The Relationship of Sitting Height Ratio to Body Mass Index and Fatness in The United States, 1988-1994

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INTRODUCTION

"The body mass index (BMI) has become a universal index of energy nutritional status in adults even though it is influenced by many factors other than energy stores. One of these is variation in height caused by variation in the length of the trunk and legs. Such variations occur between and within populations" (Norgan and Jones, 1995, p. 206).

This paper is dedicated to the memory of Dr. Nicholas Norgan, who died in March 2006. Dr. Norgan was Reader in Human Biology at Loughborough University, UK. His research focused on nutritional anthropometry and he was a world-level expert in body size and body shape. A major aspect of his research in the 1990s was the relationship of body mass index, calculated as ([weight in kg/height in m^2] x 100), to body proportions. The quotation above comes from a study of the British sample in which Norgan and Jones found that, "…adjustment of BMI for SH/S ratio [Sitting Height/Stature, also called the sitting height ratio] caused BMI to change by 1 kg/m^2 or more in 33% of women and 10% of men and by 2 kg/m^2 in 5% of women and 1% of men" (ibid, p.206). These are statistically and biologically significant changes, which indicate that body proportions have an important impact on the interpretation of BMI.

The body mass index (BMI) is a mathematical indicator of the relative weight-for-height of a person. Higher BMI scores indicate that an individual has relatively more weight-for-height than a person with a lower score. In the general population, especially of the wealthier "western" nations of Europe, North America, Australia, and also Japan, a higher BMI score usually indicates more body fatness. This is because contemporary lifestyles in these nations reduce physical activity and allow an increase in food consumption (Smith et al., 2006). There are exceptions, of course, and some people in these nations have high BMI due to elevated levels of muscle mass, skeletal mass, and other components of lean tissue. Athletes and muscle building enthusiasts are two such obvious exceptions. These people are, however, a minority and BMI does serve well as an epidemiological marker of fatness (CDC, 2004). International references (WHO, 1997) define adults with BMI values between 18.5 and 24.9 as within the "normal" range. Those with BMI from 25 to 29.5 are "overweight" and above 30 are "obese." BMI less than 18.5 indicates "thinness," meaning low fat and possible inadequate energy intake.

The appeal of BMI as a fatness indicator is so strong that its use has been extended to apply to the citizens of the middle and low-income nations of Asia, Africa, and America with little reservation. Indeed it is the most commonly used measure of documentation of the worldwide overweight/obesity epidemic for adults and children (Popkin and Doak 1998; Hall and Cole, 2006).

Dr. Norgan was critical of the overuse of BMI as a measure of body fatness, especially in non-Western populations. In one study he found that skinfold thickness was greater than expected from the BMI of Australian Aborigines (Norgan, 1994a). Australian Aborigines have relatively long legs for their height, which results in a low sitting height ratio (SHR) and, it seems, a low BMI. In a sample of 349 adult Aboriginal men and women Norgan found that, "…4% of the individual men and 14% of the individual women had [BMI] values less than 16 kg/m^2, a value regarded as indicating severe chronic energy deficiency" (p.229). Skinfold measurement, however, indicated no such deficiency.

In a related analysis of more than 18,000 non-western adults, Norgan (1994b) found that the correlation coefficients between BMI and SHR were 0.45 and 0.56 for men and women respectively. Positive correlations mean that greater BMI is associated with relatively shorter leg length. The square of the correlation coefficient represents the proportion of common variation in both BMI and SHR, in this case 21 percent for men and 31 percent for women. Furthermore, Norgan found in the same study that linear regression of BMI on SHR resulted in regression coefficients (b +/- standard error) of

0.78 +/- 0.16 (t = 4.8) in men and 1.19 +/- 0.22 (t = 5.3) in women. These regression coefficients compare with a predicted change of 0.9 kg/m^2 per 0.01 difference in SHR using a modeling approach. The predictive model proves inaccurate for both men, in which the model overestimates the change, and women, in which the model underestimates the change. Norgan concludes that the wide variation in these relationships between the sexes and between populations precludes a simple adjustment for SHR on BMI. Norgan also points out that an accurate interpretation of BMI requires additional anthropometric measurements and not just height and weight.

Norgan's findings have been confirmed in at least one other study. In a sample of 120 Chinese and Dutch adults matched for age, sex, and BMI, Deurenberg et al. (1999) found that BMI varied according to SHR. Relatively shorter legs were associated with greater BMI.

OBJECTIVES OF THE STUDY

In the present study we test the hypothesis that for the United States population, reduced leg length relative to total stature results in a greater BMI, independent of fatness as measured by skinfolds. We are, therefore, attempting to extend the findings made by Dr. Norgan for non-western populations and a to the population of a wealthy western nation. We test the hypothesis using the large database of the Third National Health and Nutrition Examination Survey of the United States (NHANES III). This is a nationally representative sample of the United States population. Based on BMI, the United States has one of the most overweight and obese populations in the world (Ogden et al., 2006). American adults are also a tall (but not the tallest) population (Eveleth and Tanner, 1990). Komlos and Baur (2004) note that the rate of increase of overweight and obesity in the United States occurred with no increase in mean stature for the long-term resident population of European descent (that is, no recent immigrants). Body fat is the most likely culprit for the epidemic of overweight and obesity. Body proportions, perhaps, also play a role and in this paper we want to know the extent to which the components of stature (sitting height and leg length) interact with body fatness (sum of skinfolds) to influence the BMI.

MATERIALS AND METHODS

We evaluate the relationship between BMI, sum of skinfolds (SSF), and SHR in the United States population for adults, ages 20 to 49 years, using data from the Third National Health and Nutrition Examination Survey of the United States (NHANES III). We chose this sample, collected from 1988-1994, because the data include the anthropometric variables height, weight, sitting height, lower leg length, and four skinfolds (subscapular, triceps, suprailiac, thigh). The sum of these four skinfolds (SSF) is an indicator of fatness independent of the BMI. The NHANES III identifies subjects by sex, age, ethnicity, and by the poverty income ratio (PIR, an index of family income relative to the poverty level adjusted for family size for a given year). 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 was the seventh in a series of these surveys based on a complex, multi-stage sampling plan. It was designed to provide national estimates of the health and nutritional status of the United States' civilian, non-institutionalized population aged two months and older in the 50 states and the District of Columbia.

The major design parameters of the NHANES III have been summarized elsewhere (NCHS, 1994). In NHANES III, 39,695 persons were selected over the six years. From this sample we extracted 8,639 cases of persons 20-49 years of age with data for height, weight, BMI, sitting height, SHR, leg length, lower leg length, and sum of the four skinfolds. In Table 1 we present the distribution of cases by ethnicity (White, Black, Mexican-American) and sex along with the means and standard deviations for each variable.

"Race/ethnicity" was self-reported or reported by the respondent of the Family Questionnaire of the NHANES III. The NHANES III defined four "race/ethnic" groups: Non-Hispanic White, Non-Hispanic Black, Mexican-American, and Other, but there are too few individuals in the "Other" category for reliable analysis. We consider the NHANES III "race/ethnic" codes as social categories and not as well defined genetic or biological groups. In this we follow the position of the American Anthropological Association (1998) that in the United States "race" and "ethnicity" are social constructs that often have biological impacts. This means anthropometric

Table 1: Ethnicity (ETHNIC), SEX, and sample sizes (N), with means and standard deviations, for age at interview (AGE, 20 – 49 years old), body mass index (BMI), lower leg length as a percent of total height (%LLL), sitting height ratio (SHR), and sum of skinfolds (SSF).

ETHNIC	*SEX*	*N*	*AGE (yrs)*		*BMI*		*% LLL*		*SHR*		*SSF (mm)*	
			Means	*SD*	*Means*	*SD*	*Means*	*SD*	*Means*	*SD*	*Means*	*SD*
White	M	1235	34.66	8.26	26.34	5.13	23.54	3.95	52.93	5.08	111.47	7.55
White	F	1507	34.27	8.13	25.54	6.31	23.53	5.15	53.47	4.43	102.10	9.11
Black	M	1282	33.32	8.05	26.50	5.65	24.88	5.51	51.23	4.84	110.98	8.68
Black	F	1620	33.17	8.05	28.67	7.51	24.65	6.97	52.13	5.78	104.89	10.89
MexAmer	M	1465	32.16	8.45	26.78	4.62	23.66	4.77	52.99	2.95	109.57	7.24
MexAmer	F	1483	32.29	8.24	27.75	6.26	23.66	5.06	53.81	5.00	103.17	9.17
Total		8639	33.27	8.24	26.99	6.14	23.18	1.75	52.48	1.54	106.81	9.76

variables, such as height, weight, and BMI, may differ significantly between "racial" groups and the cause of such differences are usually due to social, economic, and political factors that impact the way life is lived in each "racial" group (see Bogin, 2001, pp. 229-242, for a discussion of the biocultural nature of human "races").

Sitting height ratio may be an exception in that there are consistent group mean differences in relative leg length between people of African, European, and Asian origin. In a previous analysis we showed that in a worldwide sample of human beings the effect of geographic origin or "race" is small, accounting for only 3.6 percent of variance in SHR. We also showed that socioeconomic status accounts for 1.0 percent of variance in SHR, which is not statistically different from the geographic "race" effect (Bogin et al., 2001). The relatively small percent of variance in SHR accounted for by geographic origin and SES indicates that other factors are more important determinants of body shape. Indeed, there is much research support that SHR of adults reflects the quality of living conditions during the growing years, with relatively shorter leg length (higher SHR) associated with inferior living conditions, especially health and nutrition (Gunnell et al., 1998; Bogin et al., 2002; Martin et al., 2004).

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 prevalences and rates. For our purposes, however, we examine the relationships between the variables from the categories listed above. Using the NHANES III sample weights in these analyses greatly inflates the sample size, reducing standard errors and making all results appear statistically significant.

RESULTS

We present in Table 2 a multiple regression with BMI as the dependent variable and age at interview (AGE), SEX, "race/ethnicity" (ETHNIC), sum of skinfolds (SSF), sitting height ratio (SHR), and lower leg length as a percentage of total stature (%LLL) as independent variables. The analysis is for all adults, ages 20-49 years old, of the white, black, and Mexican-American ethnic groups. We also performed analyses with these variables plus the poverty income ratio, an index of relative income. This variable was not a significant predictor of BMI in the regression and did not change the statistical significance of any of the other variables. Non-compliance in answering questions about family income reduces the total sample size by more than 2000 cases, so we present here the analysis without the poverty income ratio.

The overall regression is statistically

Table 2: Multiple regression of the independent variables age at measurement (AGE), SEX, "race/ethnicity" (ETHNIC), sum of skinfolds (SSF), sitting height ratio (SHR), and lower leg length as a percentage of total stature (%LLL) on body mass index. The analysis is for all adults, ages 20-49 years old, of the white, black, and Mexican-

Regression results
No. of cases: 8592 F = 6184.36 df = 6, 8585
Multiple R = 0.90 R^2= 0.81 adjusted R^2= 0.81 p < 0.000

	Beta (standardized)	*Partial correlation*	*p-level*
SSF	0.94	0.89	0.000
SEX	0.40	0.64	0.000
ETHNIC	0.10	0.23	0.000
SHR	0.10	0.19	0.000
AGE	0.02	0.04	0.001
%LLL	-0.01	-0.02	0.049

significant and each of the independent variables is a significant predictor of BMI. The variables are listed in the order of their strength of association with BMI, using the standardized Beta weights and partial correlation coefficients. As expected for this sample, SSF is highly associated with BMI. The partial correlation of +0.89 indicates that "fatness" is equally well demonstrated by BMI or SSF. There are significant positive effects for the SEX and ETHNIC variables, which have the next largest partial correlations. The interpretation of these values is that, on average, women have greater BMI than men and blacks and Mexican-Americans have greater BMI than whites. However, there is also an interaction effect between SEX and ETHNIC not shown in Table 2. As shown in Table 1, white men have a greater average BMI than white women, but both black and Mexican-American women have greater average BMI than their male counterparts. Another component of the interaction is that black women have greater average BMI than Mexican-American women, but black men have smaller average BMI than Mexican-America men. These SEX-ETHNIC effects and interactions have been described in previous research (Zhang and Wang, 2004; Smith et al., 2006).

The variable SHR has a standardized Beta equal to that of ETHNIC but a smaller partial correlation coefficient. The relationship between SHR and BMI for all adults is illustrated in Figure 1. The positive value of the SHR Beta and partial correlation means that adults with longer total leg length relative to stature have lower BMI values. The regression equation indicates that for every increase of 0.80 units in SHR there is a one unit increase in BMI.

The variables AGE and %LLL have the smallest Beta weights and partial correlations with BMI. The AGE effect is positive, meaning that BMI tends to increase with age in these 20 to 49 year-old subjects. Note that %LLL has a negative association with BMI. This means that adults in the NHANES III sample with relatively longer lower legs compared with total stature have lower BMI.

Because of the SEX-ETHNIC interactions we next analyzed the same set of variables separately for men and women within the three ethnic groups. We used stepwise multiple regression and the results are reported in Table 3. The independent

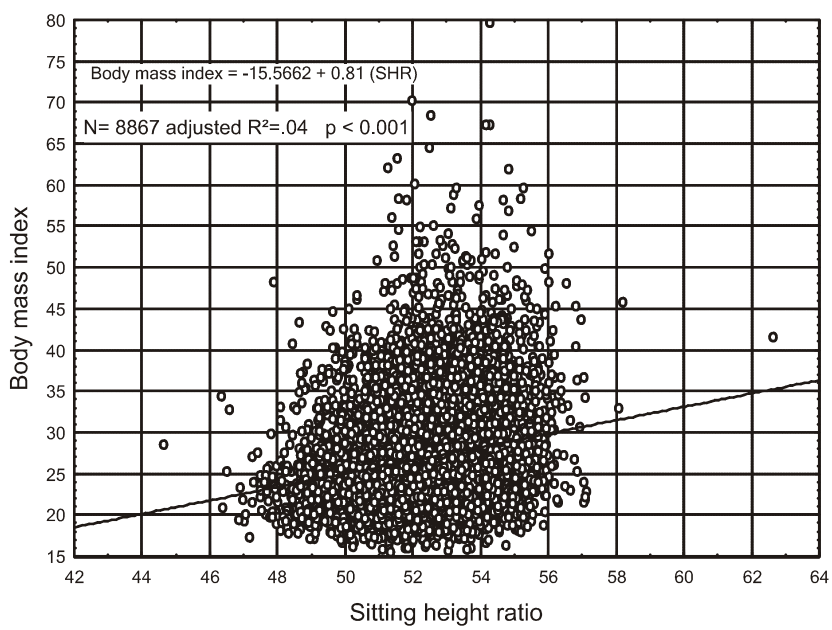

Fig. 1. Linear regression of sitting height ratio on body mass index for all adults, 20-29 years old, from the NHANES III database.

Table 3: Stepwise multiple regression for men and women for the effects of sum of skinfolds (SSF), sitting height ratio (SSF), age at measurement (AGE), and lower leg length as a percentage of total stature (%LLL) on body mass index. The analysis is for all adults, ages 20-49 years old, of the white, black, and Mexican-American ethnic groups. Only significant effects are shown in the table. Beta values indicate the relative association of each variable to BMI. The Multiple R^2 values are the coefficients of determination indicating the additional percent of variance explained by the addition of each independent variable.

Men	*White*		*Black*		*Mexican-American*	
	Beta	*Mult. R^2*	*Beta*	*Mult. R^2*	*Beta*	*Mult. R^2*
SSF	0.84	0.75	0.86	0.79	0.82	0.74
SHR	0.13	0.77	0.15	0.82	0.18	0.78
AGE	0.09	0.77	-	-	0.07	0.78
%LLL	-	-	-0.04	0.82	-	-
Women	*White*		*Black*		*Mexican-American*	
	Beta	*Mult. R^2*	*Beta*	*Mult. R^2*	*Beta*	*Mult. R^2*
SSF	0.87	0.80	0.90	0.84	0.87	0.79
SHR	0.13	0.81	0.12	0.86	0.15	0.81
AGE	-	-	-	-	-	-
%LLL	-	-	-	-	0.05	0.81

variables are listed in decreasing order of their contribution to the variance in BMI according to their standardized Beta weights and the cumulative multiple R^2. Only statistically significant ($p < 0.01$) values are presented. For both men and women, SSF has the greatest association with BMI, explaining between 74% (Mexican-American men) and 84% (black women) of the variance. SHR is a significant variable in all ETHNIC-SEX groups, contributing an additional 4% (Mexican-American men) to 1% (white women) to the explained variance in BMI. AGE and lower leg length as a percent of total height (%LLL) contributes a small (< 0.01%) but statistically significant amount to the variance in some ethnic-sex groups. Note that the %LLL Beta is negative for the black men, meaning that longer lower leg length, as a percentage of stature, is associated with lower BMI. In contrast, the Beta for %LLL for the Mexican-American women is positive, meaning greater %LLL is associated with higher BMI.

Lastly, we investigated the contribution of sitting height and leg length on BMI. To this end we performed a stepwise regression with BMI as the dependent variable and AGE, ETHNIC, SEX, SSF, SITTING HEIGHT, and LEG LENGTH as the independent variables. The results are shown in Table 4. The variables AGE and ETHNIC are not significant predictors of BMI in this regression. In decreasing order of magnitude of Beta weights and partial correlations, the remaining variables are SSF, LEG LENGTH, SEX, and SITTING HEIGHT. Both LEG LENGTH and SITTING HEIGHT have negative associations with BMI, meaning that people in the NHANES III database with greater length due to either of these measures have lower BMI. The effect of leg length is stronger than the effect of sitting height and the difference in the partial correlation coefficients is statistically significant.

Table 4: Multiple regression of the independent variables age at measurement (AGE), SEX, "race/ethnicity" (ETHNIC), sum of skinfolds (SSF), SITTING HEIGHT, and LEG LENGTH on body mass index. The analysis is for all adults, ages 20-49 years old, of the white, black, and Mexican-American ethnic groups.

Regression results
No. of cases: 8627 F = 8541.18 df = 6, 8620
Multiple R = 0.93 R^2= 0.86
adjusted R^2= 0.86 $p < 0.000$

	Beta (standardized)	*Partial correlation*	*p-level*
SSF	1.03	0.92	0.000
LEG LENGTH	-0.24	-0.43	0.000
SEX	0.20	0.36	0.000
SITTING HEIGHT	-0.17	-0.29	0.000

DISCUSSION

This new study confirms the previous work of Norgan and others that a significant relationship exists between BMI and body proportions in adults. Our new analysis also extends these findings from traditional, low income, and lower energy consumption societies (Norgan, 1994a, 1994b) and relatively small British (Norgan and Jones, 1995) Dutch and Chinese (Deurenberg et al., 1999) samples to the population of the United States, a post-industrial, generally high income, and high energy intake society. The significant relationship between BMI and sitting height ratio (SHR) is found for men and women of the three major ethnic-social groups in the United States; whites, blacks, and Mexican-Americans. Adults with relatively longer legs for their total height tend to have lower BMI. Leg length contributes more to the variance in BMI than sitting height. The percent of total stature due to the lower leg is a small, and in practical terms, unimportant factor in the determination of BMI.

Given the widespread nature of the overweight/obesity epidemic in the United States, it might be expected that all adults would be at equal risk without regard for body proportions. The influence of relative leg length (SHR) and absolute leg length on BMI, therefore, requires explanation. A first level explanation is that the head, chest, and abdomen of the body account for a greater proportion of total body mass than the arms and legs. The "sitting height" component of the SHR measures the length of the head, chest, and abdomen. Accordingly, if all other aspects of body composition are equal, then for two people of equal sitting height the BMI will be greater in the person with relatively shorter legs.

This fundamental biometric relationship is not enough to account for the findings of the present study. United States men and women with relatively shorter legs carry more subcutaneous fat, as measured by the sum of four skinfolds, than adults with relatively longer legs. The higher BMI of adults with relatively and absolutely shorter legs is not just an artifact. These people are fatter than those with longer legs. A possible explanation for this relationship comes from research in human life history and the trade-offs that occur in early development and later growth and health outcomes. Poor nutrition and health during pregnancy and during the first six years of life post-partum result in fetuses, newborns, infants and children of reduced body length, mostly due to reduced leg length (Gunnell et al., 1998; Bogin et al., 2002; Martin et al., 2004). The alterations in body proportions are likely due to competition between body segments, such as trunk versus limbs, and organs for the limited nutrients (Bogin et al., 2001).

Leitch (1951) was, perhaps, the first to propose that a ratio of leg length to total stature might be a good indicator of nutritional history and health. Noting the well-known cephalo-caudal gradient in growth, Leitch (p. 145) wrote that, "…it would be expected on general principles that children continuously underfed would grow into underdeveloped adults…with normal or nearly normal size head, moderately retarded trunk and relatively short legs." Reviewing the literature available at the time, Leitch found that improved nutrition during infancy and childhood did indeed result in a greater increase in leg length than in total height or weight. Longer-legged children were also less susceptible to bronchitis, which was then a scourge of poorly fed children. Many studies support Leitch's findings and hypothesis (reviewed in Bogin et al., 2002, see also Wadsworth et al., 2002).

Prenatal and postnatal (birth to age 7 years) undernutrition and disease account for relatively short legs in adults, but still does not explain why they are fatter than the longer-legged. We do not have a satisfactory explanation, but our findings for the United States population do conform with related research in lower income nations and developing countries. Popkin et al. (1996) report on stunting and overweight in children from Russia, Brazil, South Africa, and China. In all four nations the stunted children are significantly more likely to be overweight. In Brazil, adult men and women with short stature are more likely to have higher BMI (Velasquez-Melendez et al., 1999; Sichieri et al., 2003). Both men and women in the study by Velasquez-Melendez and colleagues had higher concentrations of serum glucose and women higher serum concentrations of total cholesterol and LDL-cholesterol.

These findings may provide entrée toward an explanation for the leg length-fatness relationship. Early life undernutrition and disease may alter human physiology toward a phenotype with a deranged lipid metabolism or a metabolism that preferentially stores fat (Barker, 1997; Frisancho, 2003; Gluckman and Hanson, 2005; Varela Silva et al., 2006). In the United States, sub-optimal nutrition (including hunger) and relatively more 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 (Federal Interagency Forum on Child and Family Statistics, 2005; Lethbridge-Cejku et al., 2006). A wide assortment of the United States population is permanently or periodically exposed to these risk factors for undernutrition and health. Our discovery of the leg length-fatness relationship for the adults in the NHANES III database may reflect the differences in nutrition and health status that still exist in the United States.

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ABSTRACT The body mass index (BMI) is the most widely used indicator of body fatness for adults. Higher BMI generally equates with greater levels of fatness. The sitting height ratio (SHR = sitting height/stature) is a relatively simple ratio of body proportions. A larger SHR indicates relatively short leg length for total stature. Previous studies show that the BMI underestimates fatness for traditional peoples with relatively long legs (a low SHR). Conversely, BMI overestimates fatness in traditional peoples suffering from undernutrition with relatively high SHR. A few studies have shown effects of SHR on BMI in small samples from urban/industrial societies. In this paper we assess the influence of SHR and lower leg length on the BMI of the United States population using the National Health and Nutritional Examination Survey of 1988-1994 (NHANES III). This nationally representative sample of 8,639 adults 20-49 years of age includes men and women of white, black, and Mexican-American ethnicity. Using stepwise multiple regression, we find that the BMI is most closely associated with body fatness (sum of four skinfolds) and then significantly influenced by SHR. The leg length component of the SHR has a greater influence on BMI than the sitting height component. Adults with relatively longer legs have lower BMI and body fatness in both sexes and all ethnic groups. The reason for this relationship is not well understood. We offer a hypothesis that early life undernutrition and disease, prenatal and postnatal, inhibits the growth of the legs and promotes a metabolic syndrome leading to greater body fatness.

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