Clinical Usefulness of a New Equation for Estimating Body Fat

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OBJECTIVE—To assess the predictive capacity of a recently described equation that we have termed CUN-BAE (Clínica Universidad de Navarra-Body Adiposity Estimator) based on BMI, sex, and age for estimating body fat percentage (BF%) and to study its clinical usefulness.

RESEARCH DESIGN AND METHODS—We conducted a comparison study of the developed equation with many other anthropometric indices regarding its correlation with actual BF% in a large cohort of 6,510 white subjects from both sexes (67% female) representing a wide range of ages (18–80 years) and adiposity. Additionally, a validation study in a separate cohort (n = 1,149) and a further analysis of the clinical usefulness of this prediction equation regarding its association with cardiometabolic risk factors (n = 634) was carried out.

RESULTS—The mean BF% in the cohort of 6,510 subjects determined by air displacement plethysmography was 39.9 ± 10.1%, and the mean BF% estimated by the CUN-BAE was 39.3 ± 8.9% (SE of the estimate, 4.66%). In this group, BF% calculated with the CUN-BAE showed the highest correlation with actual BF% (r = 0.89, $P < 0.000001$) compared with other anthropometric measures or BF% estimators. Similar agreement was found in the validation sample. Moreover, BF% estimated by the CUN-BAE exhibits, in general, better correlations with cardiometabolic risk factors than BMI as well as waist circumference in the subset of 634 subjects.

CONCLUSIONS—CUN-BAE is an easy-to-apply predictive equation that may be used as a first screening tool in clinical practice. Furthermore, our equation may be a good tool for identifying patients at cardiovascular and type 2 diabetes risk.

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The prevalence of obesity has increased dramatically worldwide (1). Obesity is defined as a state of increased adipose tissue of enough magnitude to produce adverse health consequences being associated with increased morbidity and mortality (2). In this sense, excess adiposity increases the risk, among other diseases, of type 2 diabetes, cardiovascular disease, fatty liver, sleep-breathing disorders, and certain forms of cancer (1), reducing life expectancy (2,3).

Although excess adiposity but not excess body weight is the real culprit of obesity-associated complications, the studies examining the effect of obesity-associated health risks in which adiposity is actually measured are less frequent than desired (4). Body fat percentage (BF%) can be measured by different techniques, encompassing skin-fold measurements to magnetic resonance imaging (5). Other frequently used methods for determining BF% include bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DEXA). More accurate and reproducible methods include underwater weighing and air displacement plethysmography (ADP) (5–7).

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When BF% determination is not available, BMI is the most frequently used surrogate measure of adiposity. However, BMI, although easy to calculate, exhibits notable inaccuracies not precisely reflecting body fat, changes in body composition that take place in the different periods of life or the sexual dimorphism characteristics of body adiposity (8–11). Several prediction equations that account for sex and/or age in converting weight and height to body fat have been published and are reasonably effective in overcoming the aforementioned problem, but they have been derived from small samples or from imprecise methods of measurement of body composition (10,12–14).

Because it is crucial to have available an accurate estimator of BF%, not only to better analyze the effect of adiposity on obesity-associated cardiometabolic risk but also to perform studies involving body composition in which body fat may not be actually measured, the aim of the current study was to assess the predictive capacity of a recently described equation by our group for estimating body adiposity and to study its clinical usefulness. Therefore, we conducted a comparison study of this equation with many other anthropometric indices in a large cohort of adults from both sexes representing a wide range of ages and adiposity, accompanied by a validation study in a separate large cohort and a further analysis of the clinical usefulness of this prediction equation.

RESEARCH DESIGN AND METHODS

Study design

We studied a sample of 6,510 white subjects (2,154 men, 4,356 women), aged 18–80 years, including patients visiting our department. The study was performed to evaluate the usefulness of a new equation: BF% = –44.988 + (0.503 × age) + (10.689 × sex) + (3.172 × BMI) – (0.026 × BMI^2) + (0.181 × BMI × sex) – (0.02 × BMI × age) – (0.005 × BMI^2 × sex) + (0.00021 × BMI^2 × age) where male = 0 and female = 1 for sex, and age in years, developed by multiple regression to predict BF% with a SE of the estimate (SEE) of 4.74% (15). Our equation, which may be

used as an accurate body adiposity estimator (BAE), was compared with common extensively used anthropometric measurements, including BMI, waist circumference, waist-to-hip ratio, and waist-to-height, as well as with other measurements less frequently used to estimate adiposity such as waist-to-height^2, waist-to-height^3, and weight-to-height ratios, the Rohrer index, and the recently described body adiposity index (BAI) (16). To further validate the predictability of the equation, we assessed it in a separate cohort of 1,149 white subjects (366 men, 783 women), aged 18–76 years, enrolled in another study for analyzing the adiposity-associated type 2 diabetes risk (17). Furthermore, we studied the association of BF% with cardiometabolic risk factors of 634 patients, comparing it with BMI and waist circumference. Patients with anorexia nervosa or bulimia nervosa were excluded. The experimental design was approved, from an ethics and scientific standpoint, by the hospital ethics committee. Informed consent was obtained.

Anthropometric measurements

The anthropometric and body composition determinations as well as the blood extraction were performed on a single day, as previously described (15,17). BMI was calculated as weight in kilograms divided by the square of height in meters. The Rohrer index was calculated as weight in kilograms divided by height in meters cubed. Blood pressure was measured as previously described (15,17).

Body composition

Body density was estimated by ADP (BodPod, Life Measurements, Concord, CA). Data for calculation of BF% by this plethysmographic method has been reported to agree closely with the traditional gold standard of hydrodensitometry underwater weighing (6). ADP uses the pressure-volume relationship to estimate volume and density and has been shown to predict fat mass and fat-free mass more accurately than DEXA and BIA (6,7). BF% was estimated from body density using the Siri equation.

Laboratory procedures

Blood samples were collected after an overnight fast. Plasma biochemistry was analyzed as previously described (17–19). Indirect measures of insulin resistance and insulin sensitivity were calculated by using homeostasis model assessment (HOMA) and quantitative insulin sensitivity check index (QUICKI), respectively.

Statistical analysis

Data are mean ± SD. A Bland-Altman plot was used to graphically assess the agreement between BF% determined by ADP and BF% calculated by the CUN-BAE (20). HOMA values were logarithmically transformed because of their non-normal distribution. Correlations between two variables were computed by Pearson correlation coefficient. Differences between correlations were assessed by the two-tailed Steiger Z test for comparing two dependent correlations within a population. The accuracy of the predictions was assessed by the SEE. A helpful Excel (Microsoft Corp, Redmond, WA) spreadsheet for the use of the equation can be found in the Supplementary Data. The calculations were performed using SPSS 15.0.1 software (SPSS, Chicago, IL). A P value < 0.05 was considered statistically significant.

RESULTS—Demographic characteristics of the subjects included in the comparison and validation studies are presented in Supplementary Table 1. Both cohorts consisted mainly of women

Table 1—*Correlation matrix of BF% with different BAEs and anthropometric variables*

Variable	All (n = 6,510)			Men (n = 2,154)			Women (n = 4,356)		
	BF	BMI	CUN-BAE	BF	BMI	CUN-BAE	BF	BMI	CUN-BAE
BMI	0.70	—	—	0.77	—	—	0.84	—	—
	<0.001	—	—	<0.001	—	—	<0.001	—	—
CUN-BAE	0.89	0.80	—	0.81	0.97	—	0.89	0.94	—
	<0.001	<0.001	—	<0.001	<0.001	—	<0.001	<0.001	—
BAI	0.64	0.61	0.68	0.35	0.41	0.40	0.81	0.90	0.86
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Waist-to-height	0.70	0.91	0.75	0.82	0.92	0.94	0.84	0.91	0.91
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Waist-to-height^2	0.76	0.85	0.81	0.77	0.85	0.88	0.81	0.87	0.87
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Waist-to-height^3	0.75	0.73	0.80	0.69	0.74	0.78	0.75	0.80	0.81
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Weight-to-height	0.60	0.97	0.68	0.74	0.98	0.94	0.82	0.99	0.92
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rohrer index	0.76	0.96	0.86	0.76	0.98	0.95	0.83	0.98	0.93
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Weight	0.47	0.89	0.54	0.68	0.92	0.87	0.77	0.94	0.88
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Waist	0.57	0.89	0.61	0.81	0.92	0.93	0.82	0.91	0.90
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hip	0.51	0.65	0.54	0.34	0.41	0.39	0.80	0.91	0.85
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Waist-to-hip ratio	0.15	0.44	0.16	0.49	0.46	0.54	0.47	0.46	0.53
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Data are Pearson correlation coefficients (upper) and associated P values (lower).

(67–68%). Individuals from the validation cohort were younger (42.6 ± 13.1 vs. 45.1 ± 13.1 years; $P < 0.001$) and exhibited higher weight (95.2 ± 26.1 vs. 86.1 ± 22.2 kg; $P < 0.001$), BMI (34.9 ± 8.7 vs. 31.5 ± 7.2 kg/m^2; $P < 0.001$), and BF% (42.8 ± 10.5 vs. 39.9 ± 10.1; $P < 0.001$) than subjects from the comparison cohort. The proportion of lean overweight and obese subjects in both cohorts was similar, except for the proportion of overweight individuals, which was slightly higher in the validation cohort ($P = 0.003$). Therefore, both cohorts include a wide range of age, BMI, and BF%, representing a broad spectrum of the population.

The mean BF% in the whole sample of the comparison cohort determined by ADP was 39.9 ± 10.1% (men 34.4 ± 8.7%; women 42.7 ± 9.6%), whereas the mean BF% estimated by the CUN-BAE was 39.3 ± 8.9% (men 33.8 ± 7.1%; women 42.0 ± 8.5%). Both variables showed a high correlation (whole sample $r = 0.89$, SEE = 4.66%; men $r = 0.81$, SEE = 5.20%; women $r = 0.89$, SEE = 4.36%; $P < 0.0001$ for all; Table 1). The Bland-Altman method for comparison of agreement between BF% measured by ADP and calculated by the CUN-BAE prediction equation showed a mean bias of −0.64 ± 9.22% (2 SD, −9.86 ± 8.58%; Fig. 1). A total of 6,215 subjects (95.5%) fell within the 95% CI. Linear regression analysis showed a significant dependence ($P < 0.001$) between the difference of CUN-BAE and ADP and the mean of both methods being attributable to the high sample size, which is not considered clinically relevant ($R^2 = 0.07$).

We next examined which anthropometric measurements best correlated with BF% measured by ADP. In the whole group of 6,510 subjects, BF% calculated with the CUN-BAE showed the highest correlation with actual BF% ($r = 0.89$), followed by waist-to-height^2 ratio and the Rohrer index ($r = 0.76$ for both) (Table 1). In the sample of 2,154 men, waist-to-height ratio showed the highest correlation ($r = 0.82$), followed by CUN-BAE and waist circumference ($r = 0.81$ for both). When only women were included in the analysis ($n = 4,356$), the CUN-BAE was the best estimator ($r = 0.89$), followed by BMI and waist-to-height ratio ($r = 0.84$ for both). The correlation of CUN-BAE with BF% was significantly higher than that of BMI with BF% for the whole sample and stratified by sex ($P < 0.0001$ for the three comparisons by Steiger Z tests).

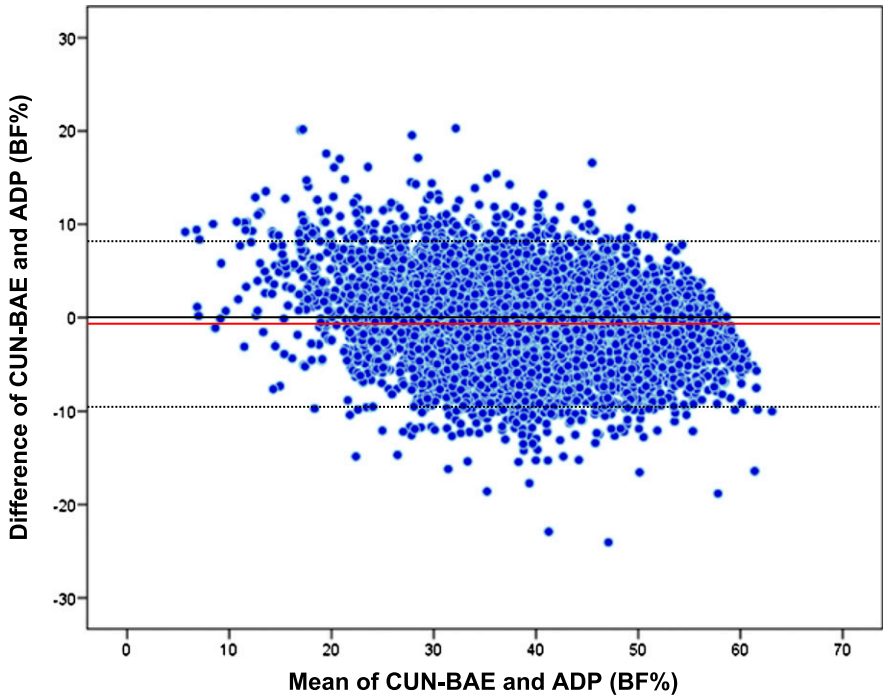

Figure 1—*Bland-Altman plot shows the limits of agreement between BF% estimated using CUN-BAE and BF% measured by ADP in the comparison sample of 6,510 subjects. The middle red line represents the mean difference between the estimated and the measured BF%. The dotted lines indicate ± 2 SDs from the mean.*

The new equation was validated in a separate cohort of 1,149 individuals. As can be observed in Fig. 2, BF% estimated by CUN-BAE showed a higher correlation with BF% measured by ADP for men ($r = 0.85$, $P < 0.0001$, SEE = 5.53%) or women ($r = 0.90$, $P < 0.0001$, SEE = 4.13%) than BMI (men $r = 0.83$, $P < 0.0001$; women $r = 0.84$, $P < 0.0001$). The correlation was also very strong when the whole sample was analyzed globally ($r = 0.90$, $P < 0.0001$, SEE = 4.62%) The correlations of CUN-BAE with BF% were again significantly higher than that of BMI with BF% ($P < 0.0001$ for the whole sample and women, $P = 0.0003$ for men). A further advantage of estimating BF% by CUN-BAE is that the well-known sex differences in BMI are dispelled because sex is included in the equation, as evidenced in Fig. 2*B*.

To evaluate the degree of association of BF% estimated with the CUN-BAE with different cardiometabolic risk factors and to compare it with BMI and waist circumference, a bivariate correlation analysis was done. This study was performed in a subgroup of 634 individuals where blood pressure, glucose level, lipid profile, and several inflammatory/prothrombotic markers were available for all of the subjects. In men, body adiposity estimated with the CUN-BAE was better correlated with systolic blood pressure ($P = 0.017$), logHOMA ($P = 0.004$), QUICKI ($P = 0.0004$), and total cholesterol ($P = 0.0005$) than BMI. Moreover, CUN-BAE was better correlated with QUICKI ($P = 0.029$) and marginally with logHOMA ($P = 0.056$) than waist circumference (Table 2). In women, BF% calculated with the CUN-BAE was better correlated with systolic blood pressure ($P = 0.002$), triglycerides ($P = 0.012$), and total ($P < 0.0001$) and LDL cholesterol ($P < 0.0001$), exhibiting weaker correlation with insulin levels ($P = 0.0001$) than BMI. Furthermore, CUN-BAE was better correlated with logHOMA ($P = 0.018$), QUICKI ($P = 0.003$), total ($P = 0.009$) and LDL cholesterol ($P = 0.023$), and C-reactive protein ($P = 0.001$) than waist circumference (Table 2). Of the 634 subjects of this sample, 224 exhibited a fasting plasma glucose level ≥100 mg/dL. Of the 224, 34 individuals had a BMI <30 kg/m^2, with 32 showing a BF% estimated with the CUN-BAE well within the obesity range (>25% for men and >35% for women). Therefore, 5% of the subjects from the sample would benefit from having a blood test after being diagnosed

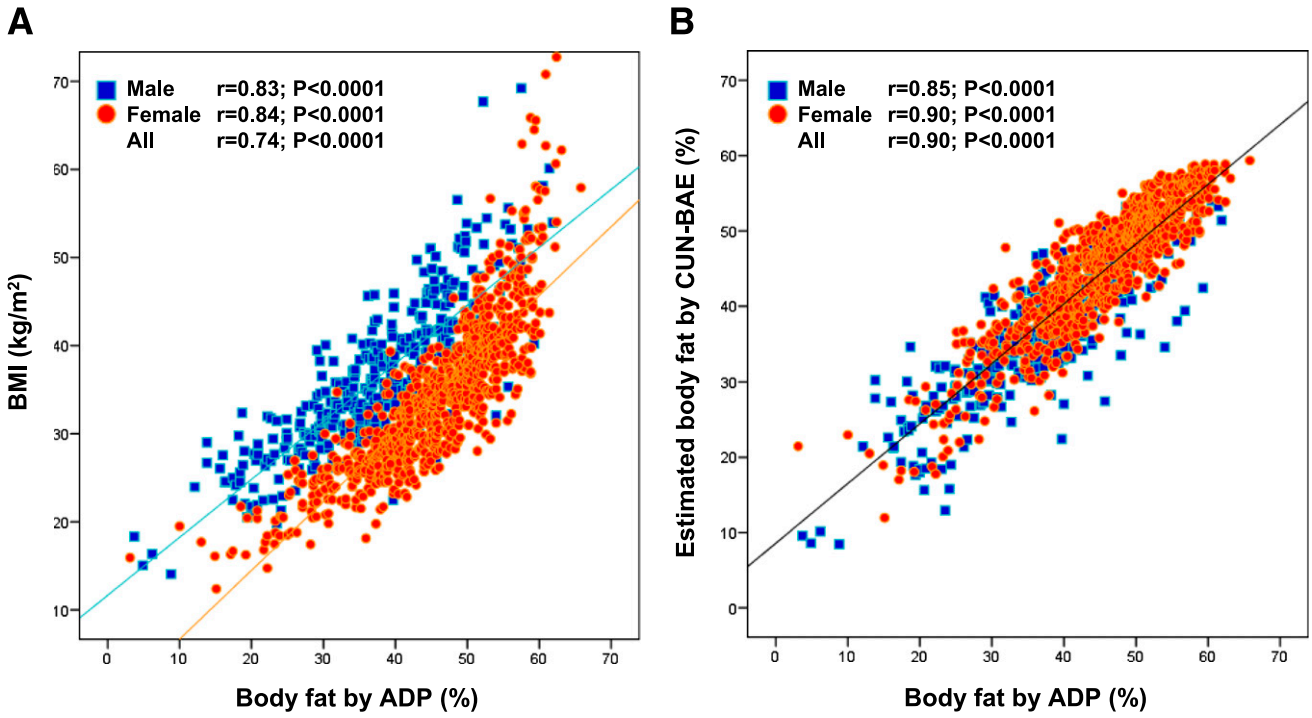

Figure 2—*Correlation stratified by sex between BF% measured by ADP and BMI* (A) *and BF% estimated using CUN-BAE* (B) *in the validation sample of 1,149 subjects (366 men and 783 women). Pearson correlation coefficients and associated* P *values are shown for the whole sample and stratified by sex. Tendency lines are shown for men and women in panel* A *and for the whole sample in panel* B.

as obese according to the CUN-BAE to discard an impaired glucose tolerance.

CONCLUSIONS—The main objective of the current study was to analyze the accuracy and utility of a new equation based on BF% measured by ADP and developed for the prediction of BF% using BMI, age, and sex (15). We herein show that CUN-BAE may estimate BF% with a good accuracy, providing a useful tool in epidemiologic and clinical studies without access to specialized body composition measurements to analyze adiposity-related cardiometabolic risks.

BMI is frequently used as an indicator of BF%. However, although it is useful in epidemiologic studies, it is highly imprecise at estimating body fat at an individual level (9,15). We herein have validated a recently described prediction equation that can estimate BF% in adults with low error rate and acceptable accuracy. The BF% calculated with the CUN-BAE correlated better with the actual BF% measured by ADP than any other anthropometric variable or BF% estimator in a sample of 6,510 individuals from both sexes with a wide range of BMI, BF%, and age.

Several prediction equations have been developed to predict body adiposity. In general, these prediction models are derived from small samples and are frequently based on not very precise body composition techniques, such as skinfolds or BIA, or are focused on specific age ranges (10,12–14). To our knowledge, only four studies have provided prediction equations developed in samples >1,000 adults from a wide spectrum of age ranges and from data obtained with body composition techniques such as underwater weighing, DEXA, or four-compartment model (16,21–23). Our equation was developed from data obtained from 6,123 subjects aged 18–80 years and encompassing BMIs between 12.4 and 72.8 kg/m^2 and BF% between 2.1 and 69.6%. In this sense, previous equations have some limitations, including having been derived from individuals with a maximum BMI of 40.9 kg/m^2 (24) and 35.0 kg/m^2 (22) or were obtained from adults aged 30–61 years and with body weights <110 kg (23), which may not be representative to apply to the whole population, affecting its accuracy.

Very recently, another index for body adiposity, named BAI, was developed based on hip circumference data of 1,733 Mexican American adults. In our hands, this index exhibited a lower correlation with BF% measured by ADP and a marked sexual dimorphism, being better correlated in women than in men, with a similar tendency than that observed for hip circumference. Although hip circumference does not seem to be a good estimator of BF% and is known to be associated with lower cardiometabolic risk, this novel index may be useful in Mexican American or African American populations (16).

One important aspect of our study is that our equation takes into account the effect of age. The relation between BMI and BF% has been shown to be dependent on age (9). Older adults, irrespective of sex, have on average more body adiposity than younger adults at any given BMI (8). Therefore, prediction equations developed to estimate BF% only from BMI, even if they are derived from a sample including subjects from all ages, will generally tend to underestimate the amount of body fat in the elderly and to overestimate it in the young (9,11). Including age in the prediction equation and the interactions of age with the linear and quadratic BMI components consistently reduces the error due to age in the BF% estimations.

Another advantage of CUN-BAE relies on better correlations with cardiometabolic risk factors than BMI and even

Table 2—*Correlation of BMI, waist circumference, and estimated BF with different cardiometabolic variables*

	Men (n = 225)			Women (n = 409)		
Variable	BMI	CUN-BAE	Waist	BMI	CUN-BAE	Waist
Blood pressure						
Systolic	0.35	0.38	0.35	0.51	0.54	0.52
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Diastolic	0.43	0.45	0.42	0.55	0.57	0.55
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Glucose	0.21	0.23	0.23	0.35	0.35	0.37
	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Insulin	0.45	0.45	0.43	0.60	0.55	0.54
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
logHOMA	0.52	0.56	0.52	0.66	0.64	0.61
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
QUICKI	−0.52	−0.56	−0.51	−0.64	−0.64	−0.59
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Triglycerides	0.10	0.12	0.11	0.34	0.37	0.37
	0.132	0.064	0.111	<0.001	<0.001	<0.001
Cholesterol						
Total	0.10	0.15	0.12	0.35	0.42	0.37
	0.134	0.029	0.063	<0.001	<0.001	<0.001
LDL	0.07	0.12	0.10	0.43	0.48	0.44
	0.276	0.076	0.129	<0.001	<0.001	<0.001
HDL	−0.06	−0.08	−0.07	−0.29	−0.27	−0.30
	0.361	0.238	0.303	<0.001	<0.001	<0.001
Fibrinogen	0.16	0.18	0.21	0.21	0.19	0.23
	0.018	0.009	0.002	<0.001	<0.001	<0.001
Homocysteine	−0.08	−0.07	−0.01	0.17	0.18	0.17
	0.242	0.278	0.829	<0.001	<0.001	<0.001
LogCRP	0.40	0.42	0.41	0.67	0.67	0.62
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
vWF	0.10	0.13	0.11	0.18	0.16	0.19
	0.132	0.053	0.115	<0.001	<0.001	<0.001

Data are Pearson correlation coefficients (upper) and associated P values (lower). HOMA values were logarithmically transformed because of their non-normal distribution. CRP, C-reactive protein; vWF, von Willebrand factor.

than waist circumference for both men and women in a subset of 634 subjects. To our knowledge, this is the first study validating a prediction equation for BF%, going a step further and studying its clinical usefulness analyzing how predicted BF% might help to explain the changes observed in these risk factors in relation to body composition. This aspect is extremely relevant because BF% has been shown to better correlate with cardiometabolic risk factor than BMI (15). Furthermore, because actual adiposity is a major risk factor for the development of prediabetes and type 2 diabetes (17), our equation may also represent a helpful tool to detect patients at risk for these conditions.

Our study has several strengths: First, our prediction equation has been developed from a large sample of 6,123 subjects from both sexes with a wide range of body adiposity, from constitutional thinness to extreme obesity, and from all adult ages (18–80 years), and has been validated in two large cohorts representing all ages and ponderal groups. Second, actual BF% data have been measured by a highly precise technique such as the ADP. This technique has been shown to predict fat mass more accurately than DEXA and BIA using hydrodensitometry as the reference method (5–7,25). Third, as mentioned before, BF% estimated with our equation may be useful when studying cardiometabolic risk factors.

However, our study has also one potential limitation that pertains to the generalizability to other populations. The present work was conducted in white subjects and needs to be extended to other populations to determine its applicability.

In summary, because the possibility of measuring BF% is not always available and the relation between BMI and BF% is highly dependent on sex and age, we have developed and validated an easy-to-apply predictive equation that may be used as a first screening tool in medical practice. Furthermore, our equation may be a useful clinical tool for identifying patients with increased cardiovascular and type 2 diabetes risk.

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J.G.-A. designed the study, enrolled patients, collected and analyzed data, wrote the first draft of the manuscript, contributed to discussion, and reviewed the manuscript. C.S. enrolled patients, collected data, contributed to discussion, and reviewed the manuscript. V.C. and A.R. enrolled patients, collected and analyzed data, contributed to discussion, and reviewed the manuscript. J.C.G., J.E., V.V., F.R., S.R., B.R., and J.S. enrolled patients, collected data, contributed to discussion, and reviewed the manuscript. G.F. designed the study, enrolled patients, collected and analyzed data, wrote the first draft of the manuscript, contributed to discussion, and reviewed the manuscript. J.G.-A. and G.F. are guarantors for the contents of the article.

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