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Concordance of the Recently Published Body Adiposity Index With Measured Body Fat Percent in European-American Adults

William Johnson[1], **William C. Chumlea**[2,3], **Stefan A. Czerwinski**[2], and **Ellen W. Demerath**[1]

[1]Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, Minneapolis, Minnesota, USA

[2]Lifespan Health Research Center, Department of Community Health, Boonshoft School of Medicine, Wright State University, Dayton, Ohio, USA

[3]Department of Pediatrics, Boonshoft School of Medicine, Wright State University, Dayton, Ohio, USA

Abstract

The body adiposity index (BAI; hip circumference (cm)/height (m)$^{1.5}$ − 18) has recently been shown to demonstrate a stronger correlation with percentage body fat (%fat) than that between the BMI and %fat in Mexican-American adults. Here, we compare the concordance between %fat from dual-energy X-ray absorptiometry (DXA) and BAI, and between %fat and BMI, in European-American adults ($n = 623$). Agreement between BAI, BMI, and %fat was assessed using Lin's concordance coefficients (ρ_c), where values <0.90 are considered poor. In the sample as a whole, the agreement between BAI and %fat ($\rho_c = 0.752$) was far better than that between BMI and %fat ($\rho_c = 0.445$) but was nonetheless relatively poor. There were large mean differences in %fat between the BAI and DXA %fat, particularly at lower levels of adiposity (<20%), and further the BAI overestimated %fat in males and underestimated %fat in females. Optimizing the BAI formula for our sample only marginally improved performance. Results of the present study show that BAI provides a better indicator of adiposity in European-American adults than does BMI, but does not provide valid estimates of %fat, particularly at lower levels of body fatness. Further research is warranted to investigate the predictive ability of BAI for various health outcomes.

The BMI is used ubiquitously to assess weight independently of height, allowing comparison of weight among individuals of different heights. The limitations of the BMI have been well documented (1,2), yet it remains the principal measure used to predict excess adiposity. Other anthropometric measures (e.g., waist circumference-to-height ratio) have been developed (3), but none has received the same acceptance as BMI in the clinical or research setting.

Correspondence: Ellen W. Demerath (ewd@umn.edu).

Disclosure

The authors declared no conflict of interest.

A new measure, the body adiposity index (BAI), has recently been proposed by Bergman *et al.* (4) to provide valid estimates of percentage body fat (%fat) in adults:

$$\mathrm{BAI}(\%\mathrm{fat})=\mathrm{Hip\ \ circumference(cm)/height(m)}^{1.5}-18 \quad (1)$$

This equation was developed in a sample of Mexican-American adults. Percentage body fat from dual-energy X-ray absorptiometry (DXA) was used as the criterion measure of body fatness. The reported correlation of BAI with %fat ($\rho = 0.790$) was higher than that of BMI ($\rho = 0.569$), although the authors did not test whether this difference in correlation coefficients was statistically significant. Also, the agreement between BAI and %fat from DXA was rather poor at lower levels of adiposity. Bergman *et al.* found similar results when cross-validating the BAI in a sample of African-Americans (4).

The utility of the BAI in other populations relies on the assumption that it not only correlates with but also accurately predicts %fat in those populations. The present study will test the concordance of the BAI with measured %fat in a sample of European-American adults to determine whether the BAI performs better than BMI as an indicator of adiposity. The BAI formula will also be optimized for this population to see if this improves performance.

METHODS AND PROCEDURES

The sample consisted of 623 (332 females) European-American individuals born between 1942 and 1990 in Southwestern Ohio, and who were enrolled in the Fels Longitudinal Study (5). The analysis sample was selected on the basis of having complete anthropometric data (weight, height, and abdominal and hip circumferences) and total body fat from DXA (Lunar DPX scanner; software version 3.4; Lunar, Madison, WI) at the same study visit (i.e., on the same day) between 20 and 50 years of age. The data presented here were collected between 1990 and 2011.

BMI (weight (kg)/height (m)^2), %fat, and BAI (equation 1) were calculated. To optimize the BAI for the Fels Longitudinal Study sample (denoted $\mathrm{BAI}_{\mathrm{Fels}}$), a number of exponent values between 1.0 and 2.0 were tested to determine which of them resulted in an index (e.g., hip circumference/height^n) that was best correlated with %fat. After deciding on the exponent, linear regression of %fat on the index was used to estimate the best intercept and slope. The resulting $\mathrm{BAI}_{\mathrm{Fels}}$ equation is given as:

$$\mathrm{BAI}_{\mathrm{Fels}}(\%\mathrm{fat})=1.26\times(\mathrm{hip\ \ circumference(cm)/height(m)}^{1.4})-32.85 \quad (2)$$

The agreement between BAI, $\mathrm{BAI}_{\mathrm{Fels}}$, BMI, and %fat was assessed using Lin's concordance correlation coefficient (ρ_c) (6). The ρ_c evaluates both the precision and accuracy of the relationship between two measurement methods, and is the product of the correlation coefficient (ρ) between paired measures and a bias correction factor (C_b) that measures how far the best-fit line between them deviates from the 45° line. If the concordance correlation coefficient equals one then there is perfect agreement between two variables; in this particular study this would mean that BAI provides a perfect estimate of %fat. Hotelling's *t*-

test for correlated correlations was used to test whether the correlation between BAI (or $\mathrm{BAI}_{\mathrm{Fels}}$) and %fat was significantly different from that between BMI and %fat. Paired sample *t*-tests were used to test differences in mean %fat between both BAI and $\mathrm{BAI}_{\mathrm{Fels}}$ and measured %fat in the sample as a whole, within each sex, and also within specific ranges of %fat. In addition, sex-specific general linear regressions of BAI, $\mathrm{BAI}_{\mathrm{Fels}}$, and also BMI on measured %fat were performed to determine the amount of variance in %fat explained by each anthropometric index.

Results

The study sample varied greatly in adiposity. Mean (s.d., range) for BMI was 25.7 $\mathrm{kg/m}^2$ (5.1, 15.9–46.9), and mean (s.d., range) for %fat was 28.3% (9.3, 6.5–53.2). Compared to the Mexican-American sample used to create the BAI (4), the mean BMI in the present study was ~4.0 $\mathrm{kg/m}^2$ lower and the mean age of 34.9 years was approximately the same.

In the sample as a whole, within each sex, and within most specific ranges of DXA %fat, mean %fat estimated by both BAI and $\mathrm{BAI}_{\mathrm{fels}}$ was significantly different from DXA measured %fat (P values <0.001) (Table 1). Both the BAI and $\mathrm{BAI}_{\mathrm{Fels}}$ overestimated %fat in males and underestimated %fat in females. At lower levels of adiposity (<20%), BAI and $\mathrm{BAI}_{\mathrm{Fels}}$ greatly overestimated %fat by as much as 20–50%, while at higher levels of adiposity (>40%) they underestimated %fat by ~5–10%. Optimizing the BAI for this population marginally improved its ability to predict %fat. At more typical and higher levels of adiposity (20–55%), the mean difference in %fat between $\mathrm{BAI}_{\mathrm{Fels}}$ and DXA was within ~8%, compared to ~15% for BAI. The $\mathrm{BAI}_{\mathrm{Fels}}$ performed better than BAI at higher levels of adiposity. For example, within the most adipose individuals (45–55 %fat), when the DXA measured %fat was compared to the estimated %fat using $\mathrm{BAI}_{\mathrm{Fels}}$ or BAI, the $\mathrm{BAI}_{\mathrm{Fels}}$ underestimated %fat by only 2.4% (i.e., 45.5 vs. 47.9%), while BAI underestimated %fat by 6.8% (i.e., 41.1 vs. 47.9%).

The concordance of BAI to %fat in European-American adults in the present study was 0.752. Using the cutoffs proposed by McBride (7) this figure indicates poor agreement. The $\mathrm{BAI}_{\mathrm{Fels}}$, expectedly, demonstrated a greater degree of concordance with %fat ($\rho_c = 0.815$) than did BAI ($\rho_c = 0.752$), although it was still less than the <0.90 cutoff used to define poor agreement. The BAI and $\mathrm{BAI}_{\mathrm{Fels}}$ performed similarly when predicting %fat when stratified by sex. Both the BAI and the $\mathrm{BAI}_{\mathrm{Fels}}$ showed markedly better concordance with %fat than did BMI ($\rho_c = 0.445$), although when the analysis was split by sex, the correlation between BAI (or $\mathrm{BAI}_{\mathrm{Fels}}$) and %fat was not significantly different from that between BMI and %fat. Also, when sex specific regressions were performed, the variance in %fat explained by BAI, or $\mathrm{BAI}_{\mathrm{Fels}}$, or BMI were 51.9, 53.4, and 53.0%, respectively, for men and 56.8, 57.6, and 55.5, respectively, for women.

Discussion

In this short communication, we test the ability of the BAI to predict %fat in a sample of European-American adults. Our primary finding was that, although the BAI is inaccurate at low levels of adiposity and demonstrates generally poor agreement with %fat, in the sample as a whole it had a better concordance and significantly stronger correlation with %fat than that between BMI and %fat.

By modifying the BAI to create a hip circumference-for-height index that best approximated %fat in adults in the present study, a more complex equation was developed, although agreement with %fat was only marginally improved. The formula of the BAI, therefore, appears to be relatively robust, and at least in this sample of European-American adults a more complex and therefore limited equation is unnecessary. The bias correction factor between the BAI and %fat in the present study ($C_b = 0.908$) was comparable to that between BAI and %fat in the Bergman *et al.* study ($C_b = 0.986$). The bias correction factor is not, however, by itself a complete measure of agreement between two variables, and, as with the present study, the agreement between BAI and %fat in the Bergman *et al.* study may have also been poor.

Findings from both this study and from that by Bergman *et al.* show that the BAI greatly overestimates %fat at lower levels of adiposity, provides better estimates between 20–35% body fat, and underestimates %fat at higher levels of adiposity. Indeed, the original paper also showed 95% limits of agreement of ~10% body fat, which denotes poor agreement. More complicated equations that use anthropometry to predict %fat in adults also exhibit significant error. For instance, BAI underestimated mean %fat by 6.8% within the most adipose adults in the present sample, and this is not largely different from the 4.6% difference found between the Jackson & Pollock (8) equation and DXA assessed %fat reported by Clasey *et al.* 9), or between anthropometry predicted %fat and objectively assessed %fat in other published studies (10,11).

Our conclusion here is that the BAI may have an advantage over BMI for ranking individuals in terms of adiposity, but it does not represent a surrogate measure of %fat in European-American adults. In the current sample, BAI had a significantly stronger correlation with DXA measured %fat than did the BMI, but the concordance with measured %fat was poor. The BAI also overestimated %fat in men but underestimated in women, and was particulary inaccurate at lower levels of adiposity.

Some would argue that %fat is not an ideal outcome as it includes the fat mass component in both the numerator and denominator and therefore overadjusts for weight (12). Perhaps development of a fat (kg)/height^n index that is uncorrelated with height would be a better outcome. That approach would have, however, not allowed a direct comparison to the Bergman *et al.* study. Rather than trying to improve the BAI, another option is to accept its limitations as a predictor of total body adiposity, but recognize and test its strengths over BMI as an indicator of excess adiposity and disease risk. The findings of this study suggest that this is where BAI may have the most utility, and further research is warranted to investigate the relationship of the BAI to depot specific fat and also the predictive ability of BAI for various health outcomes compared to that of other measures, including BMI.

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REFERENCES

1. Prentice AM, Jebb SA. Beyond body mass index. Obes Rev. 2001; 2:141–147. [PubMed: 12120099]
2. Rahman M, Berenson AB. Accuracy of current body mass index obesity classification for white, black, and Hispanic reproductive-age women. Obstet Gynecol. 2010; 115:982–988. [PubMed: 20410772]
3. McCarthy HD, Ashwell M. A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message–'keep your waist circumference to less than half your height'. Int J Obes (Lond). 2006; 30:988–992. [PubMed: 16432546]
4. Bergman RN, Stefanovski D, Buchanan TA, et al. A better index of body adiposity. Obesity (Silver Spring). 2011; 19:1083–1089. [PubMed: 21372804]
5. Roche, AF. Growth, Maturation and Body Composition: The Fels Longitudinal Study 1929-1991. Cambridge: Cambridge University Press; 1992.
6. Lin LI. A concordance correlation coefficient to evaluate reproducibility. Biometrics. 1989; 45:255–268. [PubMed: 2720055]
7. McBride GB. A proposal for strength-of-agreement criteria for Lin's Concordance Correlation Coefficient. 2005 NIWA Client Report: HAM2005-062. <http://www.niwa.co.nz>.
8. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr. 1978; 40:497–504. [PubMed: 718832]
9. Clasey JL, Kanaley JA, Wideman L, et al. Validity of methods of body composition assessment in young and older men and women. J Appl Physiol. 1999; 86:1728–1738. [PubMed: 10233141]
10. Ball SD, Altena TS, Swan PD. Comparison of anthropometry to DXA: a new prediction equation for men. Eur J Clin Nutr. 2004; 58:1525–1531. [PubMed: 15162135]
11. Bottaro MF, Heyward VH, Bezerra RFA, Vagner DR. Skinfold method vs dual-energy x-day absorptiometry to assess body composition in normal and obese women. J Exp Physiol. 2002; 5:11–18.
12. Cole TJ, Fewtrell MS, Prentice A. The fallacy of using percentage body fat as a measure of adiposity. Am J Clin Nutr. 2008; 87:1959. author reply 1959–1959; author reply 1960. [PubMed: 18541591]

Table 1

Concordance of the body adiposity index (BAI) and the BAI_{Fels} with measured total body fat (%fat) in European-American participants aged 20–50 years

			BAI[a]				BAI$_{\text{Fels}}$[b]				BMI
%Fat range	***n***	**Measured %fat from DXA (mean (s.e.))**	**Predicted %fat (mean (s.e.))**	***P* for difference from measured[c]**	**% Difference from measured**	**Pearson's correlation with measured**	**Predicted %fat (mean (s.e.))**	***P* for difference from measured**	**% Difference from measured**	**Pearson's correlation with measured**	**Pearson's correlation with measured**
0–10	8	9.1 (0.4)	19.5 (0.8)	<0.001	53.5	0.533	17.2 (1.1)	<0.001	47.1	0.548	0.614
10–15	46	12.8 (0.2)	20.7 (0.3)	<0.001	38.2	0.193	18.9 (0.4)	<0.001	32.3	0.213	0.398
15–20	69	17.8 (0.2)	23.1 (0.3)	<0.001	23	0.431[d]	22.0 (0.4)	<0.001	19.1	0.439[d]	0.170
20–25	117	22.8 (0.1)	24.8 (0.2)	<0.001	8.1	0.158	24.2 (0.3)	<0.001	5.8	0.17	0.150
25–30	116	27.4 (0.1)	26.9 (0.2)	0.052	−2	0.126	27.0 (0.3)	0.097	−1.5	0.13	0.019
30–35	114	32.3 (0.1)	29.1 (0.3)	<0.001	−9.8	0.125	29.8 (0.3)	<0.001	−7.7	0.119	0.020
35–40	78	37.5 (0.2)	32.8 (0.5)	<0.001	−12.5	0.473[d]	34.5 (0.6)	<0.001	−8	0.471[d]	0.287
40–45	53	42.5 (0.2)	36.3 (0.7)	<0.001	−14.7	0.267	39.1 (1.0)	<0.001	−8	0.266	0.217
45–55	22	47.9 (0.4)	41.1 (1.4)	<0.001	−14.2	−0.1	45.5 (1.8)	0.202	−5	−0.092	−0.015
						Concordance[e] with measured (ρ_c (s.e.) (ρ, C_b))				**Concordance with measured (ρ_c (s.e.) (ρ, C_b))**	**Concordance with measured (ρ_c (s.e.) (ρ, C_b))**
Males	291	22.2 (0.4)	24.3 (0.2)	<0.001	9.5	0.559 (0.028) (0.722, 0.775)	23.7 (0.3)	<0.001	6.8	0.668 (0.028) (0.732, 0.912)	0.561 (0.030) (0.729, 0.769)
Females	332	33.7 (0.4)	31.2 (0.3)	<0.001	−7.4	0.676 (0.026) (0.755, 0.896)	32.4 (0.4)	<0.001	−3.9	0.748 (0.024) (0.760, 0.984)	0.406 (0.026) (0.746, 0.544)
Total	623	28.3 (0.4)	28.0 (0.2)	<0.001	−1.1	0.752 (0.013) (0.828[d], 0.908)	28.3 (0.3)	<0.001	0	0.815 (0.013) (0.830[d], 0.983)	0.445 (0.025) (0.559, 0.796)

BAI, body adiposity index; DXA, dual energy X-ray absorptiometry.

[a] BAI was calculated according to the formula proposed by Bergman *et al.* (4).; BAI = hip circumference (cm)/height (m)$^{1.5}$ − 18.

[b] BAI_{Fels} was constructed as an index of hip circumference-for-height that best approximated %fat in European-American participants in the Fels Longitudinal Study; BAI_{Fels} = 1.26 × (hip circumference (cm)/height (m)$^{1.4}$ − 32.85).

[c] Differences were tested using paired samples *t*-tests.

[d] Indicates that the correlation between BAI (or BAI_{Fels}) and measured %fat was significantly different ($P < 0.05$) from that between BMI and measured %fat. Differences were tested using Hotelling's *t*-test for correlated correlations.

[e] Lin's concordance correlation coefficient (ρ_c (6)) evaluates the degree to which pairs of observations fall on the 45° line through the origin. It is the product of the Pearson's correlation coefficient (ρ) and a bias correction factor (C_b) that measures how far the best-fit line deviates from the 45° line through the origin.