Published by Oxford University Press on behalf of the International Epidemiological Association
 Advance Access publication 9 January 2008

International Journal of Epidemiology 2008;**37**:201–209
doi:10.1093/ije/dym254

OTHER ORIGINAL ARTICLES

Fatness biases the use of estimated leg length as an epidemiological marker for adults in the NHANES III sample

Barry Bogin* and Maria Inês Varela-Silva

Accepted 28 November 2007

Background We analyse the NHANES III sample to assess the suitability of measured stature and sitting height to estimate leg length (tibia + femur) and predict fatness. High rates of overweight in the United States population may lead to greater gluteo-femoral fat mass which will increase sitting height and artificially decrease estimates of both absolute and relative leg length.

Methods The analyses include 3076 women and 3233 men, 20.0–49.9 years of age of White, Black or Mexican-American ethnicity. The poverty index ratio, measured stature, sitting height, upper leg length, weight, four skinfolds, buttocks circumference and elbow, biacromial and biiliac breadths were extracted from the database. The sitting height ratio, % body fatness, % upper leg length (ULL/stature), and other indices were estimated. Correlation and principle component analysis were used to assess the relationship between measures of body fatness, relative leg length and the other variables.

Results For adults in the NHANES III % body fat is more strongly correlated with buttocks circumference ($r = 0.87$ and 0.78 for women and men), than with any measure of estimated leg length (r's range from -0.28 to -0.10 for both sexes). Principle components analysis separates fatness, stature and estimated leg length into uncorrelated factors for this sample.

Conclusion Reports of a negative association between leg length and fatness for adults of the NHANES III are likely spurious, due to greater gluteo-femoral fat thickness increasing sitting height. Future rounds of the NHANES, and similar surveys in other nations with high body fat populations, should measure lower extremity length directly to better assess its relationship to health and disease risk.

Keywords body fatness, estimated leg length, poverty, NHANES III, sitting height ratio

Introduction

Decomposing stature into its major components is proving to be a useful strategy to assess the antecedents of disease, morbidity and death in adulthood.[1–5] Human leg length (tibia + femur), trunk length and their proportions (e.g. relative leg

Department of Human Sciences, Loughborough University, Leicestershire LE11 3TU, UK.

*Corresponding author. Department of Human Sciences, Loughborough University, Leicestershire LE11 3TU, UK. E-mail: b.a.bogin@lboro.ac.uk

length or the sitting height ratio [sitting height/stature]) are used as epidemiological markers of risk for overweight (fatness), coronary heart disease, diabetes and certain cancers.[6–8] There is also wide support for the use of relative leg length as an indicator of the quality of the environment for growth during infancy, childhood and the juvenile years of development.[9–19] Human beings follow a cephalo-caudal gradient of growth, the pattern of growth common to all mammals. A special feature of the human pattern is that after birth the legs grow relatively faster than other post-cranial body segments.[20] For groups of children and youth, short stature due to relatively short legs (i.e. a high sitting height ratio) is a marker of an adverse environment.[21]

The United States Third National Health and Examination Survey of 1988–1994 (the NHANES III) is the most recent national sample to include measures of both stature and sitting height (length of the body from buttocks to crown of the head), which allows the estimation of leg length via subtraction, leg length = (stature – sitting height), and the estimation of relative leg length via sitting height ratio (SHR = sitting height/stature × 100). The lower the SHR values the longer are the legs in proportion to total stature.

Analyses of the NHANES III data report that US adults with relatively shorter legs have more body fat, greater insulin resistance and greater prevalence of diabetes than Americans with relatively longer legs.[22,23]

These findings may not be quite accurate. In the NHANES III, 57.4% of men and 56.4% of women aged 20.0–49.9 years old are overweight or obese (using the US Center for Disease Control cutoff points for the body mass index: BMI = 25.0–29.9 is overweight and a BMI = 30 + is obese). Given this level of fatness, it is possible that the accumulation of buttocks fat (gluteo-femoral fat) may underestimate and obscure accurate estimations of leg length. Several studies have measured subcutaneous fat thickness above the gluteal muscle by computed tomography scanning.[24–26] Some subjects in these studies have nearly 9 cm of subcutaneous buttocks fat. In one of these studies, greater body fatness, as assessed by BMI is shown to be positively correlated with supergluteal fat thickness ($r = 0.51$, $P < 0.01$, $n = 25$ men).[25] While subcutaneous fat is compressible, a thicker gluteo-femoral fat mass will increase sitting height and artificially decrease both absolute and relative leg length. Spurious associations between measures of sitting height and leg length on the one hand, and leg length-based risks for fatness and metabolic disease on the other hand, are likely. In this article we analyse the NHANES III sample to assess the reliability of the sitting height ratio as a proxy for leg length in adult men and women when corrected for estimated supragluteal fatness.

Methods

Population

The NHANES is a periodic survey conducted by the U.S. National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (CDC). The NHANES III, 1988–94 was the seventh in a series of these surveys. The survey is based on a complex, multi-stage sampling plan, designed to provide national estimates of the health and nutritional status of the United States' civilian, non-institutionalized population in the 50 states and the District of Columbia.

Study design

The major design parameters of the NHANES III have been described elsewhere.[27] In NHANES III, 39 695 persons, aged 2 years and older, were selected over the 6 years. The NHANES identifies subjects by sex, age, ethnicity and by the poverty income ratio, an index of family income relative to the poverty level adjusted for family size for a given year. 'Race/ethnicity' was self-reported for adults. The NHANES III defined four 'race/ethnic' groups: Non-Hispanic White, Non-Hispanic Black, Mexican-American and Other. There are too few of these 'Other' individuals for useful analysis.

'Race/ethnic' codes are social categories and not well defined genetic or biological groups (www.aaanet.org/stmts/racepp.htm). Nevertheless, U.S. Blacks have, on average, relatively longer legs than Whites and Mexican-Americans.[28,29] The causes of these group differences in relative leg length are not well understood.[12] The existence of these group differences requires analysis by 'race/ethnic' groups.

Measures

Ethnicity/race is self reported by the participants in the survey as White, Black or Mexican-American.

Sex (female or male) is self reported by the participants in the survey.

Age at interview, in years (Age) was calculated from date of birth and the date of interview.

Poverty income ratio is computed as a proportion of two components. The numerator is the midpoint of the observed family income category reported in the Family Questionnaire of the NHANES III. The denominator is the poverty threshold, based on the age of the family reference person, and the calendar year in which the family was interviewed. The poverty threshold values (in dollars) are produced annually by the U.S. Census Bureau and are adjusted for inflation.

Anthropometry measurement protocols are available.[27] Standing height and sitting height were measured directly to the nearest 0.10 cm. Leg length was calculated by subtracting sitting height from standing height. Additional anthropometry used in the present analysis includes weight, four skinfolds (subscapular, triceps, suprailiac, thigh), upper leg

Table 1 Ethnicity (ethnic), sex and sample sizes (N), with means and standard deviations for age at interview (AGE, range 20–49 years old), height, sitting height,% body fat

Ethnic	Sex	*N*	Age (years)		Height (cm)		Sitting height (cm)		% Body fat	
			Means	SD	Means	SD	Means	SD	Means	SD
White	M	1162	34.7	8.3	177.4	6.7	93.3	3.6	24.8	5.4
White	F	1209	34.3	8.1	163.8	6.4	87.2	3.4	32.9	6.2
Black	M	1137	33.3	8.1	176.9	7.1	90.1	3.7	22.5	6.4
Black	F	1087	33.2	8.1	163.6	6.4	84.6	3.4	34.4	6.9
MexAmer	M	1341	32.2	8.5	169.8	6.6	89.6	3.5	25.2	5.2
MexAmer	F	1150	32.3	8.2	157.2	6.0	84.0	3.2	36.5	6.2
Total	M	3640	33.2	8.3	174.5	7.5	90.9	3.9	24.2	5.8
	F	3446	33.3	8.2	161.6	7.0	85.1	3.6	34.6	6.6

length (femur length), biiliac breadth (maximum breadth of the hips at the highest point of the iliac crests), biacromial breadth (maximum breadth of the shoulders across the lateral borders of the acromial processes), elbow breadth (greatest breadth across the epicondyles of the humerus at the elbow) and buttocks circumference (maximum circumference of the hips). The body breadths are included as a control for body shape and as a measure of frame size, an important variable associated with body fatness.[30]

Percentage body fat was calculated using the formulas of Peterson *et al.* [31], which assume a four-compartment model of body composition. For men the formula is: % body fat $= 20.94878 + (\text{age} \times 0.1166) - (\text{height} \times 0.11666) + (\text{sum4} \times 0.42696) - (\text{sum4}^2 \times 0.00159)$. For women the formula is: % body fat $= 22.18945 + (\text{age} \times 0.06368) + (\text{BMI} \times 0.60404) - (\text{height} \times 0.14520) + (\text{sum4} \times 0.30919) - (\text{sum4}^2 \times 0.00099562)$. In both formulas the term 'Sum4' is the sum of the triceps, subscapular, suprailiac and midthigh skinfolds. In the formula for women the term 'BMI' is the body mass index (weight in kg/height in m^2).

As our measure of relative leg length we use the sitting height ratio. We feel this is more appropriate than using estimated leg length [i.e. (stature – sitting height)]. The sitting height ratio gives the percentage of total stature that is due to the length of the head, neck and trunk of the body and, therefore, partially corrects for the stature variation within the sample. The sitting height ratio is a better descriptor of body shape than stature or leg length.[12] Moreover, if buttocks fatness biases the measurement of sitting height then it also biases the estimate of calculated leg length. It seems better to analyse a ratio of the direct measurements of height and sitting height rather than a calculated estimate of leg length. We compute % upper leg length, % biiliac breadth, % biacromial breadth, % elbow breadth and % buttocks circumference by dividing each variable by standing height (e.g. buttocks circumference in cm/height in cm). BMI, an index of weight-for-height, is also included in our analyses. Relating these variables to stature allows for common comparison of lengths, breadths, mass and circumferences.[32,33]

Study sample and statistical analysis

A study sample of 6282 participants 20–49 years of age (3220 men and 3062 women) with data for all of the variables was extracted. We chose this age range to avoid the effects of growth, development and maturation for younger people. We also wish to avoid age-related changes for older adults in stature and sitting height, which in the NHANES III sample tend to decrease after age 50 relatively rapidly compared with younger adults (analysis not shown here, see also ref.[34]). Age 50 years is also a convenient cut-off point for fatness changes in the NHANES III sample. Summarizing our analyses of age changes in fatness (not shown here), women tend to increase to age 60 years, but slowly after age 50. Fatness in men tends to increase relatively rapidly to age 40 years, more slowly to age 60 years, and then stabilize to age 90.

In Table 1 the distribution of participants by ethnicity (White, Black and Mexican-American) and sex along with the means and standard deviations for age, height, sitting height, % body fat are presented.

The maximum number of men and women for any single variable totals 9023 cases. The study sample does not differ in terms of mean values for age, stature, sitting height or % body fat from the total database ($P > 0.05$). The study sample of women has smaller mean buttocks circumference and lower % buttocks circumference ($P < 0.01$). This might bias results against our hypothesis that gluteo-femoral fat thickness causes an underestimate of relative leg length.

Pearson correlation coefficients were calculated to provide a simple measure of association between each of the variables. Due to relatively large number of correlations, and the possible multicollinearity (linear dependence) between many of these variables it may be difficult to understand the underlying biological structure of the data set. Principle component analysis was used to extract uncorrelated sets of variables (i.e. factors), reduce the number of variables, and to

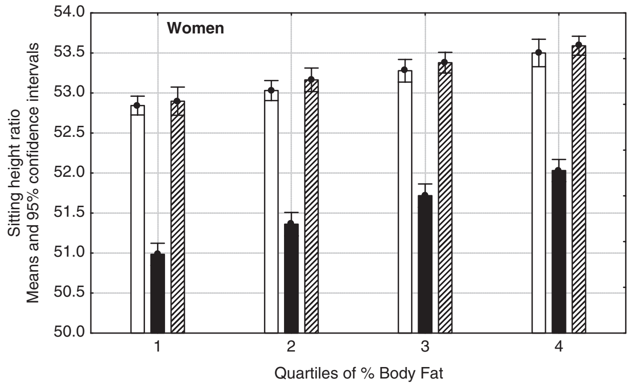

Figure 1 Means for sitting height ratio according to quartiles of % body fat in women. 'Race/Ethnicity' categories are: Whites, open bars; Blacks, solid bars; Mexican-Americans, cross-hatched bars

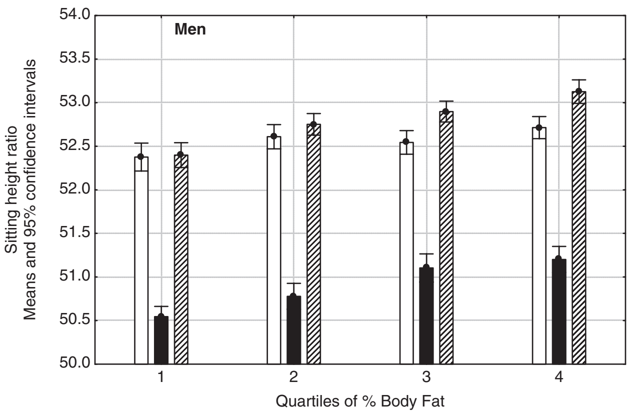

Figure 2 Means for sitting height ratio according to quartiles of % body fat in men. 'Race/Ethnicity' categories are: Whites, open bars; Blacks, solid bars; Mexican-Americans, cross-hatched bars

detect structure in the relationships between variables.

In our statistical analysis we use the reported data without any sample weights or other adjustments. Such weighting and adjustment is needed when the NHANES III data are used to estimate national prevalence and rates. In the present analysis the data are treated as a sample of convenience.

Results

We begin the presentation of results by assuming that the sitting height ratio is an accurate proxy for relative leg length. In Figure 1 we show the relationship of means for sitting height ratio according to quartiles of % body fat for adult women. Quartile 1 is the lowest and quartile 4 the highest % body fat. Similar data for men are shown in Figure 2. In women, all three ethnic groups show increases in sitting height ratio (relatively shorter leg length) with increases in % body fat ($P < 0.001$). For men, Blacks and Mexican-Americans show increases in sitting height ratio with increases in % body fat ($P < 0.01$), but Whites do not. Results of this type, that adults in the NHANES III with relatively longer legs have lower body fatness and lower BMI are reported in the literature cited previously.

The association between relative leg length and % body fat is reduced and less direct if additional variables are considered simultaneously. Presented in Table 2 is a correlation matrix for the set of variables considered here for women and men. The correlation coefficients (r) for sitting height ratio and % body fat are 0.23 for women and 0.29 for men. For % upper leg length and % body fat the r for both men and women is -0.10. While the signs of these correlations are in the expected direction (greater % body fat with relatively shorter legs) these are small-to-modest correlations given the sample size. In contrast, the r values for correlations between % body fat, BMI and % buttock circumference range from 0.87 to 0.91 for women and 0.77–0.91 for men, indicating that these three variables are strongly associated. Percentage buttocks circumference has very little association with % upper leg length ($r = -0.04$ for both sexes), but a modest association with sitting height ratio ($r = 0.25$ for women and $r = 0.32$ for men). The measurement of buttocks circumference and upper leg length are independent in terms of technique. In contrast, the measurement of sitting height includes some amount of gluteo-femoral tissue that also contributes to buttocks circumference.

Principle component analysis results for women and men are shown in Tables 3 and 4, respectively. For women, four factors have eigenvalues greater than 1.0. Factor 1, accounting for 34.68% of the variance in the dataset, is composed of loadings >0.70 for % body fat, % biiliac breadth, % elbow breadth, % buttocks circumference and BMI. The choice of a 'critical level' for factor loadings is arbitrary. Some sources suggest values greater than 0.50.[35] We chose 0.70 because it is more conservative and recommended by the software (STATISTICA) used in our analysis.[36] The negative signs of the loadings may be ignored as they are all negative, and only the relative size of the loading is important. This seems to be a body fatness/body breadth factor. Factor 2, with loadings for sitting height and standing height (15.36% of the variance), seems to be a linear skeletal dimension factor. Factor 3 is comprised of relative leg length, both the sitting height ratio and % upper leg length. The opposite signs for these loadings indicate that adults with greater sitting height ratio have, as expected, relatively shorter femurs. Factor 4 is the Poverty income ratio.

For men, five factors have eigenvalues >1.0. Factor 1 (28.46% of the total variance) is composed of % body fat, % biiliac breadth, % buttocks

Table 2 Correlation matrices for women, above the diagonal, and men, below the diagonal

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Ethnicity		−0.02	−0.09	−0.39	−0.37	−0.07	0.05	0.22	0.21	0.29	0.12	0.23	0.21
2 Poverty income ratio	−0.01		0.03	0.01	0.01	−0.01	0.01	0.01	0.01	−0.03	−0.01	−0.01	−0.01
3 Age, years	−0.12	−0.01		0.01	0.07	−0.17	0.08	0.32	0.24	0.06	0.27	0.21	0.23
4 Standing height, cm	−0.42	−0.01	0.05		0.79	0.15	−0.37	−0.22	−0.25	−0.37	−0.27	−0.25	−0.10
5 Sitting height, cm	−0.37	−0.00	0.07	0.77		−0.09	0.28	−0.08	−0.07	−0.27	−0.16	−0.10	0.01
6 % Upper leg length	−0.09	−0.00	−0.16	0.19	−0.08		−0.37	−0.10	−0.10	−0.12	−0.08	−0.04	−0.08
7 Sitting height ratio	0.08	0.01	0.03	−0.36	0.31	−0.40		0.23	0.28	0.17	0.19	0.25	0.17
8 % Body fat	0.03	−0.01	0.33	−0.10	0.10	−0.10	0.29		0.58	0.47	0.57	0.87	0.91
9 % Biiliac breadth	0.13	−0.01	0.23	−0.22	0.01	−0.15	0.33	0.61		0.38	0.44	0.61	0.60
10 % Biacromial breadth	0.28	0.00	−0.05	−0.38	−0.26	−0.07	0.19	0.28	0.38		0.44	0.47	0.50
11 % Elbow breadth	0.03	−0.00	0.20	−0.23	−0.11	−0.08	0.17	0.28	0.40	0.34		0.56	0.61
12 % Buttocks circumference	0.11	−0.00	0.14	−0.18	0.04	−0.04	0.32	0.78	0.68	0.46	0.45		0.90
13 Body mass index	0.05	−0.00	0.22	−0.00	0.16	−0.05	0.24	0.77	0.68	0.45	0.48	0.91	

Table 3 Principle components analysis for women

Variable	Mean	SD	Factor 1	Factor 2	Factor 3	Factor 4
Ethnicity	1.98	0.83	−0.37	0.53	−0.01	−0.11
Poverty income ratio	2.12	1.64	0.01	−0.04	−0.06	*0.88*
Age, years	32.73	8.17	−0.31	−0.35	−0.09	0.39
Standing height, cm	161.59	6.96	0.46	*−0.76*	0.31	−0.08
Sitting height, cm	85.11	3.55	0.24	*−0.88*	−0.18	−0.17
% Upper leg length	24.21	1.51	0.19	0.09	*0.75*	−0.01
Sitting Height Ratio	52.69	1.44	−0.36	−0.15	*−0.77*	−0.13
% Body fat	34.61	6.55	*−0.89*	−0.21	0.15	0.01
% Biiliac breadth	17.17	1.77	*−0.73*	−0.12	−0.02	0.00
% Biacromial breadth	22.75	1.14	−0.66	0.22	0.01	−0.09
% Elbow breadth	3.89	0.26	*−0.72*	−0.07	0.08	0.07
% Buttocks circumference	61.05	5.66	*−0.89*	−0.17	0.18	−0.06
Body mass index	24.78	4.45	*−0.88*	−0.28	0.23	−0.07

Variables with their means and standard deviations and factor loadings are shown. An unrotated factor analysis was used to compute the loadings. Factor loadings >0.70 are indicated by italics. Factor 1: eigenvalue 4.51, total variance 34.68%; Factor 2: eigenvalue 2.00, total variance 15.36%; Factor 3: eigenvalue 1.42, total variance 10.90%; Factor 4: eigenvalue 1.01, total variance 7.80%.

circumference and BMI. This seems to be a body fatness/lower body breadth factor. Factors 2 and 3 are essentially the same as for women. Factor 4 is Age and factor 5 is Poverty income ratio.

Discussion

The results of the principle components analyses indicate that fatness, and measures of body breadth correlated with fatness, comprise the factor which dominates the anthropometric structure of the NHANES III sample of adults. The 'fatness/body breadth' factor is not correlated with the 'linear size,' or 'relative leg length' factors in the NHANES III sample. Accordingly, the reported relationship between relative leg length and fatness in the literature, and the one we show in Figures 1 and 2 are, at least partly, spurious associations that arise from sources of bias not measured in a simple analysis.

Within factor 1, the strong correlation between % body fat and % buttocks circumference suggests that the thickness of buttocks fat is one source of bias. We are not aware of any studies that divide buttocks circumference into anatomical regions of fat. One published report finds a positive association between BMI and subcutaneous supragluteal fat thickness.[25]

Table 4 Principle components analysis for men

Variable	Mean	SD	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Ethnicity	2.04	0.83	−0.21	0.62	0.05	0.17	0.07
Poverty income ratio	2.09	1.59	0.01	0.01	0.01	0.09	*−0.99*
Age, years	33.33	8.35	−0.28	−0.29	0.07	*−0.82*	−0.05
Standing height, cm	174.45	7.53	0.35	*−0.83*	−0.20	0.12	0.02
Sitting height, cm	90.87	3.85	0.04	*−0.87*	0.29	0.30	0.04
% Upper leg length	24.48	1.41	0.22	−0.05	*−0.79*	0.20	0.01
Sitting height ratio	52.11	1.51	−0.47	−0.03	*0.72*	0.26	0.02
% Body fat	24.18	5.79	*−0.80*	−0.26	−0.09	−0.06	0.00
% Biiliac breadth	16.30	1.38	*−0.81*	−0.07	−0.01	−0.02	0.01
% Biacromial breadth	23.69	1.21	−0.59	0.37	−0.13	0.24	0.01
% Elbow breadth	4.148	0.23	−0.59	0.06	−0.13	−0.23	−0.04
% Buttocks circumference	55.81	4.29	*−0.90*	−0.13	−0.19	0.15	0.00
Body mass index	25.71	4.04	*−0.88*	−0.28	−0.22	0.10	0.00

Factor 1: eigenvalue 4.10, total variance 31.54%; factor 2: eigenvalue 2.24, total variance 17.20%; factor 3: eigenvalue 1.40, total variance 10.77%; factor 4: eigenvalue 1.07, total variance 8.25%; factor 5: eigenvalue 1.00, total variance 7.70%.

This study measured 25 men and 25 women (30% overweight and 14% obese) undergoing medical procedures that called for a pelvic region CT scan at a hospital in Ireland.

Aside from the published analyses of the NHANES III sample,[22,23] only two other studies address the relationship between variation in sitting height ratio and body fatness in adults. One is an analysis of 669 Brazilian women, which finds that individuals with relatively shorter legs carry significantly more body fat than women with relatively longer legs.[37] The authors measured height and sitting height to calculate sitting height ratio. Buttocks circumference was also measured but not included in their regression analysis, so it is possible that gluteo-femoral fat thickness biases the results to some extent. The second study is of 30 Spanish women, 35–55 years old.[38] No relationship was found between % body fat and height, trunk length or leg length. Measurement protocol is not reported, so it is possible that leg length is estimated. The small sample size may obscure important relationships.

Factor 3 of the principle component analysis includes sitting height ratio and % upper leg length. It is expected that these measure of relative leg length would be strongly, and negatively, correlated if buttocks fatness were not a bias, but less strongly correlated if sitting height is biased and upper leg length is not. The strong association in the NHANES III sample may indicate that both measures of relative leg length are biased by fatness. The method for measuring upper leg length used in the NHANES III requires palpating the knee to find the patella-femur junction, drawing a line across the knee at this junction, measuring from the mid-point of this line to the mid-point of the inguinal crease (the junction of the thigh with the lower abdomen when the participant is seated). The NHANES III manual instructs anthropometrists that, ‘No pressure is to be applied at the inguinal crease; however, folds of fat tissue may have to be lifted on some obese SP’s [subject persons] to measure at the crease’ [27] (pp. 3–9). Applying ‘no pressure’ to a fat-filled inguinal crease will underestimate true femur length.

Living conditions and growth trends in the United States

The principle component analysis finds that the poverty index ratio accounts for about 8% of the variance for both women and men in the data set. In the United States, sub-optimal nutrition and relatively frequent disease are more common for children and adults of lower income families, of recent immigration from other countries, for unemployed and under-employed families, and minority ethnic groups.[39,40] A recent report[41] indicates that since 1975 the United States born populations show a modest increase in mean stature for Whites and no increase for Blacks. These trends in height are in contrast to western European populations showing stronger positive trends in stature during the same period. The authors suggest the patterns of height growth in the United States may be attributable to the unequal distribution of health care and, ‘. . . the relatively weak welfare safety net’ (p. 283). Indeed, this same report states that the United States has the greatest income disparity, as measured by the Gini coefficient, of any of the industrialized nations. Body weight and fatness, of course, have increased at a rapid rate for the United States adult population during this same period,[42,43] and the burden of the overweight/obesity epidemic falls heaviest on those with a lower poverty income ratio.[44]

A negative relationship between sitting height ratio and the poverty index ratio for children and youth of the NHANES III is reported.[45] Fatness in these children and youth may bias this relationship, since those with relatively shorter legs also have greater sum of four skinfolds.[23] Even so, it is possible that the relatively short-legged children from families with a lower poverty index ratio do, in fact, have reduced leg growth. These lower income children may become adults with shorter stature, reduced relative leg length and greater risk for fatness and metabolic disease.[46]

Conclusion

There seems to be a significant bias when leg length and relative leg length (e.g. sitting height ratio) are estimated from stature and sitting height in populations with high percentage of overweight and obesity. In such populations, the relation of leg length to body fatness, and hence disease risk, will be overestimated. Future rounds of the NHANES, and similar surveys in other nations with high body fat populations, should measure lower extremity length directly. Measuring lower leg length is especially important as the tibia is more sensitive to changes in the health environment than is the femur or the long bones of the arm.[47–48]

It is easier to measure sitting height than leg length. In part this is because there is no consensus for choosing the appropriate anatomical landmarks. Two common methods for measuring upper and lower leg length are to have the person stand and measure subischial length (the perpendicular distance from pubic symphysis to the floor) or greater trochanter height (the perpendicular distance from the lateral margin of the greater trochanter of the femur to the floor). Palpating these landmarks in overweight and obese individuals may be difficult, time consuming and possibly embarrassing. Nevertheless, more direct measurement of leg length is called for to better assess its epidemiological value as a marker for health and disease risk and to track changes over time as an indicator of the effectiveness of health and nutrition policy and practice.

Acknowledgments

We thank Nada Beydoun for assistance in the organization of the NHANES III database prior to analysis. Prof. Robert Malina suggested a possible association between gluteal fatness and sitting height that sparked the idea for this analysis.

Conflict of interest: None declared.

KEY MESSAGES

For adults aged 20–49 years:

- Estimates of relative leg length based upon measured stature and sitting height are biased in populations with high levels of body fatness.
- Fatness, linear height/sitting height, relative leg length and socioeconomic level (as measured by the poverty index ratio) are uncorrelated principle components in the NHANES III database. This seems to be due to the high level of fatness in this sample across all 'race/ethnic,' sex, socioeconomic and age groups.
- Low socioeconomic status may reduce leg length in children and lead to greater fatness and metabolic disease in adulthood. This possibility should be explored using direct measurements of upper (femur) and lower (tibia) leg length.

References

1 Han TS, Hooper JP, Morrison CE, Lean ME. Skeletal proportions and metabolic disorders in adults. *Eur J Clin Nutr* 1997;**51:**804–9.

2 Gunnell DJ, Davey Smith G, Frankel S *et al*. Childhood leg length and adult mortality: follow up of the Carnegie (Boyd Orr) Survey of Diet and Health in Pre-war Britain. *J Epidemiol Community Health* 1998;**52:**142–52.

3 Jarvelin MR. Fetal and infant markers of adult heart diseases. *Heart* 2000;**84:**219–26.

4 Davey Smith D, Greenwood R, Gunnell D, Sweetnam P, Yarnell J, Elwood P. Leg length, insulin resistance, and coronary heart disease risk: the Caerphilly Study. *J Epidemiol Community Health* 2001;**55:**867–72.

5 Gunnell D, Whitley E, Upton MN, McConnachie A, Davey Smith G, Watt GC. Associations of height, leg length, and lung function with cardiovascular risk factors in the Midspan Family Study. *J Epidemiol Community Health* 2003;**57:**141–46.

6 Langenberg C, Hardy R, Kuh D, Wadsworth ME. Influence of height, leg and trunk length on pulse pressure, systolic and diastolic blood pressure. *J Hypertens* 2003;**21:** 537–43.

7 Lawlor DA, Taylor M, Davey Smith G, Gunnell D, Ebrahim S. Associations of components of adult height with coronary heart disease in postmenopausal women: the British women's heart and health study. *Heart* 2004;**90:**745–49.

8 Ferrie JE, Langenberg C, Shipley MJ, Marmot MG. Birth weight, components of height and coronary heart

disease: evidence from the Whitehall II study. *Int J Epidemiol* 2006;**35:**1532–42.

[9] Leitch I. Growth and health. *Br J Nutr* 1951;**5**:142–51 (reprinted *Int J Epidemiol* 2001;**30**:212–16).

[10] Tanner JM, Hayashi T, Preece MA, Cameron N. Increase in length of leg relative to trunk in Japanese children and adults from 1957 to 1977: comparison with British and with Japanese Americans. *Ann Hum Biol* 1982;**9:**411–23.

[11] Gunnell DJ, Smith GD, Frankel SJ, Kemp M, Peters TJ. Socio-economic and dietary influences on leg length and trunk length in childhood: A reanalysis of the Carnegie (Boyd Orr) survey of diet and health in prewar Britain (1937–39). *Paediatric and Perinatal Epidemiology* 1998; **12(Suppl 1):**96–113.

[12] Bogin B, Kapell M, Varela Silva MI, Orden AB, Smith PK, Loucky J. How genetic are human body proportions? In: Dasgupta P, Hauspie R (eds). *Perspectives in Human Growth, Development and Maturation*. Dordrecht, The Netherlands: Kluwer Academic Publishers, 2001, pp. 205–21.

[13] Wadsworth ME, Hardy RJ, Paul AA, Marshall SF, Cole TJ. Leg and trunk length at 43 years in relation to childhood health, diet and family circumstances; evidence from the 1946 national birth cohort. *Int J Epidemiol* 2002;**31:**383–90.

[14] Bogin B, Smith PK, Orden AB, Varela Silva MI, Loucky J. Rapid change in height and body proportions of Maya American children. *Am J Hum Biol* 2002;**14:**753–61.

[15] Bogin B, Rios L. Rapid morphological change in living humans: implications for modern human origins. *Comp Biochem Physiol A Mol Integr Physiol* 2003;**136:**71–84.

[16] Lawlor DA, Davey Smith G, Ebrahim S. Association between leg length and offspring birthweight: partial explanation for the trans-generational association between birthweight and cardiovascular disease: findings from the British Women's Heart and Health Study. *Paediatr Perinat Epidemiol* 2003;**17:**148–55.

[17] Malina RM, Pena Reyes ME, Tan SK, Buschang PH, Little BB, Koziel S. Secular change in height, sitting height and leg length in rural Oaxaca, southern Mexico: 1968–2000. *Ann Hum Biol* 2004;**31:**615–33.

[18] Martin RM, Davey Smith G, Frankel S, Gunnell D. Parents' growth in childhood and the birth weight of their offspring. *Epidemiology* 2004;**15:**308–16.

[19] Leary S, Davey Smith G, Ness A, ALSPAC Study Team. Smoking during pregnancy and components of stature in offspring 2006. *Am J Hum Biol* **18:**502.

[20] Scammon RE. The measurement of the body in childhood. In: Harris JA *et al*. (ed.). *The Measurement of Man*. Minneapolis: University of Minnesota Press, 1930, pp. 173–215.

[21] Bogin B, Varela Silva MI, Rios L. Life history trade-offs in human growth: adaptation or pathology? *Am J Hum Biol* 2007;**19:**631–42.

[22] Asao K, Kao WH, Baptiste-Roberts K, Bandeen-Roche K, Erlinger TP, Brancati FL. Short stature and the risk of adiposity, insulin resistance, and type 2 diabetes in middle age: the Third National Health and Nutrition Examination Survey (NHANES III), 1988–1994. *Diabetes Care* 2006;**29:**1632–37.

[23] Frisancho AR. Relative leg length as a biological marker to trace the developmental history of individuals and populations: Growth delay and increased body fat. *Am J Hum Biol* 2007;**19:**703–10.

[24] Nisbet AC. Intramuscular gluteal injections in the increasingly obese population: retrospective study. *Br Med J* 2006;**332:**637–38.

[25] Chan VO, Colville J, Persaud T, Buckley O, Hamilton S, Torreggiani WC. Intramuscular injections into the buttocks: Are they truly intramuscular? *Eur J Radiol* 2006;**58:**480–84.

[26] Burbridge BE. Computed tomographic measurement of gluteal subcutaneous fat thickness in reference to failure of gluteal intramuscular injections. *Can Assoc Radiol J* 2007;**58:**72–75.

[27] National Center for Health Statistics. *National Health and Nutrition Examination Survey III: Body Measurements (Anthropometry)*. Rockville, MD: Westat; 1998. Also available at: http://www.cdc.gov/nchs/data/nhanes/nhanes3/cdrom/nchs/manuals/anthro.pdf

[28] Malina RM, Brown KH, Zavaleta AN. Relative lower extremity length in Mexican American and in Black and White youth. *Am J Phys Anthropol* 1987;**72:**89–94.

[29] Norgan NG. Body-proportion differences. In: Ulijaszek SJ, Johnston FE, Preece MA (eds). *Cambridge Encyclopedia of Human Growth and Development*. Cambridge: Cambridge University Press, 1998, pp. 378–79.

[30] Linder P, Linder D. *How to Assess Degrees of Fatness*. Cambridge, MD: Cambridge Scientific Industries, 1987.

[31] Peterson MJ, Czerwinski SA, Siervogel RM. Development and validation of skinfold-thickness prediction equations with a 4-compartment model. *Am J Clin Nutr* 2003;**77:**1186–91.

[32] Huxley J. *Problems of relative growth, 2nd edn*. New York: Dover Publications, 1972.

[33] Sokol RR, Rohlf FJ. *Biometry*. San Francisco: WH Feeman, 1969, pp. 16–19.

[34] Chandler PJ, Bock RD. Age changes in adult stature: trend estimation from mixed longitudinal data. *Ann Hum Biol* 1991;**18:**433–40.

[35] Costello AB, Osborne JW. Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Prac Assess Res Eval* 2005;**10:**available online athttp://pareonline.net/getvn.asp?v=10&n=7.

[36] StatSoft, Inc. *STATISTICA (data analysis software system)*, version 7.1. www.statsoft.com, 2006.

[37] Velasquez-Melendez G, Silveira EA, Allencastro-Souza P, Kac G. Relationship between sitting-height-to stature ratio and adiposity in Brazilian women. *Am J Hum Biol* 2005;**17:**646–53.

[38] Martín Moreno V, Gómez Gandoy JB, Antoranz González MJ, Gómez de la Cámara A. Height, leg length, adiposity and metabolic-cardiovascular risk in women aged 35–55 years [Article in Spanish]. *Nutr Hosp* 2003;**18:**341–47.

[39] Federal Interagency Forum on Child and Family Statistics.. *America's Children: Key National Indicators of Well-Being*. Washington, DC: U.S. Government Printing Office, 2005.

[40] Lethbridge-Cejku M, Rose D, Vickerie J. Summary Health Statistics for U.S. Adults: National health Interview Survey, 2004. National Center for Health Statistics. *Vital Health Statistics* 2006;**10:**228.

[41] Komlos J, Lauderdale BE. Underperformance in affluence: the remarkable relative decline in U.S. heights in the second half of the 20th Century. *Social Science Quarterly* 2007;**88:**283–305.

[42] Komlos J, Baur M. From the tallest to (one of) the fattest: the enigmatic fate of the American population in the 20th century. *Econ Hum Biol* 2004;**2:**57–74.

[43] Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006;**295:**1549–55.

[44] Smith PK, Bogin B, Varela Silva MI, Gossiaux B. Prospects for Welfare Alleviation in an Obesogenic Environment. In: Lane MV (ed.). *Contemporary Poverty and Welfare Alleviation Issues*. Hauppauge, NY: Nova Scientific, 2006, pp. 1–32.

[45] Frisancho AR, Guilding N, Tanner S. Growth of leg length is reflected in socio-economic differences. *Acta Med Auxol* 2001;**33:**47–50.

[46] Bogin B. Prospects for secular trends in the growth of United States children and youth. In: Toth GA (ed.). *Auxology, To the Memory of Professor Otto G. Eiben*. Szombathely, Hungary: Savaria University Press, 2005, pp. 17–21.

[47] Jantz LM, Jantz RL. Secular change in long bone length and proportion in the United States, 1800–1970. *Am J Phys Anthropol* 1999;**110:**57–67.

[48] Stinson S. Growth variation: biological and cultural factors. In: Stinson S, Bogin B, Huss-Ashmore R, O'Rourke D (eds). *Human Biology: An Evolutionary and Biocultural Perspective*. New York: Wiley-Liss, 2000, pp. 425–63.