females in Ruff (1994)—80.5 kg—was based on an erroneous value given in the original publication for this data set (Laughlin, 1951). The true value of 53.4 kg (Laughlin, pers. comm.) was used in subsequent analyses (Ruff et al., 1997; Ruff, 2000a).

Methods

Samples

The Inupiat anthropometric data used here were collected from Wainwright, Point Hope, and Barrow, Alaska, in 1968-1971 (Jamison, 1978). The ''Eskimo'' sex/sample mean data points used to develop the original stature/bi-iliac method (Ruff, 1994) were obtained from a smaller subset of the same sample from Wainwright only (Jamison and Zegura, 1970). Only ''non-hybrid'' individuals, as determined from memory geneologies, were included in the present study. In addition, only younger adults 20-39 years of age were included, because: a) the Finnish sample is limited to younger adults (see below), b) body mass tends to increase with age in adults because of accumulation of excess adipose tissue (Ruff et al., 1991), and c) the ''target'' sample of archaeological and paleontological specimens to which the body mass estimation method would be applied are probably largely younger (or at least not aged) adults. A large battery of anthropometric measurements were taken on the original sample (Jamison and Zegura, 1970; Jamison, 1978); of these, body mass (weight), stature, bi-iliac breadth, relative sitting height [(sitting height/stature) × 100] and biacromial/bi-iliac breadth were included here. The first three dimensions were used in the body mass estimation tests; the last two are basic body proportions (trunk length/stature and shoulder/hip breadth) that may affect body mass prediction (Ruff, 2000a). Anthropometric techniques have been previously described in detail, and followed standard procedures (Jamison and Zegura, 1970).

The Finnish sample consisted of individuals 20-41 years of age who were measured in 2003-4 by two of us (M.N. and J-A.J.) using standard anthropometric methods. Most individuals originated from north-central Finland and all were ethnic Finns. The sample does not include competitive athletes, although some individuals, particularly among the males, participate in various sports and were judged (impressionistically) to be very muscular and physically fit. Body size and proportions of the study sample (see below) are

similar to those reported recently for young adult Finns (Dahlström, 1981; Silventoinen, 1998, 2000; Aalberg and Siimes, 1999), although the males in our sample are slightly taller and heavier than average.

Several Inupiats were judged to be obese and were eliminated from the sample. Although the 85th percentile for body mass index (BMI) is often used as a cut-off for obesity (Must et al., 1991a), there are questions regarding the applicability of BMI standards based on the general US population to wide-bodied and short-limbed populations such as Inupiats and Inuit (Schaefer, 1977; Ruff, 2002). Thus, a more stringent requirement was adopted here, with obesity defined as a) BMI > 95th percentile, or b) BMI > 85th percentile and triceps skinfold > 85th percentile, compared to age and sex-specific US white national standards (Must et al., 1991a,b). Using these criteria, two male and seven female Inupiats were eliminated from the study sample. This left final sample sizes of 27 male and 40 female Inupiats, and 27 male and 27 female Finns.

General characteristics of the study sample are shown in Table 1. Despite attempts to age-match the Inupiat and Finnish samples, female Finns average several years younger than any of the other sex/sample groups; possible consequences of this are discussed later. Finns are significantly taller than Inupiats, and male (but not female) Finns are

significantly heavier than Inupiats ($p < 0.001$, t-tests). Bi-iliac breadths are marginally larger in Finns ($p < 0.10$, males; $p < 0.05$, females). Relative sitting height is greater in Inupiats, i.e., they have relatively longer trunks and shorter legs than Finns ($p < 0.001$, both sexes). Shoulder to hip breadth tends to be larger in Finns, although the difference does not reach significance in males and is only marginally significant in females ($p < 0.10$). Males in both populations have larger biacromial/bi-iliac ratios than females, as in other populations (Hiernaux, 1985).

Both population samples are wide-bodied, with sex/population means for bi-iliac breadth falling near the upper limit of a modern world-wide sample (Ruff, 1994) (the male Finn mean actually slightly exceeds the previous upper limit for males). The Finns are also very tall compared to this same world-wide sample, with means for both sexes (but particularly males) surpassing the previous upper limit. In terms of individual variation in both body breadth and stature, the two combined samples far exceed the upper limits of the earlier world-wide sample means, and come close to encompassing the ranges found in earlier higher latitude humans (see Discussion). It has been shown that variation in stature has no effect on surface area to body mass ratios, and thus thermoregulation, while increasing absolute body breadth decreases relative surface area and is thus

Table 1
Study sample characteristics

Sample	Sex	n	Age (yrs)	Stature (cm)	Body mass (kg)	Bi-iliac bd. (cm)	Rel. sit. ht.[1]	Biac./bi-iliac[2]
Inupiat	M	27	29.4 ± 1.3[3] (20-39)[4]	167.4 ± 0.8 (161.1-177.5)	68.6 ± 1.5 (50.0-82.3)	29.1 ± 0.3 (25.8-32.5)	53.5 ± 0.2 (52.0-55.8)	1.38 ± 0.02 (1.25-1.55)
	F	40	30.1 ± 1.0 (20-39)	155.9 ± 0.7 (145.3-165.5)	59.6 ± 1.5 (43.8-78.6)	28.6 ± 0.2 (26.6-31.5)	54.0 ± 0.2 (52.1-54.0)	1.27 ± 0.01 (1.13-1.38)
Finn	M	27	29.6 ± 1.2 (22-41)	182.1 ± 1.2 (170.0-195.0)	82.9 ± 2.3 (63.5-104.0)	29.9 ± 0.3 (27.4-33.9)	52.3 ± 0.2 (50.4-53.9)	1.41 ± 0.01 (1.27-1.50)
	F	27	24.4 ± 0.5 (20-31)	164.4 ± 1.1 (155.4-179.6)	58.8 ± 1.6 (46.0-89.3)	27.9 ± 0.2 (25.7-30.2)	52.9 ± 0.2 (50.9-54.8)	1.30 ± 0.01 (1.16-1.45)

[1] Relative Sitting Height: (Sitting Height/Stature) × 100
[2] Biacromial/Bi-iliac breadth
[3] Mean ± SE
[4] Range

adaptive for cold climates (Ruff, 1991, 1994). Therefore, these two population samples are both climatically adapted for high latitudes, while also demonstrating significant differences in body form, i.e., much greater stature in Finns. The relatively short limbs of Inupiats [near the limit for Asian and European population samples (Eveleth and Tanner, 1976)] should also decrease relative surface area (Trinkaus, 1981; Ruff, 1994), and in this respect the Inupiats appear more cold-adapted than the Finns.

Analyses

Estimated body mass was calculated from stature (ST) and bi-iliac breadth (BIB) (both in cm) using previously developed sex-specific formulas (Ruff, 2000a) (SEE = standard error of estimate):

Males: Estimated body mass (kg) = 0.373 × ST + 3.033 × BIB − 82.5 (r = 0.898, SEE = 3.6)

Females: Estimated body mass (kg) = 0.522 × ST + 1.809 × BIB − 75.5 (r = 0.816, SEE = 4.1)

Paired t-tests were used to compare estimated with true body masses, within population and sex. In addition, body mass prediction errors (PE) and percent prediction errors (%PE) were calculated. The PEs were calculated as true − estimated, and %PEs as [(true − estimated)/estimated] × 100 (Smith, 1984). The PE and %PE are measures of the directional bias of an estimate, with positive values indicating that true body mass is larger than estimated body mass, and vice versa. The absolute values of the prediction error and percent prediction error, |PE| and |%PE|, were also calculated; these are measures of the random (nondirectional) error in estimation. Because of the highly skewed nature of these latter parameters, median rather than mean values are given in the following data presentations. Multiple analysis of variance was also used to investigate the effects of population, sex, relative sitting height, and relative shoulder/hip breadth on estimation errors. All statistical analyses were carried out using SYSTAT (SYSTAT: Statistics, 1990).

Results

True versus estimated body masses are plotted for the entire study sample in Fig. 1. Data in the figure are logged to preserve proportionality throughout the entire size range (i.e., absolute distances are equivalent to percentage differences in raw space). Average prediction errors by population and sex are given in Table 2, with sample distributions for %PE and |%PE| shown in Figs 2a and 2b, respectively.

Average directional bias in prediction errors (PE and %PE) is very small—2 kg (3%) or less—and statistically nonsignificant in most of the sex/population samples, except in male Finns, who are underestimated by almost 7 kg (9%) on average (p < 0.001, paired t-test between true and predicted body mass). Random error (|PE| and |%PE|) averages 3-7 kg (5-11%), and is highest in female Inupiats. For both directional and random errors, a majority of individuals in the study sample fall within 10% of predicted values, and more than three-quarters fall within 15% (Fig. 2). This is also true of every sex/population subgroup
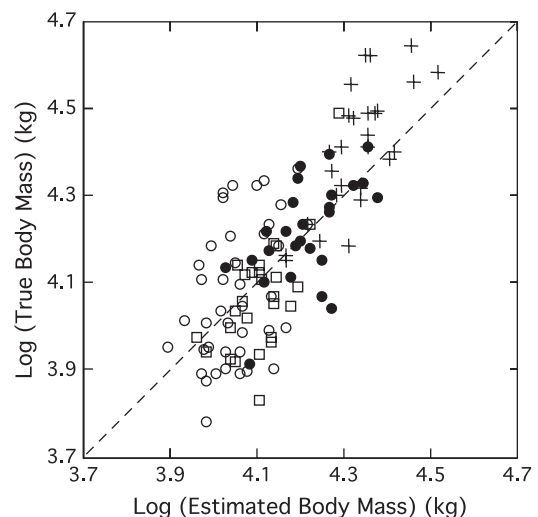

Fig. 1. True (measured) body mass versus body mass estimated from stature and bi-iliac breadth in the current study sample. Dotted line represents equivalence between true and estimated values. Open circles: female Inupiats; filled circles: male Inupiats; open squares: female Finns; crosses: male Finns.

Table 2
Average body mass prediction errors

Sample	Sex	PE (kg)[1]	%PE[2]	|PE| (kg)[3]	|%PE|[3]
Inupiat	M	0.6	1.0%	3.9	5.9%
	F	1.9	3.4%	6.6	11.2%
Finn	M	6.8*	8.8%	7.1	9.3%
	F	−2.0	−3.4%	3.4	5.4%

*$p < 0.001$, paired t-test between true and estimated values.
[1] Mean prediction error: true − estimated
[2] Mean percent prediction error: [(true − estimated)/estimated] × 100
[3] Median (see text)

except female Inupiats, where 40-45% fall within 10% and 65-70% fall within 15% of predicted values.

Part of the increased random error in female Inupiats is due to a group of 5 high outliers (Fig. 1). These women tended to be older (mean age 34 years, range 28-39), with higher BMIs (mean 30.8) and triceps skinfolds (mean 19.8 mm) than other women in this sample ($p < 0.001$, BMI, $p = 0.10$, triceps skinfold, t-tests with other Inupiat females). Thus, somewhat increased fatness may account for the higher than predicted weight of these individuals.

This explanation does not apply to male Finns, however, who were both systematically underestimated and had relatively high random estimation error. Four high outliers in this group (Fig. 1) had high BMIs on average (29.6, $p < 0.001$, t-tests with other male Finns), but did not have large skinfolds (maximum 8 mm). The explanation for estimation bias in male Finns in general may lie in part with overall body proportions, as described below.

The effects of population, sex, and two body proportions—relative sitting height and biacromial/bi-iliac breadth—on body mass prediction error (%PE) are assessed through multiple analysis of variance in Table 3. Only biacromial/bi-iliac breadth has a significant effect on prediction bias ($p < 0.01$). In similar analyses carried out within sex, only males show a significant effect of biacromial/bi-iliac breadth on %PE ($p < 0.05$; females $p > 0.10$). As would be expected, there is a positive correlation between this body proportion and %PE in males ($r = 0.365$, $p < 0.01$), i.e., males with relatively wide shoulders are heavier than predicted based on the stature/bi-iliac formula. As noted earlier, male Finns tend to have wide shoulders (Table 1), which may in part explain their systematically underestimated body masses.
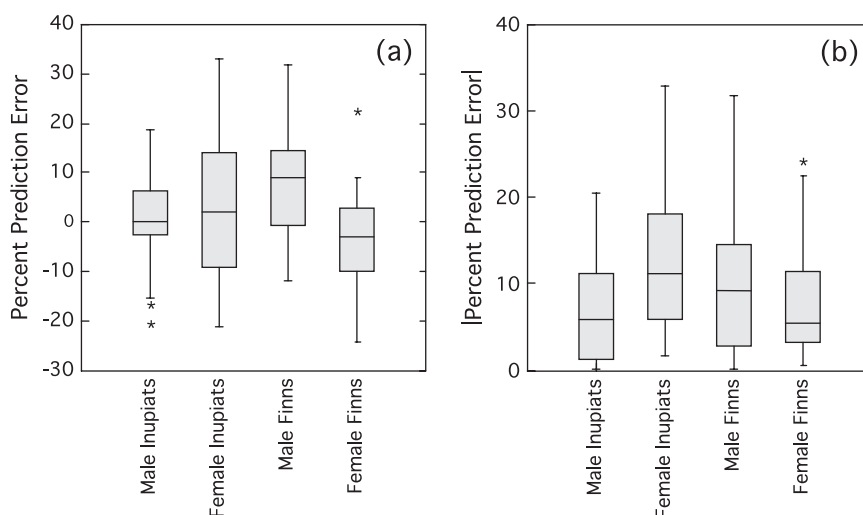

Fig. 2. Box plots of percent prediction errors (%PEs) of body mass in sex/population samples. a) Directional %PE: [(true − estimated)/estimated] × 100. b) Random %PE: absolute value of %PE. Box plots show median, interquartile range (box edges), values within 1.5 × interquartile range from median (whiskers), and outliers (asterisks).

Table 3
Multiple analysis of variance, dependent variable body mass percent prediction error

Source	Mean square	F-ratio	P
Population	42.87	0.29	0.59
Sex	1.25	0.01	0.93
Rel. sit. ht.[1]	0.02	0.00	0.99
Biac./bi-iliac[2]	958.13	6.41	0.01
Error	149.55		

[1] Relative Sitting Height: (Sitting Height/Stature) $\times$ 100
[2] Biacromial/Bi-iliac breadth

The two most positive outliers in Fig. 1 have biacromial/bi-iliac ratios of 1.49 and 1.50, near the maximum for males in the total sample (Table 1).

Discussion

The results of this study generally confirm the validity of the stature/bi-iliac method for estimating body mass (Ruff, 2000a), albeit with some caveats discussed below. While the method has been previously validated in temperate and lower latitude samples (Ruff, 2000a), this is the first such test among specifically high latitude individuals, who tend to have large and wide bodies, more similar in some respects to those of earlier higher latitude humans (Ruff, 1994, 2002; and see below). Although Alaskan Inupiats were included in the original data set from which the stature/bi-iliac method was developed (Ruff, 1994), there is little chance for circular reasoning in testing the equations on individuals from the same general population here. First, the majority of Inupiats used in the present study (15/27 males, 26/40 females) were from villages other than Wainwright, Alaska, the source for the original data set (Jamison and Zegura, 1970). Also, the original sample was older, ranging from 25 to 74 years of age, compared to 20-39 years here. Thus, few of the same individuals were included in both studies. And, of course, only the male and female means, not the individual data, were included in the original study.

However, while the stature/bi-iliac method worked well for the majority of individuals in the present sample, the systematic deviation of male

Finns, who are both taller and wider-bodied than any of the samples used in formulating the original method, suggests that their inclusion in the world-wide reference sample could alter body mass estimates for earlier humans who were similarly large-bodied. The female Finns in our sample also represent a new data point for this reference sample. Therefore, it is of interest to re-calculate stature/bi-iliac body mass estimation equations based on the world-wide sample (Ruff, 1994), adding in the Finnish male and female means. (Inupiats had already been included in the previous equations, so their data points were left unaltered.) The new equations, based on 32 male and 26 female world-wide population means, are:

Males: Estimated body mass (kg) = 0.422 $\times$ ST + 3.126 $\times$ BIB $-$ 92.9 (r = 0.913, SEE = 3.7)

Females: Estimated body mass (kg) = 0.504 $\times$ ST + 1.804 $\times$ BIB $-$ 72.6 (r = 0.819, SEE = 4.0)

Regression coefficients are different from the original equations, especially for males, although correlations and standard errors of estimate are similar (compare with equations given earlier). Table 4 shows the effect of applying these new equations to 11 middle Pleistocene, Neandertal, and "early anatomically modern" humans from higher latitudes ($>30°$). All specimens except those from Atapuerca (Arsuaga et al., 1999) and Jinnuishan (Rosenberg et al., 1999) were included in a previous more comprehensive analysis (Ruff et al., 1997). Statures were calculated from long bone lengths (Trotter and Gleser, 1952) as in the previous analysis, except that US black formulas (as opposed to the mean of US black and white formulas) were used for the early anatomically modern (early Upper Paleolithic) specimens, based on new evidence that they had more "tropical" limb proportions (Holliday, 1997; Formicola, 2003). Thus, the "old" body masses for these are different than those used in the previous study (Ruff et al., 1997). Not all of the specimens in Table 4 have wide bodies—the Skhul, three Predmosti, and Dolni Vestonice specimens are better characterized as intermediate between tropical and high latitude modern humans in body

Table 4
Prediction of body mass from stature and bi-iliac breadth in some earlier higher latitude humans

Specimen	Sex	Stature[1]	Bi-iliac (skel.)[2]	Bi-iliac (living)[3]	BM (old)[4]	BM (new)[5]	Dif. (new−old)
Atapuerca Pelvis	M	174.5[a]	34.0	36.8	94.1	95.7	1.6
Jinniushan	F	167.9[a]	34.4	37.2	79.5	79.2	−0.3
Kebara 2	M	166.0[a]	31.3	33.6	81.4	82.3	0.9
La Chapelle-aux-Saints	M	162.0[a]	30.0	32.1	75.3	75.8	0.5
Skhul 4	M	176.0[b]	28.0	29.8	73.4	74.4	1.0
Predmost 3	M	173.5[b]	27.9	29.6	72.1	73.0	0.9
Predmost 4	F	155.3[b]	26.5	28.0	56.2	56.2	0.0
Predmost 14	M	166.7[b]	26.3	27.8	63.9	64.2	0.3
Paviland 1	M	171.6[b]	28.6	30.5	73.9	74.8	0.8
Grotte des Enfants 4	M	181.1[b]	29.3	31.3	79.9	81.3	1.4
Dolni Vestonice 14	M	178.0[b]	25.7	27.1	66.0	66.8	0.8

[1] Statures (cm) estimated from long bone lengths using formulas in Trotter and Gleser (1952): a) whites, b) blacks. Atapuerca's stature estimated using mean of femoral length estimates (47.5 cm) given in Arsuaga et al. (1999).

[2] Bi-iliac breadth of skeletal specimen (cm).

[3] Estimated living bi-iliac breadth (skeletal bi-iliac breadth $\times 1.17 - 3$) (cm) (Ruff et al., 1997).

[4] Body mass (kg) estimated from stature and (living) bi-iliac breadth using previously determined formulas, not including Finn sample (Ruff, 2000a).

[5] Body mass (kg) estimated from stature and (living) bi-iliac breadth using formulas derived here, including Finn sample (see text).

form (Ruff, 1994). They are included here in part for completeness and to further test the new equations on more moderate body shapes.[2]

The difference between new and old body mass estimates is small for all specimens (Table 4). New estimates are slightly higher for all males, ranging from 0.3 to 1.6 kg. Perhaps not surprisingly, the maximum difference is found among two males who are both wide-bodied and moderately to very tall (Atapuerca and Grotte des Enfants 4), i.e., individuals who are most similar to the new male Finnish sample. However, even here the difference between estimates is quite small (under 2%). New estimates for the two Neandertals (Kebara 2 and La Chapelle) are within 1 kg of the original estimates. The two females have almost identical new and old estimates, again not surprisingly since female Finns were less extreme outliers compared to the original reference sample, so that their inclusion had little effect on the regression equation.

In sum, the new equations provide similar body mass estimates to earlier estimates, but perhaps should be preferred since they include information from a wider range of modern body types, especially those that may have characterized some earlier higher latitude populations.[3] Therefore, we recommend their use in future analyses of this kind.

Several factors may influence the accuracy of body mass estimation using the stature/bi-iliac method. The greater tendency for women than men in the Inupiat sample to increase in body mass and triceps skinfold thickness with age (through the 5th decade) has been previously noted (Jamison and Zegura, 1970; Auger et al., 1980), and may account for the increased prediction errors (especially random) observed here among female Inupiats. A general tendency for adults to gain weight in the 3rd and 4th decades of life is characteristic of many populations (Ruff et al., 1991). The Finnish women in our sample were younger on average than any of the other subgroupings, which may explain their relatively low true compared to skeletally estimated

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[2] The one other early human specimen to which the stature/bi-iliac method can be applied is KNM-WT 15000 (Walker and Leakey, 1993), although his body shape is distinctly tropical (Ruff and Walker, 1993). His (adult) estimated body mass using the new male formula is 73.0 kg, compared to 71.7 kg using the old formula.

[3] Interestingly, when the new equations are applied to the young adult male Finnish sample reported by Dahlström (1981), using his means of 179.1 cm for stature and 28.5 cm for bi-iliac breadth, a body mass of 71.8 kg is predicted, very close to the mean reported body mass for this sample of 72.1 kg.

body masses. [The samples in the original stature/bi-iliac reference data (Ruff, 1994) were not limited to younger adults.] Both directional and random estimation errors are significantly different between Finnish and Inupiat women (p < 0.05, t-tests). However, if Inupiat women are limited to those in the same age range as the Finns—20-31 years (mean 25.9 ± 0.8 years)—there are no significant differences in any of the prediction errors among women between populations. Thus, even within younger adults, age may affect the accuracy of body mass predictions. This may be especially true among women: in our sample there is a significant interaction between sex and age in determining %PE of body mass (p < 0.01, ANOVA), and only among women is there a significant effect of age on %PE [p < 0.01, regression on age; this remains near-significant (p = 0.06) if population is included as a co-factor]. Thus, more error will be introduced if the body mass of individuals or samples of very different age are compared using the method.

The marked influence of relative shoulder breadth (biacromial/bi-iliac) on body mass prediction errors using the stature/bi-iliac method confirms earlier findings based on elite athletes (Ruff, 2000a). That study also found no consistent effects of relative sitting height, or lower limb length, on prediction accuracy. Also, as here, relative shoulder breadth was only a factor among males, not females. Male Finns in our sample have particularly broad shoulders relative to hips—their biacromial/bi-iliac ratio is greater than that of all but one of the 14 European population samples tabulated by Hiernaux (1985) (and the one sample with a greater ratio was derived from data for 18-year-olds, which may not be comparable to those for true adults). The average biacromial/bi-iliac ratio of our sample is similar to that reported by others for young adult male Finns (Dahlström, 1981). As noted earlier, this may account, at least in part, for the systematic underestimation of body mass in male Finns, although this is probably not the only factor involved, since male Inupiats have only slightly smaller biacromial/bi-ilac breadths than male Finns and yet are not underestimated.

Given the general importance of relative shoulder breadth, the critical issue with respect to

archaeological/paleontological applications is whether this body proportion can in some way be factored into body mass estimation methods. The use of sex-specific formulas is one way to do this, since it is well known that in all populations males have relatively broader shoulders and females relatively broader hips (e.g., Hiernaux, 1985; also present study data). However, beyond this general observation, it is difficult to relate anthropometric variation in body proportions directly to skeletal variation, primarily because, unlike pelvic breadth, shoulder breadth cannot be measured accurately from skeletal material. Clavicular length may give some indication of shoulder breadth, although it is not equivalent. While skeletal bi-iliac breadth may be converted into living bi-iliac breadth, allowing use of anthropometric data in body mass estimation equations (Ruff et al., 1997), we are unaware of any data relating clavicular length to biacromial breadth. The limited data that are available for clavicular length indicate little ecogeographic (climatic) variation in relative clavicular length (Trinkaus, 1981), unlike relative (and absolute) bi-iliac breadth, which shows strong ecogeographic patterning (Roberts, 1978; Ruff, 1994). Biacromial breadth also shows less ecogeographic variation than bi-iliac breadth: among both males and females, European populations average 15% larger in bi-iliac breadth, but only 8% larger in biacromial breadth than African populations (calculated from data in Hiernaux, 1985). Among earlier higher latitude humans, European Neandertals apparently had very long clavicles relative to humerus length, but Near Eastern Neandertals and European Upper Paleolithic-associated modern humans did not (Trinkaus, 1981), despite at least some of these latter specimens possessing moderately wide to very wide pelves (Table 4). Thus, it is difficult to calculate or even predict absolute or relative shoulder breadth for skeletal samples. More data relating to shoulder breadth, both skeletal and anthropometric, are necessary to further refine "morphometric" body mass estimation techniques.

Relative muscularity is another factor that obviously affects the accuracy of the stature/bi-iliac method. The body mass of world-class

athletes in "weight" events like shot-put and weight-lifting are significantly underestimated using this method (Ruff, 2000a). However, the body mass of other athletes, e.g., distance runners, are overestimated, and athletes that combine adaptations for speed and agility in addition to strength (like wrestlers and decathletes/pentathletes) tend to be relatively well estimated. No measures of muscularity were available for the Inupiats and Finns in the present study sample, but it is possible that some of the variability in estimation error is attributable to that factor. (A few of the positive outliers among the male Finns are known to be particularly "athletic.")

The other source of uncertainty in applying the stature/bi-iliac method to skeletal remains is, of course, the estimation of stature, which is most commonly calculated through regression equations based on long bone lengths, as we have done here for the Paleolithic samples. In doing so it is critical to use reference samples that are as closely matched as possible to the sample of interest in terms of body proportions (Holliday and Ruff, 1997; Auerbach and Ruff, 2004). If this is not possible to do, e.g., because of uncertain body proportions and/or population affinities, then an alternate body mass estimation technique, such as one based on lower limb articular size, may be more appropriate (Auerbach and Ruff, 2004).

Conclusions

Body mass in two high latitude population samples of younger adults—Alaskan Inupiats and Finns—can be estimated with reasonable accuracy using equations based on stature and bi-iliac breadth and a world-wide reference sample (Ruff, 2000a). Most individuals fall within 10% of estimated values, and the great majority within 15%. The only significant systematic deviation occurs in male Finns, whose body mass is underestimated by about 9% on average. Factors that influence estimation errors include shoulder-to-hip breadth in males and age in females. New estimation equations that incorporate the new Finn data give body mass estimates similar to those from the old equations when applied to

a sample of earlier higher latitude humans (late middle Pleistocene through late Pleistocene). However, because the Finns add to the range of variation represented in the modern human reference sample, these new equations may be more broadly applicable, particularly to tall and wide-bodied males.

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