A reanalysis of the factors influencing basal metabolic rate in normal adults[1]

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ABSTRACT A multiple regression analysis of several factors influencing basal metabolic rate (BMR) was performed using data for 223 subjects from the classic metabolism studies published by Harris and Benedict in 1919. These data had previously been analyzed by Kleiber using metabolic body size, the three-fourths power of body mass, as a predictor of BMR. His prediction equations were separated by sex and each contained components for age and height. Factors in the present analysis included sex, age, height, body mass, and estimated lean body mass (LBM). Lean body mass was found to be the single predictor of BMR. A best estimate prediction equation: BMR(cal/day) = 500 + 22 (LBM) is proposed. The previously presumed influences of sex and age are shown to add little to this estimation. *Am. J. Clin. Nutr.* 33: 2372–2374, 1980.

Standard physiology texts list sex, age, and body composition as factors related to basal metabolic rate (BMR) in man. Indeed, differences due to age and sex exist when BMR values are expressed as calories per unit of body surface area. The physiological basis for a body surface relationship has been questioned by Kleiber (1). His expression of BMR on the basis of metabolic size retains age and sex differences. Benedict (2) reported that body mass and body surface area were both inadequate indices for the expression of BMR and suggested that the mass of active protoplasmic tissue might be useful. In this regard, Miller and Blyth (3) proposed lean body mass (LBM) as a metabolic standard and demonstrated that LBM was a better predictor of oxygen consumption than surface area in 47 young men. The inverse relationship between age and basal oxygen consumption recently has been shown to be wholly attributable to changes in LBM (4, 5). Sex differences have not been examined using LBM as a predictor of BMR. The present study estimates LBM as a function of sex, age, and body mass before a regression analysis for the influence of several variables on BMR.

Methods

Data for 223 healthy adult subjects from the classic metabolism studies of Harris and Benedict (6) were used in the present analysis. Sixteen other male subjects were omitted as they were identified as trained athletes. Age, height, and body mass values for 120 males and 103 females were taken directly from the published tables. Values for BMR in calories per day were recalculated and rounded to the nearest 10 cal, representing the maximum possible statistical significance assuming that oxygen consumption per minute was accurate to 10 ml.

Since the body composition of the subjects are not reported, estimates of LBM were calculated from the equations below, where M is body mass in kg and A is age in years, assuming all subjects to be normal. These were derived by substitution and rearrangement of the prediction equations for total body water published by Moore et al. (7).

$$\text{male LBM} = (79.5 - 0.24\ M - 0.15\ A) \times M \div 73.2$$

$$\text{female LBM} = (69.8 - 0.26\ M - 0.12\ A) \times M \div 73.2$$

A multiple regression analysis for the predictors of BMR was performed using the SPSS program (8). As Kleiber (9) previously reported an analysis of this same data for a body surface area correlation with BMR, this variable was not included.

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Results and Discussion

The stepwise inclusion of variables into a prediction equation for BMR is summarized in **Table 1.** The most predictive variable is LBM, accounting for 70% of the variability of BMR. The strength of this predictor is perhaps surprising considering the assumption of normality and inherent variabilities in the estimation of LBM. The prediction equation for BMR from LBM by regression is:

$$\text{BMR (cal/day)} = 501.6 + 21.6\ \text{(LBM)}$$

The 95% confidence limit for the slope of this regression is ± 1.9 so that a prediction error of 10% is expected for an individual BMR.

Addtional variables add little to the estimation. Whereas age is the second variable added, this negative component is compensated for by an increased constant term, i.e.,

$$\text{BMR (cal/day)} = 601.2 + 21\ \text{(LBM)} - 2.6\ \text{(age)}$$

At the mean values of 29 years and 46 kg LBM, this second equation changes the predicted BMR by only 1.4 cal/day. This agrees well with the previously cited studies (4, 5) in which the age contribution was shown to be due simply to changes in body composition.

Kleiber (9) analyzed these same data in 1932 and proposed the computation of the three-fourths power of body mass as an estimate of metabolic size. As this term does not reflect the contributions of sex and age to body composition, his prediction equations for BMR based on metabolic size (1) are separated by sex and each contains an age component. The present analysis shows sex to contribute little beyond the estimation of LBM. In this respect, sex may even be less important for individuals who deviate markedly from normal. It is illustrative that if these data are separated by sex prior to analysis, the predictive utility of LBM for BMR remains. At the mean LBM for each sex, the largest deviation between separate sex and composite regression is 10 cal/day, occurring in the male group, and for 95% of the LBM values, estimates of BMR agree within 20 cal/day.

The use of sex and age in the computation of LBM does not bias the regression analysis. If sex or age had an independent correlation to BMR, it would not be altered by this added factor in the analysis. It would be valuable to compare the prediction equation presented here to a set of data containing measured LBM and oxygen consumption from a statistical sample of mixed sex.

Miller and Blyth (10) reported that oxygen consumption correlated well with LBM (r = 0.92) in 79 college students of whom 78 were male. However, their regression equation for computing LBM from oxygen consumption consistently overestimates LBM for males relative to the present formula by an average of 7.8 kg. In fact, this regression yields LBM values greater than the body weight for 34% of the males in the Harris Benedict data set.

A comparison of BMR calculated on the basis of body surface area or by the present regression equation is of interest. In the former, one must use separate conversion values for each sex. At the mean values for height and weight in **Table 2**, body surface area (for either sex) is 1.68 cm^2. The adult male BMR is estimated using 36.8 cal/m^2/hr while the adult female BMR is estimated at 35.1 cal/m^2/hr (11). The respective BMR estimates are thus 1480 and 1420 cal/day. The mean measured values is 1490 cal/day which is identical to the estimate from the present regression at the mean LBM regardless of sex. A comparison of other representative

TABLE 1
Regression analysis for the predictors of BMR

Step	Variable entered[a]	Multiple R	Adjusted R^2	F ratio
1	LBM	0.84	0.70	517.5
2	Age	0.85	0.72	284.3
3	Height	0.85	0.73	193.6
4	Sex	0.86	0.73	150.2
5	Body mass	0.86	0.73	120.5

[a] Each step of the regression adds a variable to the previous predictors.

TABLE 2
Summary of regression data

Variable	Mean[a]	SD	Units
BMR	1490	210	Cal/day
Age	29	11	Yr
Height	168	8	Cm
Body mass	59.8	11	Kg
LBM	45.8	8	Kg

[a] n = 120 males + 103 females from Reference (6).

TABLE 3
A comparison of BMR estimates calculated from body surface area (BSA) or LBM

Type	Height	Weight	LBM[a]	Body surface[b]	BMR	
					BSA[c]	LBM[d]
	cm	*kg*	*kg*	m^2	*cal/day*	
Lean male	164	45	39.5	1.46	1290	1350
Medium male	174	70	55.7	1.85	1630	1710
Heavy male	195	120	75.7	2.55	2250	2140
Lean female	162	40	30.5	1.37	1150	1160
Medium female	164	55	39.0	1.60	1350	1340
Heavy female	175	85	51.2	1.98	1670	1610

[a] Assume age 30 year, using text formulae. [b] Surface = $\text{weight}^{0.425} \times \text{height}^{0.725} \times 0.007184$. [c] 36.8 cal/m²/hr for males or 35.1 cal/m²/hr for females at age 30 (11). [d] Regression equation in text independent of sex.

data are presented in **Table 3.** Notice that the BMR estimates calculated from body surface for the lean male and medium female are similar, as are their LBM estimates from the formulae. This suggests that perhaps estimations of BMR based on body surface area owe their utility to a hidden correlation to LBM within each sex. Miller and Blyth (3) reported this for their male subjects.

Conclusion

The suggestion of Benedict (2), made over 65 years ago, that active body mass determines BMR is supported. Sex and age are factors influencing the body composition of an individual, but body composition is the principle determinant of BMR. An equation using LBM as the single predictor of BMR in normal adults can replace the present cumbersome tables for separate sexes and ages. Basal metabolism in normal adults can be estimated from a simple linear equation where:

$$\text{BMR (cal/day)} = 500 + 22\ (\text{LBM})$$

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