Relationship between Body Mass Indices and Measures of Body Adiposity

DENNIS A. REVICKI, PHD, AND RICHARD G. ISRAEL, EDD

Abstract: We examined the relationship between various body mass indices (BMIs), skinfold measures, and laboratory measures of body fat in 474 males aged 20–70 years. Evaluations included height, weight, skinfold thickness, and hydrostatic measurements of adiposity. The weight-height ratio (W/H), Quetelet index (W/H^2), Khosla-Lowe index (W/H^3), and Benn index (W/H^P) were calculated. The correlations among the various BMIs were high, ranging from 0.91 to 0.99, and all were strongly correlated with weight (rs = 0.81 – 0.98), while only W/H^2 (r = –.03) and W/H^P (r = –.01) were not correlated with height. The W/H^2 and W/H^P had the strongest correlation with hydrostatic and skinfold measurements, although all the BMIs were significantly correlated with these measurements. Results suggest that the Benn index and the Quetelet index are equally valid estimates of body fat in respect to their relationship with hydrostatic measures. (*Am J Public Health* 1986; 76:992–994.)

Introduction

Obesity and weight gain are associated with a variety of conditions detrimental to health, well-being, and longevity.[1] A recent National Institutes of Health (NIH) Consensus Development Panel stated that obesity is an important contributing factor in the prevalence of hypertension, hypercholesterolemia, diabetes mellitus, coronary artery heart disease, and various cancers.[2] Obesity, however, has proved a difficult characteristic to quantify.

Body mass indices (BMIs) are frequently included in epidemiologic studies as estimates of body adiposity. A number of body mass indices have been developed, all derived from body weight and height measurements. The more popular BMIs include the weight-height ratio W/H, Quetelet index W/H^2, Khosla-Lowe index W/H^3,[3] and Benn index W/H^P.[4] These indices are widely used in large epidemiologic and health investigations because of their simplicity of computation and cost effectiveness. More accurate and precise laboratory measurements of adiposity exist, but are costly and difficult to implement in large community studies.

The Quetelet index is the most widely accepted BMI, and is generally correlated with skinfold thickness measurements of body fat.[5–7] Recent research suggests that the Benn index possesses more desirable measurement characteristics (i.e., unbiased by height and strongly correlated with weight) in heterogeneous populations.[8] Garn and Pesick[9] believe the choice of a particular index is arbitrary in light of the high inter-correlation among the BMIs. However, there is some question whether the different BMIs are in fact interchangeable measures of obesity.[10,11]

The main problem is that measures of relative weight are unable to distinguish between adiposity, muscularity, and edema.[5] Skinfold measurements are usually used as the criterion for evaluating the utility of various body mass indices in estimating adiposity in adults and children.[6,12,13] Although skinfold thickness measurements are the best nonlaboratory method for estimating body fat, they represent indirect estimates of body adiposity.[9,13,14]

This study examines the relationship between four BMIs, W/H, W/H^2, W/H^3, W/H^P, and skinfold thickness and hydrostatic measures of body adiposity.

Address reprint requests to Dennis A. Revicki, PhD, Senior Health Scientist, Health Services Research and Development Special Projects Office (152), Veterans Administration Medical Center, Perry Point, MD 21902. Dr. Israel is Director, Human Performance Laboratory, East Carolina University, Greenville, NC. This paper, submitted to the Journal September 3, 1985, was revised and accepted for publication December 30, 1985.

Methods

A sample of 447 males from Greenville, North Carolina aged 20 to 70 years were evaluated in the Human Performance Laboratory between July 1981 and December 1984. The average age of the subjects was 38 years; 90 per cent of the sample was White. Measurements were made of weight (lbs), height (inches), skinfold thickness, and hydrostatic body density by a trained research assistant.

The skinfold procedure for determining body fat involved seven skinfold sites taken on the right side of the body: chest, axilla, triceps, subscapular, abdominal, suprailium and thigh.[15] The skinfold was grasped firmly by the thumb and index finger; the Harpenden caliper was placed perpendicular to the fold approximately 1 cm from the thumb and finger. The dial was read to the nearest 0.1 mm approximately five seconds after releasing the grip. Two measures were taken at each site. If a repeated measure varied by more than 1 mm, a third measure was taken. The sum of seven skinfold sites was calculated and applied to sex specific regression equations to determine body density.[15] Per cent fat was calculated from body density using the Siri equation.[16]

Per cent body fat was also determined hydrostatically. Subjects reported with a swimsuit which was weighed dry. Dry land weight was determined and converted to grams and the swimsuit's weight was subtracted from this value. While suspended from a nine-kilogram Chatillon autopsy scale, subjects were instructed to submerge themselves by flexing at the waist and to expire all the air from their lungs. This procedure continued until three identical readings were recorded. No more than 10 consecutive hydrostatic weight measurements were required to obtain dependable readings.

Body density was determined from the subject's underwater weight. Per cent body fat was calculated by Siri formula.[16] Residual volume was determined using procedures described by Wilmore.[17] A standardized correction factor of 100 ml was added to the residual volume to adjust for visceral gases. Potential sources of experimental error in estimation of body composition based on hydrostatic weighing include consecutive trial testing, measuring residual volume, and intestinal gas content. It was not possible to obtain body fat estimates using this technique in 5.6 per cent of the sample. For the most part, these subjects had difficulty tolerating the underwater weighing procedure.

The BMIs W/H, W/H^2, W/H^3, and W/H^P were calculated from height and weight data. The exponent value, p, in W/H^P was determined using the method described by Benn: B(H/W), where H was mean height and W was mean weight for the sample.[2] The regression coefficient B results from a

TABLE 1—Mean Body-Mass Indices, Height, Weight, Skinfold Fat Per Cent and Hydrostatic Fat Per Cent

Body Mass Indices	N	Mean	SD
W/H (× 10)	447	26.9	4.5
W/H² (× 1,000)	447	38.3	6.3
W/H³ (× 100,000)	447	54.7	9.2
W/H^P (× 1,000)	447	58.8	9.6
Height (inches)	447	70.2	2.5
Weight (lbs)	447	188.7	33.7
Skinfold Fat %	443	21.7	8.1
Hydrostatic Fat %	422	23.8	7.3

TABLE 2—Zero-order Correlations between Four Body Mass Indices, Weight and Height

	Body Mass Indices			
Body Mass Indices	W/H	W/H²	W/H³	W/H^P
W/H²	.97			
W/H³	.91	.98		
W/H^P	.98	.99	.97	
Weight (lbs)	.98	.91	.81	.92
Height (inches)	.19	−.03	−.24	−.01

linear regression of weight on height. The value of p was 1.8993.

The following computations were performed on the data: zero-order correlation coefficients between the four BMIs and weight, height, skinfold measures and hydrostatic laboratory measures; partial-correlation coefficients,[18] adjusting for age, between the four BMIs and weight, height, skinfold measures, and hydrostatic laboratory measures; and 95 per cent confidence intervals (CI) for the correlations between the BMIs, skinfold measures, and hydrostatic laboratory measures.

Results

Mean height, weight, W/H, W/H^2, W/H^3, W/H^P, skinfold fat per cent, and hydrostatic fat per cent for the sample are included in Table 1. The mean percentage of body adiposity estimated using skinfold thickness and hydrostatic laboratory techniques is comparable in magnitude.

The zero-order correlations between the four BMIs, height, and weight are reported in Table 2; partial-correlations among the BMIs, weight and height adjusted for age are included in Table 3. Table 4 contains the correlations, partial-correlations and 95 per cent confidence intervals for the BMIs and the body fat measures. The correlations among the various BMIs are high, ranging from 0.91 to 0.99. The average correlation among the indices is 0.97 which is reduced to 0.93 when the effects of age are partialed out.

The correlation between hydrostatic and skinfold thickness body fat measurements equals 0.84 (CI = 0.81, 0.87). Skinfold thickness per cent body fat estimates are correlated 0.01 with height and 0.71 with weight. Comparable correlations between per cent body fat estimated using laboratory hydrostatic methods and height and weight are 0.02 and 0.66, respectively.

It has been recommended that the most desirable BMI is the one that correlates minimally with height and maximally with weight.[5,19] All of the BMIs are strongly correlated with weight (see Table 2), but only W/H^2 and W/H^P are not significantly correlated with height. When age is partialed out, only the Benn index remains uncorrelated with height in this sample.

TABLE 3—Partial Correlations Adjusting for Age between Four Body Mass Indices, Weight and Height

	Body Mass Indices			
Body Mass Indices	W/H	W/H²	W/H³	W/H^P
W/H²	.96			
W/H³	.85	.96		
W/H^P	.99	.97	.88	
Weight (lbs)	.97	.86	.69	.95
Height (inches)	.15	−.13	−.38	.09

TABLE 4—Correlations, Partial Correlations Adjusting for Age, and 95% Confidence Intervals between Four Body Mass Indices, Skinfold Fat Per Cent and Hydrostatic Fat Per Cent

	Body Mass Indices			
Body Fat Measures	W/H	W/H²	W/H³	W/H^P
Correlations (Confidence Intervals)				
Skinfold Fat %	.75	.76	.73	.76
	(.71, .79)	(.72, .80)	(.68, .77)	(.72, .80)
Hydrostatic Fat %	.70	.71	.69	.71
	(.65, .75)	(.66, .75)	(.64, .74)	(.66, .75)
Partial Correlations (Confidence Intervals)				
Skinfold Fat %	.70	.74	.72	.72
	(.65, .74)	(.70, .78)	(.67, .76)	(.67, .76)
Hydrostatic Fat %	.52	.58	.58	.54
	(.45, .59)	(.51, .64)	(.51, .64)	(.47, .60)

The BMIs are strongly related to body fat determinations based on skinfold thickness and hydrostatic weighing techniques (see Table 4). The Benn index and Quetelet index had the highest correlations with hydrostatic measures of body fat, although there are minimal differences in the magnitude of the correlations for all four BMIs. Similar, although somewhat larger, correlations are found between the BMIs and skinfold thickness body fat estimates. The partial correlations controlling for age are attenuated but comparable for skinfold thickness measurements. After age-adjustment, the correlations between the BMIs and hydrostatic measurements are lower and show that W/H^2 and W/H^3 have the highest correlation. Inspection of the derived confidence intervals in Table 4 suggests that there is a relatively small degree of sampling error in the correlations and partial correlations.

The sample standard error of estimate values for predicting skinfold fat per cent and hydrostatic fat per cent raw scores from individual BMIs were calculated. In predicting skinfold fat per cent measures, the standard error of estimate was 5.36 for W/H, 5.26 for W/H^2, 5.53 for W/H^3, and 5.26 for W/H^P. Similar standard error of estimate values were computed in the prediction of hydrostatic fat per cent from the BMIs. The Quetelet and Benn indices both had standard error of estimate values of 5.14, while corresponding values for W/H and W/H^3 were 5.21 and 5.28, respectively. These values indicate that there exists considerable error associated with the prediction of body fat using the different BMIs.

Discussion

A good BMI is one that correlates minimally with height and maximally with weight.[5,19] In general, the correlations between the body mass indices and weight and height from this study support findings of previous research.[3,6,7,19] Contrary to the results reported by Lee, *et al*,[8] W/H^P was no more consistently unbiased than W/H^2 with and without age-adjustment. Clearly this finding is due to the close similarity between the exponent values in the two BMIs (e.g., 1.9 versus 2.0). The results suggest that estimates of body fat using the Benn index and the Quetelet index are equivalent insofar as their relationship to skinfold thickness and hydrostatic measurements are concerned.

Only a moderate proportion of variance is shared by the BMIs and the more direct measures of body adiposity. The proportion of variance shared with the skinfold thickness measurements average 0.56 with a range from 0.53 to 0.58. The proportion of shared variance with hydrostatic techniques average 0.49 (range 0.48–0.50). These findings suggest that there is considerable measurement error in using the BMIs as surrogate estimates of body adiposity. The magnitude of the standard error of estimate values associated with the prediction of hydrostatic derived measures of body adiposity using the BMIs reflects this moderate relationship.

The usual definition of obesity is the amount of fat in an individual's body that exceeds some arbitrary percentage.[1] Obesity has proved a difficult attribute to quantify. The use of BMIs is likely to result in an unknown proportion of individuals being identified as obese when in actuality they possess large lean body mass in proportion to height and subsequently a low percentage of body fat.

In a recent study of the relation between obesity and lung cancer, Lee and Kolonel found that the derived odds ratios for lung cancer differed in magnitude and direction depending on the BMI used. They concluded that the body mass indices are not interchangeable in assessing obesity in case-control studies.[11] This finding may be explained, in part, by the varying specificities associated with BMIs. Research by Lee and Kolonel suggest that the different BMIs are not interchangeable indicators of obesity.[10,11]

Skinfold thickness determination of the percentage body fat may provide a more acceptable estimate of obesity for health surveys. The correlation between percentage fat assessed by hydrostatic weighing and seven site skinfolds was 0.84. The average time involved in obtaining accurate skinfold thickness measurements for this study was five minutes. Nevertheless, skinfold thickness is not a totally reliable measure of obesity because of the considerable variation in adipose tissue deposits in different body sites.[20] There is also some question whether skinfold thickness is more closely related to laboratory estimates of fat body mass than combinations of height and weight.[21] Their utility in large epidemiologic studies remains to be demonstrated.

Ideally obesity should be determined by direct measures of the proportion of adipose tissue, such as somatyping, hydrostatic, or total body potassium measurements.[1,22] In this study, body fat determinations were obtained for over 94 per cent of the participants. Hydrostatic laboratory measurements represent accurate and precise methods for estimating body adiposity, but may be difficult and expensive to utilize in large studies of community populations.

Health researchers should exercise caution in the utilization of BMIs as indirect estimates of body fat. In this study, the BMIs were only moderately correlated with direct hydrostatic determination of body fat. Substantial error was present in the prediction of hydrostatic measures from the BMIs. Whenever feasible it is recommended that direct assessment of body adiposity be used in studies of the relationship between obesity and risk of disease. Although skinfold thickness measurements are an acceptable compromise, they may not represent a completely dependable substitute for direct laboratory methods.

ACKNOWLEDGMENTS

An earlier version of this paper was presented at the Society for Epidemiologic Research Annual Meeting, during June 1985, in Chapel Hill, North Carolina.

REFERENCES

1. Van Itallie TB: Obesity: adverse effects on health and longevity. Am J Clin Nutr 1979; 32:2723–2733.
2. National Institutes of Health: Health implications of obesity. Consensus Development Conference Statement, Vol. 5, No. 9. Bethesda, MD: National Institutes of Health, Office of Medical Applications of Research, 1985.
3. Khosla T, Lowe CR: Indices of obesity derived from body weight and height. Br J Prev Soc Med 1967; 21:122–128.
4. Benn RT: Some mathematical properties of weight-for-height indices used as measures of adiposity. Br J Prev Soc Med 1971; 25:42–50.
5. Billewicz WZ, Kemsley WFF, Thompson AM: Indices of adiposity. Br J Prev Soc Med 1962; 16:183–188.
6. Keys A, Fidanza F, Karvonen MJ, Kimura N, Taylor HL: Indices of relative weight and obesity. J Chronic Dis 1972; 72:329–343.
7. Killen J, Vanderburg D, Harlan WR: Application of weight-height ratios and body indices to juvenile populations. The National Health Examination Survey Data. J Chronic Dis 1978; 31:529–537.
8. Lee J, Kolonel LN, Hinds MW: Relative merits of the weight-corrected-for-height indices. Am J Clin Nutr 1981; 34:2521–2529.
9. Garn SM, Pesic SD: Comparison of the Benn index and other body mass indices in nutritional assessment. Am J Clin Nutr 1982; 36:573–575.
10. Lee J, Kolonel LN, Hinds MW: Relative merits of old and new indices of body mass: a commentary. Am J Clin Nutr 1982; 36:727–728.
11. Lee J, Kolonel LN: Are body mass indices interchangeable in measuring obesity-disease associations? Am J Public Health 1984; 74:376–377.
12. Selzer CC, Stoudt HW, Bell B, Mayer I: Reliability of relative body weight as a criterion of obesity. Am J Epidemiol 1970; 92:339–350.
13. Cronk CE, Roche AF: Race and age-specific reference data for triceps and subscapular skinfolds and weight/stature. Am J Clin Nutr 1982; 35:347–354.
14. Frisancho AR, Flegel PN: Relative merits of old and new indices of body mass with reference to skinfold thickness. Am J Clin Nutr 1982; 36:697–699.
15. Pollock ML, Schmidt DH, Jackson AS: Measurement of cardiorespiratory fitness and body composition in the clinical setting. Compre Ther 1980; 10:12–27.
16. Siri WE: Gross composition of the body. *In:* Lawrence JH, Tobias CS (eds): Biological and Medical Physics. New York: Academic Press, 1956.
17. Wilmore JH, Vodak PA, Parr RB, Girandola RN, Billing JE: Further simplification of a method for determination of residual lung volume. Med Sci Sports Exerc 1980; 12:216–218.
18. Hays WL: Statistics for the Social Sciences, 2nd Ed. New York: Holt, Rinehart, and Winston, 1973.
19. Florey C: The use and interpretation of ponderal index and other weight-height ratios in epidemiologic studies. J Chronic Dis 1970; 23:93–103.
20. McLaren DS, Ajans ZA, Awdeh Z: Composition of human adipose tissue, with special reference to site and age differences. Am J Clin Nutr 1965; 17:171–176.
21. Dugdale AE, Griffiths M: Estimating fat body mass from anthropometric data. Am J Clin Nutr 1979; 32:2400–2403.
22. Chien P, Peng MT, Chen KP, Huang TF, Chang C, Fang HS: Longitudinal studies on adipose tissue and its distribution in human subjects. J Appl Physiol 1975; 39:825–830.