Original Research Communications—methods

A new predictive equation for resting energy expenditure in healthy individuals[1-3]

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ABSTRACT A predictive equation for resting energy expenditure (REE) was derived from data from 498 healthy subjects, including females (n = 247) and males (n = 251), aged 19–78 y (45 ± 14 y, $\bar{x} \pm$ SD). Normal-weight (n = 264) and obese (n = 234) individuals were studied and REE was measured by indirect calorimetry. Multiple-regression analyses were employed to derive relationships between REE and weight, height, and age for both men and women ($R^2 = 0.71$): REE = 9.99 × weight + 6.25 × height − 4.92 × age + 166 × sex (males, 1; females, 0) − 161. Simplification of this formula and separation by sex did not affect its predictive value: REE (males) = 10 × weight (kg) + 6.25 × height (cm) − 5 × age (y) + 5; REE (females) = 10 × weight (kg) + 6.25 × height (cm) − 5 × age (y) − 161. The inclusion of relative body weight and body-weight distribution did not significantly improve the predictive value of these equations. The Harris-Benedict Equations derived in 1919 overestimated measured REE by 5% ($p < 0.01$). Fat-free mass (FFM) was the best single predictor of REE ($R^2 = 0.64$): REE = 19.7 × FFM + 413. Weight also was closely correlated with REE ($R^2 = 0.56$): REE = 15.1 × weight + 371. *Am J Clin Nutr* 1990;51:241–7.

KEY WORDS Resting energy expenditure, indirect calorimetry, 24-h energy requirement, obesity, healthy adults

Introduction

The accurate prediction of energy requirements for healthy individuals has many useful clinical applications. The most obvious use is in weight management of both normal-weight and obese individuals. The obese population, defined as > 120% of ideal body weight (IBW), as established by the 1959 Metropolitan Desirable Weight Tables (1), is estimated to constitute ~23% of the white, black, and hispanic adult population in the United States (2). Additionally, dieting is a common practice in individuals of all weight categories. It has been reported that 77% of all women (48% overweight, 20% normal weight, and 9% underweight) and 42% of all men (28% overweight, 10% normal weight, and 4% underweight) are dieting at any time (2). Unfortunately, many of these individuals are not aware of their energy requirements and may attempt to regulate their energy balance at an unknown level.

Recent emphasis on the health consequences of obesity has encouraged researchers to improve the definition and assessment of obesity and has further promoted the development of new weight-management strategies (3). Assessment now often includes reference to overall body composition [percent body fat (%BF)] and fat distribution patterns [waist-to-hip ratio (WHR)] (3). Additionally, obesity was identified as a risk factor for cardiovascular disease, with increasing mortality in obese individuals with a body mass index (BMI) > 25 kg/m^2 (4, 5). The risk of cardiovascular disease increases with weight gain and decreases with weight loss (5), and elevated risk is also associated with increased abdominal fat, or a WHR > 0.90 in women and > 1.0 in men (6). Today's health-conscious society provides both the challenge and opportunity to practice preventive medicine by helping these at-risk patients to achieve and maintain a healthy body weight. Important to this practice is an accurate method of assessing overall energy requirements in both normal-weight and obese individuals.

The assessment of 24-h energy expenditure (24-EE, in kcal/d) is a requirement for establishing caloric prescriptions for patients. The best predictor of 24-EE is the resting energy expenditure (REE), as determined by indirect calorimetric measurement, which accounts for 65–70% of total 24-EE. The thermic effect of food (TEF) and physical activity (PA) account for the remaining 10–15% and 20–30%, respectively, of 24-EE (7, 8). Because TEF and PA are highly variable from day to day and difficult to quantify, REE is most often used as an overall predictor of 24-EE. Usually, an individual's REE is multiplied by an activity factor to arrive at the 24-EE. For example, in moderately active, healthy adult individuals, a factor of 1.6 for women and 1.7 for men has been used (9).

The most widely used predictive equations for REE were developed on 136 men and 103 women by Harris and Benedict ~70 y ago (10). Through the 1950s these important equations were validated within ±5% by other researchers. More recently, however, investigators have questioned their continued appli-

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cability in our modern population, with its obvious differences in body size and composition, levels of PA, and diet and also in light of the availability of improved equipment and technology for measuring REE (11). In 1980 Cunningham (12) confirmed the hypothesis proposed originally by Benedict that metabolically active body mass, or lean body mass (LBM), is the best predictor of REE. On the basis of that finding, Cunningham proposed a simplified formula for predicting REE from LBM (12). Subsequent studies have addressed sex-specific differences, which can be predicted by LBM because women have a smaller proportion of LBM and greater fat mass when compared with men (13).

Studies reported by Daly et al in 1985 (11) also indicated that the Harris-Benedict Equations (HBE) overestimated measured basal energy expenditure by 10–15% in their population of 201 healthy men and women. More recently, Owen et al (14) reported studies confirming that the HBE overpredicted the REE in healthy women by 7–24% and men under the age of 50 y by 9.2% (15). These studies also demonstrated that body weight and fat-free mass (FFM) were highly correlated with REE. The present study, which included both normal-weight and obese men and women ranging in age from 19 to 78 y, demonstrated that the HBE overestimated measured REE by 5% whereas the Cunningham formula overestimated measured REE by 14–15%. The Owen formulas were most closely associated with our measured REE, predicting values within −4% in females and 0.1% in males. The potential for metabolic efficiency as a result of chronic dieting (16, 17) and the need for separate equations for obese people (18) remain of significant interest.

With improved technology and the availability of simplified and practical equipment, indirect calorimetry has been applied recently in outpatient settings to measure individual energy expenditure. However, because the equipment is expensive and trained personnel and time are required, it is not yet practical to obtain REE on every patient. It is also important to remember that the cost is often prohibitive ($75–$150) without reimbursement by third-party payment. Assessments of LBM and %BF are more commonly made on patients by various techniques. The use of skinfold calipers at selected sites is the most popular and practical method for general outpatient office settings. However, training personnel and obtaining reliable measurements (especially in obese subjects) still pose multiple problems which discourage the routine use of skinfold measurements.

The goals of this study were to *1)* mathematically derive a predictive equation for REE based on a sample of 498 healthy normal-weight and obese individuals, *2)* assess the usefulness of the more recent measures of body composition (%BF) and distribution (WHR) in predicting REE, and *3)* assess the predictive value as well as the overall practicality of the new equations compared with those currently being applied.

Subjects and methods

Data from subjects enrolled in a 5-y investigation of the relationships of energy nutrition and obesity to cardiovascular disease risk (RENO Diet-Heart Study) served as the basis of this study. Baseline data were completed on 508 subjects, and the 498 subjects on which REEs were successfully completed were included in this study. Informed consent to participate in this study was obtained from each subject at the beginning of the study, which was conducted in accord with ethical standards outlined and approved by the University of Nevada institutional review board.

Subjects

Subjects were recruited according to a 2 × 2 × 5 factorial design where sex (males vs females) and weight (normal weight vs obese) were stratified by five different age groups according to decade (20–29, 30–39, 40–49, 50–59, and 60+ y). The selection of subjects was biased toward the working class, defined as either the subject or spouse being employed ≥ half-time for the past year. An additional entry requirement was reportedly good health with < 1 sick day/mo for the past year and no major current illnesses or psychological problems.

Descriptions of the subjects and the variables selected for study are summarized in **Table 1.** The final sample included 247 females, ranging in age from 20 to 76 y (44.6 ± 14.0 y $\bar{x}$ ± SD), and 251 males, ranging in age from 19 to 78 y (44.4 ± 14.3 y). Of the women, 135 were classified as normal weight (80–< 119% IBW) and 112 were classified as obese (≥ 120% IBW) and of the men, 129 were classified as normal weight and 122 as obese. An attempt was made to exclude those who were extremely underweight (< 80% IBW) and those who were morbidly obese (> 180% IBW). However, in our final population one individual was < 80% IBW and two were > 180% IBW.

Indirect calorimetry

The major dependent variable for this study was REE (kcal/d) as obtained by indirect calorimetry by use of a metabolic measurement cart with a canopy hood (Metabolic Measurement Cart Horizons System, Sensor Medics, Anaheim, CA). Measurements were taken on all subjects by trained and certified nutritionists using a standardized protocol. Subjects were instructed to fast and abstain from exercise for 12 h before the test and to refrain from smoking ≥ 1 h before testing but for 12 h if possible. Subjects were placed under the canopy hood in a relaxed, supine position and a standardized relaxation tape was played. Measurements were repeated on all subjects until a 3-min steady state was achieved. The entire test took ~20 min per subject to complete. Standard computer programs (*MMC Horizon System,* Sensor Medics) converted O_2-CO_2 gas exchange into REE.

Height and weight

Body weight to the nearest 0.55 kg was determined before the REE measurement on a standard physician's beam scale with the subject in street clothes and without shoes. Height was measured to the nearest 0.63 cm on a standardized, wall-mounted height board according to established protocol (without shoes; heels together; subject's heels, buttocks, shoulders, and head touching the vertical wall surface; and with line of sight aligned horizontally). Percent of IBW was determined by use of the 1959 Metropolitan Height Weight Tables (1), and BMI was calculated with weight (kg) and height (m) measurements (kg/m^2).

Skinfold thicknesses and circumferences

Percent BF was assessed by using skinfold and circumference measurements taken at selected sites by trained technicians us-

TABLE 1
Characteristics of study population*

Percent ideal body weight	Weight	Height	Age	Percent ideal body weight	Body mass index	Waist-to-hips ratio	Percent body fat	REE
	kg	*cm*	*y*	*%*			*%*	*kcal*
Women								
<100% (n = 52)	54.9 ± 4.5	164.8 ± 5.2	38.5 ± 12.7	92.8 ± 4.4	20.3 ± 1.0	0.73 ± 0.05	30.0 ± 4.5	1245 ± 161
100–119% (n = 83)	63.7 ± 5.5	163.9 ± 5.8	48.8 ± 13.6	108.8 ± 5.9	23.8 ± 1.3	0.76 ± 0.06	28.7 ± 5.5	1253 ± 153
120–139% (n = 61)	76.2 ± 6.6	164.7 ± 6.4	45.1 ± 14.5	129.5 ± 6.4	28.4 ± 1.5	0.80 ± 0.07	36.1 ± 4.5	1390 ± 165
≥140% (n = 51)	89.4 ± 11.0	163.7 ± 7.7	43.3 ± 13.4	153.1 ± 11.3	33.5 ± 2.5	0.82 ± 0.07	41.5 ± 5.5	1561 ± 231
All women (n = 247)	70.2 ± 14.1	164.2 ± 6.3	44.6 ± 14.0	119.7 ± 22.4	26.2 ± 4.9	0.78 ± 0.07	31.7 ± 8.6	1349 ± 214
Range	46–120	146–186	20–76	78–193	17–42	0.63–0.98	12–51	927–2216
Men								
<100% (n = 26)	68.5 ± 5.8	178.9 ± 6.3	37.4 ± 14.1	94.8 ± 4.0	21.5 ± 0.9	0.86 ± 0.04	10.7 ± 5.3	1627 ± 251
100–119% (n = 103)	80.2 ± 7.5	178.5 ± 7.1	45.5 ± 14.4	110.9 ± 5.2	25.2 ± 1.1	0.90 ± 0.05	17.6 ± 4.9	1687 ± 277
120–139% (n = 82)	92.2 ± 7.3	178.0 ± 6.3	46.0 ± 13.6	128.5 ± 5.4	29.1 ± 1.2	0.93 ± 0.05	21.9 ± 5.1	1837 ± 240
≥140% (n = 40)	108.7 ± 13.1	178.3 ± 7.3	42.6 ± 14.3	151.9 ± 10.8	34.4 ± 2.4	0.96 ± 0.06	28.4 ± 6.0	1976 ± 345
All men (n = 251)	87.5 ± 14.4	178.3 ± 6.8	44.4 ± 14.3	121.5 ± 18.0	27.5 ± 4.1	0.92 ± 0.06	19.8 ± 6.9	1776 ± 297
Range	58–143	160–201	19–76	84–186	19–42	0.8–1.1	5–39	1030–2849
Total								
All women and men (n = 498)	78.9 ± 16.7	171.3 ± 9.6	44.5 ± 14.1	120.6 ± 20.3	26.9 ± 4.6	0.85 ± 0.10	25.8 ± 9.8	1564 ± 336
Range	46–143	146–201	19–78	78–193	17–42	0.63–1.1	4.7–51	927–2849

* $\bar{x}$ ± SD, except ranges. REE, resting energy expenditure.

ing Harpenden calipers and standardized techniques. The Jackson-Pollock method, which sums three skinfold thicknesses, the thigh, triceps, and suprailium for women (19) and the thigh, chest, and abdomen for men (20), was used. Although the Durnin-Womersley method, which uses the sum of four skinfold measurements (biceps, triceps, subscapular, and suprailium for both males and females), and bioelectrical impedance were also performed on our population, the Jackson-Pollock method and formulas were selected for use in our study because its use with large, heterogeneous populations was recommended (21). FFM was calculated by weight (kg) − fat (kg) where fat (kg) is weight (kg) × %BF.

The waist was measured at the obvious indentation or smallest circumference on the midtorso (at ~2.5 cm above the umbilicus). The hip measurement was then taken at the widest circumference on the torso (~15–18 cm below the umbilicus). Because these are often difficult measurements, the judgment of the investigator was often necessary to determine the proper measurement points. The WHR was then calculated.

Data analysis

Relationships between measured REE and weight, height, age, sex, FFM, %IBW, BMI, and WHR were assessed by use of the *SPSS-X* program (SPSS Inc, Chicago) to arrive at Pearson correlation coefficients and simple and stepwise multiple-regression analyses of the data. Predictive equations were developed and compared with commonly used equations. Data analysis was limited in certain circumstances because of missing values for %BF and WHR measurements. The stepwise multiple regressions, which included estimates of FFM, were limited to 482 of the 498 subjects. In the analysis sex was entered as a dummy variable with males assigned a value of 1.0 and females, a value of 0.

Results

The analysis of measured body composition variables and their respective influences on REE poses a complex problem. With Pearson correlation analysis (**Table 2**), %FFM was shown to correlate most highly with REE (r = 0.80) for the entire group of males and females. This finding supports the concept that the amount of active protoplasmic tissue (FFM) is highly related to REE, as shown in other studies (12–15). The relationship between REE and FFM in both sexes prompted the further assessment of men and women as a single group. Stepwise multiple-regression analysis including all variables yielded a predictive equation for REE in which FFM alone yielded an R^2 value of 0.64.

$$\text{REE} = 19.7 \times \text{FFM} + 413 \quad (R^2 = 0.64) \qquad (1)$$

The stepwise addition of weight, age, height, and WHR increased the R^2 value to 0.70; the remaining variables (sex, %IBW, and BMI) did not contribute further to the predictive value of the equation. Although FFM was most highly correlated with REE, weight and height also demonstrated high r values (0.73 and 0.69, respectively). Not surprisingly, weight and height were highly correlated with FFM (r = 0.79 and 0.81, respectively) and in this sample sex was also highly correlated (r = 0.83) with FFM.

Upon assessing the interrelationships of the variables and realizing that the measurement of either REE or FFM in the outpatient setting is generally impractical and difficult without trained personnel and equipment, we focused our attention on developing a simple and practical equation for predicting REE. The exclusion of FFM from the stepwise multiple-regression analysis resulted in a new predictive equation with weight alone contributing to an R^2 of 0.56.

$$\text{REE} = 15.1 \times \text{weight} + 371 \quad (R^2 = 0.56) \qquad (2)$$

TABLE 2
Pearson correlation coefficients for resting energy expenditure (REE) and other predictive variables*

Predictive variable	REE	Weight	Height	Age	Percent IBW	BMI	WHR	Sex
Women (n = 244)								
Weight	0.71083							
Height	0.40271	0.34905						
Age	−0.35181	−0.06073	−0.17486					
%IBW	0.57979	0.91331	−0.04760	0.01133				
BMI	0.57489	0.90743	−0.06276	0.01095	0.99910			
WHR	0.24627	0.45641	−0.03809	0.31701	0.50423	0.50575		
%FFM	0.59470	0.76208	0.49363	−0.17697	0.59925	0.59137	0.25454	
Men (n = 238)								
Weight	0.52870							
Height	0.43560	0.41604						
Age	−0.33944	−0.06565	−0.21575					
%IBW	0.33732	0.86245	−0.08051	0.05097				
BMI	0.33134	0.85640	−0.09243	0.05503	0.99984			
WHR	0.06555	0.38897	−0.09398	0.47639	0.47976	0.48101		
%FFM	0.66389	0.80618	0.57549	−0.36844	0.56547	0.55710	0.11261	
Total (n = 482)								
Weight	0.72607							
Height	0.68669	0.59922						
Age	−0.26104	−0.05172	−0.12933					
%IBW	0.35497	0.77152	−0.02699	0.02799				0.01964
BMI	0.41390	0.81459	0.03956	0.03014	0.99393			0.12260
WHR	0.54599	0.62579	0.51223	0.26669	0.34780	0.42240		0.73716
%FFM	0.80231	0.79480	0.81371	−0.15285	0.32494	0.40541	0.67949	0.83333

* IBW, ideal body weight; BMI, body mass index; and WHR, waist-to-hip ratio.

The addition of %IBW, age, and sex increased the correlation to $R^2 = 0.71$. However, we felt that looking up %IBW in a table required an additional step that physicians might not routinely do. Also, because %IBW is dependent on weight, height, and age we felt that a more accurate estimate of REE would result if these variables were measured directly. An equation that excluded %IBW was derived and its predictive value equalled that of equations containing FFM and %IBW. This new equation could be easier to use because only variables that are routinely measured in the physician's office are included.

Equation 3 predicts REE for both men and women in our population, with the included variables accounting for 71% of the observed variability in REE (ie, $R^2 = 0.71$).

$$\text{REE} = 9.99 \times \text{weight} + 6.25 \times \text{height} - 4.92 \times \text{age} + 166 \times \text{sex (males, 1; females, 0)} - 161 \quad (3)$$

Addition of quadratic and/or interactive-variable combinations did not improve the R^2 of this equation. In fact, the R^2 value of ~0.70 seemed to be a barrier above which we could not more accurately predict REE, regardless of the combination of the selected variables or the subset of the population analyzed. This would lead one to conclude that there is a variability of ≥ 30% in REE that cannot be explained on the basis of the variables assessed in this study. This may be due to individual differences in genetically determined or acquired metabolic efficiency, which merit further investigation.

The effects of sex and obesity on REE were extensively explored by analyzing men and women, and normal weight (< 120%IBW) and overweight (≥ 120%IBW) individuals separately. The relationship (simple regressions) and formulas between REE and FFM are shown in **Figure 1** and the relationship between REE and weight is shown in **Figure 2.** No significant differences were observed between the simple regression lines for FFM in men and women within the range of values studied.

$$\text{For males, REE} = 22.5 \times \text{FFM} + 209 \quad (R^2 = 0.44)$$

$$\text{For females, REE} = 20.8 \times \text{FFM} + 369 \quad (R^2 = 0.36)$$

Significant differences were observed between the slopes of the simple regression lines for REE and weight in each weight category although this may be partially explained by the selection of 120%IBW as an arbitrary reference point. The slope of the regression lines for all males vs all females was not significantly different for REE vs weight.

$$\text{For males, REE} = 12.3 \times \text{weight} + 704 \quad (R^2 = 0.36)$$

$$\text{For females, REE} = 10.9 \times \text{weight} + 586 \quad (R^2 = 0.50)$$

With these basic relationships in mind, we proceeded with stepwise multiple-regression analyses of subsets of the population based on sex and %IBW. This extensive process did not reveal any relationships or equations surpassing the predictive value of equation 3, which was derived from the entire population. For example, equations 4 and 5, below, derived for men and women separately do not improve the R^2 of 0.71 obtained in equation 1. For that matter, the R^2 of 0.68 obtained when the variable sex is omitted (Eq 6) is also a very good predictor of REE.

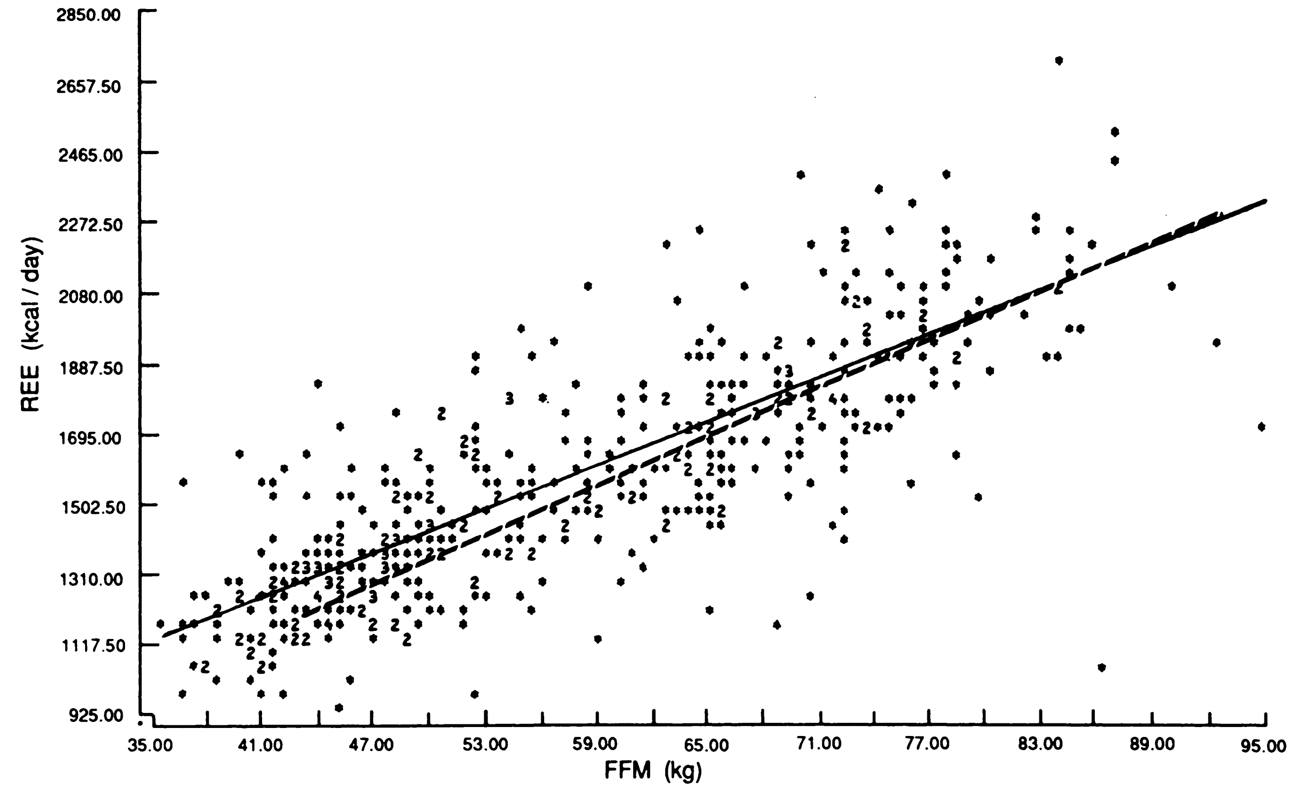

FIG 1. Correlation between REE and FFM for men (n = 238; dashed line) and women (n = 245; solid line). For men, REE = 22.5 × FFM + 209; for women, REE = 20.8 × FFM + 360.

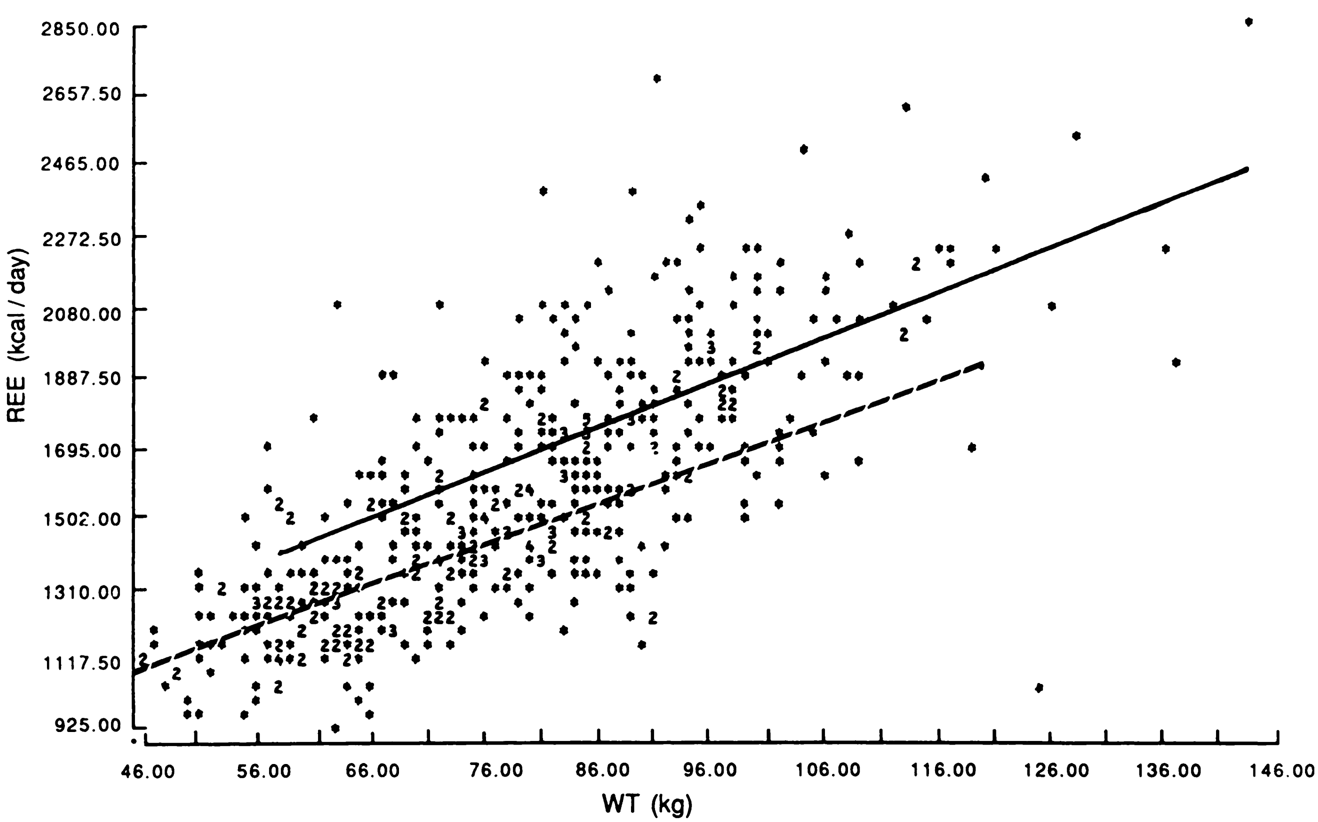

FIG 2. Correlation between REE and weight for men (n = 251; dashed line) and women (n = 247; solid line). For men, REE = 12.3 × weight + 704; for women, REE = 10.0 × weight + 586. Numerals in graph indicate number of values at that point.

TABLE 3
Comparisons of measured REE and REE estimated by different predictive equations, with and without lean body mass (LBM), in subjects of the RENO Diet-Heart Study*

	Measured	MSJE†	Owen (14, 15)	HBE (10)	Cunningham (12)
			kcal/d		
REE without LBM					
Males (n = 251)	1776 ± 297	1775 ± 192	1771 ± 147	1861 ± 249‡	—
Females (n = 247)	1349 ± 214	1348 ± 179	1299 ± 101‡	1417 ± 158‡	—
REE with LBM					
Males (n = 238)	1757 ± 280	—	—	—	2015 ± 182‡
Females (n = 245)	1347 ± 214	—	—	—	1534 ± 135‡

* $\bar{x} \pm$ SD.
† Mifflin–St Jeor Equations, this study.
‡ Significantly different from measured REE, $p < 0.01$.

For males separately, REE = 9.98 × weight

$$- 5.41 \times \text{age} + 7.94 \times \text{height} - 273 \quad (R^2 = 0.47) \quad (4)$$

For females separately, REE = 9.91 × weight

$$- 4.38 \times \text{age} + 4.26 \times \text{height} + 149 \quad (R^2 = 0.62) \quad (5)$$

For all without sex, REE = 10.52 × weight

$$- 12.18 \times \text{height} - 4.32 \times \text{age} - 1160 \quad (R^2 = 0.68) \quad (6)$$

In the interest of practicality, one equation may be better than two and, in light of the favorable strength-of-fit comparison above, equation 6 may be preferable to the separate equations for males and females. If the most accurate prediction of REE is required, separate equations for males and females should be used. The sex (males, 1; females, 0) and constant terms may be combined in equation 1 to simplify it further and yield different constants for males and females.

We propose the following Mifflin–St Jeor Equations (MSJEs) for females and males:

For females, REE = 9.99 × weight

$$+ 6.25 \times \text{height} - 4.92 \times \text{age} - 161$$

For males, REE = 9.99 × weight

$$+ 6.25 \times \text{height} - 4.92 \times \text{age} + 5$$

Further simplification with rounding off of numbers did not affect the overall predictability (r = 1.0) and the following formulas may encourage the use of the formulas.

For females, REE = 10 × weight (kg)

$$+ 6.25 \times \text{height (cm)} - 5 \times \text{age (y)} - 161 \quad (7)$$

For males, REE = 10 × weight (kg)

$$+ 6.25 \times \text{height (cm)} - 5 \times \text{age (y)} + 5 \quad (8)$$

Discussion

Table 3 outlines comparisons of REE as measured in our population (n = 498), with estimates from the MSJEs, the original HBE developed in 1919, (10) the newer equations developed more recently by Owen et al (14, 15), and the 1980 equations that use LBM, developed by Cunningham (12). As expected, our equations are the best predictors of REE in our subjects, with those most recently derived by Owen et al having the next least mean difference from measured REE (−4% in females and 0.1% in males). Although the Owen equations that use only weight are simpler than the simplified MSJE (7 and 8), which use weight, height, and age, they may be less accurate in predicting values for individuals at the extremes in age (20 and 60+ y) and differing body composition (LBM, percent fat) and weight (%IBW, BMI). Further studies are being conducted to assess these differences in our population by use of MSJEs that also just use weight (2) or FFM (1), respectively. Both the HBE (+5%) and Cunningham equations (14–15%) significantly overpredicted REE in our population (by paired t tests on individual means, $p < 0.01$), with the Cunningham equation based on LBM yielding the greatest differences from measured REE in both males and females.

The HBE has been reported (11–15) to overpredict measured REE by an average of ≥ 15% in modern populations. This observation may be explained by a comparison of the original Harris-Benedict (HB) sample with our own subject population. There are marked differences between means for weights and ages. The mean weights in the HB group (males, 64.1 ± 10.3 kg and females, 56.5 ± 11.5 kg) were much lower than they were in our study (males, 87.5 ± 14.4 kg and females, 70.2 ± 14.1 kg). Additionally, the mean ages for the HB group were significantly lower (27 ± 9 and 31 ± 14 y for males and females, respectively) than the average age of 44 ± 14 y for males and females in our study. This may also partially explain differences in the overall equations. Our population included men and women with weights ranging across a full spectrum from low to high and with ages ranging from the 20 to 60+ y. On the other hand, the HB population was obviously quite lean and did not represent the full age spectrum of the US adult population, which renders it somewhat limited for use today.

In summary, the relationships between REE and several variables were studied to derive predictive equations for practical, clinical use in weight management today. The result of this process was to confirm that REE is determined largely by FFM (Eq 1) but is highly correlated with total body weight as well (Eq 2). The addition of other routinely available values (height, age, and sex) builds on the predictive value of weight in determining REE. The addition of other measures of body composition (BMI and %IBW) and body-weight distribution (WHR) do not contribute significantly to the determination of REE. We believe that the MSJEs more accurately predict REE in healthy normal-weight and moderately overweight men and women than do other equations. Additionally, the practicality of the MSJEs in an office setting is enhanced because they use commonly available information. Equations 7 and 8 may appear somewhat burdensome but their simplicity and use of common, rounded-off factors (with only the constant for females and males changing) may enhance their application. Furthermore, they are more applicable to today's US population than the widely used HBE, derived in 1919. Further studies are needed to more accurately predict the energy requirements of the obese population.

Our equations are limited to their derivation from our study population. Although their predictive value compares favorably with other equations applied to our data set, their clinical utility can only be assessed by testing in other populations. Their strength and significance lie in *1*) their derivation from a larger, modern-day population (stratified for age, weight, and sex), *2*) the use of advanced equipment and technology for the measurement of actual REE, and *3*) a reasonably high correlation between REE and weight, height, and age ($R^2 = 0.71$). Also, because the mean %IBW of our sample was near 120% (mean BMI of 26 for women and 27 for men), an equation weighted toward this mean may be very useful in assessing caloric needs in a large subset of the US population where both weight and height have been continuing to rise [mean BMI 22–27 for women and 24–26 for men as reported by seven population studies (22)]. Those who respond best to dietary and exercise modifications (5, 23) are in this mildly–moderately-obese category (ie, < 80%IBW).

The limitations of any predictive equation for REE must also be considered. Direct metabolic measurements are preferable in individuals where a precise determination of REE is indicated. In addition, the other components of 24-EE (PA and TEF) should be studied to assess more accurately the individual total daily caloric requirements. Finally, the 30% unexplained variability in REE observed in our study should be studied further to determine the effect on REE of such factors as PA, weight-gain and weight-fluctuation patterns, eating patterns, and dietary composition, as well as the individual's degree of obesity or weight status. ∎

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References

1. Metropolitan Life Foundation. New weight standards for men and women. Stat Bull Metropol Life Insur Co 1959;40:1–4.
2. Forman MR, Trowbridge FL, Gentry EM, et al. Overweight adults in the United States: the behavioral risk factor surveys. Am J Clin Nutr 1986;44:410–6.
3. Consensus Development Panel, National Institutes of Health. Health implications of obesity. Bethesda, MD: US Department of Health and Human Services, 1985.
4. Lew EA, Garfinkel L. Variations in mortality by weight among 750,000 men and women. J Chronic Dis 1979;32:563–76.
5. Bray GA. Obesity and the heart. Mod Concepts Cardiovasc Dis 1987;56:67–71.
6. Lapidus L, Bengtsson C, Larsson B, et al. Distribution of adipose tissue and risk of cardiovascular disease and death: a 12 year follow up of participants in the population study of women in Gothenburg, Sweden. Br Med J 1984;289:1257–61.
7. Ravussin E, Burnand B, Schutz Y, Jequier E. Twenty-four hour energy expenditure and resting metabolic rate in obese, moderately obese and control subjects. Am J Clin Nutr 1982;35:566–73.
8. Jequier E, Schutz Y. Long-term measurements of energy expenditure in humans using a respiration chamber. Am J Clin Nutr 1983;38:989–98.
9. Committee on Dietary Allowances, Food and Nutrition Board, National Research Council. Recommended dietary allowances. 9th ed. Washington, DC: National Academy Press, 1980.
10. Harris JA, Benedict FG. A biometric study of basal metabolism in man. Washington, DC: Carnegie Institution of Washington, 1919. (Carnegie Institute of Washington publication 279.)
11. Daly JM, Heymsfield SB, Head CA, et al. Human energy requirements: overestimation by widely used prediction equation. Am J Clin Nutr 1985;42:1170–4.
12. Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. Am J Clin Nutr 1980;33:2372–4.
13. Cunningham JJ. Body composition and resting metabolic rate: the myth of feminine metabolism. Am J Clin Nutr 1982;36:721–6.
14. Owen OE, Kavle E, Owen RS. A reappraisal of caloric requirements in healthy women. Am J Clin Nutr 1986;44:1–19.
15. Owen OE, Holup JL, D'Alessio, DA. A reappraisal of the caloric requirements of men. Am J Clin Nutr 1987;46:875–85.
16. de Boer JO, van Es AJH, Roovers LCA, et al. Adaptation of energy metabolism of overweight women to low-energy intake, studied with whole body calorimeters. Am J Clin Nutr 1986;44:585–95.
17. Brownell KD, Greenwood MRC, Stellar E, Shrager EE. The effects of repeated cycles of weight loss and regain in rats. Physiol Behav 1986;38:459–64.
18. Foster GD, Wadden TA, Mullen JL, et al. Resting energy expenditure, body composition, and excess weight in the obese. Metabolism 1988;37:467–72.
19. Jackson AS, Pollock ML, Ward J. Generalized equations for predicting body density of women. Med Sci Sports 1980;12:175–82.
20. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 1978;40:497–504.
21. Scherf J, Franklin BA, Lucas CP, et al. Validity of skinfold thickness measures of formerly obese adults. Am J Clin Nutr 1986;43:128–35.
22. Simopoulos A. Characteristics of obesity: an overview. In: Wurtman RJ, Wurtman JJ, eds. Human obesity. Ann NY Acad Sci 1987;499:4–13.
23. Stunkard AJ. The current status of treatment for obesity in adults. In: Stunkard AJ, Stellar E, eds. Eating and its disorders. New York: Raven Press, 1984.