International Journal of Obesity (1998) 22, 842–846
© 1998 Stockton Press All rights reserved 0307–0565/98 $12.00
http://www.stockton-press.co.uk/ijo

Weight–height relationships among eight populations of West African origin: the case against constant BMI standards

AE Long, TE Prewitt, JS Kaufman, CN Rotimi, RS Cooper and DL McGee

Department of Preventive Medicine and Epidemiology, Loyola University Medical Center, Maywood, IL 60153, USA

OBJECTIVE: To ascertain whether constant body mass index (BMI) standards are appropriate in genetically similar populations.
DESIGN: Data are taken from the International Collaborative Study of Hypertension in Blacks (ICSHIB), an observational study.
SUBJECTS: Individuals of African descent who were included in ICSHIB. Subjects lived in eight different sites: Barbados; Cameroon (urban and rural); Jamaica; Manchester, UK; Maywood, IL; urban Nigeria; and St Lucia.
MEASUREMENTS: Weight and height.
RESULTS: Constant BMI standards effectively argue for the constancy of slope of the linear regression equations of ln(weight) on ln(height) across populations. Linear regression results indicate that the height/weight relationship implied by the use of constant BMI standards, is not found in these populations and that there is much variation across groups.
CONCLUSION: The use of constant BMI standards in classifying individuals prognostically may be unwise, even in genetically similar populations.

Keywords: BMI; height; weight; obesity

Introduction

Weight for height standards have a long history. The earliest versions were based on insurance company tables that provided the weight associated with the lowest mortality for individuals of a given height.[1] More recently, weight standards have been based on body mass index (BMI, which is defined as wt(kg)/ht(m^2)). The most recent standards for the US population suggest a target BMI of 19–25 for all individuals.[2]

There are two possible explanations for using this index. First, it can be derived on physiological grounds.[3] These principles imply that, if the logarithm of weight is regressed on the logarithm of height, the linear relationship will have a slope of 2. The second justification for the use of BMI, is that it results in an index that is highly correlated with weight, but independent of height.[4]

In this report we examine these two justifications for using BMI as an index of obesity. We use data from age-stratified samples of genetically similar populations of African ancestry, living in vastly different environments. The sampling scheme assured similar age distributions at all of the sites. First, in order to examine whether BMI would be the index of choice, based on the relationship between weight and height in these populations, we derive this relationship and note its heterogeneity between samples. We then examine the correlation between BMI and height, and note that BMI is often not independent of height.

Methods

Data

The International Collaborative Study of Hypertension in Blacks (ICSHIB) was designed to collect standardized data on blood pressure, anthropometrics, health status and demographic characteristics on participants of African origin, at sites in Africa (Cameroon and Nigeria), the Caribbean (Barbados, Jamaica and St Lucia), UK (Manchester) and the US (Maywood, IL, a suburb of Chicago). The purpose of the study was to examine whether differences in the level of blood pressure in these different populations of similar genetic makeup[5,6] could be explained, at least partially, by personal and environmental factors. In this report, we use the ICSHIB data on weight and height from eight sites (Cameroon participants were sampled

---

Correspondence: Dr Daniel L. McGee, Department of Preventive Medicine and Epidemiology, Loyola University Medical Center, 2160 S. First Avenue, Maywood, IL 60153, USA.
Received 8 August 1997; revised 9 April 1998; accepted 20 April 1998

from both urban and rural settings). We also present the results separately for men and women, resulting in 16 samples.

Data were collected according to a standardized protocol across sites.[7,8] Weight was measured to the nearest 0.1 kg on electronic scales, uniform to all sites.[9] Height was measured to the nearest 0.1 cm using a stadiometer consisting of a steel tape fastened to a straight wall and a wooden headboard.[10] An attempt was made to standardize the measurement procedures at all sites. Scales were tested daily using standard weights and staff from the coordinating center in Chicago, made frequent trips to the sites to both observe procedures and to repeat measures. All data were extensively edited upon their arrival in the US. Additionally, prior to analysis, we examined the bivariate distributions of height and weight for outliers, defining them as points for which the regression leverages became extreme, for which a scatterplot of height on weight indicated that the individuals were quite extreme, and for which the values did not appear biologically plausible. Only a few such points were discovered and they were deleted prior to analysis.

Statistical methods

We log-transformed the variables, and performed ordinary linear regression of ln(weight) on ln(height), with weight in kg and height in m. If the use of BMI is to be justified on physiological grounds, this regression should result in a line with slope 2 in each of the samples. To look at the same question from another standpoint, we are interested in the shape of the relationship

$$\frac{Wt}{Ht^{\beta}} = \text{constant}$$

that best characterizes the population. This relationship can be inferred from the log variables and linear regression, as:

$$\ln(W) = \beta \ln(H) + \alpha,$$

which can be re-expressed as

$$\frac{W}{H^{\beta}} = e^{\alpha}.$$

Thus the slopes of the regression equations serve as the exponents on the height variable, while the intercepts (exponentiated) serve as the constants in the relationship. If $\beta = 2$ for all samples, BMI is the correct measure in all of them. Given that $\beta = 2$, if α is the same in all samples then a single standard may be appropriate (for example, a BMI of 19–25 is ‘normal’). If the α are different, then the relationship would have to be shifted: 19–25 might be ‘normal’ in one population, whereas 20–27 would be appropriate in another population, etc.).

Results

Table 1 presents the average weight, height, and BMI for both genders in the ICSHIB sites. As has been noted previously,[10] both the average weight and average height increase as the focus shifts from Africa to the Caribbean, UK and the US. Table 2 presents the gender specific regression equations by site. Several features of these estimated equations can be noted. First, nearly half of the slopes of the regression lines differ greatly from 2, indicating that if we sought the best relationship of the form weight/height$^{\beta}$, it is unlikely that $\beta = 2$ would be chosen (a glance at Table 2 shows that most slopes are below 2). This is consistent with the results of an international study by Goldbourt and Medalie,[11]

Table 1 Average values for anthropometric variables in the International Collaborative Study of Hypertension in Blacks (ICSHIB), by site and gender

Site	*n*	*Height (m)(s.d.)*	*Weight (kg) (s.d.)*	*BMI (s.d.)*
Men				
Barbados	329	1.719 (0.074)	76.4 (13.2)	25.9 (4.3)
Cameroon, r	742	1.701 (0.070)	68.1 (10.4)	23.5 (3.1)
u	614	1.724 (0.072)	74.5 (12.1)	25.1 (3.6)
Jamaica	596	1.721 (0.066)	70.4 (13.9)	23.7 (4.2)
Manchester	412	1.684 (0.070)	78.1 (13.2)	26.4 (4.2)
Maywood	709	1.765 (0.073)	84.5 (17.9)	27.1 (5.5)
Nigeria	520	1.684 (0.074)	61.3 (11.1)	21.6 (3.5)
St Lucia	492	1.734 (0.075)	72.9 (11.4)	24.3 (3.7)
Women				
Barbados	481	1.602 (0.063)	75.2 (16.3)	29.3 (6.3)
Cameroon, r	717	1.607 (0.065)	60.6 (11.9)	23.5 (4.3)
u	752	1.621 (0.057)	71.0 (13.6)	27.0 (4.6)
Jamaica	833	1.607 (0.062)	72.1 (17.4)	27.9 (6.4)
Manchester	456	1.603 (0.067)	70.9 (15.4)	27.6 (5.6)
Maywood	811	1.634 (0.064)	82.2 (20.8)	30.8 (7.6)
Nigeria	674	1.583 (0.067)	56.6 (12.3)	22.6 (4.7)
St Lucia	593	1.628 (0.068)	72.3 (17.0)	27.3 (6.2)

BMI=body mass index; r=rural; u=urban.

where the slope ranged from 1.11–2.27 (their conclusion was that, among integer exponents, 2 is the best). The average slope, calculated assuming a random effects model[12] for the groups presented in Table 2, is 1.69 (95% confidence interval (CI): 1.54, 1.85). Second, although the search for a measure of obesity that is independent of height implies a belief that there is a strong relationship between weight and height, the strength of this relationship (as judged by the value of R^2) is, in fact, quite weak. Finally, in addition to the heterogeneity of slopes, there is clearly heterogeneity of the constant terms in the linear regression.

To examine the homogeneity of the estimated parameters among the samples, we performed a regression of ln(wt) on ln(ht), including in the model indicator variables for sample membership and interaction terms between these indicators and ln(wt). The slopes of the regression lines differed significantly ($F(15,9699) = 2.82$, $P = 0.0002$). The significance of the interaction terms in the model tests whether the slopes differ significantly amongst the samples.[13] We infer from this analysis that there is significant heterogeneity of the slopes of the relationship between log weight and log height amongst the samples. Similarly, we confirmed that the constant terms differed significantly in the models.

Table 3 presents the correlation between BMI and weight and height in the different samples. While the correlation between BMI and height is most often small, there is generally some residual negative correlation. Thus, BMI does not universally result in a measure that is independent of height.

Table 2 The gender-specific regression equations for each site in the International Collaborative Study of Hypertension in Blacks (ICSHIB). Log weight regressed on log height, with height in meters and weight in kilograms

Site	*Intercept (s.e.m.)*	*Slope (s.e.m.)*	R^2
Men			
Barbados men	3.62 (0.11)	1.29 (0.21)	0.11
Cameroon, r	3.17 (0.06)	1.96 (0.12)	0.28
u	3.30 (0.07)	1.84 (0.14)	0.23
Jamaica	3.13 (0.10)	2.03 (0.18)	0.17
Manchester	3.48 (0.10)	1.59 (0.19)	0.15
Maywood	3.48 (0.10)	1.65 (0.17)	0.11
Nigeria	3.15 (0.08)	1.82 (0.16)	0.21
St Lucia	3.61 (0.08)	1.21 (0.15)	0.11
Women			
Barbados	3.81 (0.11)	1.04 (0.24)	0.04
Cameroon, r	3.22 (0.07)	1.84 (0.16)	0.16
u	3.12 (0.08)	2.34 (0.17)	0.19
Jamaica	3.39 (0.10)	1.82 (0.21)	0.09
Manchester	3.48 (0.10)	1.62 (0.22)	0.11
Maywood	3.70 (0.11)	1.38 (0.21)	0.05
Nigeria	3.29 (0.08)	1.57 (0.18)	0.10
St Lucia	3.38 (0.10)	1.80 (0.21)	0.11

r=rural; u=urban.

Discussion

Neither justification of BMI, as a physiological constant or as a measure independent of height, is consistent with our analysis. The estimated parameters from the regression equations differ across the studies, which implies that the correct transformation to describe the height and weight relationship, is not the same in all populations. Using BMI often does not result in a measure that is independent of height.

These problems have been noted previously. It has been suggested, that BMI as an index might be somewhat confounded by differing ratios of leg length to height in genetically different populations.[14,15] These authors state that the ramification of this differing leg length is that the relationship between weight and height is not constant across genetically dissimilar populations. Here, we demonstrate that the weight–height relationship also differs among genetically similar populations in different environments.

Table 3 Correlations between body mass index (BMI) and height (ht), and BMI and weight (wt) by site and gender, with 95% confidence intervals (CI)

Site	*BMI/ht*	*CI*	*BMI/wt*	*CI*
Men				
Barbados	−0.179	(−0.282, −0.073)	0.870	(0.841,0.894)
Cameroon, r	−0.023	(−0.095, 0.049)	0.836	(0.813,0.857)
u	−0.050	(−0.128, 0.030)	0.853	(0.829,0.873)
Jamaica	0.018	(−0.061, 0.100)	0.919	(0.906,0.931)
Manchester	−0.140	(−0.232, −0.042)	0.876	(0.856,0.900)
Maywood	−0.080	(−0.153, −0.007)	0.915	(0.903,0.927)
Nigeria	−0.058	(−0.141, 0.031)	0.870	(0.847,0.889)
St Lucia	−0.227	(−0.310, −0.142)	0.839	(0.810,0.863)
Women				
Barbados	−0.173	(−0.269, −0.096)	0.929	(0.912,0.937)
Cameroon, r	−0.045	(−0.118, 0.029)	0.911	(0.898,0.923)
u	0.072	(0.001, 0.143)	0.928	(0.918,0.937)
Jamaica	−0.033	(−0.099, 0.037)	0.946	(0.937,0.952)
Manchester	−0.066	(−0.158, 0.026)	0.919	(0.903,0.932)
Maywood	−0.097	(−0.164, −0.028)	0.950	(0.943,0.956)
Nigeria	−0.080	(−0.157, −0.007)	0.925	(0.912,0.934)
St Lucia	−0.049	(−0.130, 0.032)	0.932	(0.920,0.942)

r=rural; u=urban.

Although age may be a factor in determining the weight-height relationship within a population, it will not play a role in the heterogeneity of the relationships among our samples, since the sampling scheme assured similar age distributions at all of the sites.

The heterogeneity of the regression lines demonstrated in Table 2 are not surprising, given the differences in the bivariate distributions of weight and height demonstrated in Table 1. Since the slopes are a function of the ratio of the standard deviations and the correlation, even if the correlation remained constant, one would expect heterogeneity in the slopes. Similarly, the intercept is a function of the slopes and the average values so that differences in the average values and slopes should lead to differences in the intercepts.

Although it has been argued that BMI serves as a height-independent measure of weight,[15] this was not universally the case in our samples and was not the case in some national samples in the US.[4] There is a small inverse correlation between BMI and height in most samples. For the case in which the actual regressions indicates a slope smaller than 2, this small 'residual confounding' results in an over-classification of 'obesity' among shorter individuals and an under-classification of 'obesity' among taller individuals. The amount of misclassification depends on the actual definition of obesity that is used, as well as the slope for the population.

It is clear both from the regression analyses and from the descriptive information in Table 1 that different populations have different bivariate distributions of height and weight. Consider, for example, the women of Barbados, as shown in Figure 1: these women had the smallest regression slope (1.04). The use of constant BMI line standards asserts that individuals along those lines are 'equivalent' in some sense (for example, Kaufman *et al*[16] classified those above a BMI cut-point of 27.3 for women and 27.8 for men as 'overweight': in Figure 1 we include the BMI = 19 and BMI = 25 lines). These constant BMI lines are clearly at odds with the regression line. If we were to tip the BMI lines to run parallel with the regression line (i.e., use a standard appropriate for the population, given by the dotted lines parallel to the regression line in Figure 1), the effect would be to reclassify certain people as follows: 1, some shorter, heavier people as normal; 2, some taller, heavier people as obese; 3, some shorter, lighter people as excessively thin; and 4, some taller, lighter people as normal. This example is, of course, the most extreme example available from our analyses (Table 2) and not all of the regression equations presented would have resulted in this extreme deviation. However, it was chosen to illustrate how far off constant BMI standards could be. BMI represents an attempt to distill the health information contained in two variables (height and weight) into one. This 'convenience' comes at a price: the loss of some information. Even the exponent (2) of the BMI relationship is a matter of convenience (chosen as it was to be an integer). Our results indicate that a single BMI standard should not be used: rather, a standard should be developed for each population. This conclusion is in agreement with work by other researchers,[17,18] who also found BMI inconsistencies between groups.

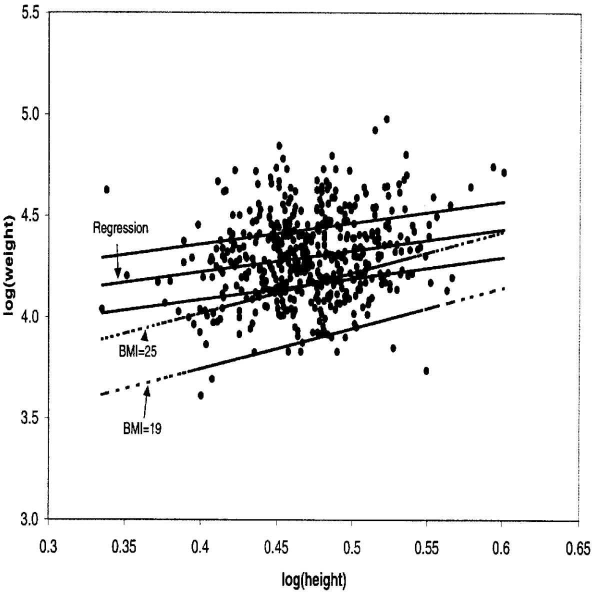

Figure 1 Heights and Weights in Barbados (women). The women of Barbados had the smallest slope. Here we show two (parallel, solid) body mass index (BMI) lines (19 and 25, with the 25 line above the 19 line), compared to the regression line (solid) for the women. The use of constant BMI line standards asserts that individuals along those lines are 'equivalent' in some sense (for example, 'All those with a BMI of 25 or above are obese.'). These constant BMI lines are clearly at odds with the regression line. Using the constant regression slope lines would lead to a different classification of many individuals in the population (specified by the dotted lines).

One must decide on the proper level at which one may employ BMI standards, or if one can employ them at all. The polar extremes are these: either employ a single BMI relationship for all people, or for none (meaning that each individual is unique). Between these poles are attempts to group individuals in such a way that single BMI-type standards are appropriate. Our conclusion is simply that the group comprising of the people of the African diaspora, is too large to be treated by a single gender-specific BMI standard: it appears that BMI is not qualitatively identical across these genetically similar populations of African descent, perhaps due to differences in body shape or build, perhaps due to nutrition, perhaps due to climate; and so BMI may not be a consistent metric for health outcomes across these populations.

Although a single number that quantified a standard for universally defining obesity is attractive, it is not necessary. Population specified standards have been suggested previously[14] and using a single one-dimensional standard has not historically been used for US standards. The original US standards published by the insurance industry[1] included both weight and height and were different for men and women as well as for 'framesize'.

Acknowledgement

This work was partially funded by grants from the National Institutes of Health (HL45508 and DK52329).

References

1 Chicago Society of Actuaries and Association of Life Insurance Medical Directors of America, *Build Study 1979*. Chicago, IL, 1980.

2 USDA Committee on the Dietary Guidelines for Americans. *Report of Dietary Guidelines Advisory, to the Secretary of Health and Human Services and the Secretary of Agriculture*. US Department of Agriculture, Agricultural Research Service: Washington, 1995.

3 Quetelet MA. *A Treatise on Man and the Development of his Faculties*. Burt Franklin: New York, 1841.

4 Micozzi MS, Albanes D, Jones DY, Chumlea WC. Correlations of body mass indices with weight, stature, and body composition in men and women in NHANES I and II. *Am J Clin Nutr* 1986; **44**: 725–731.

5 Li Z. A multiplicative random effects model for meta-analysis with application to estimation of admixture component. *Biometrics* 1995; **51**: 864–873.

6 Chakraborty R, Kamboh MI, Ferrell RE. Unique alleles in admixed populations: A strategy for determining hereditary' population differences of disease frequencies. *Ethnicity and Disease* 1991; **1**: 245–256.

7 Lohman TG, Roch AF, Mortorell R (eds). *Anthropometric Standardization Reference Manual*. Human Kinetics Books: Champaign, Illinois, 1988.

8 Ataman SL, Cooper R, Rotimi C, McGee D, Osotimehin B, Kadiri S, Kingue S, Muna W, Fraser H, Forrester T, Wilks R. Standardization of blood pressure measurement in an international comparative study. *J Clin Epidemiol* 1996; **49**: 869–877.

9 Cooper RS, Rotimi CN, Ataman SL, Osostimehin B, Kadiri S, Muna W, Kingue S, Fraser H, Forrester T, Bennett F, Wilks R. The prevalence of hypertension in seven populations of West African origin. *Am J Public Health* 1997; **87**: 160–168.

10 Rotimi CN, Cooper RS, Ataman SL, Osostimehin B, Kadiri S, Muna W, Kingue S, Fraser H, McGee D. Distribution of anthropometric variables and the prevalence of obesity in populations of West African origin: the International Collaborative Study on Hypertension in Blacks (ICSHIB). *Obes Res* 1995; **3**: Supplement 3.

11 Goldbourt U, Medalie JH. Weight-height indices. *Br J Preven Soc Med* 1974; **28**: 166–125.

12 DerSimonian R, Laird N. Meta-analysis in clinical trials. *Controlled Clin Trials* 1986; **7**: 177–188.

13 Draper NR, Smith H. *Applied Regression Analysis*. (2nd edn) Wiley, 1981.

14 Gordon T, Kagan A, Rhoads G. Relative weights in different populations. *Am J Clin Nutr* 1975; **28**: 304–305.

15 James WPT. The epidemiology of obesity. In: Cadwick DJ, Cardew G, eds. *The Origins and Consequences of Obesity*, Ciba Foundation, 1996; pp 1–11.

16 Kaufman JS, Durazo-Arvizu R, Rotimi CN, McGee DL, Cooper RS. Obesity and hypertension prevalence in populations of African origin: Results from the International Collaborative Study of Hypertension in Blacks. *Epidemiology* 1996; **7**: 398–405.

17 Luke A, Durazo-Arvizu R, Rotimi C, Prewitt TE, Ogunbiyi O, Owaje E, Schoeller DA, McGee D, Cooper RS. Relationship between body mass index and body fat in black population samples from Nigeria, Jamaica and the United States. *Am J Epidemiol* 1997; **145**: 620–628.

18 Gallagher D, Visser M, Sepulveda D, Pierson RN, Harris T, Heymsfield SB. How useful is body mass index for comparison of body fatness across age, sex and ethnic groups? *Am J Epidemiol* 1996; **143**: 228–239.